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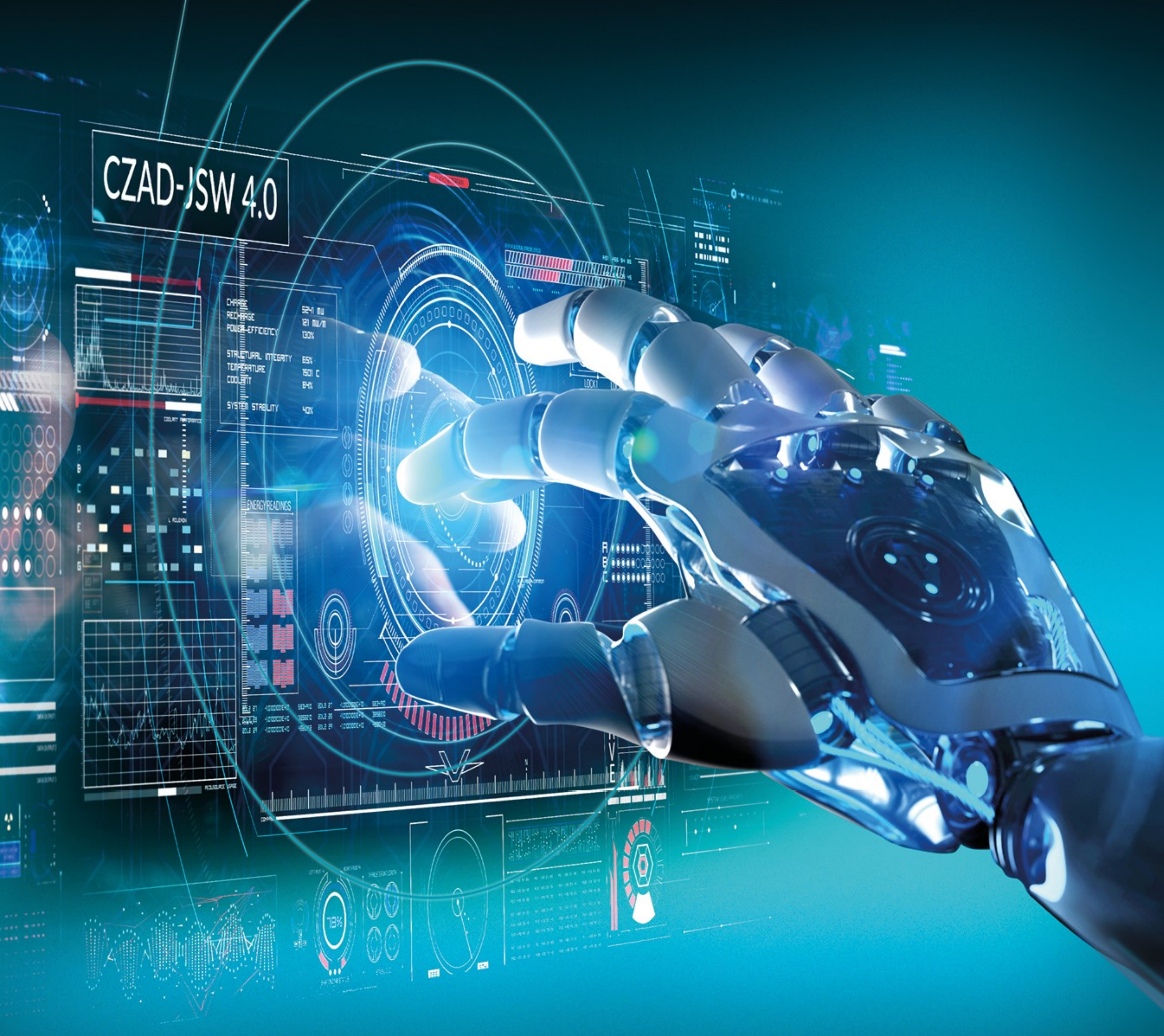
SCIENTIFIC EDITOR



Automation and monitoring of the production process in underground mines – Polish experience in implementing the **INDUSTRY 4.0 paradigm**

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Artur DYCZKO – Scientific Editor

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Scientific Editor:

Artur DYCZKO – Instytut Gospodarki Surowcami Mineralnymi i Energią PAN
(Mineral and Energy Economy Research Institute of the Polish Academy of Sciences)

Authors:

Chapter 1÷4, 13, 14

Artur DYCZKO – Instytut Gospodarki Surowcami Mineralnymi i Energią PAN
(Mineral and Energy Economy Research Institute of the Polish Academy of Sciences)

Chapter 5÷8

Kazimierz MIŚKIEWICZ – Politechnika Śląska *(Silesian University of Technology)*
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Chapter 9

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Joanna ROGALA-ROJEK – ITG KOMAG *(KOMAG Institute of Mining Technology)*

Chapter 10

Artur DYLONG – Politechnika Śląska *(Silesian University of Technology)*
Kazimierz MIŚKIEWICZ – Politechnika Śląska *(Silesian University of Technology)*

Chapter 11

Artur DYLONG – Politechnika Śląska *(Silesian University of Technology)*

Chapter 12

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Grzegorz MUTKE – GIG - Państwowy Instytut Badawczy *(National Research Institute)*
Zbigniew SZREDER – JSW S.A. *(JSW Coal Mine)*

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(AGH University of Krakow)

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Design of Cover:
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(KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland)

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1. Introduction

Artur Dyczko

Jastrzębska Spółka Węglowa (JSW) SA is the largest European producer of coking coal, which has been included by the EU on the list of critical raw materials and is necessary for the smelting of steel, and thus for the production of a key material in most branches of European industry. Thus, JSW SA is a producer of raw materials that indirectly determine economic growth and, consequently, job creation. At the same time, it is a corporate group undergoing transformation towards a low-emission economy, engaging in research projects aimed at offering innovative products of the future technologies.

May 5, 2021, the European Commission set out the foundations of the EU industrial strategy. The strategy was intended to enable a dual transformation - ecological and digital, making EU industry more competitive on a global scale and increasing Europe's open strategic autonomy. The day after the announcement of the new industrial strategy, the World Health Organization announced the outbreak of the COVID-19 pandemic [Dyczko, 2023].

COVID-19 crisis has had a strong impact on the EU economy. Depending on the ecosystem and the size of the enterprise, its effects varied. The crisis has highlighted the interdependence of global value chains and demonstrated that a globally integrated and well-functioning uniform market plays a key role. Among the steel-consuming sectors, sector hit the hardest by the Covid-19 pandemic has been the automotive. The number of new car registrations in the EU fell at a record pace - by almost 24% in 2020. This is the largest decline in the number of registered new cars since the beginning of such statistics.

The main objective of the New EU Industrial Strategy remains to support economic growth and prosperity in Europe. European industry provides 35 million jobs and accounts for 20% of the EU's total value added. That is why it is so important to maintain its competitiveness globally, which cannot be achieved without access to raw materials critical for the industry development, often also called strategic.

The List of Critical Raw Materials is announced periodically every three years by the EU; the current list was published by the European Commission on September 3, 2020 and includes 30 positions. The first list published in 2011 included 14 raw materials, during the next assessment in 2014 there were 20 of them. After a review in 2017, the list was expanded to 27 raw materials.

The largest producers of coking coal in the world are China, Australia, USA, Russia and India, where approximately 90% of global production is concentrated. The European Union currently imports approximately 75% of the coking coal it consumes from the countries as far as Australia, the United States, Canada, Mozambique and Russia. Poland (Jastrzębska Spółka Węglowa) is currently the only producer of this critical raw material in Europe. Current production of coking coal in the European Union in 75% comes from mines owned by JSW [Ozon, 2019; Dyczko, 2023].

Jastrzębska Spółka Węglowa was established on April 1, 1993, bringing together seven underground mining plants: Borynia, Jastrzębie, Krupiński, Morcinek, Moszczenica, Pniówek,

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Zofiówka. A number of changes and organizational transformations aimed at optimizing operating costs and increasing the overall efficiency of the enterprise management recently led to an efficient operation of four hard coal mines. Since January 1, 2023, when the "Jastrzębie-Bzie" mine was assigned to the " Borynia-Zofiówka" coal mine as "Bzie Section" and a new three-sections mine called "Borynia-Zofiówka-Bzie" was created, there have been four operating underground mining plants in the structures of the JSW SA:

– Coal Mine " Borynia-Zofiówka-Bzie " in Jastrzębie-Zdrój,
– Coal Mine "Budryk" in Ornontowice,
– Coal Mine "Knurów-Szczygłowice" in Knurów,
– Coal Mine "Pniówek" in Pawłowice.

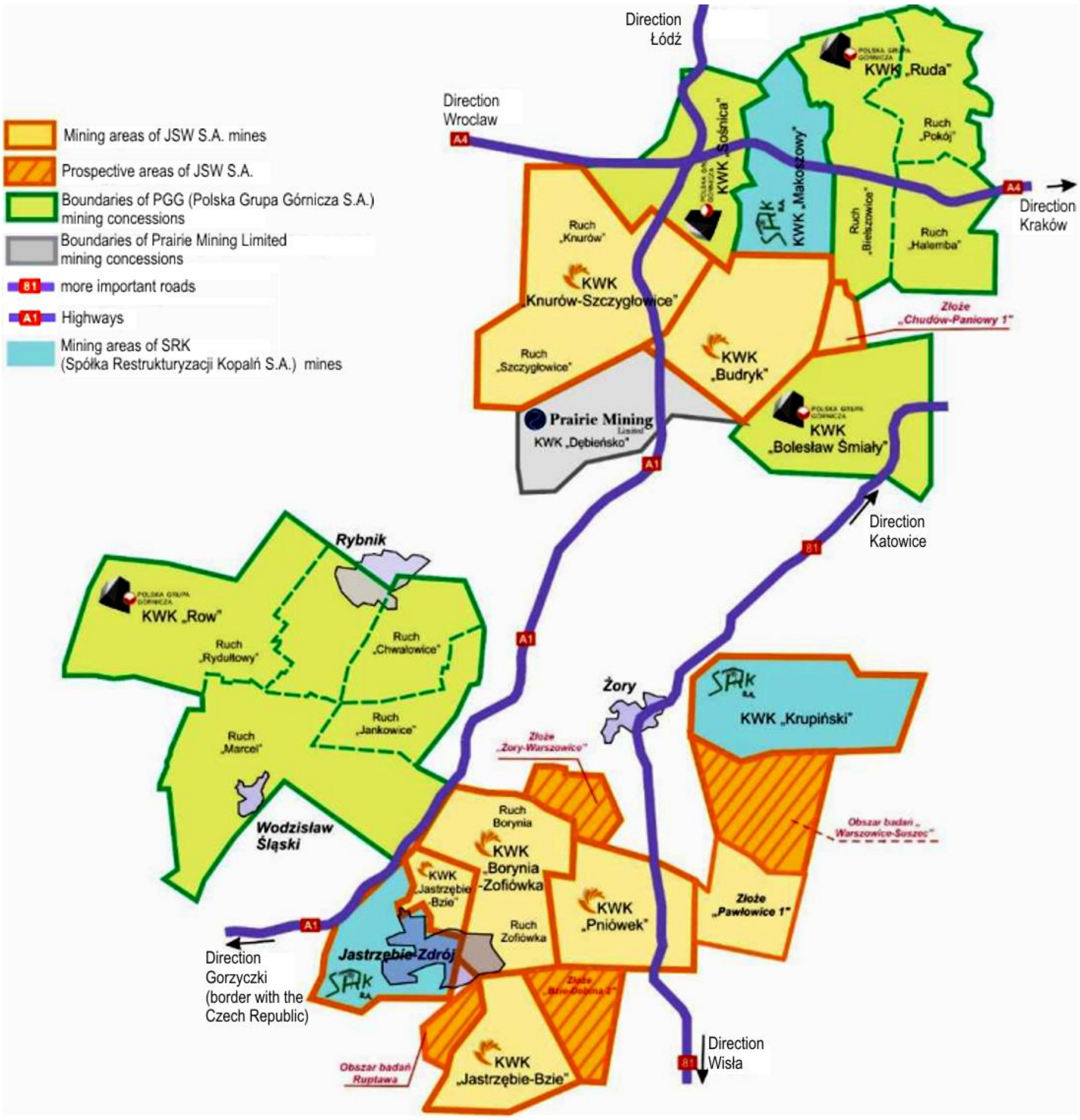

Fig. 1.1. Location of the mining areas of JSW SA mines

In terms of the administration, mining activities of JSW SA are concentrated in the southern part of the Silesian Voivodeship, in the vicinity of the following towns: Jastrzębie-Zdrój, Żory, Knurów, Mikołów, Gliwice, Świerklany, Pawłowice, Mszana, Ornontowice, Gierałtowice and Czerwionka-Leszczyny, operating in total area of 197.21 km^2. The Company operates in the southwestern part of the Upper Silesian Coal Basin GZW. Fig. 1.1 shows a diagram of the location of mining areas of JSW SA mines, as well as of the Polska Grupa Górnicza (PGG SA) and mines under closing down (transferred to Spółka Restrukturyzacji Kopalń - SRK SA) [Ozon, 2019].

The area of the southwestern part of the Upper Silesian Coal Basin, historically named Rybnicki Okręg Węglowy (ROW – Rybnik Coal District), is estimated at approximately 1,300 km^2. ROW has a well-developed infrastructure of road and railway networks. The largest cities in the district include: Rybnik, Jastrzębie-Zdrój, Żory, Racibórz and Wodzisław Śląski.

Currently, the JSW SA Corporate Group (JSW SA Group) employs over 30,000 people, of which over 20,000 are employees of the Jastrzębie mines, approximately 19.4% of which work above ground. The staff has a lot of experience. Retiring mining workers with the greatest length of service are replaced by the workers with mining qualifications or work experience in mining, as well as graduates of schools and universities educating in mining professions.

JSW SA currently holds shares in 17 companies, including 10 private limited companies and seven stock companies. JSW SA has a dominant stake in 11 companies, including 100% of the share capital in four companies and over 50% of the share capital in seven companies.

At present the JSW SA Capital Group includes as follows: JSW SA is engaged in mining of hard coal, a production of coke and a management of carbon-derivative products. As part of its activities, it tries to use raw materials in a rational and sustainable manner, while taking into account the requirements of both environmental protection and the protection of local and supra-local social interests. For over half a century, it has been intensively exploiting the richest deposits of coking coal in Europe.

As a result of the activities undertaken in 2015÷2019, new concessions were obtained for the following deposits: Jas Mos 1, Szczygłowice, Pniówek, and the validity period of existing concessions for the Budryk and Knurów deposits was extended. This allowed the Company to be legally secured in terms of the possibility of mining hard coal until 2050. Currently, JSW SA holds 11 mining concessions, including the latest mining concessions granted in 2019 for the previously unexploited Bzie-Dębina 1-Zachód deposit and three research concessions – Table 1.1 [Ozon, 2019].

JSW SA mining concessions

Table 1.1.

DEPOSITS COVERED BY CONCESSION *(concessions for the extraction of hard coal and methane as an accompanying mineral)*		CONCESSION NO.	DATE OF GRANTING THE CONCESSION	EXPIRY DATE OF THE CONCESSION
Coal Mine BORYNIA-ZOFIÓWKA	Borynia " deposit "Szeroka I" mining area	7/2009	27/10/2009	31/12/2025
	"Zofiówka" deposit "Jastrzębie Górne I" mining area	5/2010	14/05/2010	31/12/2042
Coal Mine JASTRZĘBIE - BZIE	"Bzie-Dębina 2 - Zachód" deposit "Bzie - Dębina 2-Zachód" mining area	15/2008	01/12/2008	31/12/2042
	"Bzie-Dębina 1 - Zachód" deposit "Bzie - Dębina 1-Zachód" mining area	2/2019	May 23, 2019	31/12/2051
	Mos 1" deposit "Jastrzębie III" mining area	1/2019	05/02/2019	31/12/2025

Coal Mine BUDRYK	"Budryk" deposit "Ornontowice I" mining area	13/94	March 21, 1994	31/12/2043
	"Chudów-Paniowy 1" deposit "Ornontowice II" mining area	3/2005	18/04/2005	31/12/2044
Coal Mine KNURÓW-SZCZYGŁOWICE	"Szczygłowice" deposit "Szczygłowice" mining area	4/2019	30/08/2019 valid from January 1, 2020.	31/12/2040
	"Knurów" deposit "Knurów" mining area	60/94	April 21, 1994	15/04/2044
Coal Mine PNIÓWEK	"Pniówek" deposit "Krzyżowice III" mining area	5/2019	8/11/2019 valid from January 1, 2020.	31/12/2051
	"Pawłowice 1" deposit "Pawłowice 1" mining area	3/2012	21/06/2012	31/12/2051

Jastrzębska Spółka Węglowa mines coking coal, mainly orthocoking type 35 ("hard") and gas-coking type 34 ("semi-soft"). However, the production structure is determined not only by the extracted coal, but also by the enrichment of the output by mechanical coal processing plants. Currently, the Company offers for sale not only coking coal, an ingredient for the production of very good quality metallurgical coke, but also coal for energy purposes, which has certain coking properties, but a much higher ash content (20÷25%) and lower calorific value (approx. 20÷24 MJ/kg). The Mineral Expert Report prepared in accordance with the Australian Resource Reporting Code (JORC Code), which classifies deposit elements into resources and reserves, determined the total amount of documented hard coal resources at:

– without taking into account the period of validity of the mining concessions of JSW SA mines:
  - balance sheet resources 7,038,024 thousand Mg
  - industrial resources 2,217,835 thousand Mg
  - operational resources (potential extraction) 1,197,063 thousand Mg
– quantity determined for the period of validity of the mining concessions:
  - balance sheet resources 7,038,024 thousand Mg
  - industrial resources 962,946 thousand Mg
  - operational resources 564,630 thousand Mg.

JSW SA mines are characterized by variable geological and mining conditions. The exploited deposit is accessible via 41 shafts, and the mining fronts are located at various depths (from 560 to 1,300 m), which, given the high level of natural hazards, requires appropriate preventive measures. Thickness of the exploited seams ranges from 1.2 to 12.5 m. A large number of faults, characteristic for the southern part of the Upper Silesian Coal Basin, forces mining to be carried out in accordance with the limits set by the course of natural disturbances. This is reflected in the the longwall lengths, which rarely exceed several hundred meters, which consequently leads to their frequent reinforcement changes. Coal is mined in JSW SA mines using a longwall system with a roof caving away from the boundaries. Coal is extracted from fully mechanized longwalls. The winning from the longwall face is hauled using a collective haulage system (conveyors). It is mixed with rock and coal from roadways run within the coal seam.

Annually, JSW SA mines extract nearly 30 million gross tons of coal and develope on average approximately 70 km of roadways with their own workers and approximately 10÷15 km with external companies (these are mainly investment workings). Bearing in mind that coal ready for sale in JSW SA constitutes for ~55÷60% of the total output, ultimately approximately 15 million Mg of pure coal reaches the market. Of this, approximately 10 million Mg is coal for metallurgical purposes (coking) and 5 million is thermal coal. On average, 22 to 26 longwalls are operated annually, with an average output of 3.5 to 6 thousand net Mg of coal per day. This relatively low extraction from the longwall in JSW SA mines is caused primarily by very difficult geological and mining conditions in which mining is carried out. The greatest problems are caused by the methane threat, which is combated using ventilation methods and extensive methane drainage systems consisting of boreholes, pipeline networks and surface methane drainage stations.

Methane drainage from mines is carried out by surface and injector methane drainage stations. Inflow of gas from various sources enables the stabilization of the the methane-air mixture, which results in its more effective management. JSW SA mines, apart from the "Budryk" and "Pniówek" coal mines, have group air conditioning systems. The "Pniówek" coal mine has a central air-conditioning system operating in a trigeneration system based on absorption refrigerators and energy use of mixtures from methane drainage.

Due to the risk of rock bursts, specialized equipment is used at the plants, including seismometers and seismic probes. The methane threat is monitored using sensors operated by methane measurement centers included in the SMP and CST systems, supported by the SwuP-3 methane measurement dispatcher system. The company's mines are equipped with numerous sensors for measuring carbon monoxide, smoke, differential pressure, air flow, water level, temperature, dam opening and electrical current flow.

Mining plants have extensive ventilation, drainage, air conditioning, technological (compressed air, emulsion, process water) and fire safety networks. These networks include appropriate energomechanical or electrical devices (fans, cooling units, pumps, compressor units, power supply devices and control systems) and installations (pipelines, cables) through which individual media are distributed.

Horizontal transport is carried out using extensive conveyor belt lines, a network of mining railways, floor and suspended railways. The total length of underground transport roads in individual mines ranges from 30 to 60 km, and the total length of the conveyor belt haulage is up to 40 km. Vertical transport (hoisting mined material, transport of people and materials) is carried out using mining skip hoists.

Transport of excavated material from the heading faces is carried out using light scraper conveyors, BOA and SIGMA belt conveyors. Roadway loaders used in JSW SA mines are mostly of the following types: Niwka B, Eimco-612, EL-160LS, DH-250, WUŁ-2, PSU-7000 and PSU-9000.

The mines have extensive communication and data transmission systems, including: plant-wide wired telephone communication systems of the DGT Millenium and Siemens Hi Path type, intrinsically safe underground communication systems of the UTI system, SAT alarm and

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loudspeaker communication systems, integrated SMP and CST security systems, radio communication, communication systems for rescue operations, telemetric security systems, technological supervision and CCTV systems, wired control and signaling systems, personal and device identification systems. Intrinsically safe telecommunications devices and alarm systems are equipped with modern telecommunications power plants supported by local combustion generators ensuring guaranteed power supply (mostly uninterruptible) for at least 12 hours. The company's individual organizational units are connected via an integrated WAN IT network with a ring structure, ensuring high redundancy.

The plants operate extensive industrial ICT networks and multiple transmission systems of the FOD-900 type. The control rooms are equipped with modern systemic telephones, synoptic boards, and SCADA systems that enable monitoring of safety and production parameters as well as visualization of technological processes. Available equipment significantly supports maintenance and improves the crew's work safety.

Bus teletransmission networks are mostly built using symmetrical local telecommunications cables (TKM type) on the surface and mining telecommunications cables (TKG) on the surface and underground. The fiber optic network is regularly expanded using single-mode YOTKGtsFoyn (shaft) and YOTKGtsFtlyn (pavement) cables.

Modern, microprocessor-based automation systems include most of the basic energomechanical machines and distribution devices. Data visualization systems connected to them support mine maintenance, enabling remote diagnostics of equipment condition and control of basic safety parameters. The video monitoring system is equipped with modern CCTV stations and IP cameras.

Since 2011, the Pniówek coal mine has had a zoned crew location system covering the entire mine. Currently, there are approximately 100 gates intended for zone localization on two operational levels (850 and 1030). There are approximately 5,000 badges installed in the lamps. System records the number of people staying in particular zones. Existing infrastructure of the crew location system in the mine was also used to launch the material logistics system (KAJTO). The KAJTO system currently uses approximately 2,500 battery tags mounted on trucks and transport containers.

In 2017, the Management Board of JSW SA, while analyzing the premises for verifying the currently prepared Business Strategy of the Capital Group, noticed a group of conditions and limitations - with particular emphasis on the resource base - that may affect the implementation of the Strategy of JSW SA in the perspective of 2030. As stated in the conducted analyses, a very significant limitation of the assumed production capacity by 2030 will be the deteriorating geological and mining conditions of the extraction process, including:

– the average mining depth in JSW SA mines will increase from 880 m in 2018 to 1,035 m in 2031, i.e. it will increase by 11 m per year,
– in the increase in the primary temperature of the rock mass from 40°C in 2018 to 45°C in 2031, which will be a consequence of the increase in depth,

- the methane threat, which has been clearly increasing in recent years, will continue this trend in subsequent years of the Company's operations,
- in the years 2010÷2031, the average length of the haul, as well as the time it takes for the crew to reach the face, will increase by over 30%,
- exploitation plans for subsequent years show that the location of the longwall fields are placed increasingly further from the shafts, which has a significant impact on operating costs in the Company's mines,
- analysis of the trend of the risk indicator leads to a conclusion that the exploitation risk resulting from the nuisance of geological and mining conditions will increase and thus limit the planned mining capacity of the longwalls,
- analysis of production structure of the commercial coal over the life of the mines shows that maintaining a stable production structure will be very difficult.

The above conditions, which may ultimately affect JSW SA in maintaining the status of the largest producer of high-quality type 35 hard coking coal in Europe, resulted in the Company's Management Board deciding to base the Company's development in 2017÷2020 on technical and technological diversification of the production process based on knowledge, innovations, research projects and cooperation with industry leaders. The Company's Management Board also saw this action as a unique opportunity to quickly transform the Polish coal company based in Jastrzębie Zdrój into a Modern European Raw Material Company with 4.0 ambitions.

Therefore, guided by the properly understood need for the Company's development in the technical and operational area, Board decided to engage all available funds and resources in 2017÷2020 to assess the possibility of adapting the best technologies used in the global mining industry in order to increase the efficiency of the production process and an increase in the share of coking coal in the production structure of JSW SA. For this purpose, the JSW 4.0 Program was established, which assumed the development, testing and implementation of the latest techniques and technologies in Jastrzębie mines [Ozon, 2019].

The formula of cooperation between JSW SA and the suppliers of the above-mentioned technology was a technological dialogue, the aim of which was to identify the best solutions from a systemic perspective in the field of monitoring the production process and the safety of mining crews, including: communication, localization of employees in particularly hazardous zones and the use of advanced data analytics methods.

The first step to enabling technological dialogue was organizing, by the initiative of JSW SA, an international conference called International Mining Forum 2017. Invited were representatives of leading suppliers of modern technological systems for mining, national and international research institutes and leading raw material companies in Poland. These activities constituted the JSW SA Strategy in the area of R&D+I adopted by the Management Board of JSW SA in December 2017, and corresponded closely to the Strategy of the Capital Group until 2030. It was developed and adopted by the Supervisory Board of JSW SA in 2018 and referred to the vision of knowledge-based economy, i.e. investing in the area of R&D&I. During the sessions of the International Mining Forum 2017, a number of important relationships were

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established between industry, science and technology suppliers, which in the following months turned into projects.

The tool for achieving the objectives of the R+D+I Strategy was a separate entity within the Capital Group, established in mid-2017 (symbolically during IMF 2017) - JSW Innowacje SA, by transforming the Polski Koks SA. The company was designed to serve as the Center for Research, Innovation and Inventions in the Group and was to become a base for the implementation of research and development projects, both in the area of JSW SA's core business and other segments (coking and coal-derivatives, service and production of JZR mining machines, IT, logistics, etc.).

The role of the new Company (JSW Innowacje) was to provide new technologies in the form of research projects - first as prototypes developed for the Company's needs, then as tests of the *proof of concept* implemented in real conditions at one of JSW SA's mine. When the expected results are achieved, solution was to be validated in other JSW SA plants.

This monograph explains, describes and documents the DIGITAL TRANSFORMATION that took place in the Jastrzębie mines in 2016÷2020. The book covers processes related to underground wireless communication, monitoring of work safety conditions, automation of entire processes and use of advanced data analytics of key production parameters in the mines of Jastrzębska Spółka Węglowa. It presents the experience of entire research teams gained during strategic projects implemented within nearly four years, documenting the greatest breakthrough technology in the Polish mining industry in many years.

The monograph consists of 14 chapters and it contains list of basic literature used in this publication. The introduction (chapter one), in addition to a brief discussion of the content of individual chapters, presents basic information about the structure of the JSW Capital Group, and in particular about the Company’s mines.

The second chapter presents the idea of implementing the basic program of the new development concept of JSW SA until 2030 called "**JSW Smart Mine 4.0**". This program was an element of the company's digital transformation towards Industry 4.0, as the real breakthrough in the business strategy of the JSW SA Capital Group for 2018÷2030 was a new approach to the digitalization of entire business process and entrusting its implementation to JSW IT Systems Ltd. The book presents in greater detail the new role and, consequently, the new operating logic of the company responsible for IT/OT (*Information Technology/ Operational Technology*) in the JSW Group. Main assumptions of the new IT development strategy, and especially OT, for the entire capital group were presented, with particular emphasis on the method of organizing and standardizing the architecture and technical infrastructure management policy of IT/OT systems.

The third chapter of the monograph presents origins of the construction of the first **Center for Advanced Data Analytics** (CZAD) in the Polish mining industry. Mechanisms used in JSW SA analyses were discussed, the potential contained in the exploration of multidimensional data structures, machine learning and the use of *Big Data* was assessed.

The fourth chapter of the monograph presents the concept of construction and the process of implementing a Production Management System in the mines of JSW SA based on the demand and quality of the exploited raw material. Solutions broadly described on the pages of this monograph allow for a real increase in the effectiveness of quality management of both the selected deposit and the commercial product offered to end customers. Heuristic, technical architecture of the JSW SA production line management system proposed by the author allows for analyzing the profitability of the production process on a drawn-out basis in the area of mines, processing plants and coking plants, ultimately increasing production efficiency by up to 20%. The system is the foundation of the entire mining production control process carried out in real time by the Quality Office and the Center for Advanced Data Analytics established especially for this purpose at the Company's Management Board.

The fifth chapter of the monograph concerns mobile telecommunications, audio communications with the so-called mobile workstations, which include suspended and floor railway operators as well as traction locomotive drivers. For this purpose, the Management Board of JSW SA decided to significantly expand the network of radiating cables (by over 150 km) and build a modern digital radio communication system. Radio communication with a radiating cable not only creates the possibility of communicating with all railway and rail transport operators, but also enables the transmission of technological data from these machines, which is important in creating a safety policy for mining crews and systems supporting the management of an underground mining plant. Mobile telecommunications using a radiating cable is also an important element of the JSW 4.0 Smart Mine.

The sixth chapter presents the development of fiber-optic telecommunications networks in JSW SA mines, which are the basic medium for transmitting technological data to dispatch supervision centers. Particular attention was paid to the construction of explosion-proof devices used in the fiber optic networks of JSW SA methane mines and to the fiber optic infrastructure (underground and surface) as the main element of the mine telecommunications networks. Architecture of the video monitoring system in individual JSW SA mines was also presented, along with a description of the cameras, computers, monitors and accompanying devices used in these networks, installed as underground access points in potentially explosive atmospheres. The entire issue was discussed in the context of the communication standard adopted by JSW SA, which is to form the basis of the "**JSW Smart Mine 4.0**" program in the future.

The seventh chapter of the monograph analyses systems for locating people and equipment used in JSW SA mines, and discusses in detail current state of the access control systems used (working time and attendance records) and zone localization of people and mining equipment. Radiocommunication systems for identifying and locating people in underground mines are classified as security systems. All radio zone localization systems available on the market were characterized, as well as first results of the underground tests (in particularly hazardous areas of mine workings) of four intrinsically safe systems, the real time localization systems (RTLS), which were carried out in several JSW SA mines.

Systems for monitoring technological processes in underground mines are presented in a comprehensive manner in chapter eight. Classic dispatch monitoring systems (synoptic boards still in operation in the control rooms of JSW SA mines) are discussed, up to modern dynamic dispatch visualization systems based on SCADA software, the task of which is to visualize the operating status of many different devices and technological systems (data

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transmission) from individual shearers or entire longwall systems and continuous transport systems), up to data visualization of various safety systems (e.g. gasometry, condition of dams, fans) as well as, in certain cases, also control of distribution fields in power networks. The latest HADES visualization system developed at JSW ITS recently was presented. It will be used in the control rooms of all JSW SA mines. The entire topic is shown on the background of the new architecture proposed by JSW SA based on the data exchange standard developed by the mines in the IT/OT infrastructure. It constitutes the essence of the “Policy of Jastrzębska Spółka Węglowa SA regarding the management of the architecture and technical infrastructure of IT/OT systems" adopted by the Management Board of JSW SA in October 2020.

The ninth chapter was devoted to load-bearing capacity monitoring in powered roof support, and to the construction, by the JSW SA - Center for Advanced Data Analytics, of a system *Data Historian*, in which data generated by local powered support monitoring systems are automatically aggregated, processed and prepared for complex analyses. In 2018, the Management Board of JSW SA decided that the system for monitoring the load-bearing capacity of the powered roof support will be gradually expanded to cover all longwall systems of the Company's mines in the near future. In 2022, out of approximately 22 active longwalls in JSW SA mines, 17 longwall systems were equipped with a powered support monitoring system.

The tenth chapter discusses typical gasometric systems used in JSW SA mines. Methods of measurement, processing, visualization and archivization of signals from sensors and other devices (e.g. dam opening devices) operating in zones at risk of methane and/or coal dust explosions are presented. The principles of measuring methane and other gases and parameters of the mine atmosphere in a typical gasometric system were briefly characterized. Gasometric systems currently used in JSW SA Coal Mines were discussed, with emphasis on the currently used sensors (measuring mine atmosphere parameters) and other elements of these systems (e.g. analog and two-state control units of these systems).

The eleventh chapter characterizes the networks of methane drainage systems used in JSW SA Coal Mines, selected elements of these networks and the unique IT system implemented there, used to monitor the concentration of methane captured in mining excavations, as well as its fully automated operation and integration with dispatch systems.

The twelveth chapter presents a general picture of the safety systems used in JSW SA mines, dedicated to monitoring seismic phenomena. Characteristics of the monitoring systems used, analysis of the mechanisms of earthquake outbreaks and their source parameters in the aspect of assessing seismic risk in mines are presented in a condensed form. Selected seismological equipment used in mines and the method of selecting parameters for determining seismic energy in mine networks are discussed in cross-section. All considerations are presented in the light of the assessment of the seismic and rock burst hazard in mining excavations using seismological criteria from the recent experiences of JSW SA mines.

The issue of cybersecurity in the mining-and-power sector is discussed in chapter thirteen, with a pressure on issues related to managing the business continuity of mining plants, including increasing the resistance of these organizations to business disruptions and minimizing effects of their occurence. History and and operational scope of one of industry’s first Centers for

Exchange and Analysis of Information regarding cybersecurity incidents (ISAC) in the country, established in 2022 at the Central Mining Institute - National Research Institute (GIG), were presented. Finally, the main assumptions of the "Safe Digital Silesia 2030" strategy were presented, including the establishment of Silesian CyberSecurity Hub as an element of the Silesian Computing Cloud, which is part of the Government Computing Cloud in the area of monitoring the transformation of the Polish mining-and-power sector. Chapter’s ending discusses the scope of activity of the COMPETENCE CENTER IN THE FIELD OF SECURITY, OPERATIONAL ANALYTICS AND MANAGING HAZARDOUS SITUATIONS IN INDUSTRY, which came to be from the alliance of the Silesian University of Technology and the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, aimed at the construction of a DIGITAL ECONOMY as a factor of technological development of the mineral raw materials sector and fair energy transformation of Silesia.

The fourteenth chapter of the monograph is a summary that synthetically collects arguments proving that the main postulates of the JSW **Smart Mine 4.0** program developed and implemented in 2017÷2021 by the Management Board of JSW SA allowed for the construction of an effective and modern operating model of JSW SA mines, which actively influences the increase in value, efficiency and work safety through increased integration and automation of processes and innovative IT/OT solutions throughout the entire production and commercial cycle.

Ladies and Gentlemen, by deciding to implement the JSW 4.0 Smart Mine project in Poland, which includes, among others, construction of mobile and fiber-optic infrastructure for production monitoring, location of the crew and launch of the first mining center CZAD, we wanted to prove that the implementation of the **Industry 4.0** paradigm in Polish mines is not a nuissance, it is an opportunity for development! The project was and remains a response to the challenges facing the entire Polish mining industry in the upcoming years and should constitute a valuable inspiration for its further development.

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2. Management of the IT and industrial automation, its role, importance and supervision in the implementation of the idea of SMART MINE JSW 4.0

Artur Dyczko

The market of mineral raw materials, and in particular hard coal, has recently become very unpredictable. The situation in the power sector is becoming problematic for entrepreneurs who must flexibly adapt their companies to changing market conditions in order to maintain the so-called " *business-like* " nature of their mining projects. In the JSW SA Corporate Group, which mines hard coal and produces coking coal, profit is generated at the level of the entire Group, where mines are an important, initial link in the production cycle, with specific production costs. There are two paths to shaping mining costs:

– pragmatic, consisting in rationalization of costs where they arise (saving measures),
– selecting deposits according to quality (controlling of production allocation).

Effective implementation of the above activities requires precise assessment instruments at the level of mines, regions, fields and production faces. These instruments are deposit, technological, and economic parameters, which, together with safety margins for each parameter, shape the profitability of undertaken projects. The intensive exploitation of the coal deposit by the Jastrzębie mines for over half a century has led to a significant depletion of resources, which created the need to reach for increasingly difficult to exploit and poorer quality parts of the deposit located on the outskirts of the current mining areas. Since the continued operation of all JSW mines depends on mining in such areas, it is becoming more and more justified to ask the following questions:

"Is the exploitation of lower-quality and technically more difficult parts of the deposit economically profitable?", "How to skillfully control the exploitation to optimally, from both economical and technical viewpoint, obtain the raw material for as long as possible?"

The Management Board of JSW SA decided to provide answers to the questions posed above by preparing a study entitled: The Company's strategy for 2018÷2030.

In parallel to the strategy being built, intensive restructuring processes were underway at JSW SA, starting mid-2016, with the aim of securing the stability and continuity of production of the JSW SA Group during potential future economic downturns. For these activities to be effective, it was agreed that the main line of defense of the Group would be a redefined management model for the IT and investment areas of the Company. As a result, projects focused on: increasing the Company's value, work efficiency, improving the condition of the natural environment, improving safety and working conditions were undertaken. The JSW SA Group Strategy, finally adopted in 2018, defined goals for key areas of responsibility in order to, on the one hand, reduce the risks and business challenges associated with them, and, on the other hand, to maximize opportunities resulting from socio-economic changes and the technological revolution, including:

- the management of the deposit - embracing the long-term development program of JSW SA mines based on 3D deposit modeling, production optimization and constant, online analysis of quality parameters of mined material (Minescape and Deswik systems),
- standardization and automation of the planning, scheduling and production optimization process - including the extraction and processing of the run-of-mine along with the management of production means, resulting in the increase in the efficiency of the production process (HBŚ, HRK, EX),
- managing the safety of mining crews - incorporating a number of initiatives enabling localization of employees underground, especially in zones of particular danger along with an analysis of the situational awareness of the exploitation front closed in decision loop in the dispatch center,
- construction of the Center for Advanced Data Analytics - organizing and standardizing the sensor communication of the production infrastructure in JSW mines in the field of communication and data transmission enabling monitoring, control and supervision over the failure-free operation of machines and devices in conditions of associated mining hazards, together with the automation of: collection, processing and analysis of huge amounts of process data (MIS system of management dashboards, PI System, monitoring of the support units, SCADA HADES),
- digital transformation of investment processes and production support - involving the implementation of the Program and Project Management System in the Corporate Group, launch of a modern purchasing platform and the construction of an electronic document circulation system, including the handling of investment applications (systems: IPMA, EOD, EPM, Logintrade.pl),
- cybersecurity of the information processing space and the data exchanges taking place in IT networks of JSW Group, which is set to be the foundation of solutions from scope of industry 4.0, Internet of Things, intelligent mine and circular economy (SIEM system).

The goals defined in this way directly influenced the focus of the key initiatives of the new Strategy around the four value levers of JSW, which are improving operational efficiency, cost efficiency, investment efficiency and the safety of mining crews, constituting the essence of the JSW **4.0 Smart Mine program** aimed at transforming the Company towards Industry 4.0 [Ozon, 2017].

The Company's Management Board was aware of the fact that in order to realistically think about the transformation of the JSW Group towards the Industry 4.0 paradigm and the circular economy, it had to change the perception of the production process among both employees and contractors. For this purpose, for the first time in the history of JSW SA, full coordination and, to a large extent, implementation of key initiatives of the JSW Strategy until 2030 was entrusted to JSW IT SYSTEMS (JSW ITS), which was to develop, test and implement solutions connecting mining machines in the JSW Group production with modern information technologies enabling operational analysis covering the entire value chain of the JSW Group - from the exploration of the deposit, implementation of the schedule, through placing an order and delivery of components for ongoing production, up to the shipment of goods to customers by trains or ships - this approach was implemented under the slogan **“JSW 4.0 - Production Quality from the Deposit to the Sea”**.

JSW ITS, implementing the main postulates of the JSW Intelligent Mine 4.0 program, unified communication standards in mining plants, organized procedures for the transmission, storage and protection of OT data, proposed a completely new model of IT development within the JSW Group, involving entire teams of engineers in mines and companies in its implementation. In short, it began a change in the perception of IT throughout the JSW Group, a process for which the Deputy President of the JSW Management Board for Strategy, Investment and Development was directly responsible. Without a doubt, the process of computerization of the JSW Group implemented in the years 2016÷2021, the fundamental opening of which were organizational changes in JSW ITS and the takeover of 100% control over the computerization of JSW, was part of the next cycle of increasing the innovativeness of the Polish mining industry. It set a new, hopefully permanent, direction of development of the raw materials industry, in which creative destruction has, and still does, played a key role in stimulating the entrepreneurship of the economy both in Poland and abroad.

Created in 1942 by economist Joseph Schumpeter, the theory of "creative destruction" suggests that business cycles operate under the influence of long waves of innovation. In particular, when markets are disrupted, key industry clusters have a huge impact on the entire global economy – Fig. 2.1.

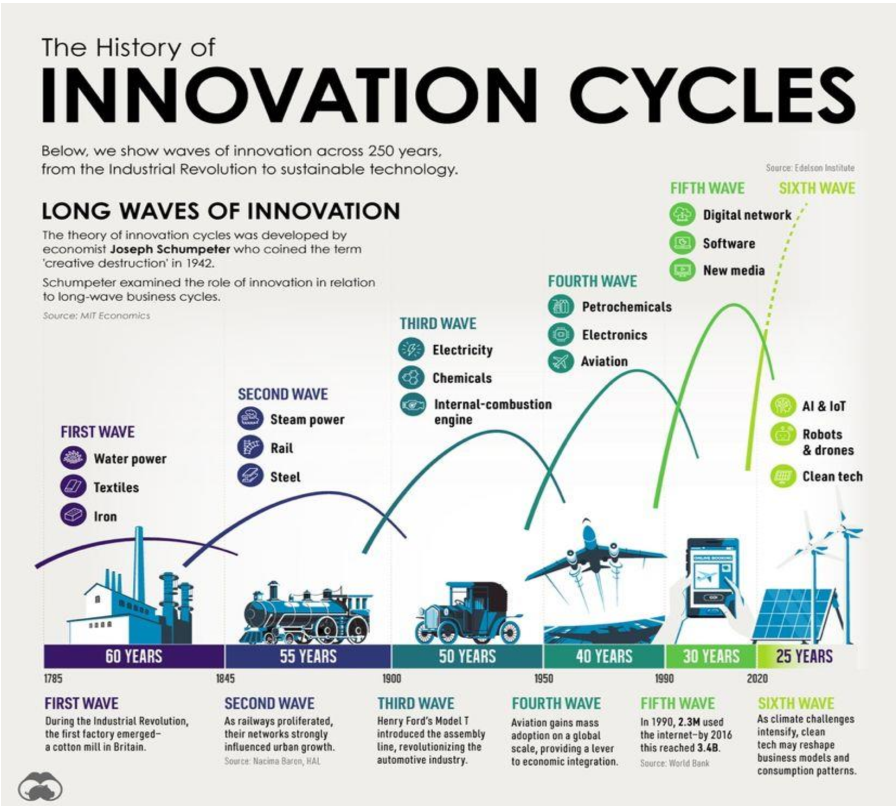

Fig. 2.1. Innovation cycles of the world economy since 1785 [Majchrzyk, 2021]

From the first wave of textile and hydropower development in the Industrial Revolution to the Internet in the 1990s, humanity has experienced six waves of innovation and solved the problems associated with their key breakthroughs. **During the first wave of the Industrial Revolution,** hydropower played a key role in the production of paper, textiles and iron products. Unlike the mills of the past, full-scale dams powered turbines using complex belt systems. Advances in the textile industry brought the first factory, and cities grew around them. With **the Second Wave**, between about 1845 and 1900, significant advances were made in rail, steam, and steel transportation. The railroad industry itself influenced countless industries, from iron and oil to steel and copper. This contributed to the creation of large railway monopolies. The advent of electricity to power light and telephone communications during **the Third Wave** dominated the first half of the 20th century. Henry Ford introduced the Model T, and the assembly line changed the automotive industry. Cars were closely associated with the expansion of the American metropolis. Later, **in the fourth wave**, aviation revolutionized the travel and tourism industry. After the appearance of the Internet in the early 1990s, barriers to access to information completely disappeared. New media changed political discourse, news cycles, and communications in **the fifth wave**. The Internet has marked a new frontier of globalization, a borderless landscape of digital information flows. **The sixth wave**, marked by artificial intelligence and the digitization of everyday objects (IoT), robotics and drones, currently paints a completely new picture of the world and economy [Majchrzyk, 2021].

Being fully aware of the changes taking place, and especially the pace of the transforming economy, the JSW Management Board noted in the Company's Strategy for 2018÷2030 that the ongoing digitization of the global mining sector as an element of the industrial revolution in mining is a unique opportunity for the JSW Group to increase resilience of its national industrial supply chains, improve the environmental performance of the minerals sector, and increase transparency and dialogue with citizens and communities affected by mining activities.

2.1. The history of the development of IT and industrial automation in the JSW Group

The beginning of organized IT in the Jastrzębie mines is associated with the establishment of the Information Technology Center (CIROW) on November 1, 1998. The company was established on the basis of IT services of mines as a result of the restructuring of the Polish mining industry, and its partners were employees of the IT Departments of JSW and the Central Mining IT Center (COIG), branch No. 6 in Rybnik, and legal entities, i.e.: JSW and COIG.

From the beginning of its operations, the company's basic tasks were to provide comprehensive IT services for companies of the JSW capital group. CIROW did not have branches because the nature of its business required the implementation of some tasks directly at the clients' premises. The organizational structure of the company reflects the model of providing services in the field of direct IT support, organizing work in 11 locations. Due to the takeover of IT services in individual works and companies of the JSW Group, teams were created to service customers according to geographical division. This method of operation resulted in the duplication of many functions and overlapping of responsibilities for individual areas, and the support model was based mainly on local teams, which generated too high costs. This state of affairs led to the decision to further integrate IT within the JSW Group.

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The next stage of integration of the IT area took place in 2009, when JSW SA became the majority owner of CIROW by purchasing shares from natural persons - employees. In the initial period of CIROW's operation, the scope of support for JSW SA plants focused mainly on activities in the area of infrastructure and IT systems supporting administrative and office activities (IT), which did not include support for operational and production areas (OT). In 2011, when JSW SA debuted on the Stock Exchange, the CIROW’s name was changed to Advicom Ltd.

JSW Group going public significantly accelerated the process of building and consolidating the Group, which contributed to the standardization and centralization of office infrastructure in the area of IT, as well as the development of systems supporting the settlement of transactions in financial terms (ERP). During this period, individual companies of the JSW Group still had their own independent IT organizations. Therefore, striving for corporate consolidation of the JSW Group, we started to introduce one standard for the scope of IT services in the Group, enabling the effective provision of IT services. For this purpose, in 2011, the Management Board developed and adopted the "Strategy of the JSW Group in the field of IT support for the JSW Group for the years 2011÷2015", which focused mainly on the centralization and consolidation of IT functions in the Group, which were to ensure unification and improvement of quality IT services for key economic processes implemented throughout the JSW Group.

The historical context of the involvement of IT companies CIROW, Advicom and JSW IT Systems in the development of the JSW Group along with the change in the Company's share structure in the period from 1998 to 2021 is presented in Fig. 2.2.

Centralization of activities in the field of computerization of the JSW Group allowed for building competences and support processes for the most important business areas and improving the scope and quality of IT services. Additionally, uniform technological standards and uniform service processes (Central IT Helpdesk) were introduced, thereby increasing the stability, quality and security of the IT environment throughout the Group.

Important and fundamental for the initiatives undertaken is the fact that the Strategy of 2011, which was updated in 2014, introduced a service model in the Group, in which the first SLAs (Service Level Agreements) were concluded and the Integrated Management System was implemented, basing on the PN-ISO/IEC 27001 and PN-ISO/IEC 20000 standards.

Another breakthrough in the computerization of the JSW SA Group was in 2015, when Advicom carried out an organizational transformation by launching a new functional operating model that allows for the effective and stable quality provision of a wide range of IT services for the entire JSW SA Capital Group.

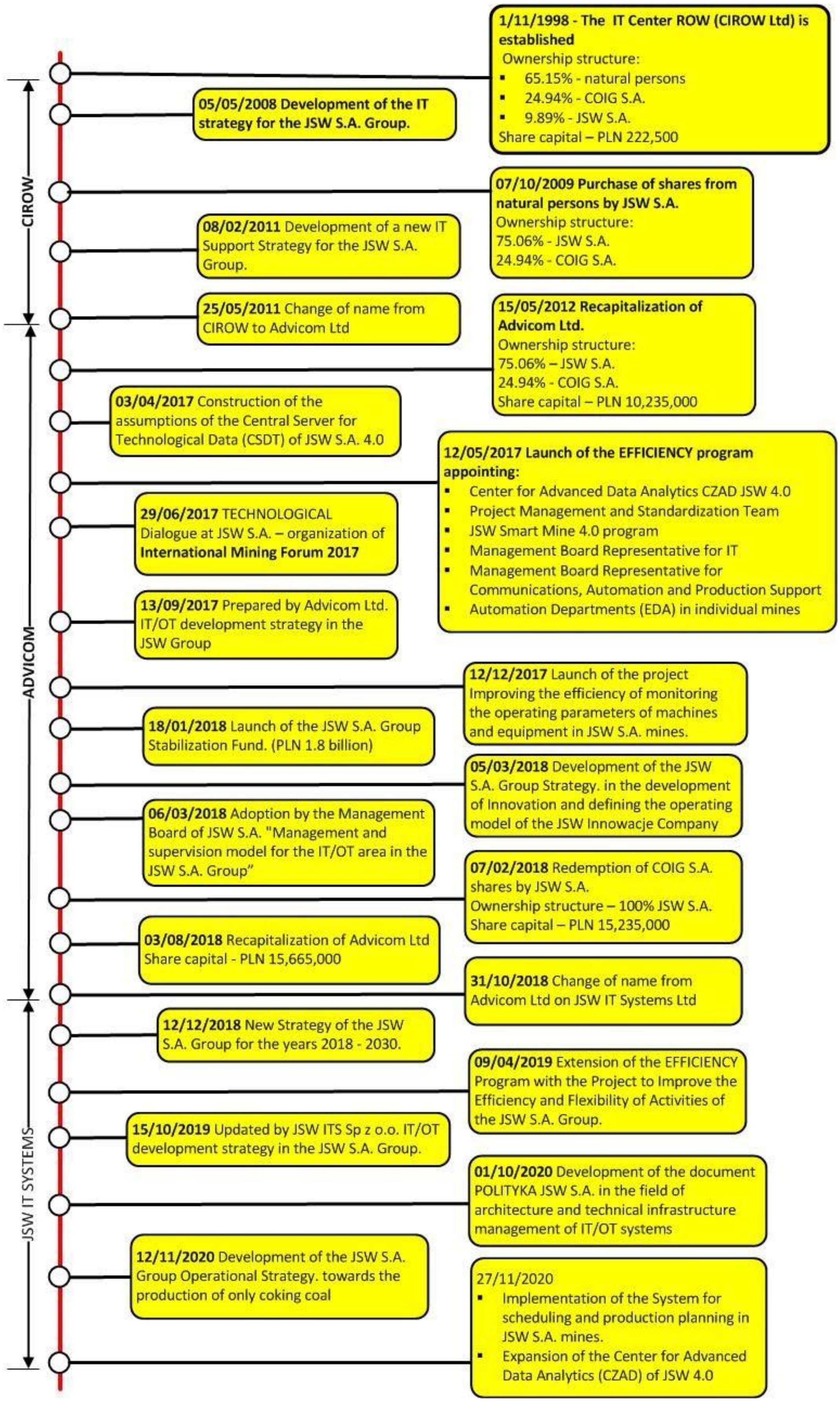

Fig. 2.2. Historical context of the involvement of IT companies CIROW/ Advicom /JSW IT System in the development of the JSW SA Group over the years 1998÷2020

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This model was changed in 2017 by introducing functional management and supervision over the IT area of the JSW Group, not only in the traditionally understood IT, but primarily towards the development of industrial IT supporting coal mining, processing and coke production [Ozon, 2017; Ozon, 2019]. During preparation for this model, over 90 projects in the area of Data Governance were identified and launched, improving the IT network infrastructure and changing the knowledge management system. New investment directions were set, the organization of the main business processes was changed - also on the side of mining plants, the functional scope and required competences of entire teams were changed, and the architecture and technical infrastructure management policy of IT/OT systems were organized and standardized – Fig. 2.3. [Ozon, 2017; Ozone, 2019]. Ultimately, the new model of management and supervision over the IT/OT area in the JSW Group was approved on March 6, 2018 by the JSW Management Board and currently constitutes the foundation of the business processes of the entire Group.

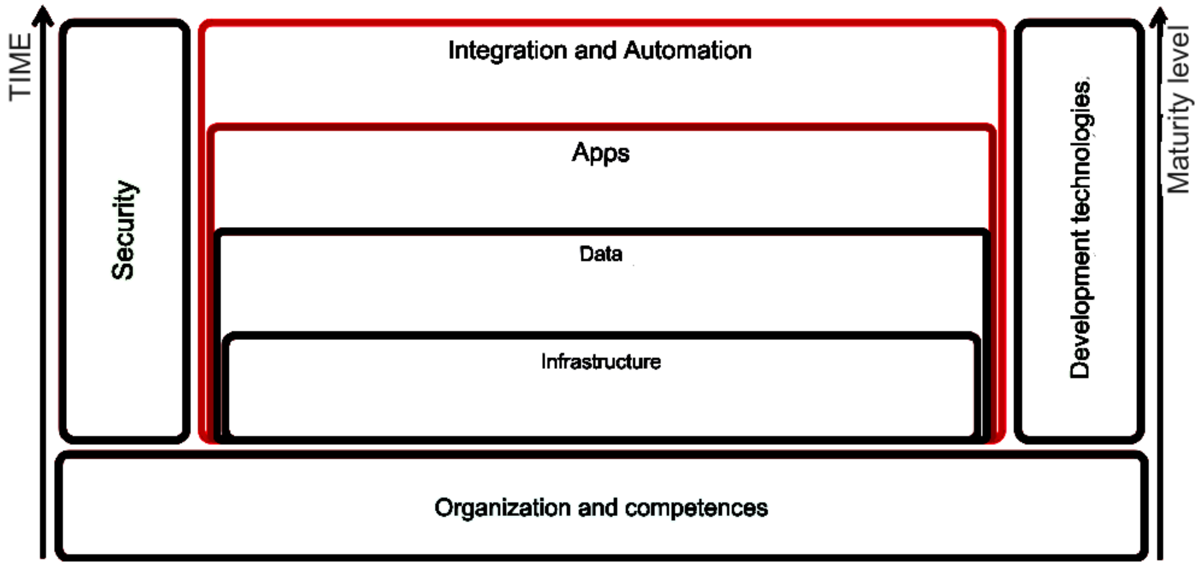

Fig. 2.3. A new model of IT/OT architecture in the JSW SA Group [Ozon, 2019]

Another milestone in the technical and organizational transformation in the JSW SA Group was the Board of JSW SA introducing the new JSW SA business strategy for 2018÷2030, in which, for the first time in history, the strategic goal, apart from increasing the value of the Capital Group, was **independence of the core business from business cycles and changes in coal prices**.

The current business model of the JSW Group for 2018÷2030 is presented in Fig. 2.4.

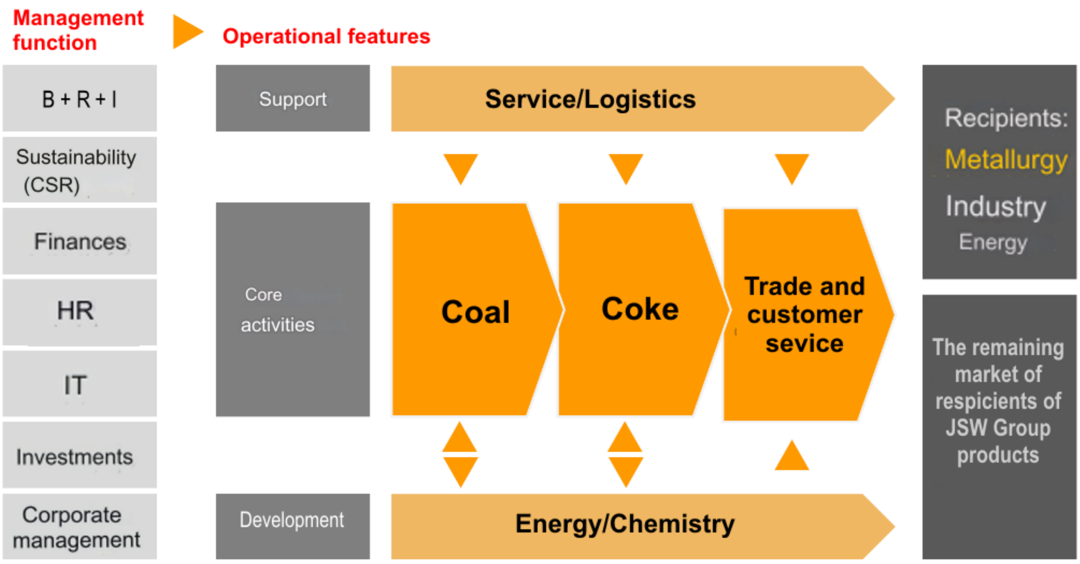

Fig. 2.4. The business model of the JSW Group presented in the strategy for 2018÷2030 [Ozon, 2017]

The new business strategy of JSW SA for 2018÷2030 forced a fundamental change in the approach to IT management in the entire coal and coke group, which was reflected already in October 2019 in the new IT/OT development strategy in the JSW Group, where new tasks related to were the maintenance and development of IT in the areas of telecommunications and industrial automation of the entire JSW Group. In the strategy, taking into account the target **reference model of the IT/OT architecture,** a total of 33 strategic **technical projects were defined** under individual **strategic pillars** and **strategic and tactical objectives,** grouped in 4 **strategic pillars,** covering a total of 61 **partial projects** – Fig. 2.5.

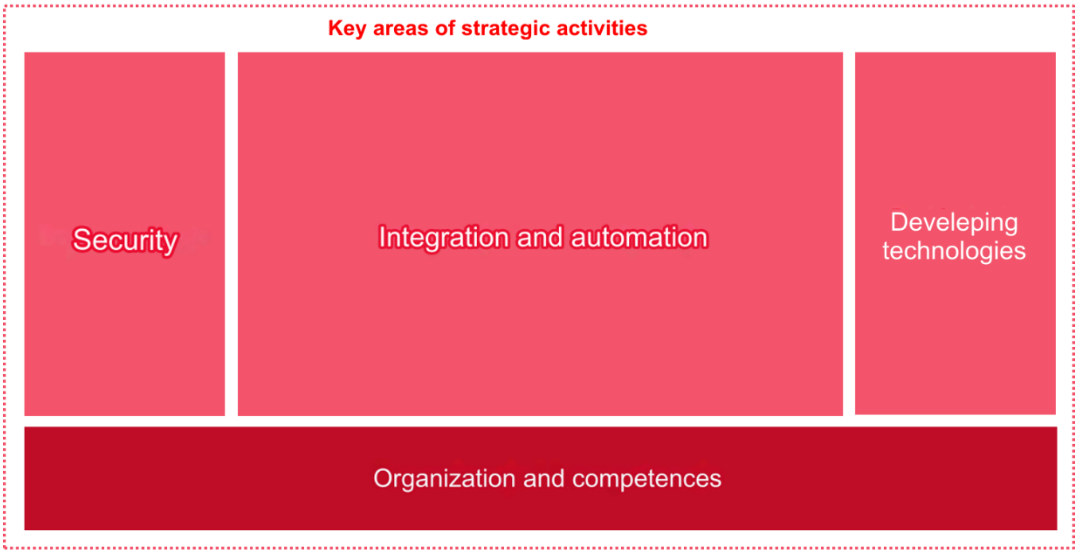

Fig. 2.5. IT/OT Architecture Reference Model – **Strategic Objectives** [Podsumowanie zarządcze, 2017]

A key element resulting from the analysis of the business context of the JSW SA Strategy for 2018÷2030 is the role of the IT/OT area in directly or indirectly supporting key areas of the value chain of the entire JSW SA Group. One of the basic tools for achieving strategic goals in the business strategy is the **Efficiency and Smart Mine JSW 4.0. program**, focusing on the digitization and automation of key economic processes of the JSW Group – Fig. 2.6.

Fig. 2.6. IT/OT architecture reference model – **tactical goals** [Ozon, 2019]

2.2. Model of management and supervision over the IT/OT area in the JSW Group

A key element during the update of the IT/OT Strategy in the JSW Group, determining the assumptions and strategic goals, was the identification of the needs, challenges and expectations of the JSW Group with regard to IT, both in the business sphere as well as in other other spheres, and in particular defining the Pillars for building the Business Strategy through IT [Ozon, 2019].

The existing Pillars of building a business strategy by IT focused on increasing the Efficiency of production organization, Efficiency of processes (in the areas of support, development and management processes) and Efficiency of decision-making, providing tools to achieve the above-mentioned goals. Innovation was indicated as the foundation of these activities, which was to be the basis of the approach and the solutions used – Fig. 2.7.

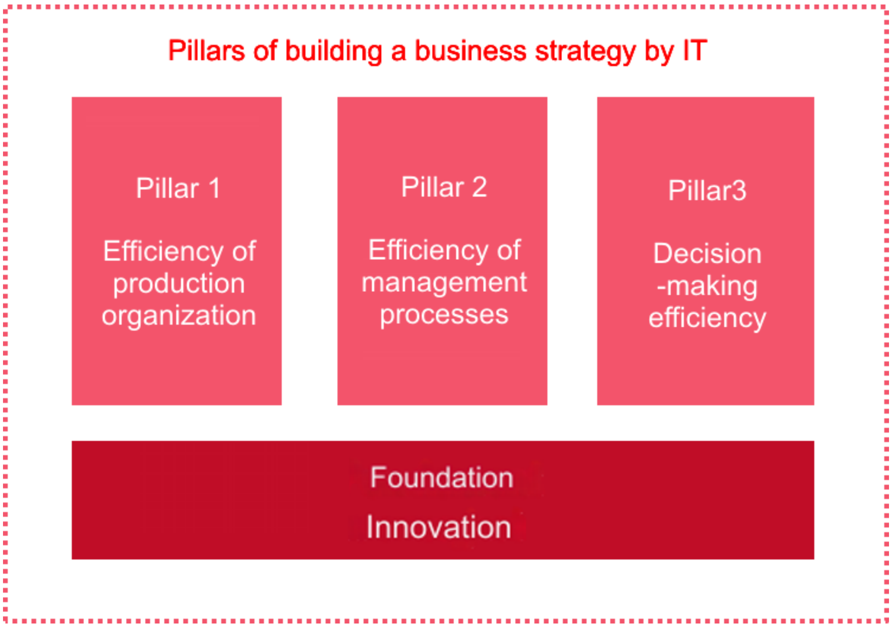

Fig. 2.7. Current Pillars of building the JSW Group's business strategy through IT [Ozon, 2019]

The business strategy of the JSW Group defined the vision of the JSW Group as a key supplier of strategic raw materials for the steel industry, hence the core activity of the JSW Group was and is the mining and processing of coking coal. The vision of the JSW Group also defines a new role of IT, in particular automation and computerization of the production line, as one of the elements supporting the strengthening of the position of a leading and innovative producer of coking coal and a leading supplier of coke on the European market. Other areas influencing the strengthening of the market leader's position include the quality of the products offered, innovations, occupational safety and environmental protection.

The business model of the JSW Group's core operations included the full cycle of coal mining and coke production (including trade and end customer service). Additionally, development areas were strengthened, in particular in the area of energy and chemicals, where a large potential for optimization in R&D areas was identified. The basic support functions (service, logistics, services) and management functions of the Group were intended to actively support the core business area of the JSW Group.

As already mentioned, JSW operates in a difficult, rapidly changing business environment, which imposes a number of conditions and requirements on the company in relation to expectations resulting directly from the implemented business strategy. The developed strategy for 2018÷2030 indicated that key non-strategic business expectations regarding IT result from both the increase in expectations related to the increase in the Company's security level (confirmed by the Zofiówka mine section disaster) and structural changes of the JSW Group related to the acquisition and integration of new business entities (takeover of PBSz), as well as increasing the efficiency and effectiveness of operations and the level of maturity of IT management processes and adapting the scope and competences of the IT team to the implementation of strategic projects – Fig. 2.8.

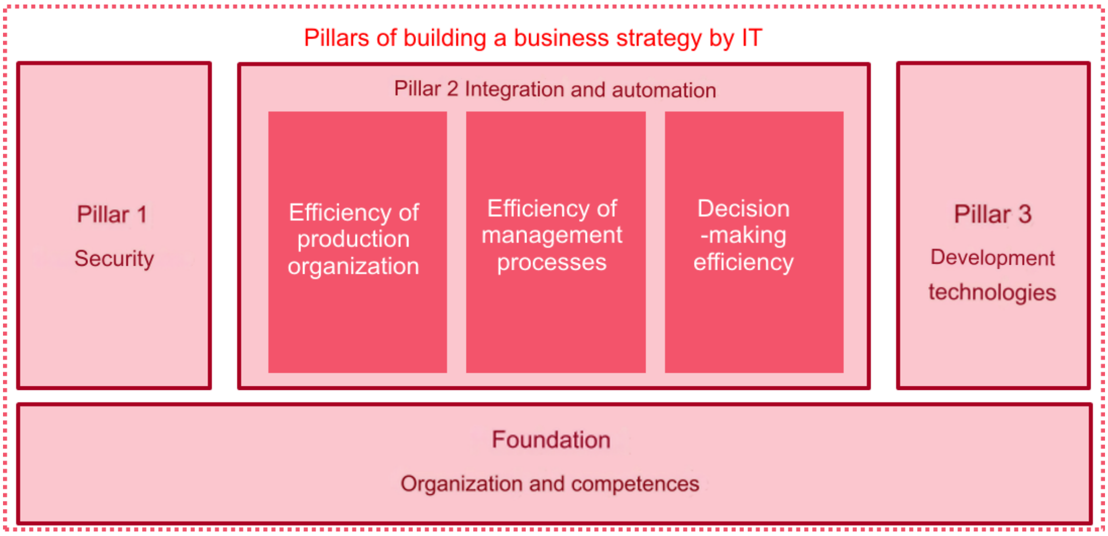

Fig. 2.8. Updated pillars of building the JSW Group's business strategy through IT [Ozon, 2019]

The new list of challenges and expectations towards IT consisted of eight IT challenges resulting from the JSW Group Strategy and five business expectations, other than strategic (non-strategic). During the preparation of the new strategy, current challenges and expectations were verified, divided into strategic and non-strategic based on the expected challenges in 2018÷2030, including:

- stabilization of coke production and sales and modernization of processing plants in terms of supporting the computerization and digitization of individual infrastructure elements in key business processes (production), optimizing the process of monitoring these processes and supporting the implementation of the QUALITY PROGRAM;
- increasing the safety of mining crews, leaving the priorities for the JSW Group unchanged. Safety, which has always played and still plays a large role in all activities IT/OT area, which may increase the security of both crews and data system, will be a priority in the implementation of the IT/OT Strategy;
- providing IT/OT infrastructure for existing plants and new mining fields (equipping new mines);

- ensuring standardization and consistency of IT/OT architecture for enterprises acquired by the JSW Group in order to expand the portfolio of products and services provided by JSW;
- ensuring an increase in the efficiency of core and auxiliary operations, which, as it was agreed, would not be possible to achieve without IT/OT support;
- stimulation of innovation of the JSW Group, which continues to be a priority for business and an element that directly affects the competitive advantage of JSW SA on the market.

The new PILLARS of the JSW Group Strategy in the IT/OT area have redefined the list of key business expectations and structural and organizational changes, including:

- Increasing the level of security, taking into account the disaster in the Zofiówka Mine. This requirement applies to both IT support in the field of crew safety, operational security and cybersecurity;
- Increased innovation in the field of applied technologies and solutions both in the scope of core activities, development areas such as energy and chemical projects (e.g. optimization of energy consumption, optimization of ventilation and methane drainage processes, optimization of production processes in the chemical area, etc.), management processes and support of the JSW Group;
- Development and adaptation of IT competences and implementation capabilities, in particular in the field of integration and automation of IT and OT systems, software development and cybersecurity. Appropriate management of resources and competences should enable support for the implementation of the IT/OT Strategy, implementation of strategic development projects related to, for example, the design, preparation and implementation of projects related to the construction of new mines, e.g. for the Bzie-Dębina mine or support for projects related to ongoing purchase transactions. and integration of the acquired companies {Post Merger Integration projects, e.g. PBSz}, i.e. activities *related* to carrying out integration projects in the field of architecture and providing appropriate IT support;
- Optimization of architecture management and optimization of development and operation/maintenance costs of the IT/OT environment in the JSW Group;
- Ensuring implementation capabilities and improving the quality and efficiency of processes related to the provision of the required IT service portfolio.

The key assumption adopted when creating the new IT/OT Strategy was that the individual defined strategic IT/OT activities must support the key pillars of building the JSW Group's business strategy. Therefore, the basis for developing a new IT/OT Strategy was to define the key Pillars for building the JSW Group's business strategy through IT. Each Pillar defined the area in which IT, implementing the IT/OT Strategy for the JSW Group, should create added value for the entire Group [Ozon 2019].

As already mentioned above, the previous Pillars of building the Group's business strategy through IT focused on increasing the efficiency of production organization, process efficiency (in the areas of support, development and management processes) and the effectiveness of decision-making, providing tools to achieve the above-mentioned goals. Innovation was indicated as the foundation of new activities, which was to be the basis of the approach and the solutions used.

The foundation of the new strategy was an efficient IT organization, equipped with an appropriate set of competences, on which a set of integrated and automated IT solutions was built, supporting the efficiency of production, management processes and decision-making, making use of the new technologies. In accordance with the adopted concept, the following strategic areas were recognized as key strategic activities in the updated IT/OT Strategy of the JSW Group: security, integration and automation, development technologies, organization and competences.

Updated strategic and non-strategic expectations defining IT requirements and the main pillars of building the JSW Group's business strategy constituted the basis for redefining the Mission and Vision of IT in the JSW Group and setting the plan for:

– IT Governance management model *(IT Management)*,
– IT/OT architecture model,
– model of relationships with IT/OT service and infrastructure providers,

In other words, the IT/OT Strategy in the JSW SA Group was updated, which translated into updated Strategic and Tactical Goals and the Strategic Project Portfolio.

In Fig. 2.9. schematic connections of individual elements of the IT/OT Strategy are presented.

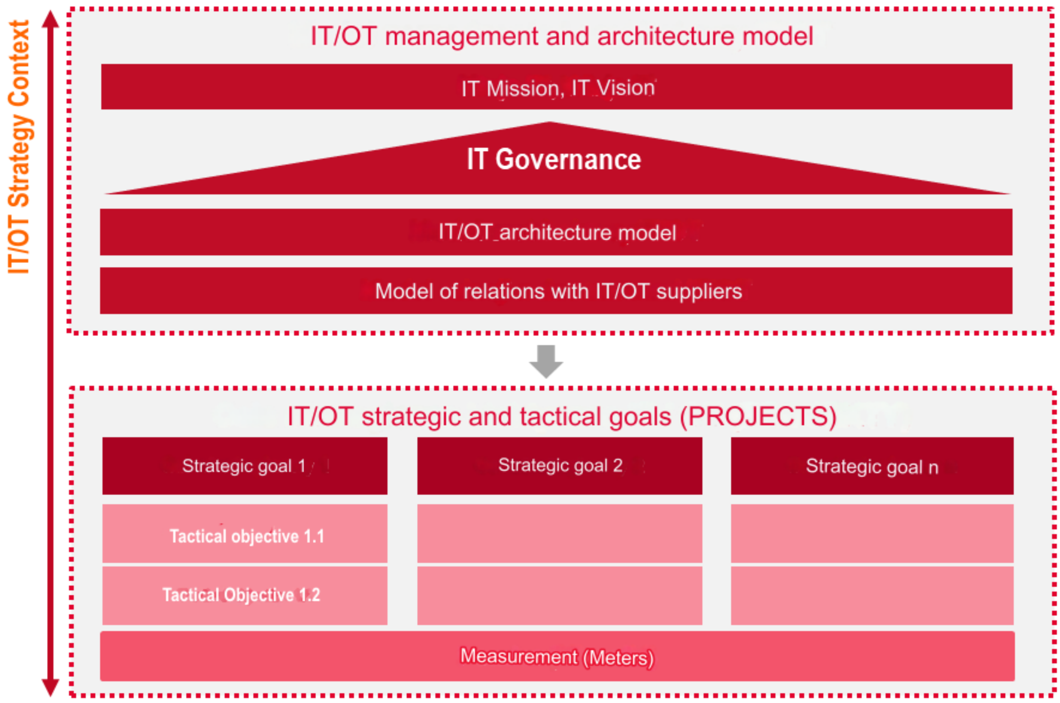

Fig. 2.9. IT/OT Strategy Context [Podsumowanie zarządcze, 2017]

The current mission of the IT/OT area assumes that IT is a provider of the highest quality services, in accordance with the needs and in close cooperation with the JSW Group companies, in a cost-effective manner and striving for continuous improvement of IT functions.

Taking into account the increasing level of technological advancement and current activities in the IT/OT areas, it became necessary to expand the IT Mission, as it was stated that IT should move from a service role to a partner role in creating ideas and implementing solutions used to build the value of the JSW Group. Therefore, the updated IT Mission of the JSW Group was defined as follows [Ozon, 2019]: IT, working with the JSW Group companies in a partnership model, creates innovative ideas and provides modern IT/OT technological solutions that increase the efficiency, quality and security of key economic processes.

The current vision of IT/OT was focused on IT supporting business areas and using innovation, assuming that IT actively increases the value and efficiency of the JSW Group and provides a platform and co-creates innovations. However, taking into account the changing business needs, technological advance and increasing process and organizational maturity and IT/OT architecture, both on the business side of the JSW Group and on the JSW ITS side, it became necessary to also update the IT/OT vision in the JSW Group. During the conducted analyses, it was identified that the IT/OT vision should refer to a broader extent to the issue of increasing the integration and use of telecommunications (OT) data to optimize and automate entire business processes in the full coal and coke production cycle among companies within the JSW Group.

Therefore, the new vision of IT and OT in the JSW Group was defined as follows: IT actively increases the value, efficiency and security of the JSW Group through integration and process automation and innovative IT/OT solutions [Ozon, 2019].

The current IT/OT Strategy assumed the establishment of the CIO Office at the JSW level in order to centralize the management of all IT areas and the IT/OT Strategy project. As part of the operationalization of the new IT/OT Strategy, the "Model of management and supervision of the IT/OT area in the JSW Group" was developed and implemented. The model adopted on March 6, 2018 assumed the establishment of an IT Team within the Investment and Computerization Office in JSW and an IT Representative in the JSW Group, who is also the President of the Management Board of JSW ITS and the Communications and Automation Representative cooperating with the IT Representative. The proposed personal union allowed for organizing the IT and OT area in the JSW Group by transferring key functions of the CIO Office from the level of JSW to JSW ITS, which significantly accelerated the decision-making process. This model made it possible to centralize and organize the division of competences within individual structures in terms of responsibility for the implementation of the IT/OT Strategy. In order to coordinate all activities related to the implementation of the new IT/OT Strategy, the IT/OT Strategy Implementation Program was launched, which, in accordance with the assumptions of the IT/OT Strategy, included:

- a full range of business tasks in the coal-coke cycle (including both mining and coking processes, as well as important development processes, e.g. chemistry, energy and management and support processes, respectively),
- integration of IT and OT solutions,
- synergy of the solutions in the application layer, using already implemented solutions at the infrastructure level.

The IT/OT Strategy implementation program was supervised by the proposed Management Structure and was conducted and monitored in accordance with the Project Management Methodology in the JSW SA Group.

2.3. Management structure of the IT/OT Strategy Implementation Program

In order to integrate and increase the effectiveness of activities under the IT/OT Strategy and to introduce clear responsibility and accountability for its implementation, structures managing the IT/OT Strategy implementation program were established. It was deemed necessary to reactivate and launch the Steering Committee, which included selected members of the JSW Management Board, key business stakeholders and people responsible for Strategy and Development, Investments and Controlling of the Company.

2.3.1. Organizational changes at JSW SA

To improve the activities carried out at JSW in the IT/OT area, a Coordinator of the IT/OT Strategy implementation program was appointed. The program coordinator coordinated all operational activities and, most importantly, managed strategic projects. Additionally, he had the support of the Project Management Office (PMO), the scope of which included:

- defining solution standards in the IT and OT areas,
- management of integrated architecture of IT/OT solutions,
- strategic project management (PMO) under the Program,
- financial controlling of projects implemented under the Program.

The implementation of the IT/OT Strategy at JSW required the creation of the Automation and IT Office at the JSW level, which ultimately organized and consolidated responsibility for all activities carried out in this area at JSW. The Director of the Automation and IT Office eventually also took on the role of supervising the work of the Automation and Teletransmission Team at the level of the Company's Headquarters, coordinating the implemented activities, including: investment in all JSW SA mines, through close cooperation in these areas with the established Mine Automation Departments (EDA), the CZAD Team and the JSW SA IT Team.

Fig. 2.10 shows the relationship model between the Steering Committee of the IT/OT Strategy implementation program, the Coordinator of the IT/OT Strategy implementation program, the IT Management function in JSW ITS as the Support Office for the IT/OT Strategy Implementation Program Coordinator, the Director of the Automation and IT Office in JSW and JSW mines involved in the implementation of strategic projects.

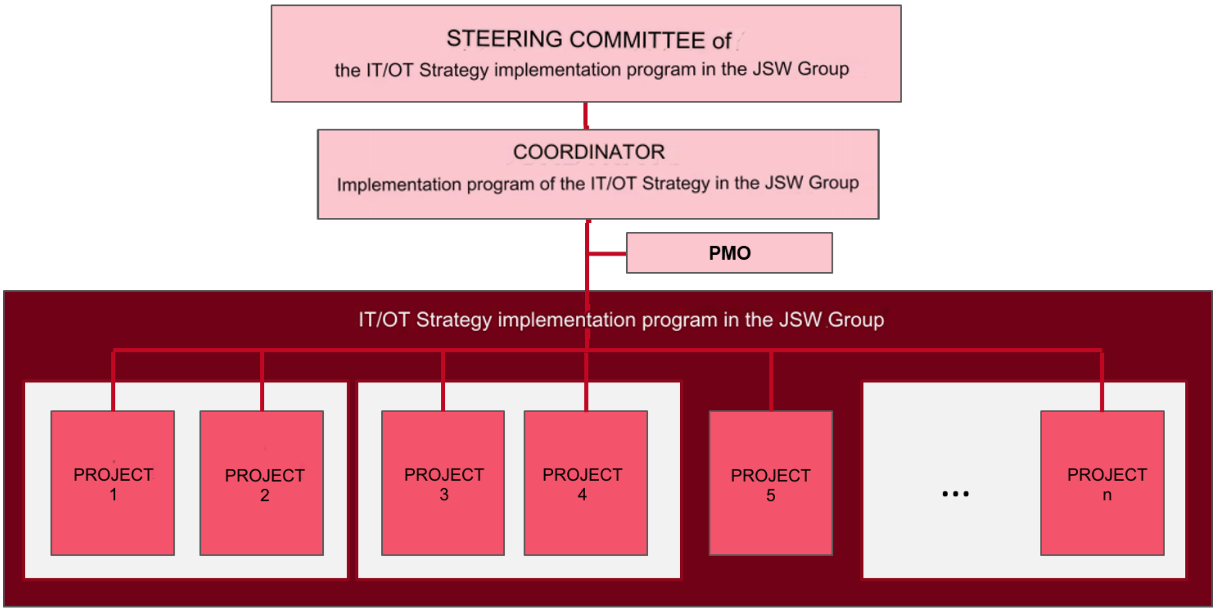

Fig. 2.10. Model of the relationship between the Steering Committee of the IT/OT Strategy Implementation Program [Podsumowanie zarządcze, 2017]

This structure shows how important an element of effective implementation is for the cooperation between the Coordinator of the IT/OT Strategy Implementation Program, the Director of the Automation and IT Office and the Cybersecurity Coordinator at JSW SA, in order to ensure that security requirements, in particular in the area of cybertechnology, which will be met and implemented as part of strategic projects in the area of cybersecurity. Fig. 2.11 shows a diagram of the management structure of the IT/OT Strategy Implementation Program, imposed on the organizational structure of the JSW Group.

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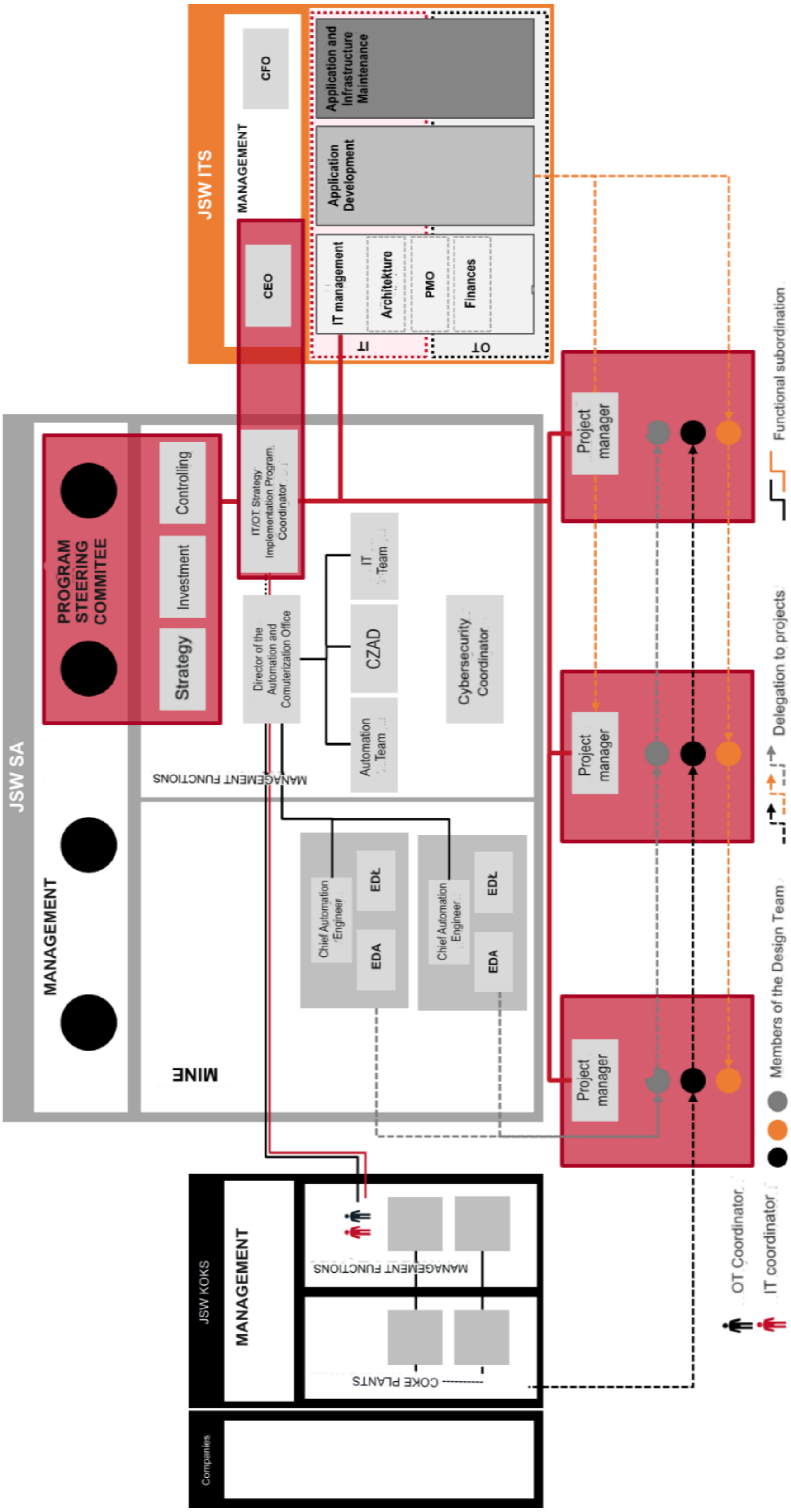

Fig. 2.11. Management structure of the IT/OT Strategy Implementation Program [Podsumowanie zarządcze, 2017]

2.3.2. Update of the management and supervision model of the IT/OT area in the JSW Group

"The model of management and supervision over the IT/OT area in the JSW Group" in force until 2016 was focused primarily on IT projects, therefore the new strategy forced it to be changed and modified in such a way as to:

– extend its scope so that it is not focused on the area of IT projects, but integrates IT/OT areas;
– redefine the scope, division of competences and responsibilities between IT and OT areas, as well as the method of settling costs related to the implementation of the IT/OT Strategy;
– introduce integrating solutions in the scope of coordination and management of project activities related to all IT /OT projects at JSW SA;
– introduce a uniform model for accounting for investment outlays and costs related to implemented projects, maintenance, service and development of implemented IT/OT solutions throughout the JSW Group.

For this purpose, the scope of responsibilities and the operating model of organizational units responsible for ICT solutions in mines were defined, i.e. for the EDA departments - Automation Department and EDŁ - Communication Department, in relation to the IT/OT Strategy projects, the function of Chief Automation Engineer was separated in the mine structures, being in charge of organizational structure of the mine responsible for coordinating the implementation of the IT/OT Strategy in the industrial processes of the mining plant, especially underground. Additionally, to ensure centralization of competences and enable appropriate planning and synchronization of work under the IT/OT Strategy implementation program, the scope of competences and responsibilities of JSW ITS was extended.

An important move, as it turned out in hindsight, was the creation of the Automation and IT Office at the JSW level, which consolidated responsibility for all activities carried out in the IT/OT area in the JSW Group. Its director supervised both the Automation and Teletransmission Teams, coordinating activities within individual mines through cooperation in these areas with the appointed: Chief Automation Engineers, CZAD and the IT Team. Such design of the organizational structure of the new IT/OT Strategy, in particular the cooperation of the coordinator of the IT/OT Strategy implementation program and the Director of the Automation and IT Office, working closely with the JSW Cybersecurity Coordinator, allowed to ensure the ultimate success of the implementation.

In Fig. 2.12 the assumed responsibility model of JSW ITS as a company centralizing services for the IT and OT area in the JSW Group is presented, and Fig. 2.13 shows the required direction of competence changes within the new structure of JSW ITS, enabling the expansion of the competences of this company in key areas, i.e. **management, development** and **maintenance of systems** both in the IT and OT domains.

The development of competences implemented at JSW ITS should cover both the area of IT systems and of OT systems. Transformation activities also require the implementation of effective personnel management methods, in particular in terms of improving recruitment processes and employee retention and location processes.

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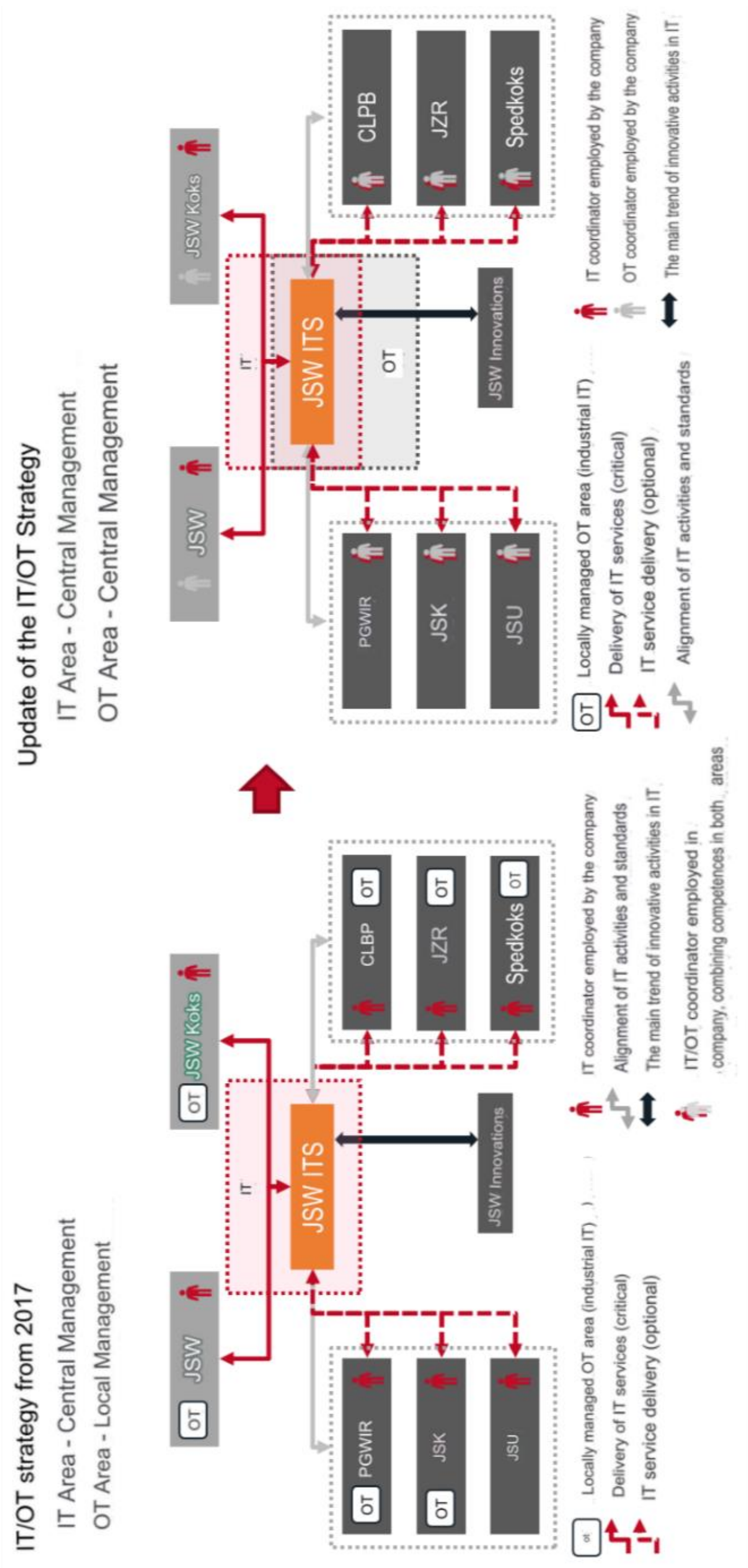
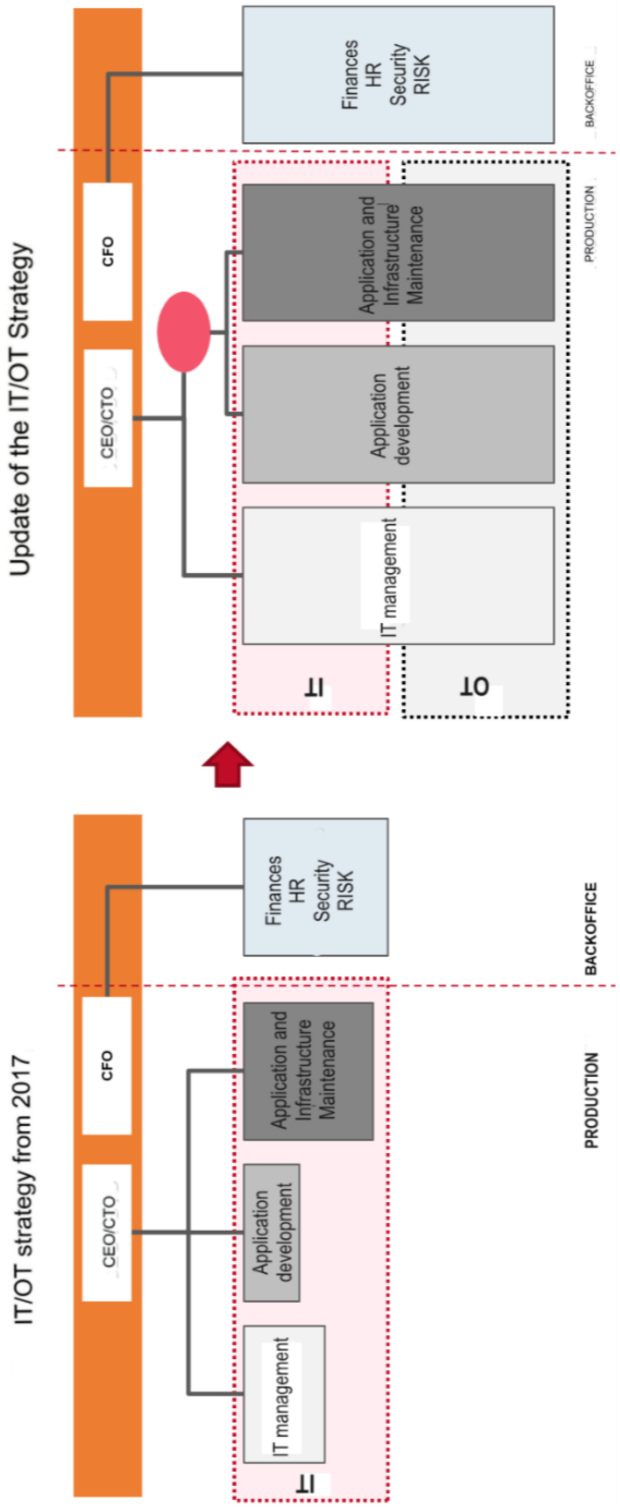


Fig. 2.12. Proposed Structure of the IT/OT Area in 2019 [Podsumowanie zarządcze, 2019]



Rys. 2.13. Proposed functional model of competences within IT/OT areas required for implementation in JSW ITS [Podsumowanie zarządcze, 2017]

In Fig. 2.14 the reference operational model of key business processes supported by JSW ITS in the areas **of Management, Development** and **Maintenance of IT/OT Systems** proposed in the new IT/OT Strategy is presented.

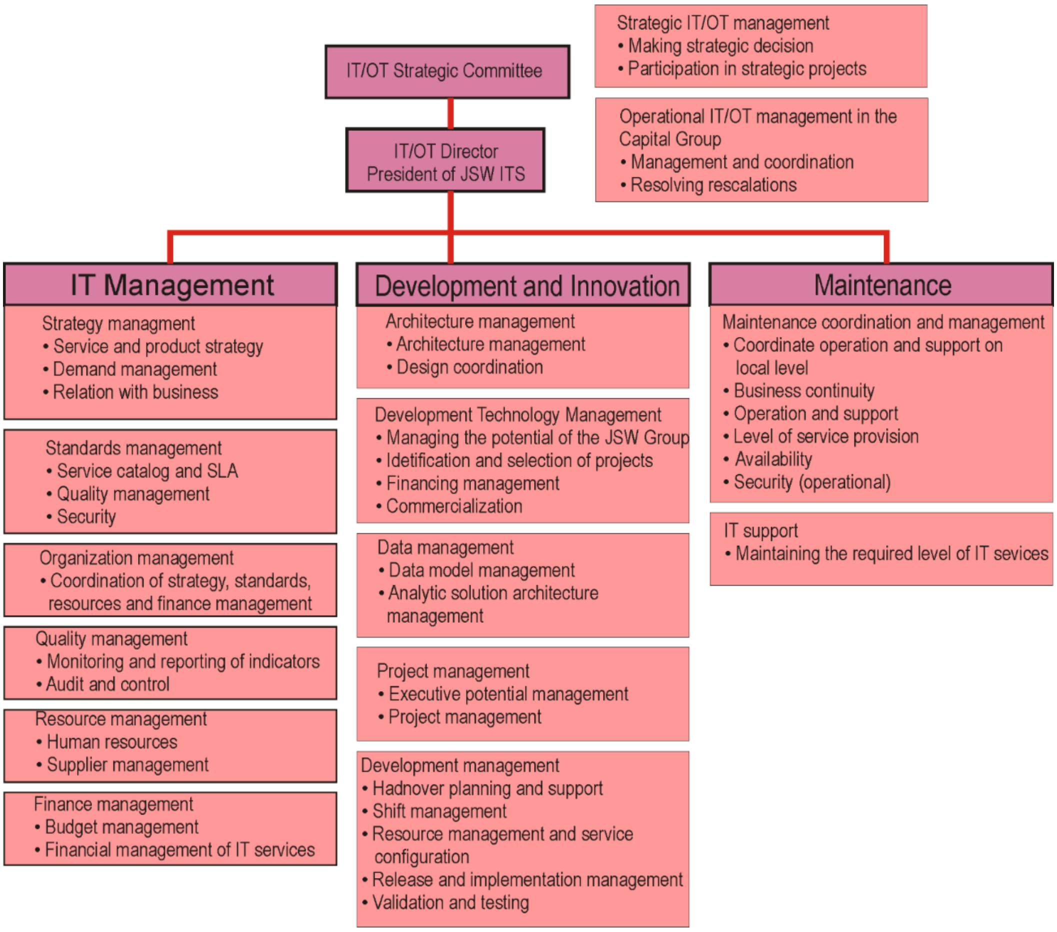


Fig. 2.14. Reference Operating Model and Functional Division [Podsumowanie zarządcze, 2017]

2.4. Assessment of the maturity of IT/OT processes in the JSW SA

During the transformation activities undertaken, the implementation status of the IT/OT Strategy for the JSW Group was analyzed several times, each time trying to assess the maturity of information and technological processes. The assessment was carried out using the COBIT Implementing and Optimizing the Information and Technology Governance Solution methodology, which is an international standard for research and assessment of information security in IT and telecommunications systems. The analysis performed allowed to determine the level of maturity of IT/OT processes in the company and to outline future expectations regarding the efficiency and effectiveness of IT/OT processes, so that the efficient implementation of the IT/OT Strategy and further maintenance of systems at the level required by the Strategy are possible.

As already mentioned, the last assessment of IT/OT process maturity was performed in the JSW Group in 2019, it was based on the COBIT 4.1 model and was conducted for all 34 processes grouped into four areas:

1. "Planning and Organizing",
2. "Acquisition and Implementation",
3. "Delivery and Service",
4. "Monitoring and Evaluation".

Using an original methodology based on the CMM model (Capability Maturity Model), the following process maturity levels were adopted:

1. initiated/ad hoc process,
2. repeatable and intuitive process,
3. defined process,
4. managed and measurable process,
5. optimized process.

Each time, the Strategy maturity assessment resulted from a self-assessment performed by the management staff and key employees of JSW ITS, and the assessment results were subject to in-depth analysis and compared to assessments performed in 2011 and 2014. During the assessment, expected target level of maturity of the processes that should be achieved so that JSW ITS is able to efficiently implement the requirements of the IT/OT Strategy for the JSW Group was also analyzed. Below there is a summary of process groups in 4 areas of analysis, i.e.:

1. **PO Area – Planning and Organizing**
   - PO1 Defining IT strategic plans.
   - PO2 Defining the information architecture.
   - PO3 Determining the directions of technological development.
   - PO4 Defining IT processes and organization and relationships with IT.
   - PO5 IT investment management.
   - PO6 Communication of management objectives.
   - PO7 Human resources management in IT.
   - PO8 Quality management.
   - PO9 IT risk assessment and management.
   - PO10 Project management.
2. **Area A – Acquisition and Implementation**
   - AI1 Defining solutions.
   - AI2 Software acquisition and maintenance.
   - AI3 Acquisition and maintenance of IT infrastructure.
   - AI4 Providing documentation and training.
   - AI5 Purchasing IT resources.
   - AI6 Changing Management.
   - AI7 Installing and approving solutions and changes.

3. **DS Area – Delivery and Service**
   - DS1 Defining and managing service levels.
   - DS2 Supplier Service Management.
   - DS3 Capacity and Performance Management.
   - DS4 Ensuring service continuity.
   - DS5 Ensuring systems security.
   - DS6 Identification and allocation of costs.
   - DS7 User Training.
   - DS8 Service Desk and Incident Management.
   - DS9 Configuration Management.
   - DS10 Problem Management.
   - DS11 Data Management.
   - DS12 Management of the physical environment.
   - DS13 Operations Management.
4. **ME Area – Monitoring and Evaluation**
   - ME1 Monitoring and assessing IT metrics.
   - ME2 Monitoring and assessing internal control.
   - ME3 Ensuring compliance with external requirements.
   - ME4 Ensuring IT Governance.

In Fig. 2.15 a comparison of changes in the maturity level of individual processes in **the Planning and Organizing** group over the years from 2011 to 2019 was presented.

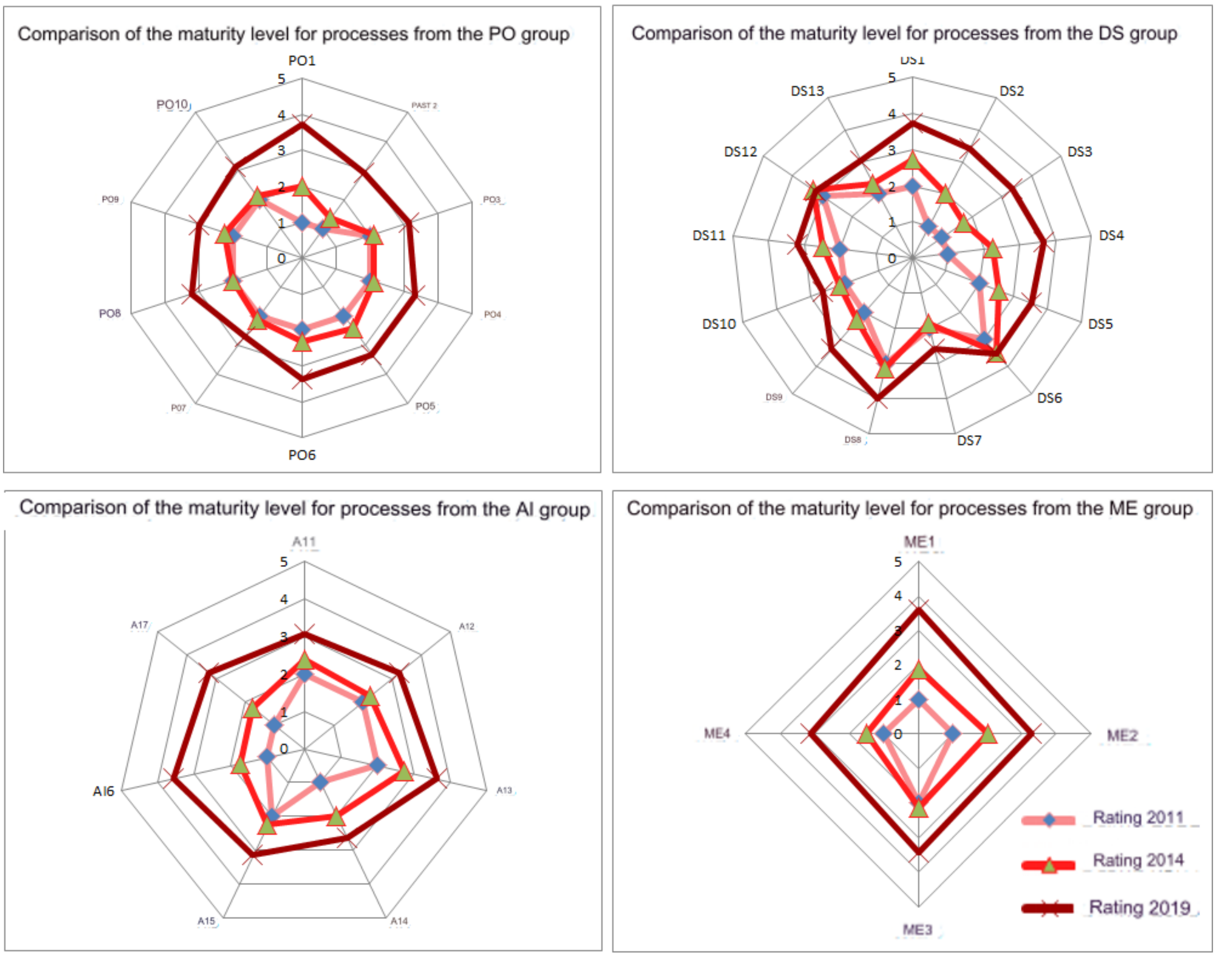


Fig. 2.15. Comparison of changes in the maturity level of individual IT/OT processes in process groups based on assessments made in 2011, 2014 and 2019 [Podsumowanie zarządcze, 2019]

Fig. 2.15 presents a comparison of the assessment of the state of processes over the years 2011÷2019. Based on the results of the conducted analyses, it can be indicated that in the given period there was advance in all processes.

In Fig. 2.16 a comparison between the maturity level expectations in individual processes in 2011 and the achieved maturity in 2019. Apart from selected areas defined in 2011, the expected level of process maturity was achieved already in 2019. For some processes, in particular: PO3, PO4, PO5, PO9, DS9, DS10, DS12, AI1 and AI2, further improvement activities are required to achieve the maturity level assumed in 2011.

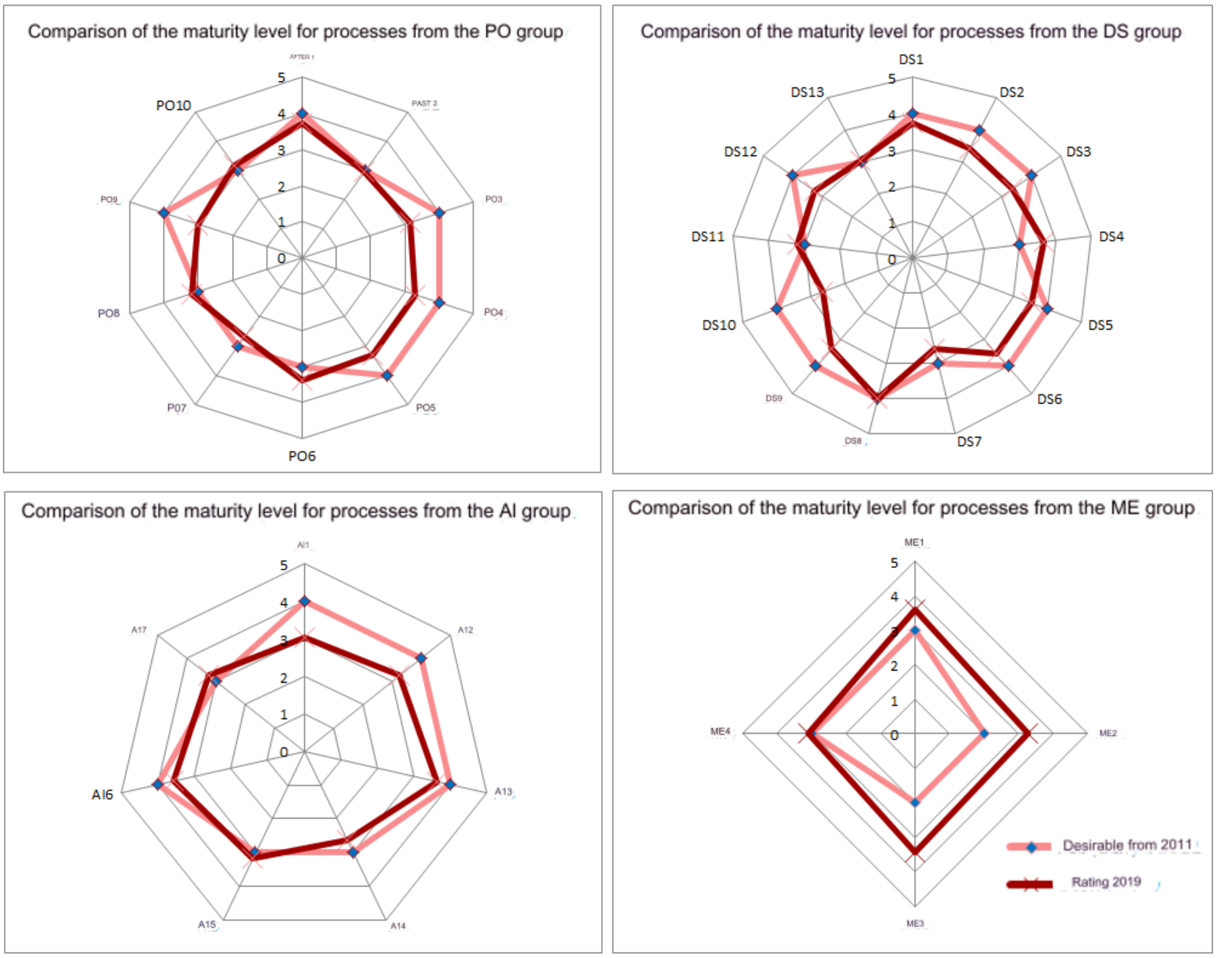


Fig. 2.16. Comparison of maturity level expectations of individual IT/OT processes in 2011 and achieved maturity level in 2019 [Podsumowanie zarządcze, 2017]

In Fig. 2.17 it is presented how expectations regarding the desired level of process maturity change between 2011 and 2019. Increasing the achieved level of maturity increases expectations compared to the desired level.

In Fig. 2.18 a comparison of changes in the maturity level of individual processes from 2011 to 2019 was presented.

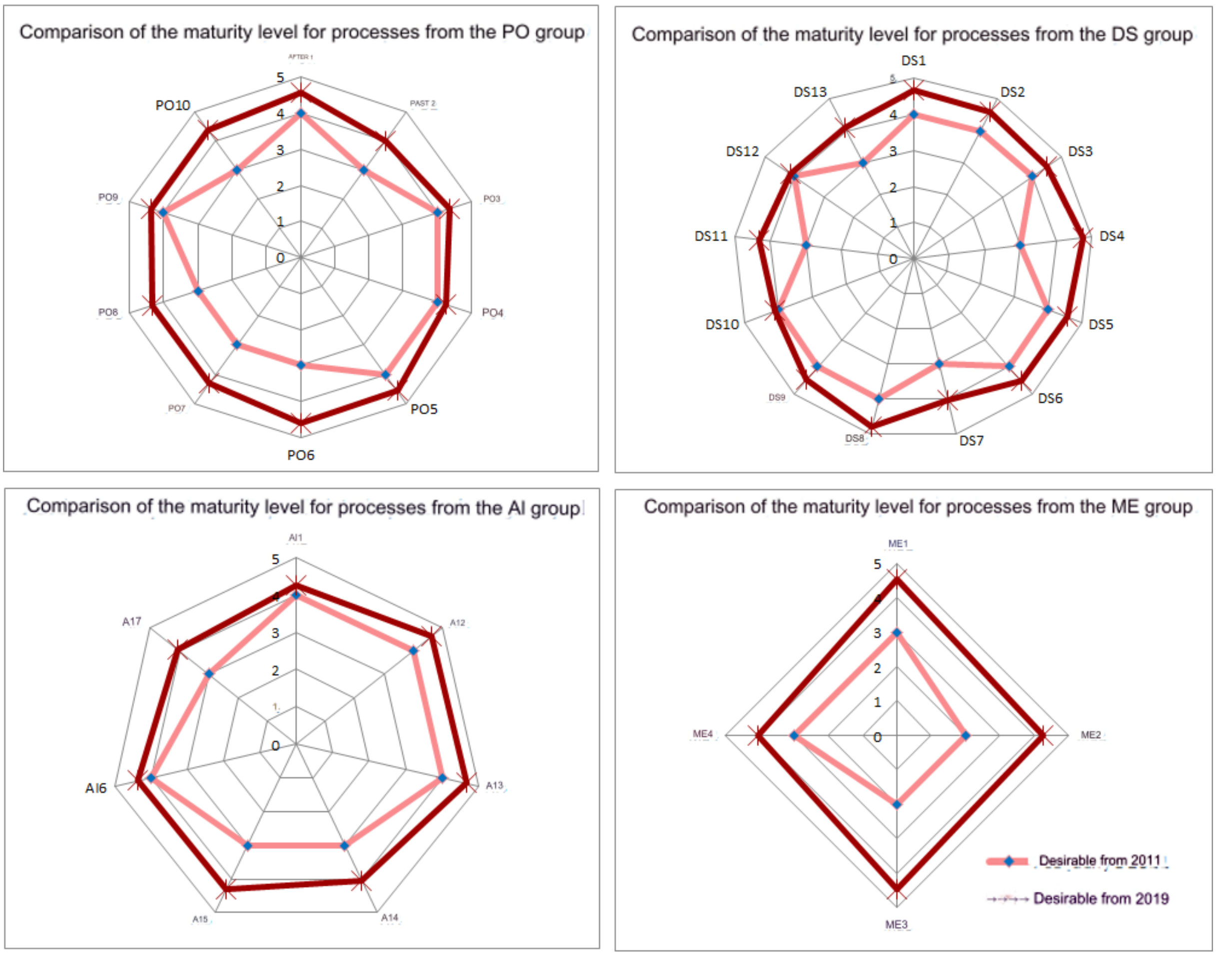


Fig. 2.17. Comparison of changes in the maturity level expectations of individual IT/OT processes from 2011 to 2019 [Podsumowanie zarządcze, 2017]

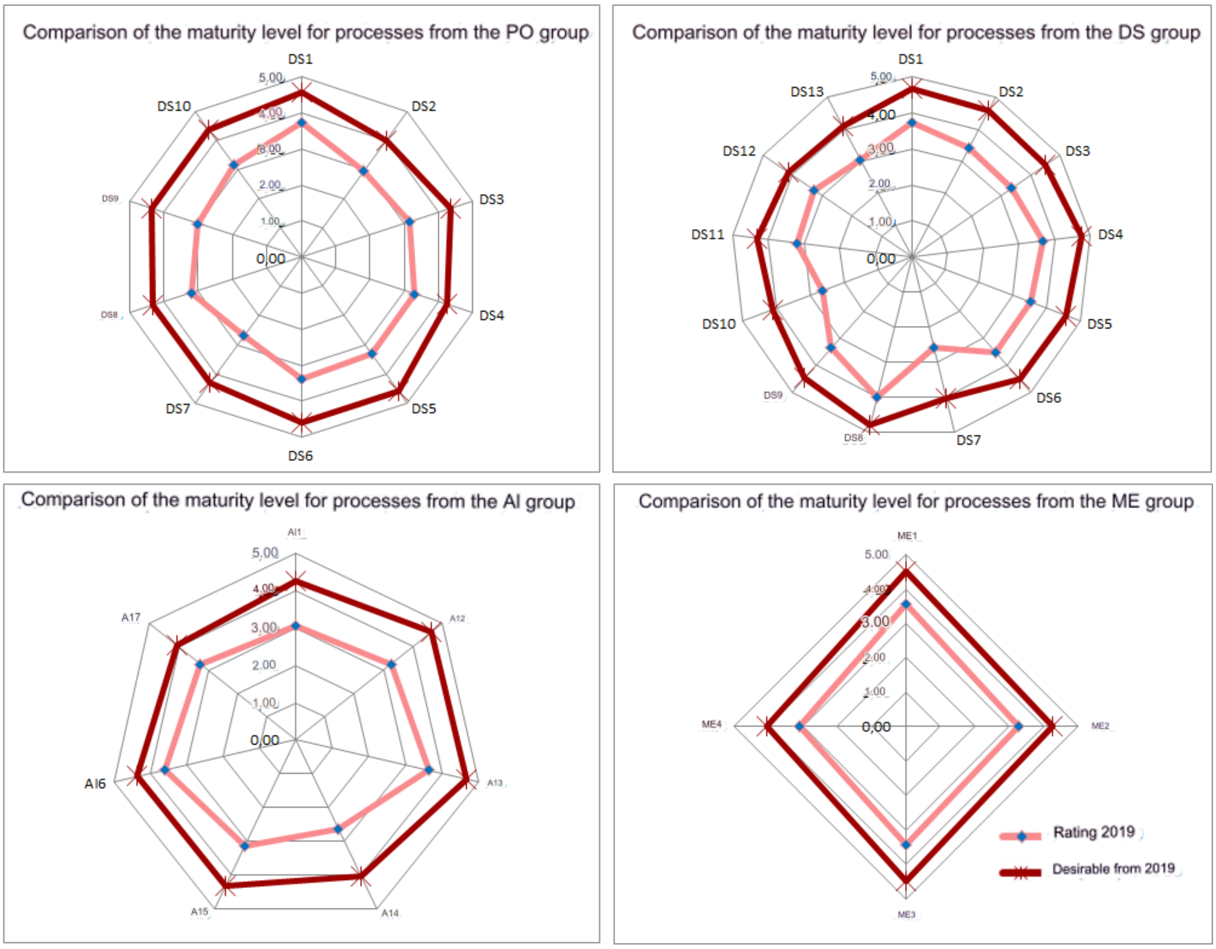


Fig. 2.18. Comparison of changes in the achieved maturity level of individual IT/OT processes from 2011 to 2019 [Podsumowanie zarządcze, 2017]

The above results indicate that over the years in which the analyses were performed, the level of maturity of IT/OT management processes has been increasing systematically. At the same time, as the complexity of systems and new business requirements increased, expectations regarding the efficiency and quality of service in particular areas of IT/OT management also increased.

2.5. Assessment of the transformation of IT/OT processes in the JSW SA

2.5.1. Tasks completed and planned for implementation

The aim of building a new IT/OT functional model in the JSW Group was to increase the efficiency of the organization in the context of challenges related to the planned implementation of IT systems for the Group's business segments. The development of the organization, the acquisition of new service entities and the wide range of services provided required profiling of organizational units to ensure increased efficiency of IT/OT processes and satisfaction of users of the services provided (business customers).

As part of the implemented project, a structure of organizational units has been prepared that will provide new opportunities for IT development by increasing the maturity of processes and increasing the effectiveness of technology, while ensuring development prospects for IT/OT staff. As part of the project portfolio adopted in the Strategy, the following elements of the transformation of IT/OT processes in the JSW Group were identified, important from the point of view of creating a new functional model:

- **eliminating technological debt** in the field of technical infrastructure and communications, enabling the use of modern technologies in control and production process management:
  - the network infrastructure was expanded by laying approximately 170 km of fiber-optic cables and 165 km of radiating cable to expand the radio communication system for transport in underground workings, digital radio communication was launched in the underground workings,
  - continuous monitoring of gas flow at measuring points in methane drainage pipelines was launched,
  - LAN and WAN networks, company server rooms were modernized and the possibility of providing the so-called **private cloud** services was introduced (which imitates the IT service delivery model typical of the so-called "public clouds" but is located in total within the corporate network and serves users of a specific organization),
  - standards and tools for collecting technological data were developed and IT and OT data warehouses were built,
  - a number of cybersecurity solutions have been implemented, in accordance with the accepted technological security architecture model.
- **eliminating technological debt** in the field of applications supporting business areas, which prevented the implementation of more advanced business projects supported by ICT technologies, and systematically increasing the use of IT in business processes:
  - applications supporting key functions performed by individual business areas were launched; these activities enabled, among others, consolidation and analysis of financial data of the entire JSW Group,
  - **Center for Advanced Data Analytics** (**CZAD**) was launched,
  - digital model of exploited deposits was built,
  - the following IT systems have been implemented or significantly developed:
    - uniform Digital Map,
    - SCADA/HADES systems,
    - System Ewidencja EX
    - System PI,
    - ERP systems,
    - Hyperion Planning and Hyperion Financial Management systems,
    - analytical reporting platform – Business Objects,
    - Microsoft Enterprise Project Management System,
    - Electronic Document Circulation – EOD.
- **eliminating technological debt** in the field of data collection and processing, in order to increase the efficiency and increase the effective operation of the entire organization:
  - standardization and acquisition of technological data, commissioning CZAD,
  - implementation of IT/OT data warehouses and analytical and reporting systems,

- development of analytical and reporting systems and management information dashboards (MIS),
- construction of the Central Reactive Power Compensation System.

Additionally, a number of activities were implemented to support IT/OT technologies in two strategic programs: Quality and Efficiency.

2.5.2. Transformation of the IT/OT area – Quality Program

As part of the Quality Program, a Quality Policy was adopted and work was carried out which enabled the introduction of strategic production and product quality management for the first time in the history of the JSW Group. For this purpose:

- Systems were implemented in the area **of reconnaissance of coal deposits, development of 3D maps**, modeling of expected parameters of extracted coal, possibility of analyzing the most effective mining paths - **expansion of the Unified Digital Map** with qualitative and simulation aspects,
- Actions were taken to implement the LIMS **quality research management system**. *Laboratory Information Management System)* in CLP-B (Central Measurement and Research Laboratory, belonging to the JSW Group), which aims to define quality data flow paths between industry systems, digitization and increasing the frequency of the qualitative testing process of mining and processing products, feedback integration with predictive models and management – digitization of processes in CLP-B**,**
- **The construction of an integration layer** was started so that all quality data would go to the central quality management system, which will monitor the quality of the deposit, plan production and quality, control and monitor the quality of production processes, and integrated reporting in the full production, logistics and commercialization,
- Based on the analysis of data inputs and outputs, **measurement standards** of ZMPW and the underground part of mine were developed in order to obtain information on the quality and volume of production, which was to allow the selection **of key parameters for controlling technological processes**. Specific technical requirements for the measurement system made it possible to take action in scope of design and implementation for production of a conveyor belt strain gauge scales produced by JZR - IIoT device *(Industrial Internet of Things)* own production.

2.5.3. Transformation of the IT/OT area – Efficiency Program

As part of the Efficiency Program, in order to keep monitoring systems and teletransmission infrastructure fully operational, **automation departments were established** in all JSW mines. Additionally, **selected technological processes** relevant to maintenance in mines were monitored, and **CZAD was prepared and implemented**. Additionally, JSW SA implemented organizational and technical solutions in the field of:

- improving efficiency in **monitoring the operation of machines and devices** in mines,
- expansion of **teletransmission networks - fiber optic**,
- starting **monitoring of key machines** responsible for the production process,

- automating **the collection and analysis of production data** - online knowledge about the extracted material in terms of quality, quantity, weight, along with possibility of correlation with the demand for the mixture in the coking plant - expansion **of the production process measurement system** and **the installation of scales and analyzers** in production processes, analysis of operating parameters of machines and devices that are recorded on the Central Technological Data Server, which is a superior system storing data generated in the production process,
- introducing an analysis of the mining process, collecting coherent information from monitoring systems and sensors for shearers and plows, service management, downtime prediction - creating a comprehensive model integrating **systems of SCADA and CZAD classes**,
- implementation of **telecommunications infrastructure and communication systems,** enabling the improvement of underground work safety, monitoring the location of miners, providing information about threats and external factors - expansion of **RCP systems**, including active informing miners, e.g. about environmental parameters,
- initiating activities aimed at incorporating all stages of production into one data model that is continuously fed with real-time data, building **analytical and reporting** models and systems.

2.5.4. Assessment of the transformation of IT/OT processes in the 2019÷2024 Strategy

In 2019, another analysis of the implementation status of the IT/OT Strategy was carried out, which led to the preparation of another update of the IT/OT Strategy for the JSW Group. The adopted documents included a review of the so-called **strategic pillars**. It was assumed that the foundation of activities was **an efficient IT organization**, equipped with an appropriate set of competences, on which a set of integrated and automated IT solutions was built, supporting **the efficiency of production, management processes and decision-making**, supported by the Security Pillars and the use of development technologies.

The IT Mission and Vision, the IT Governance management model, the establishment of the target IT/OT architecture model, relations with IT/OT infrastructure service providers and, ultimately, the IT/OT Strategy in the JSW Group were also redefined. The adopted strategic projects were updated in four key strategic areas: security, integration and automation, development technologies and organization and competences, which consist of 33 strategic projects and 61 partial projects. During the update of the Strategy, the assumptions related to the schedule of the current implementation of strategic projects adopted for 2019÷2024 were also verified, which assumed the creation of a target architectural model in four steps:

- **Step 1 and 2 - IT centralization and unification of IT /OT infrastructure** - activities carried out as part of previously implemented activities; projects completed so far in organizational sphere, consolidating IT functions within the entire JSW Group and completed projects related to eliminating technological gaps and unification and standardization of infrastructure and data;

- **Step 3 – Digitization of key IT/OT areas** – in advance, covered by the updated IT/OT Strategy; projects for digitization of individual key functional areas supporting basic business processes and activities aimed at increasing the level of security;
- **Step 4 – IT/OT integration and automation** – to be implemented in the future, covered by the updated IT/OT Strategy projects for the integration of individual functional areas to enable process and financial optimization as well as process automation leading to increased company value.

2.5.5. Assessment of the implementation of strategic projects of Critical Priority

Projects of Critical priority will have the greatest impact on increasing the efficiency of processes: production, management and decision-making, as well as increasing human safety. The area of cybersecurity is also critical due to the increasing level of integration and dependence of individual IT/OT systems on each other.

- **Safety of Mining Crews** - technology has been selected, tender documentation for the Zofiówka Mine is being prepared.
- **Modernization of RCP** - modernization of RCP on Borynia Section and Zofiówka Section has been completed, work is underway at Budryk Mine.
- **Cybersecurity** - as part of the project, the IT systems security service and the realization of requirements of the Act of July 5, 2018 on the National Cybersecurity System were launched.
- **Purchasing management** – a purchasing platform was launched in JSW, JSW KOKS and JZR.
- **Project management** – the project related to the implementation of the EPM class system was completed.
- **Document management** – investment application support has been launched on the EOD platform, and work is underway to implement a system for electronic transmission of documents within JSW and among JSW Group companies.
- **Management of means of production** - stage II of the project was initiated in 2021. The project contains the preparation of a set of dashboards regarding basic machines operating in JSW mines. A new version of the original application for managing explosion-proof equipment was implemented.
- **Production scheduling** – the Deswik system has been launched and work is underway on its integration with other systems.
- **Production monitoring** - an inventory of the equipment of ZPMW (processing plant) transport lines was completed.
- **MIS** – CZAD with JSW ITS generates management and operational dashboards (longwalls/faces) for the needs of JSW's main decision-makers. Work has begun to develop a standard for assessing the effectiveness of the roadway drilling process.
- **Data integration platform** - data integration at the IT/OT data warehouse and PI System level.

- **OT systems** – implementation of specialized systems integrated with sensors for ventilation and mechanical departments.
- **JSW SCADA** – the HADES system was launched, a proprietary environment for visualizing and operating selected production systems at JSW.
- **IT Governance** – an IT/OT management and supervision model was implemented in the JSW Group.
- **IT organization** - a new Business Process Management Competence Center was created at JSW ITS, and the Operational Technologies Competency Center is currently being organized.
- **Resources and competences** – human resources are constantly supplemented and employee training is conducted.

2.5.6. Assessment of the implementation of strategic projects in the JSW Group of Important Priority

Projects in the IT/OT Strategy of the Important priority are as crucial for increasing the efficiency of the processes of production, management and decision-making as projects of the Critical priority, but their implementation is largely dependent on the budget capabilities of the JSW Group. Implementation of projects of Important priority will also increase operational security, understood as the ability to ensure the continuity of production and operational processes. The IT/OT strategy also indicates that it is important to ensure the quality and maturity of processes related to the provision of the required IT service portfolio and to create an environment supporting Agile activities in the business and IT/OT areas. Agile is a set of principles and a method of conduct that allows for flexibility in action, adapting activities to emerging circumstances and needs, which leads to more efficient achievement of goals.

- **Security integration** - the Technical Security team at JSW ITS has been expanded, PAM, DLP and SIEM class tools are being implemented to increase the level of technical and operational security.
- **Operational security** - CCTV video monitoring, enabling the observation of particularly endangered places and strategic points of the technological line of JSW mines. A project is underway to replace the central data backup system and IT/OT systems.
- **Risk management** – in 2021, it is planned to implement a corporate risk management system at JSW.
- **ERP optimization** – new ERP systems were implemented in Carbotrans, PBSz and JSK. In preparation for implementation in JZR, PGWiR and JSW IT Systems.
- **Testing the quality of coal and coke -** the implementation of a system supporting the work of LIMS laboratories has begun at CLP-B. Work is underway to develop the architecture of a system that comprehensively supports product quality management in the JSW Group. Work is being carried out on automation in the field of continuous measurement of quality parameters of excavated material and measurement of its weight.
- **Resource management** – work is underway to optimize the material logistics management process and on a new version of the "Wozy" system supporting this area.

- **Expansion of CZAD** - the launched project aims to increase the number of generated analyses and reports based on new data sources from technological processes at JSW and to develop analytical competences in CZAD.
- **Control room infrastructure** - rescue operations headquarters at the Borynia-Zofiówka Coal Mine were modernized. Designs for the modernization of the control room at the Pniówek Coal Mine and the Borynia-Zofiówka Coal Mine were developed.
- **Agile** – the implementation of JSW ITS's proprietary applications is carried out in accordance with the assumptions of agile methodologies.
- **IT processes** – the Integrated Management System implemented in JSW ITS based on the ISO 20000 and ISO 27000 standards ensures continuous monitoring and improvement of IT processes.

2.5.7. Assessment of automation activities

As part of the implementation of this Strategy, the Automation and IT Office was established within the structures of the JSW Management Board Office, within which the following activities were carried out:

- standardization of business processes implemented by individual plants,
- expanding the scope of CZAD telecommunications data analyses,
- improving cybersecurity, IT systems security management, security related to Covid restrictions and cost optimization,
- creation of EDA / EDŁ departments (monitoring the maintenance of machinery and equipment operation supervision systems, including teletransmission networks and IT systems),
- maintenance of the Shared Services Center (hereinafter referred to as SSC),
- modernization of CCTV video monitoring systems that monitor production processes responsible for mining, as well as places related to natural hazards and strategic points of technological lines,
- launching a system for measuring gas parameters in methane drainage pipelines,
- construction of a Backbone Teletransmission Node (SWTx), enabling the collection and distribution of data from monitoring the operating parameters of devices in longwall and roadway systems.

Activities in the field of automation and computerization development were aimed at increasing the safety and efficiency of the entire production process, using modern technologies. Monitoring of machines and devices also has a direct impact on efficiency, allowing for the optimization of energy consumption and reducing the mechanical wear of machines and devices. Security in this respect is understood as:

- security of business continuity (ongoing monitoring of machine operation and failure, time of response to events, visualization of the production process, possibility of real-time control RTC – *Real-Time Clock*),

- employee safety – modernization of RCP systems, construction of a system for managing the safety of mining crews, automatic supervision of the crew movement in particularly hazardous areas,
- cybersecurity – the increasing use of IT/OT technologies in machines requires creating an appropriate management and security system for OT systems.

2.5.8. Assessment of quality management activities

In 2019, JSW SA adopted the Strategy and Policy for deposit and product quality management, which, due to the digitization and integration of deposit data and production planning, enabled the introduction of production and product quality management in the full coal-coke production cycle and commercial processes. The implementation and integration of quality testing processes, digital identification of coal deposit and its parameters, and automated planning and scheduling of production and quality based on this information allowed for the introduction of production control and obtaining increased, stable parameters of commercial coal. Due to the implementation and integration of systems in the area of quality management, it is now possible to:

- model the production management and forecast its key parameters in order to achieve a stable level of production quality for coking coal recipients and coke producers,
- plan and manage the preparatory and extraction activities to obtain and maintain the required levels of physicochemical parameters of the product,
- implement the selective mining by controlling the quantity and quality of excavated material - introducing control of excavated material with various parameters and the process of selective enrichment,
- separate the product streams in terms of their quality, based on established key quality parameters and market demand, in order to maximize sales prices - in 2020, price increases were achieved for coals supplied to strategic suppliers due to a stable level of coking parameters of the produced coking coal,
- eliminate the purchases of low-phosphorus coal from outside the JSW Group.

The above-mentioned effects, obtained due to the computerization and automation of deposit and product quality management processes, led to the stabilization of key contract parameters and an increase in prices obtained at the interface with key customers. Digitalization and automation of obtaining quality data throughout the entire production cycle also enabled the monitoring and management of complaint processes.

2.6. Summary of strategic management directions in the area of IT and industrial automation in the JSW Group

The effectiveness and quality of IT services largely depend on the perfection of operational procedures and support procedures for IT systems constituting the basis of the services. The nature of these procedures is that they are effective in the short term. The effectiveness and quality of services in the long term are secured by activities related to maintaining the system in the condition consistent with the requirements of the business side. To summarize the digital

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transformation in the JSW Group, it should be noted that it was implemented in the following stages:

Stage 1 – IT centralization

The first step in the implementation of the IT/OT Strategy was IT centralization and activities consolidating IT functions within the entire JSW Group. Since 2010, activities have been carried out to centralize IT functions at JSW in a dedicated special purpose vehicle. IT services for subsequent companies added to the JSW Group were entrusted to Advicom. In 2011, the company implemented the Integrated Management System based on the ISO 27000 and ISO 20000 standards. In 2015, a project to transform the operation of Advicom was implemented. In the new functional model, IT services were provided by Competence Centers in cooperation with local and organizational support teams.

Stage 2 – Implementation of a uniform IT/OT infrastructure

In the following years, key projects were aimed at eliminating the technological gap and unifying and standardizing the infrastructure and data layers. First, they covered the IT area, and since 2017 also OT. The main projects involved the construction of LAN and WAN network infrastructure, construction of the primary and reserve Data Processing Center, implementation of the IT Data Warehouse and Business Intelligence tools. A platform for consolidating data from JSW Group companies was built at the level of the Management Board Office and the Shared Services Center.

Since 2017, the network infrastructure has been expanded underground and in areas directly related to production. An OT data warehouse was built and tools for advanced data analytics were implemented. Standards for data transmission and security have also been developed.

Stage 3 – Digitalization of key IT/OT processes

The third step is the implementation of projects aimed at digitalizing individual key functional areas that support basic business processes and activities aimed at increasing the level of security. The main projects implemented during this period include: deposit modeling and production scheduling, electronic document circulation, expansion of CZAD, launch of ERP systems, launch of tools supporting project and program management, standardization of SCADA systems, planning model in the JSW Group, increasing the safety of mining crews, expansion of cybersecurity systems. Key projects to be completed in order to implement Stage 3 of the IT/OT Strategy in the JSW Group are as follows:

- **Crew safety** – implementation of a system to ensure the safety of mining crews underground. In the first stage in Zofiówka Mine.
- **Production monitoring** - it is planned to prepare a set of automatic dashboards regarding basic machines operating in JSW mines.
- **JSW SCADA** – development of the proprietary HADES system for visualization and control of selected production processes.
- **Cybersecurity** – development of organizational and technical security systems.

- **Control room infrastructure** - improving the operation of the control room by applying new technological (infrastructural) standards and improving the visual quality and comfort of employees' work.
- **Document management** – digitalization of document handling in subsequent business processes on the EOD platform.
- **Coal and coke quality testing** - automation in the field of continuous measurement of production quality parameters.

Stage 4 – IT/OT integration and automation

The fourth step is the implementation of projects related to the integration of individual functional areas in order to enable process and financial optimization and process automation leading to increasing the company's value. Projects implemented in this step must first be focused on integrating security management and process integration and monitoring. Then, it will be possible to launch projects leading to the implementation of systems that optimize and automate business processes in key strategic areas.

The decisions made and the transformation activities carried out allowed for the construction of an effective and modern operating model of the IT organization in the JSW Group, which actively influences the increase in the value, efficiency and security of the JSW Group through increased integration and automation of processes and innovative IT/OT solutions throughout the entire production and commercial cycle. The digitalization and integration of key economic processes makes it possible to increase the efficiency, quality and safety of the JSW Group's operations at present.

Nowadays, JSW IT Systems operates in accordance with its adopted Mission, which is to "create innovative ideas in a partnership model, in cooperation with the JSW Group companies, and provide modern IT/OT technological solutions that increase the efficiency, quality and security of key economic processes."

With employment of 245 people at the end of 2021 (an increase of 71 people since 2011), the Company currently serves 20 entities belonging to the JSW Group, including 19 on the basis of SLA contracts (*Service Level Agreement)*. It also supplies goods and services to 11 entities from outside the JSW Group, the companies that were excluded from the JSW Group as a result of ownership transformations or that cooperate closely with the JSW Group.

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3. Center for Advanced Data Analytics (CZAD JSW 4.0) - organizational and technical concept, role and importance in implementation of the idea of SMART MINE JSW 4.0

Artur Dyczko

The situation on the mineral raw materials market and the increasing depth of deposits make using correct methods of solving heterogeneous, complex planning and optimization issues essential in the struggle to increase the efficiency of the mining process.

The constantly changing environment means that the processes of information exchange and processing become an increasingly important element of business activities, having a significant impact on the market position of a mining company and, consequently, its competitiveness.

In 2017, as a part of new JSW SA Group Strategy, **The EFFICIENCY Program** was established, the main assumption of which was the implementation of a number of technical and organizational solutions of an innovative character aimed at increasing mining efficiency while ensuring the safety of working people. underground and minimizing the negative impact of activities on the environment [Ozon, 2017].

These activities were intended to improve the flexibility of the Group's operations, in particular in areas such as:

- Organizational area:
  - Transformation of the JSW Group into a project-managed organization. Building a project management culture in the Group. Implementation of modern project management methods in all areas of the Group. Developing competences, methodologies and standards of project management in the Group.
  - Creation of the Project Management and Standardization Team, at the level of the Company's Management Board, in the Investment, Strategy and Office Development.
  - Creation of the Group Quality Management Office at the Company Management Board level, responsible for the construction and maintenance of the central geological model of the deposit along with strategic exploitation schedules.
  - Establishment of the Methane Drainage and Management of Energy Media Office at the level of the Company's Board Management along with the construction of structures in mines that rebuild their own competences in the field after over 25 years of methane drainage process in mines.
  - Establishment of the CZAD JSW 4.0 Advanced Data Analytics Center at the Company's Management Board level along with the establishment of Automation Departments (EDA) in all mines in order to expand and maintain systems for monitoring machine operating parameters and devices.
  - Establishing transport coordinators at JSW mines.
  - Changing the scope of activities of the Board of Directors in order to improve the quality of communication among key decision-makers in the Company.

- Establishing process teams to exchange experiences between plants in individual elements of the production process.
- Conducting specialized training to deepen the knowledge of the staff working in the company's longwall and heading faces.

– Technical Area:

- Increased speed of mining operations.
- Modernization of machines and devices of the mining equipment.
- Implementation of independent roof bolting support system installed by a Bolter Miner.
- Expansion of mechanical lining and anchoring technology in order to improve the stability of the workings and increase the speed of the underground operations.
- Increasing the number of gates reused for longwalls run on their other side.
- Monitoring of corridor headings with independent roof bolting support.
- Expansion of fiber optic networks in underground parts of mines.
- Introduction of underground digital mobile communication using a radiating cable in the Company's mines.
- Line management system for JSW SA in the aspect of stabilizing and improving the quality of excavated material and maximizing economic effects.
- Implementation of a pressure monitoring system in units of powered support (mainly to supervise the work of key, "difficult" longwalls).
- Launch of the Mining Crew Safety Program, which is intended to ultimately prepare recommendations for the JSW Management Board regarding the selection of modern solutions in order to significantly improve communication standards, identification and monitoring of employees working underground.
- Retrofitting JSW mines in the field of transport of people, materials, machines and equipment.
- Shortening the time needed for the crew to reach the mining faces.
- Increasing methane capture and management.
- Improving the working comfort of mining crews (air conditioning).
- Monitoring integration – Central Technological Data Server.
- Development of an IT/OT communication standard in the JSW Group.
- Improving the effectiveness of preparatory activities as well as installation and liquidation of equipment in workings.

– Assets Area:

- Support for infrastructure and pro-efficiency investments.
- Improving the investment planning management process in relation to current and expected requirements related to the operations of the JSW Group.
- Assessment of the technical condition of assets, increase in available time and working time of longwall shearers - transformation of the IT/OT area.
- Launching a continuous inventory of key production resources.

- Optimization of production asset management (acquisition and use).
- Expansion of production activities and unification of equipment within JZR.
- Using the potential of mine assets (machinery and devices) in order to optimally use them in all the Company's mining plants.
- All activities related to the selection of machines and devices in order to achieve the production tasks.
- Modernization of transport of crew, excavated material, machines, devices and materials - unification of the logistics system, elimination of bottlenecks.
- Modernization and optimization of the excavated material haulage network and employee transport.

The main areas of the Company's operation defined in this way directly influenced the focus of key program initiatives around the four value levers of the JSW Capital Group: improving operational efficiency, cost efficiency, investment efficiency and improving the safety of mining crews, constituting the essence of the **JSW SMART MINE 4.0** program – a flagship development concept covering the transformation of the JSW Capital Group towards Industry 4.0. As a result of its implementation, many barriers in the functioning of information systems were overcome, a coherent architecture of the information system was developed and implemented, resulting in the standardization of data recording and processing using the so-called "computational intelligence" methods, which allowed company to extract useful and understandable knowledge from the data, supporting decision-making e.g. at the level of strategic, tactical and operational planning. Currently, in JSW, this knowledge is the basic resource of the company, determining the possibility of intelligent functioning in the changing mining, geological and business situation [Ozon, 2017].

The implementation of the JSW 4.0 SMART MINE idea in the Jastrzębie mines has been identified from the start with the automation of production processes and the expansion of monitoring systems. This action was and is justified and desirable, as it contributes to increasing the available level of information within the Group and results in increased work security. Paradoxically, however, the increase in the amount of data in the enterprise's information system may cause information chaos. The desire to counteract this phenomenon may lead to the separation of information available in technical systems from their use only to support operational control. At JSW SA, from the very beginning, the panacea for all consortiums regarding the amount of data and possible information chaos was the establishment and creation of the modern **Center for Advanced Data Analytics,** commonly known among JSW Group employees as **CZAD JSW 4.0**.

The newly established organizational unit was officially launched in June 2017, defining the genesis of its creation around the processes of monitoring and managing all activities aimed at ultimately increasing the productivity of the production process carried out in the Company, in particular monitoring the operation of machines and devices in real time and implementing the philosophy of proactive maintenance.

The Management Board of JSW SA saw the initial benefits resulting from the creation of the **Advanced Data Analytics Center** (**CZAD JSW 4.0**.) in the structures of the JSW Group in [Ozon, 2017]:

- Improving the efficiency of management of production means and supporting activities that are crucial for the proper conduct of the production process and enterprise management, using access to full information contained in business and technical systems, based on monitoring the operation of machines and devices in real time.
- Optimization of technological and business processes based on the analysis of the values of performance indicators calculated on the basis of current and historical data.
- Obtaining consistent information on the technical condition of machines and devices allowing for the assessment of the effectiveness of asset management.
- Reducing the costs of maintaining key machines and devices by reducing their failure rate.
- Reducing the consumption of energy and other media by introducing optimization in the process of mining, transporting and processing coal based on tracking control systems.
- Possibility of using elements of predictive maintenance, understood as forecasting future events based on the analysis of current and historical data using diagnostic methods.
- Developing *Data mining* processes based on visualizations, neural networks, numerical methods, statistical analyses.
- Prospect of switching to proactive *Condition Based Maintenance* (CBM) – e.g. detecting changes in the machine's condition, that may lead to failure, using data analysis.
- Possibility of performing multivariable analyses of very large sets of technical data (*Big Data*).

Fig. 3.1 presents the main goals and requirements for **CZAD JSW 4.0** (orange), purple indicates areas optimized under other projects of the EFFICIENCY Program, especially those related to improving the efficiency of managing the Company's fixed assets.

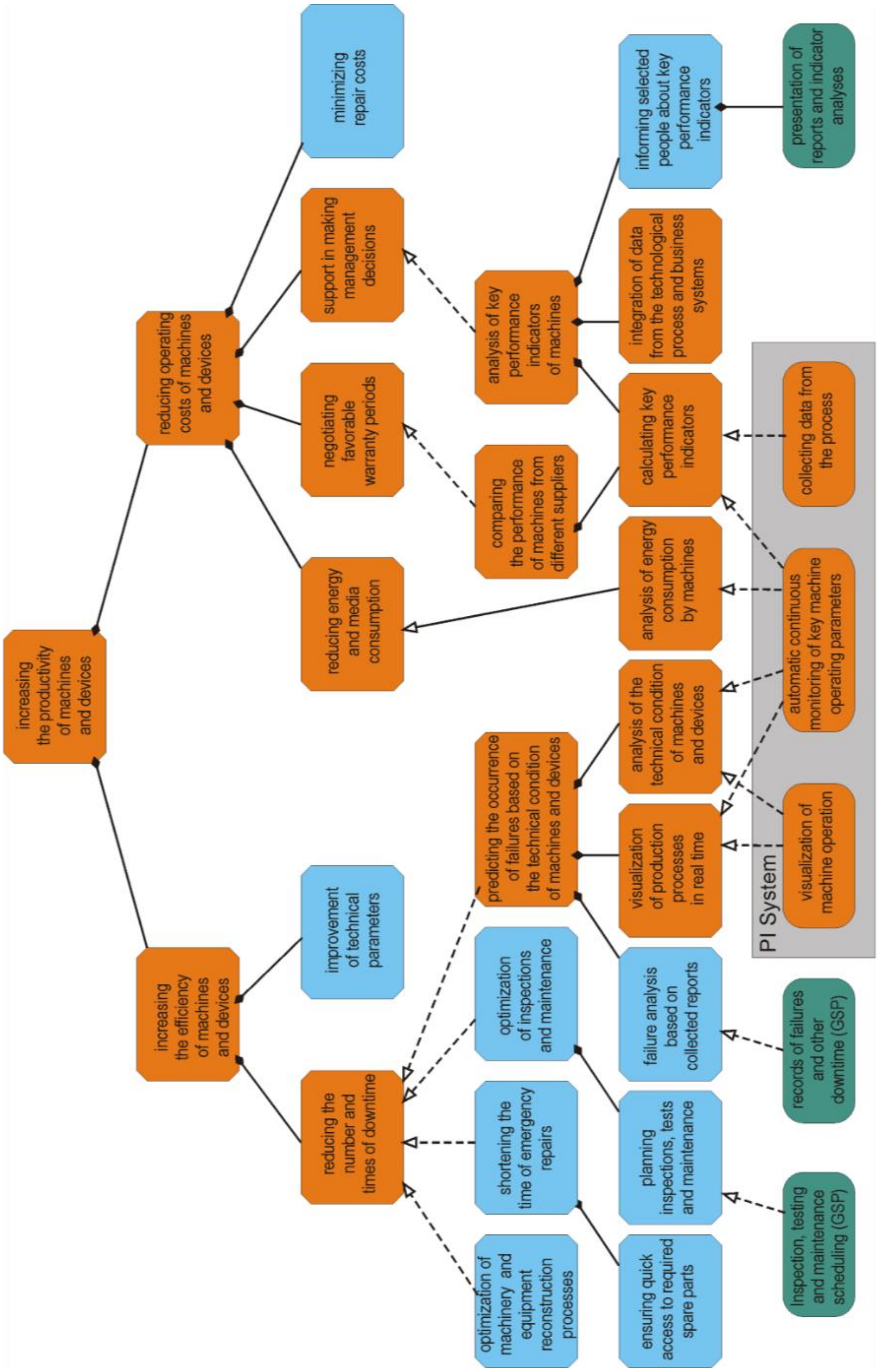

Fig. 3.1. Tasks carried out in the Center for Advanced Data Analytics (CZAD JSW 4.0.) resulting in the increase in the productivity of machines and devices

This chapter of the monograph presents the origins of the construction of the first Center for Advanced Data Analytics in the Polish mining industry. The mechanisms of analyses used at JSW SA were discussed, and the potential contained in the exploration of multidimensional data structures, machine learning and the Big Data techniques used was assessed.

The issue of standardization of the architecture of basic control and measurement systems and technical systems performing data acquisition and processing functions, important from the perspective of the operation of intelligent information systems of the JSW Group, was discussed in detail, including the developed standards:

- data exchange, architecture and IT/OT infrastructure in the JSW SA Group standard,
- guidelines in the field of IT/OT solutions for the created Specifications of Essential Terms of Orders in the JSW SA Group,
- conditions of access to separated networks in JSW SA plants,
- providing data from IT systems operating in separate networks.

Finally, all considerations were presented in the context of the prepared and implemented "POLICY for the management of the architecture and technical infrastructure of IT/OT systems", the first one in the Polish mining industry.

The use of automation systems results naturally from the JSW Group Strategy for 2018÷2030 in terms of increasing work safety and efficiency. Mining automation is a discipline that still has enormous potential. However, a fully automated mine with machines endowed with hypothetical intelligence is a rather distant vision. In the long run, it is worth ensuring real support for processes that are and will most certainly continue to be conducted in the future by people.

Based on the examples cited and potential areas of application indicated, an attempt was made to determine the role and importance of data processing systems in realizing the vision of a Smart Mine. We tried to demonstrate the functionality, from the moment of drilling test holes, through the processes of scheduling and optimization of the mine design, selection of equipment and technologies, to ongoing support for decisions made by the dispatcher, engineers, and the company's management, that proves the intelligent character of the management environment. An environment that allows for the effective management of all information received from the micro and macro environment of the enterprise in a systematic and permanent manner.

JSW 4.0 is a learning company, i.e. it uses its own experience and available information resources in a systematic and active way to improve its market position.

The development and implementation of the architecture of an intelligent information system by Jastrzębie mines, which is a response to the growing information needs and requirements of the market and the business environment, sets the target for the development of an intelligent vision of the mining enterprise operating in the 21st century [Ozon, 2017].

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3.1. Data processing systems – their role and importance in implementing the idea of the JSW Smart Mine 4.0

Concepts such as IoT (*Internet of Thing*) or M2M (*Machine to Machine*) are increasingly involved in the mining reality in the form of applications and industry-dedicated technical solutions. The original idea of a smart mine was permanently defined in the Intelligent Mine project implemented in 1998÷2002 by the Helsinki University of Technology. The project focused largely on operational activities, aiming at full automation and real-time monitoring of production processes as the target of development [Polak, 2014a].

In 2009–2010 in Sweden, in cooperation with KGHM "Polska Miedź" SA, the SMIFU (*Smart Mine of the Future*) project was implemented. As its extension, the I2Mine project (*Innovative Technologies and Concepts for the Intelligent Deep Mine of the Future*), in which - apart from KGHM "Polska Miedź" SA - Kompania Węglowa SA, participated, among others. The implementation of both projects was motivated by the increased nuisance of the production process resulting from the increasing depth of the deposits. Deteriorating geological and mining conditions pose new challenges for the industry in counteracting threats, which results, among other things, in the need to automate production.

Some projects initiated since 2004 have been thematically similar as a part of the activities of the DMRC consortium (*Deep Mining Research Consortium*) in Canada, the Mine of the Future program implemented since 2008 in Australia by Rio Tinto and the EU-IPSUM project *(Intelligent Production Systems for a Sustainable Supply and Use of Mineral Resources*) implemented by the Institute of Mining Engineering RWTH in Aachen [Spišak, 2010].

Taking into account the costs of technological development and the need for a deep reorganization of the mine's operating model, the original concept of the Intelligent Mine - apart from cases of current barriers resulting from geological and mining conditions - is currently not the most urgent direction in the evolution of hard coal mines. The ubiquity of IT systems supporting individual areas of operation of mining enterprises leads to focusing attention on the issue of increasing efficiency and productivity, rather than further automation.

Improving efficiency is a natural, further direction of development after the stages of mechanization and automation of mining. The complexity and unique character of optimization issues can be discouraging because they impose both a framework of thinking in terms of continuous improvement and the need to use complex data processing techniques. A consistent approach to optimization issues requires the creation of special organizational structures, including the establishment of interdisciplinary task teams, typical e.g. for the TPM strategy (*Total Productive Maintenance*).

In JSW SA it was decided to assign to the Center for Advanced Data Analytics CZAD JSW 4.0. a task to develop a comprehensive, multi-dimensional analysis and interpretation of data from the Control, Measurement and Automation systems of mining machines and devices, resulting in the implementation of an analytical system using methods of processing large amounts of data in real time [Polak 2014a, c].

Systems based on the use of digital techniques have for years been treated as an extension of the human intellect, currently providing significant support in the field of optimization methods. A mine, as an economic organization, co-created by people deliberately pursuing specific economic goals, has collective intelligence. This intelligence is inextricably linked to aspects of knowledge management in the organization, at the same time constituting a prototype of the operation of distributed intelligence algorithms (Swarm Intelligence, SI). Due to natural limitations in human data processing capabilities, as well as available human resources, much of the knowledge remains hidden in "raw" data. In the current conditions, due to their number in transaction and record-keeping systems and technical systems, the issue of proper data processing plays a special role in the process of discovering and using knowledge. It is the processing functions, from the moment the IT system registers an event, measures an electrical quantity or activates the executive functions of the automation system, that largely determine the practical usefulness of the expensive process of remote acquisition or manual data recording.

Hence, when operationalizing the idea of the JSW Smart Mine 4.0 among the considered methods of building an intelligent organization, it was considered how to transform seemingly dead channels and information systems into an intelligent environment supporting management processes, in particular supporting decision-making. Ultimately, it was determined that the systems in question should be characterized by hypothetical intelligence implemented in the engineering process, the basic feature of which is the ability to effectively use experience and effectively condense information into its content.

The basic goals of using intelligent systems in mining include:

- Data mining - aimed at obtaining hidden knowledge, supporting decision-making processes by building inductive reasoning systems, enabling practical use of acquired experience.
- Creating domain systems using simulation models enabling analysis of the operation of real systems or solving complex planning or optimization problems.
- Creating active systems with the ability to learn and adapt, including technological process control systems, especially in conditions of lack of access to full information (fuzzy logic).

Having a knowledge base, in the form of a declarative set of facts that clearly describe past experiences, is a common element of all the above-mentioned applications. Intelligent behavior results primarily from the fact of having the required knowledge (Fig. 3.2).

The combination of data structures and properly selected interpretation methods operating on them is the foundation of intelligent behavior resulting from the identification of cause and effect relationships (understanding). This enables effective behavior towards new situations and tasks, based on knowledge acquired as a result of previous experience (reasoning).

The implementation of all these processes would be impossible if it were not for the structured knowledge base that is the basis for operation of *Intelligent Decision Support System* (IDSS).

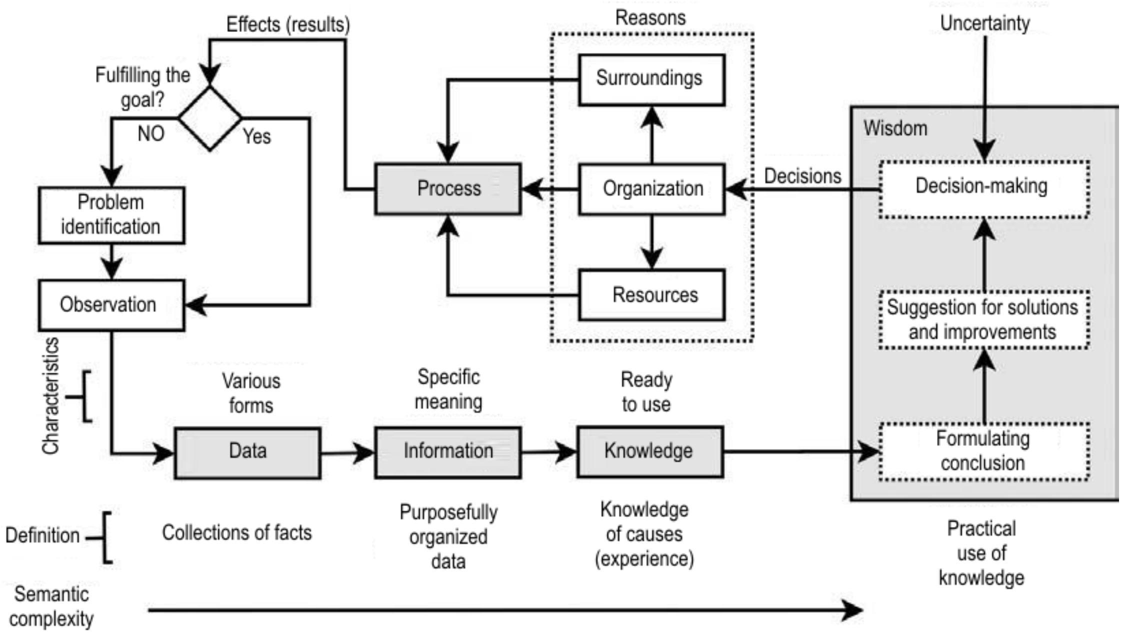

Fig. 3.2. Decision support in optimization processes [Polak, 2014a]

The availability of appropriate sets of input data describing an event or process largely determines the effectiveness of *Knowledge Discovery in Databases (KDD)* processes such as *Data Mining (DM)* and *Exploratory Data Analysis (EDA).*

As a result of the conducted analyses, it was determined that from the perspective of implementing the idea of the JSW Smart Mine 4.0, it is extremely important to develop permanent requirements and information standards in this area, enabling the construction of comprehensive, thematically oriented warehouses (*DW - Data Warehouse*) and data processing systems. Hence, as already mentioned above, JSW considered it necessary to develop, at the initial stage of conceptual work, standards for:

– data exchange, architecture and IT/OT infrastructure in the JSW SA Group,
– guidelines in the field of IT/OT solutions for the created Specifications of Essential Terms of Orders in the JSW SA Group,
– conditions of access to networks separated in JSW SA plants,
– providing data from IT systems operating in separate networks.

3.2. Architecture of data processing systems in mining

The basic "senses" of the mine - apart from voice communication tracks and image transmission systems - are control and measurement equipment along with production automation systems. Considering the benefits resulting from the use of fiber optic technology, it is expected that the amount of recorded data will continue to increase. When considering the architecture of data processing systems, we should first focus on this most dynamically developing area.

A modern mine control room is a hub that receives thousands of different pieces of information. The growing number of information channels, readings and messages may result in information chaos over time. Human perception becomes insufficient in the light of the need to quickly and error-free analysis of a number of stimuli arriving in real time. Therefore, current control room designs – through, among others, arrangement and selection of communication systems, appearance of visualization boards - are intended to focus the attention of the dispatcher or dispatchers on the most important elements [Polak, 2014a].

Despite the optimization of interfaces, it should not be expected that remote diagnostics of technical conditions, including several hundred motors - built on conveyor belt systems - will be possible to process directly by humans. When the observed parameter changes, among others: as a function of load and belt speed, the information that is interesting from the point of view of assessing the technical condition of the motor is hidden, and the value graph itself is insufficient to read it. It then becomes necessary to use data processing methods based on process models and residual assessment. This allows, for example, several hundred thousand measurements performed daily to be reduced to synthetic information about the technical condition. It is possible to implement, among others: by implementing the method presented in the literature [Li, 2004].

The use of correctly selected data processing techniques is extremely important from the point of view of eliminating the information gap in the area of diagnostics and from the perspective of developing the system for organizing the processes of operating machines and devices (Fig. 3.3).

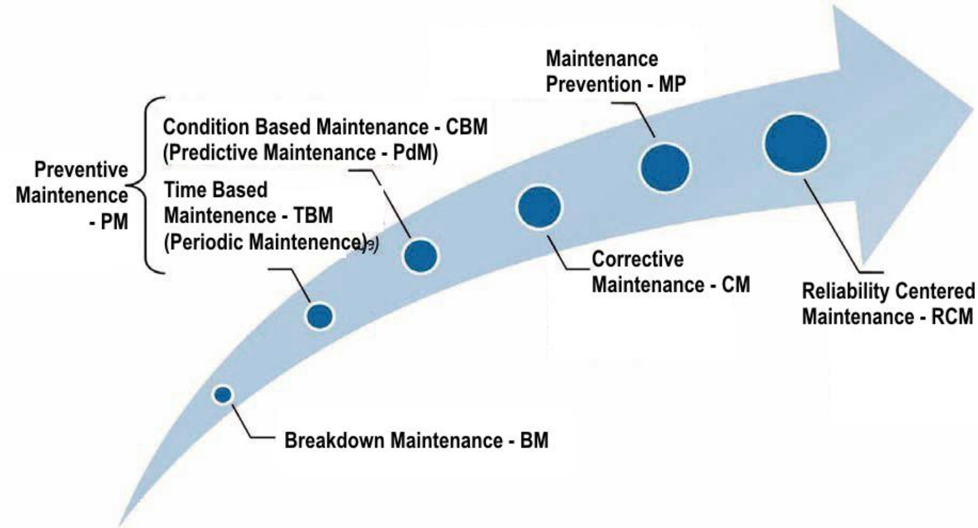

Fig. 3.3. Evolution of basic service strategies [Polak, 2014a]

An example of data analysis covering the operation process of mobile machines operating in an underground mine has been presented in the literature [Hall, 1997; Hall, 2000]. New opportunities are created by the use of intelligent exploration techniques on complete data sets covering the intensity of use, burdensome working conditions, failure rates, diagnostic measurements and costs, which have been successfully implemented, among others, at KGHM “Polska Miedź” SA [Kicki, 2010; Polak, 2016].

The use of intelligent data processing systems in the field of diagnostics of the technical condition and analysis of functionality of equipment is particularly justified in the context of measurement of uncertainty typical for distributed industrial installations and the occurrence of significant, unmeasurable disturbances. The operation of learning networks makes it possible to model non-linear objects and is characterized by the ability to generalize knowledge. This provides a potentially wide range of applications for neural, fuzzy or hybrid models, including: in terms of diagnostics of the technical condition or assessment of key measures of the efficiency of mining machines and equipment [Brzychczy, 2009; Brzychczy, 2012; Polak, 2014a].

Data processing designed by an engineer is not less important than the choice of artificial intelligence techniques. It includes, among others: selection of relevant data and definitions of methods for pre-processing measurement signals, including: statistical, temporal or spectral analysis. Taking into account the number and operating conditions of basic mining machines and equipment, obtaining detailed characteristics of pre-failure states for the needs of machine learning or expert systems does not cause a major problem. A potential source of these data is the currently used support systems for plant maintenance and control of safety parameters. These systems include the following basic groups of solutions:

– basic control systems built on the basis of universal communication subsystems,
– telemetry systems and recording of safety parameters,
– systems for monitoring the operating parameters of technical facilities based on data exchange between the master system and industrial automation systems,
– telemechanics and parameter control systems of power networks and devices, operating in communication with EAZ controllers,
– balance and settlement systems for energy and utility consumption,
– working time registration systems, identification and location of employees, means of transport, materials and equipment.

Data on the operation of key machines and devices, which also largely describe the course of production processes, are scattered in individual technical systems. Integration of data from individual areas is often not performed due to legal and organizational conditions. It can be assumed that as long as there are conditions that support maintaining the current state, apart from occasional data export, their systemic use will not be widely implemented in the mining industry. Taking into account the importance of these data - not only in terms of diagnostics, but also in improving production organization, assessing the efficiency of the use of machines and devices and process simulation - it is difficult to claim that mining industry operates in an intelligent management environment. All the more so because the functionality and efficiency of SCADA (*Supervisory Control And Data Acquisition*) systems dedicated to the mining industry in terms of implementing complex algorithms for processing time sequences and spatial information is very limited.

The integration of the above-mentioned environments should be considered in terms of the integration of data collected in system databases or the construction of a process bus in the open OPC (*OLE for Process Control*) standard with visualization in HMI (*Human-Machine Interface*) systems. Apart from the concept of covering all areas with an additional, superior SCADA system, this increases the complexity of the system structure and results in increased unreliability.

In addition to operational support tools, business IT systems operate in mines. In the area of production and asset management, these include:

– systems of managing basic means of production,
– explosion-proof machinery and equipment registration systems,
– production reporting systems,
– financial and accounting systems,
– systems for deposit modeling, production planning and scheduling,
– spatial information systems.

The systems mentioned above constitute an important supplement to the data recorded by SCADA stations. Some of them are modules of integrated ERP (*Enterprise Resource Planning*) management systems, including: SAP, SZYK2. Apart from management accounting and a few exceptions, including: Lubelski Węgiel "Bogdanka" SA [Kicki, 2010; Pole, 2014a; Dyczko, 2013] or Jastrzębska Spółka Węglowa SA [PEWWK, 2014]; the above-mentioned areas are not permanently integrated with each other or use dispersed, "soft" IT technologies.

The issues of systemic use of collected data include, in particular, technical aspects of their provision, proper identification, preparation, assessment of completeness, quality and reliability. In order to maintain a uniform information standard, it seems reasonable to develop a standard for the acquisition and exchange of data in the area of technical systems (Fig. 3.4).

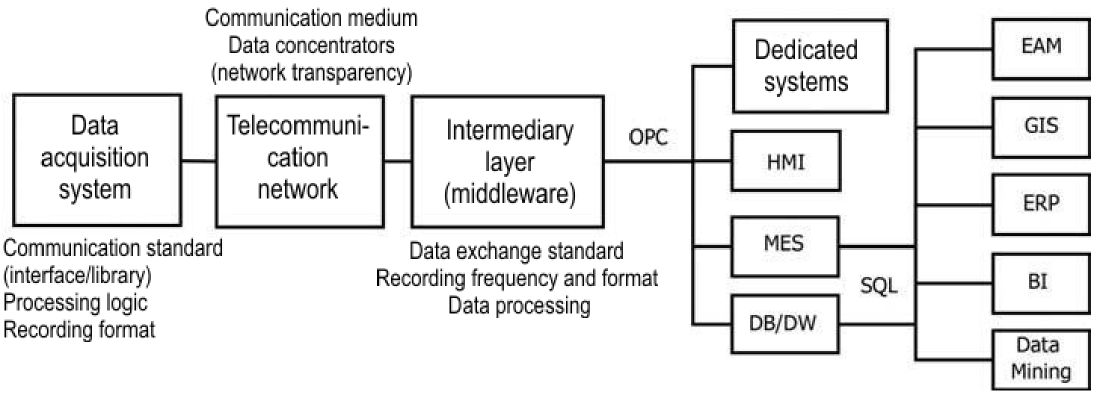

Fig. 3.4. Layers of standardization of solutions [Polak, 2014a]

The flow of information - from the data-generating system, control and measurement equipment through telecommunications networks to the master software or intermediate layer - should meet the basic assumptions in the field of the applicable architecture of enterprise information systems. Architecture is understood as resources, rules, models and standards according to which the organization acquires, creates, maintains and modifies elements of the information system. A number of publications have been devoted to this topic since the early 1990s, including: [Bentley, 1998; Cook, 1996; Cortada, 1998]. An example of a comprehensive approach to expanding the information system of a mining enterprise as the architecture of the solution developed for recording operating parameters of mining machines, is shown in Fig. 3.5.

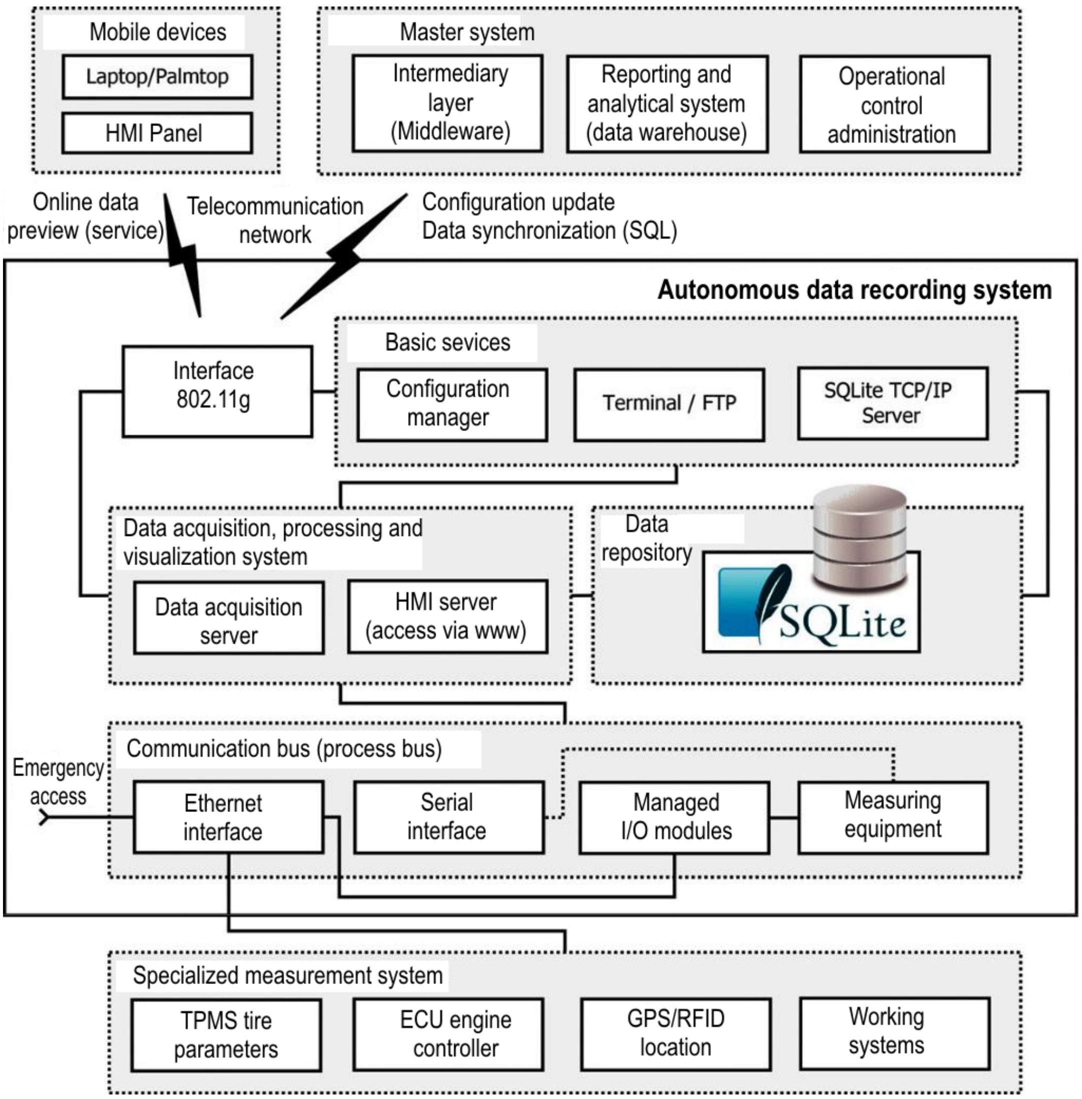

Fig. 3.5. Architecture of ASRPP – Autonomous System for Recording Work Parameters [Polak, 2014a]

This system enables the registration of a number of information about the operating status of the mining machine. The implementation of the solution, according to the *bottom-up strategy*, and the lack of the need for superordinate control of parameters in real time, enables data exchange with superior systems via a direct connection to the registration system database, in the form of SQL *(Structured Query Language)* queries. The system additionally provides the access to historical data and direct viewing of parameters online via a web browser and prepared visualization boards (including the operator's cockpit and diagnostic connection). The high scalability of the system in terms of expansion with additional input/output modules, the use of only common standards for data exchange and the autonomy of the solution allow for the construction of a universal standard for data registration for the needs of analytical and reporting systems.

Apart from the issues of measurement accuracy, an important research problem is determining the methods and period of data aggregation at the level of the recording system. Combining a number of measurements involves the loss of information about the mutual correlation of signals. When data aggregation is required, it seems reasonable to maintain the basic structure of interdependencies and perform aggregation in the context of individual dimensions, the same as it is implemented in the OLAP model (*OnLine Analytical Processing*) (Fig. 3.6).

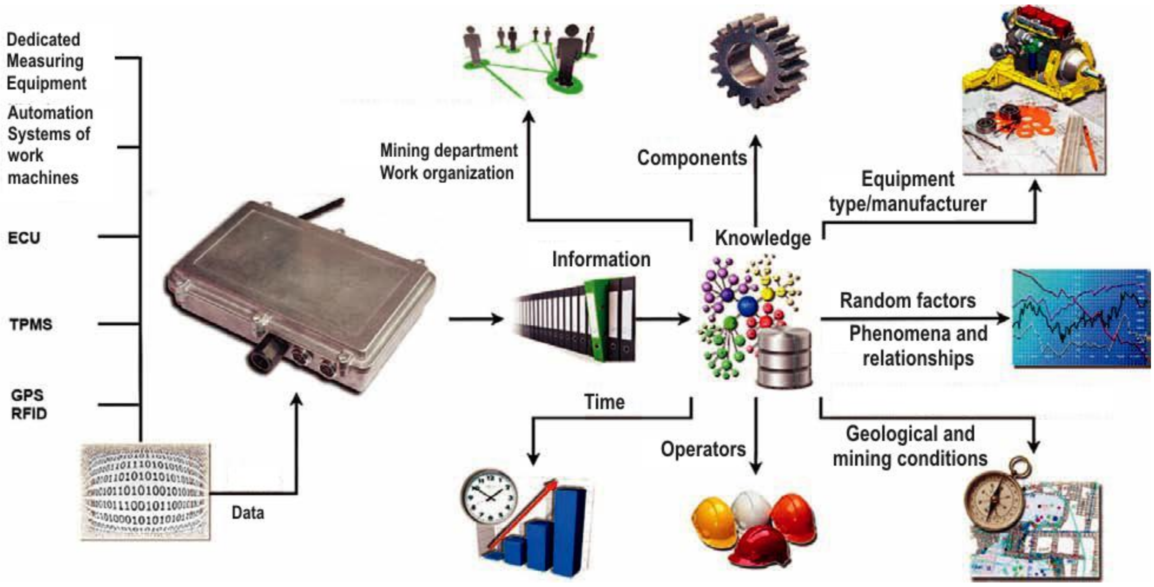

Fig. 3.6. Illustration of the process of mining data from ASRPP - Autonomous System for Registration of Work Parameters [Polak, 2014a, c]

The flexibility of the described solution comes, among others, from the possibility of dynamically formulating a query at the level of reading data from the recording system. This is particularly important in the context of signals requiring a very high sampling frequency and the use of data processing or pattern recognition algorithms directly at the level of the data acquisition system. An example may be the interpretation of momentary pressure changes in the working system in order to identify the number of machine operation cycles. The described approach allows for a significant reduction in the amount of information sent between two systems, which is extremely important in the event of technical limitations in the field of transmission. Dynamic formulation of SQL queries used during synchronization allows for a flexible change of the method and period of data assignment while maintaining access to the original, detailed measurements.

Client-server communication between the master system (client) and the recording system (server), implemented in an open standard, and the possibility of simple implementation of data processing methods on the device side enable adaptation to the requirements of the reporting and analytical system in the field of multidimensional data exploration.

The content of repositories, which are the basis for the functioning of intelligent decision support systems, may be a direct response to dynamically changing information needs.

Standardization and determination of the target architecture of enterprise information systems in individual areas of activity is a key process both from the perspective of the functioning of intelligent information systems and the need for data integration itself. Work carried out for the mining industry in this area, including: JSW SA and KGHM “Polska Miedź” SA allow for the development and implementation of open standards connecting the enterprise's information areas. This prevents mines from becoming directly dependent on equipment and software producers. It results in adapting future solutions to the requirements of the enterprise's information architecture, and not the enterprise to the functionality of the purchased products [Kicki, 2010; Polak, 2014a; Polak, 2016].

3.3. JSW SA Central Technology Data Server as a component of the platform enabling the processing of huge sets of information in real time

The development and implementation of the Central Server for Technological Data (CSDT) began in 2017 at the Center for Advanced Data Analytics (Fig. 3.7) as part of a comprehensive plan to increase the efficiency of production management and standardize the broadly understood area of automation and IT systems supporting the production processes of JSW SA.

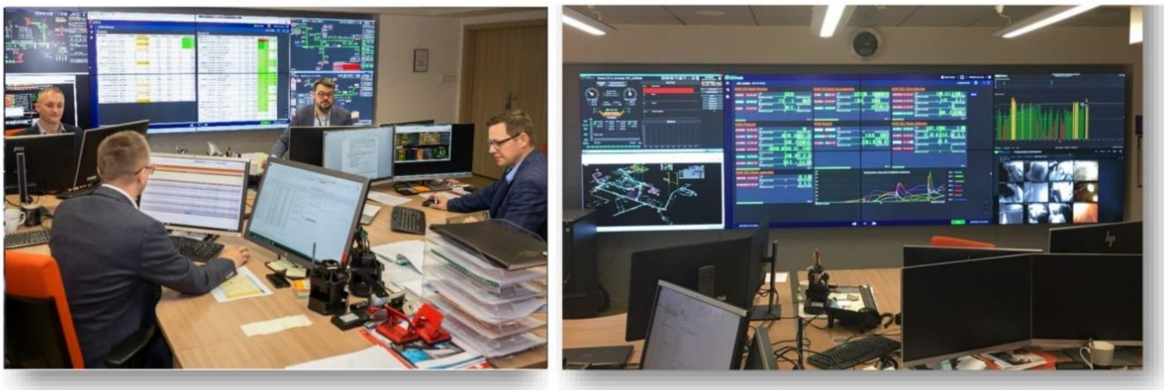

Fig. 3.7. Room of the JSW 4.0 Advanced Data Analytics Center

In parallel with the construction of the Central Server for Technological Data (CSDT), other technical and organizational changes were launched, including:

- creation of the Center for Advanced Data Analytics within the structures of the Management Board Office;
- creation of Automation Departments in the structures of all mines;
- development of systems for monitoring the operating parameters of machines and devices in the areas of network infrastructure and automation devices;
- standardization of solutions in IT/OT areas.

The implementation of the Central Server for Technological Data (CSDT), as an integral part of the IT system supporting the management of data from the JSW SA production process, was based on the OSIsoft platform enabling the processing of huge sets of information in real time and allowing for easy integration with business systems, while ensuring the ICT security of the systems' industrial automation. At JSW SA, similarly to other mining companies, several types of transmission and automation systems (SCADA) are used to manage production processes. All data are collected locally in technical systems that are not integrated with each other, which made it difficult and sometimes even impossible to conduct advanced analyses of these data. In addition, a major challenge for maintaining the entire architecture was the high variability of machines and equipment workplaces, resulting directly from the specificity of mining processes – Fig. 3.8.

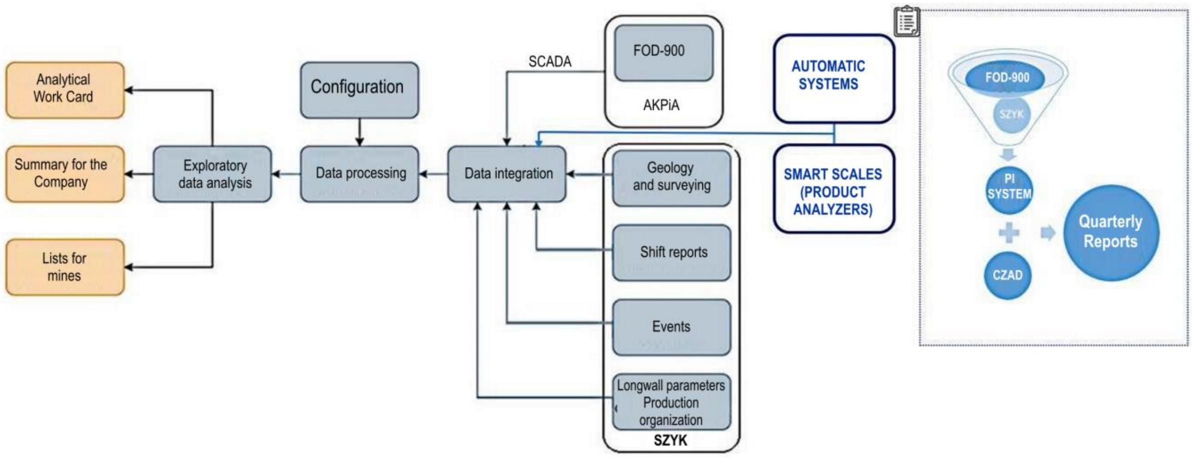

Fig. 3.8. Data exchange scheme in CZAD between domain systems of JSW SA mines

OSIsoft was selected as the base platform that meets the CSDT requirements, enabling the processing of information from several hundred thousand real-time recording devices (PI DA). This is one of the historian class systems that processes data in the form of time series that can be saved at any frequency set by the user and stored for any long time, which distinguishes it from SCADA systems – Fig. 3.9.

For the purpose of obtaining data from source systems, five types of interfaces were used, such as: OPC, OPC UA, MODBUS, RDBMS and UFL, although there are over 400 interfaces available that enable to connect any production system in a short time, while buffering data (PI Node Interface) on in case of loss of connection.

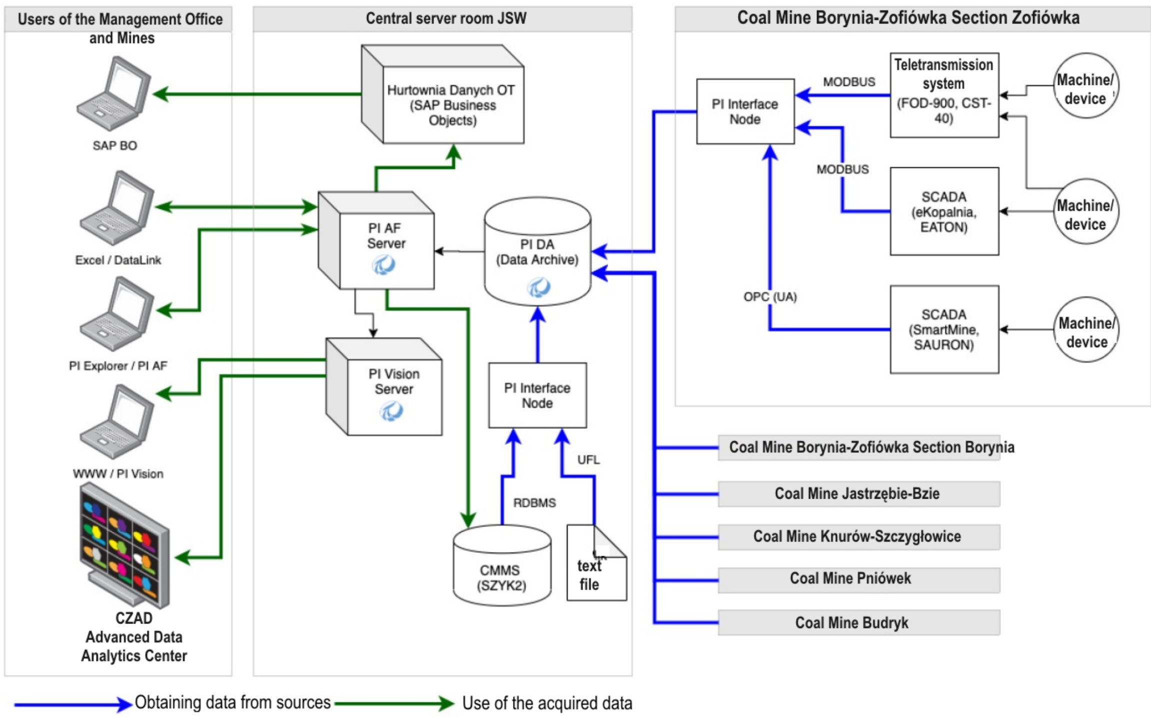

Fig. 3.9. Basic elements of CSDT architecture in the JSW SA Group

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One of the basic functionalities of the PI System included in the Asset Framework (AF) module made it possible to map the company's key fixed assets according to one common model, giving them a business context, which is so important from the moment they are installed in the workplace – Fig. 3.10.

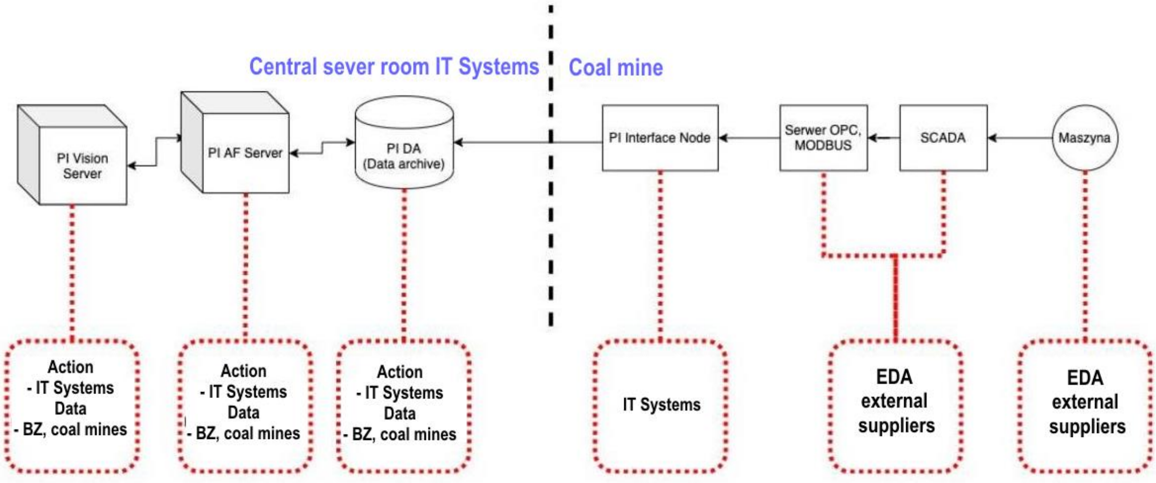


Fig. 3.10. Elements of CSDT architecture divided into locations of system components

The analyses implemented in this module and performed in real time made it possible to standardize data obtained from various types of source systems. Integration with the CMMS system (*Computerized Maintenance Management System)* used in the company made it possible to obtain the context of the machine workplace, technical parameters resulting from the Operation and Maintenance Documentation and mine operation plans into the PI System. In return, the PI System provides aggregated data on the operating times of longwall machines, which until recently required manual entry of data by mine maintenance services. Another example of the integration process is the implementation of an analysis identifying downtime events of longwall systems (PI Event Frame) along with the process of transmitting them to the CMMS system.

Automating this process minimized human errors and significantly shortened the time needed to record stops. Integration with the SAP Business Objects system, which performs the functions of an IT/OT data warehouse, enabled the achievement of the following goals:

- periodic generation of reports on the efficiency of longwall systems;
- automatic generation and publication of standardized operational reports from operation of longwall machines;
- providing users with raw and aggregated data generated by technical systems for the purpose of performing advanced business analyses.

A very important aspect that must not be forgotten is the security of critical infrastructure management, which also includes local monitoring and control systems operating in separate technical networks. The PI System, through one-way information transfer, constitutes an excellent barrier against cyberattacks, behind which there are dedicated systems that feed it with data.

The implementation of the Central Technological Data Server in JSW SA completely changed the approach to the use of data coming directly from the production process. The platform enables to collect information from all enterprise systems in one place, giving the user easy access to current and historical raw data, which they can freely analyzed.

The initial configuration of CSDT began with defining and standardizing failure dictionaries and logical operating times of machines and devices, establishing:

– nominal (available) time = planned time of present work of people and machines in the longwall,
– effective time = present operating time of all machines in the system at the same time, i.e. shearer + armoured conveyor + beam stage loader,
– nominal time utilization rate = (effective time /nominal time)* 100%.

The Central Server for Technological Data (CSDT) is primarily an improvement in the management efficiency of production means and support for activities that are crucial for the proper conduct of the production process and enterprise management. It uses access to full information contained in business and technical systems based on monitoring the operation of machines and devices in real time. It allows for the automation of reporting processes (monthly generation of analytical work sheets for longwall systems, transfer of information about failures and machine stops directly from the automation systems). Its task is to implement predictive maintenance of the Jastrzębie mines, build a predictive maintenance strategy through the use of Predictive class tools, which will ultimately enable actions to extend the operating time of the equipment in use, reduce the overall costs of its maintenance and shorten the maintenance planning time.

The purpose of building CSDT together with the development of in-depth management reporting is to provide the engineering staff, maintenance services and those managing the continuity of the production process with a new quality in terms of information support for planning processes and self-improvement of the coal mining process in JSW SA. CSDT enabled the transition to proactive maintenance of JSW mines. Implementation of maintenance strategies based on the technical condition of machines and devices (CBM – Conditional Based Maintenance) enabled the development of CBM principles for the needs of mine maintenance services.

Fig. 3.11 shows a view of the CSDT main panel. Examples of visualization boards created from the data collected by CSDT are shown in Figures 3.12÷3.22.

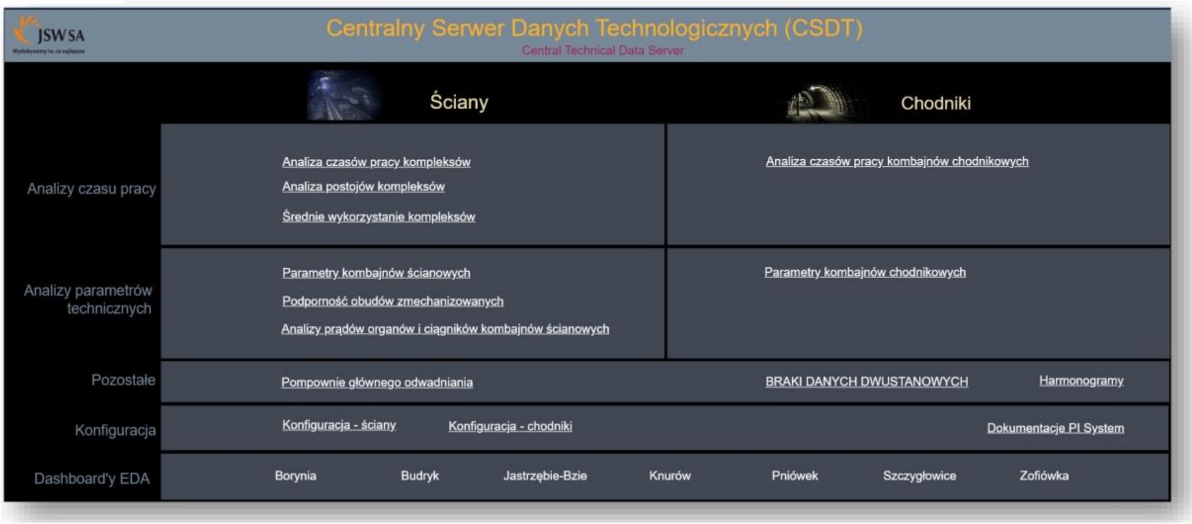


Fig. 3.11. Central Server for Technological Data (CSDT) – main panel view

Fig. 3.12 shows a visualization of the operation of machines in the longwalls of JSW SA mines. The operating parameter of each machine was the average operating time of the machine in individual minutes, expressed as a percentage (in the range of 0 - 100%). Fig. 3.13 shows an example of the visualization of shutdown events in a longwall system, specifying the start time, end time and duration of shutdowns, and Fig. 3.14 shows the visualization of the time histories of the load currents of the longwall machines and the position of the shearer in the longwalls of JSW SA mines. Fig. 3.15 shows a visualization of the operation of the main drainage pumps in the JSW SA mines. Fig. 3.16 is an example of visualization of the operation of the longwall system with the conveyor haulage system, where the operating status of the machines is marked in appropriate colors.

Fig. 3.17 shows a visualization of the operation of the belt conveyor with a description of the events of filling the belt conveyor and the ineffective operation of the belt conveyor. Figures 3.18 and 3.19 show examples of monitoring the load bearing capacity of powered roof support units, along with identifying anomalies in the support cycles.

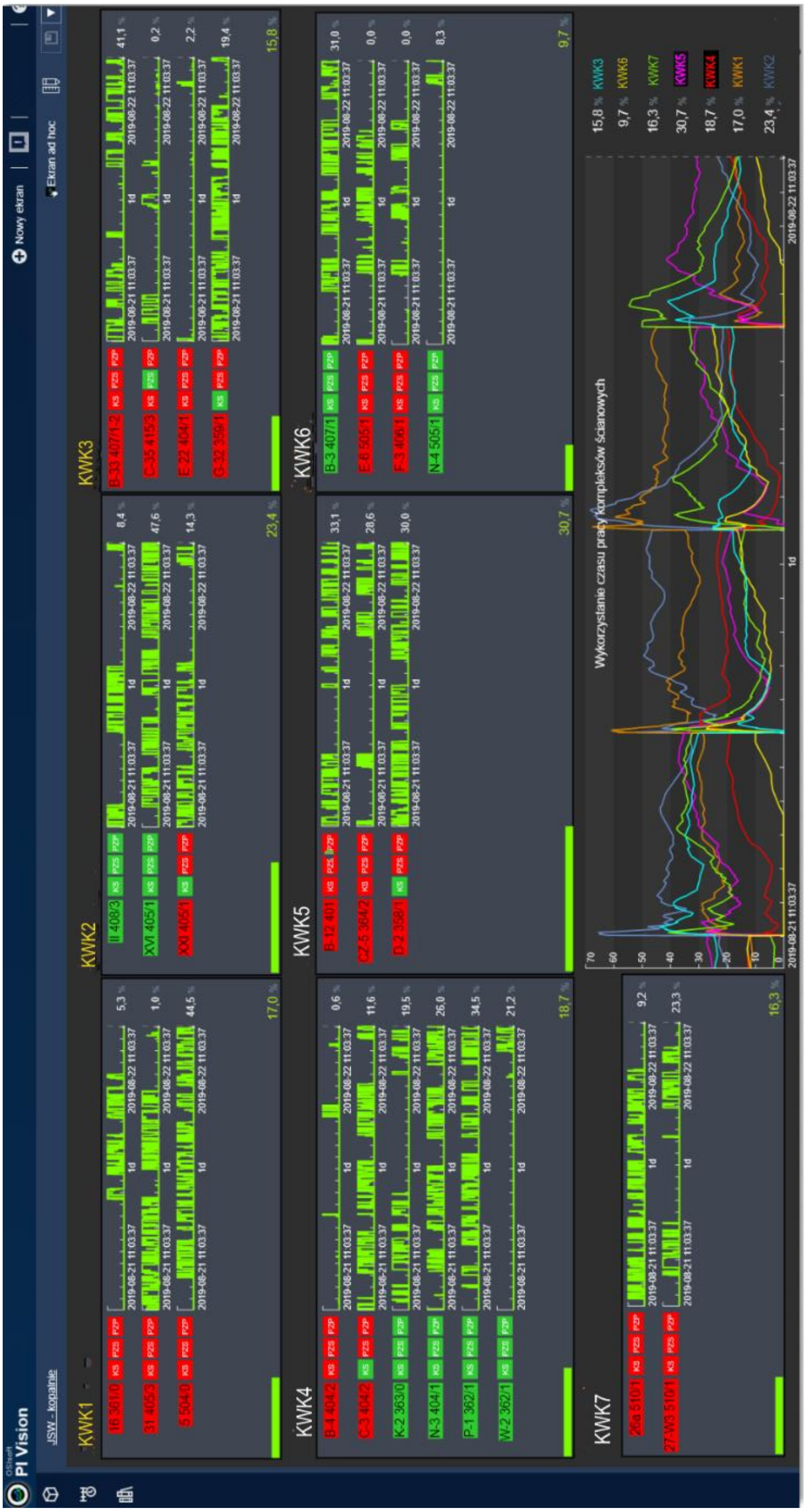
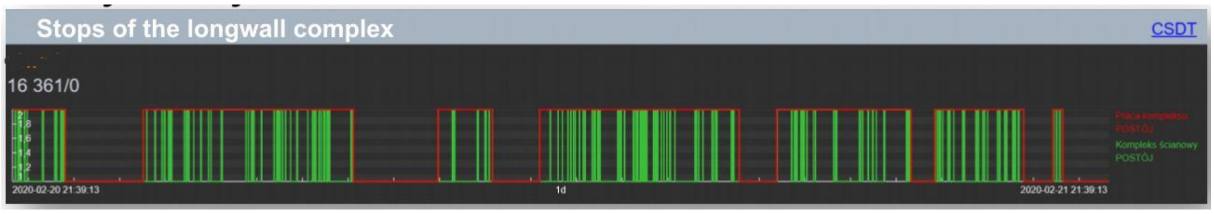
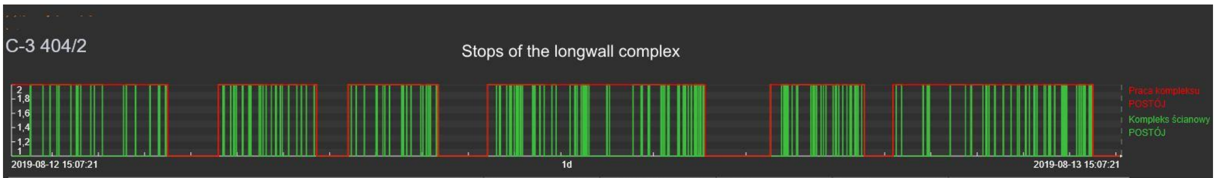


Fig. 3.12. Central Technological Data Server (CSDT) - visualization of the operation of machines in longwall systems of JSW SA mines



Name	20.02.... [1.00:47:43] 21.02....	Duration	Start Time	End Time
Postój MP (KN) 16 361/0 2020-02-20 22:48:210		102,7 Minutes	20.02.2020 22:4...	21.02.2020 00:31:05
Postój MP (KN) 16 361/0 2020-02-21 05:07:140		110,8 Minutes	21.02.2020 05:0...	21.02.2020 06:58:04
Postój MP (KN) 16 361/0 2020-02-21 08:09:240		62,4 Minutes	21.02.2020 08:0...	21.02.2020 09:11:46
Postój MP (KN) 16 361/0 2020-02-21 13:33:350		49,2 Minutes	21.02.2020 13:3...	21.02.2020 14:22:45
Postój MP (KN) 16 361/0 2020-02-21 17:19:070		31,6 Minutes	21.02.2020 17:1...	21.02.2020 17:50:45
Postój MP (KN) 16 361/0 2020-02-21 19:47:160		38,8 Minutes	21.02.2020 19:4...	21.02.2020 20:26:02
Postój MP (KN) 16 361/0 2020-02-21 20:38:530		110,4 Minutes	21.02.2020 20:3...	21.02.2020 22:29:18



Event name	Resource	Start time	End time	Duration	Reason
Stop MP (PN) C-3 404/2 2019-08-12 18:30:020	C-3 404/2	2019-08-12 18:30:02	2019-08-12 19:35:43	1h 5m	
Stop MP (PN) C-3 404/2 2019-08-12 21:43:180	C-3 404/2	2019-08-12 21:43:18	2019-08-12 22:24:08	40m 50s	
Stop MP (PN) C-3 404/2 2019-08-13 00:20:390	C-3 404/2	2019-08-13 00:20:39	2019-08-13 01:24:49	1h 4m	
Stop MP (PN) C-3 404/2 2019-08-13 06:07:160	C-3 404/2	2019-08-13 06:07:16	2019-08-13 07:31:48	1h 24m	
Stop MP (PN) C-3 404/2 2019-08-13 09:33:420	C-3 404/2	2019-08-13 09:33:42	2019-08-13 10:11:07	37m 25s	
Stop MP (PN) C-3 404/2 2019-08-13 14:30:020	C-3 404/2	2019-08-13 14:30:02	W toku	37m 19s	

Fig. 3.13. Central Server for Technological Data (CSDT) – visualization of longwall systems shutdown events

Fig. 3.20 shows an example of identifying the status of a longwall shearer based on the analysis of the currents consumed by the drives of the working parts and the haulage unit. The following statuses were distinguished: no data, standstill, work without feed, work with feed, cutting.

Fig. 3.21 presents examples of visualization of the state of data transmission from the machines of the longwall system. Data from the machines are obtained from machine controllers (current values and the location of the shearer with AKP, i.e. control and measurement equipment) and from the FOD-900 binary signal transmission system (e.g. current sensors). Fig. 3.21 distinguishes the following transmission states: no data source, no data from AKP and OK. An example of visualization of the lack of data transmission from I&C (Control, Measurement and Automation Equipment) is shown in Fig. 3.22.

Fig. 3.14. Central Server for Technological Data (CSDT) – visualization of machine operating parameters (supply currents of individual machine drives, shearer position); KBS – longwall shearer, POZ – position of the shearer in the longwall, PZS – armoured face conveyor, PZP – beam stage loader

Fig. 3.15. Central Server for Technological Data (CSDT) – visualization of the operation of the main drainage pumps

Fig. 3.16. Central Technological Data Server (CSDT) – visualization of the operation of the longwall system along with the conveyor haulage system

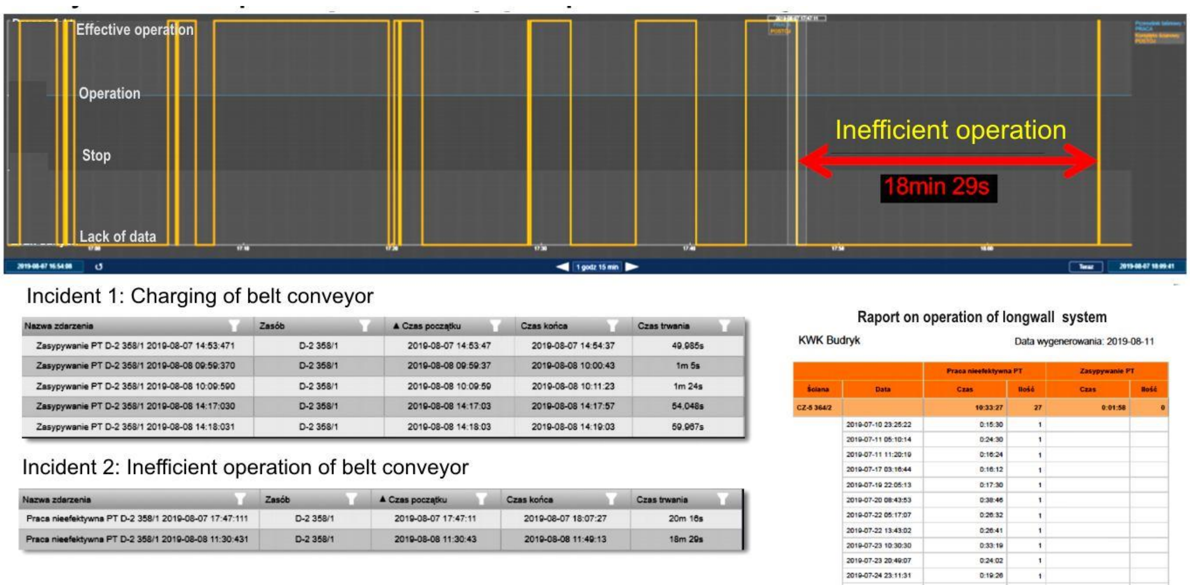


Fig. 3.17. Central Technological Data Server - visualization of the operation of a belt conveyor illustrating the cooperation of CSDT with SAP BO (analysis of dependencies between the operation of several machines)

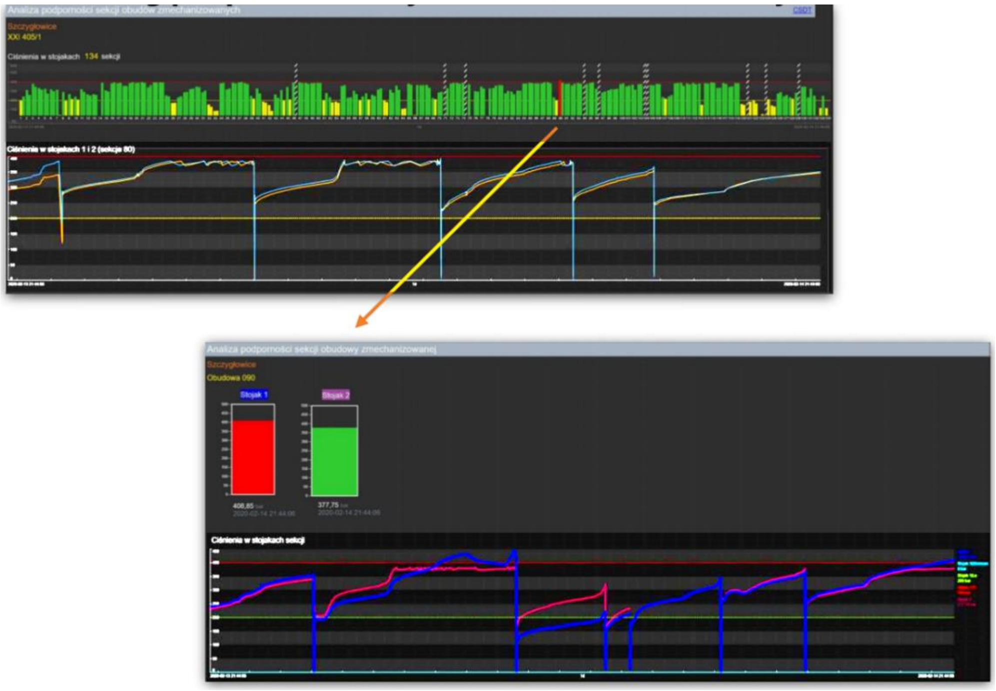


Fig. 3.18. Central Server for Technological Data (CSDT) – monitoring of the load capacity of powered roof supports sections – identification of anomalies and support cycles

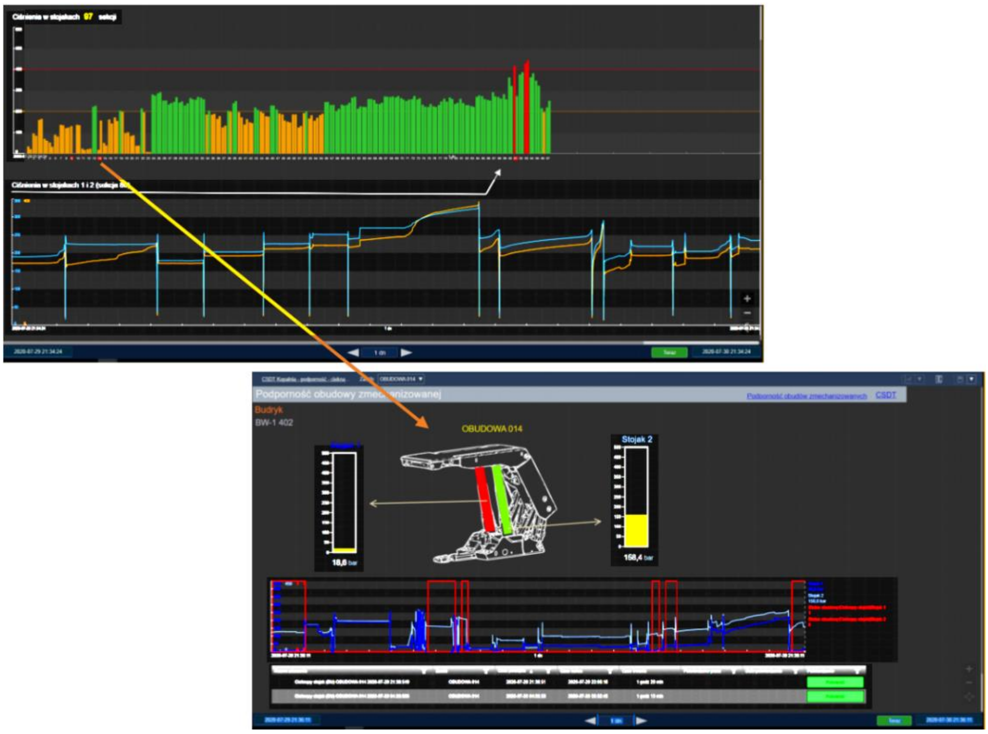
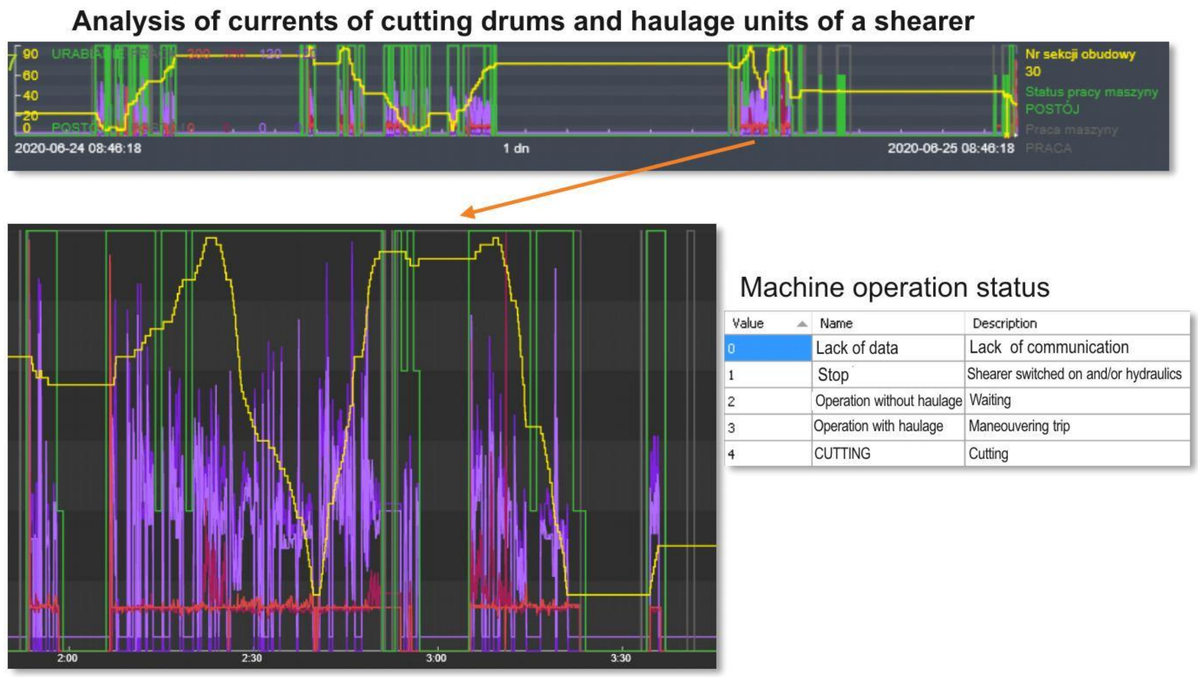


Fig. 3.19. Central Server for Technological Data (CSDT) – monitoring of the load-bearing capacity of powered roof supports sections



Rys. 3.20. Central Server for Technological Data (CSDT) – Analysis of currents in the cutting drums and the haulage unit of the longwall shearer – identification of the status of the longwall shearer

Fig. 3.21. Central Server for Technological Data (CSDT) – an example of visualization of data transmission from the machines of the longwall system

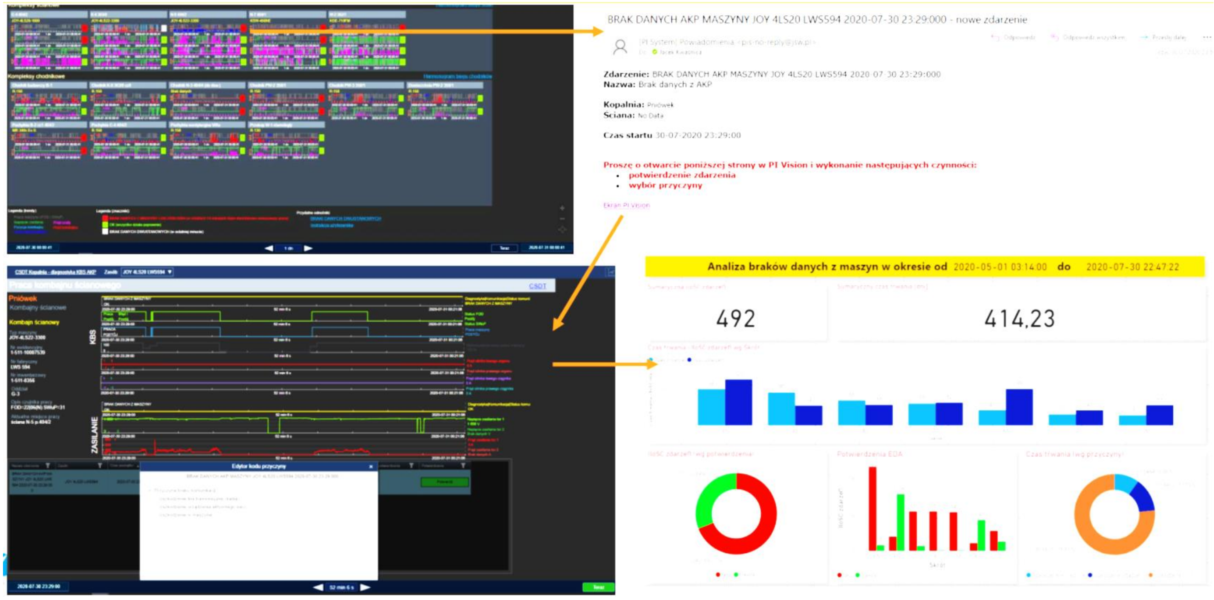


Fig. 3.22. Central Technology Data Server - visualization of missing I&C data (analysis of communication status)

Modernization activities carried out on a large scale and on a huge scale in the field of maintenance, of course, also had a financial dimension. Deloitte, in one of its reports on digital transformation towards Industry 4.0, stated that implementing a predictive maintenance strategy increases equipment uptime by 10 to 20%, reduces overall maintenance expenses by 5% to 10%, while reducing maintenance planning time from 20 to 50%, which in the case of such a large enterprise as JSW SA allows to significantly reduce the costs of each day of production. Hence the determination of entire teams of analysts, IT specialists, miners and electricians in using dedicated techniques and information technologies to systematize and disseminate information on maintenance and mining longwalls within the company.

The expansion of CSDT with new reporting methods, the use of artificial intelligence to expand the knowledge on the course of operations, the identification of factors of disturbances in natural, technical and organizational conditions as well as the economic effects of business anomalies are not far in the future, but the realities of work of the JSW Center for Advanced Data Analytics 4.0 nowadays.

Data collected in CSDT from PI System allows to create reports in the form of dashboards containing production data and selected economic indicators. A symbol of the new quality in reporting and data analytics at JSW SA was the launch for the first time in June 2018 of a new report (the so-called Management Dashboard - Fig. 3.23) distributed directly to the Company's Management Board and key management personnel.

The Management Dashboard contains the following elements:

– daily production of commercial coal (planned and achieved) divided into steam coal (WE), type 35 coking coal and type 34 coal,
– daily coal sales (planned and achieved) divided into steam coal, type 35 coking coal, type 34 coal,

- daily advance of development activities (planned and achieved),
- daily coal production divided into individual mines,
- coal production cumulatively since the beginning of the year, divided into individual mines,
- daily advance of development activities divided into individual mines,
- advance of development operations cumulatively since the beginning of the year, divided into individual mines,
- available financial resources of the company,
- coal stocks divided into steam coal, type 34 coking coal, type 35 coal,
- quality parameters of coking coal CSR, CRI for individual mines,
- prices of Premium Low Vol, TSI Premium Hard, Semi Soft, Coal CIF ARA,
- JSW SA exchange rate, dollar exchange rate.

In addition, operational dashboards have been developed for longwall management (Dashboard Ranking of Longwalls) and management of roadways (Dashboard Ranking of Roadways), which allow for an objective assessment of the operation of longwalls and roadways and enable improvement of production results.

The Longwall Ranking dashboard shown in Fig. 2.24 contains the following elements:

- daily production planned and achieved on a given day for all longwalls in individual mines,
- ranking of daily logical times for all longwalls,
- ranking of total longwall mining over the last 30 days,
- deviations from the extraction plan for individual longwalls during the last 30 days.

The Roadway Ranking dashboard shown in Fig. 2.25 contains the following data:

- deviations from the advance plan during the last 30 days for all roadways,
- average roadway course for all mines,
- ranking of roadway advance over the last 30 days,
- the number of roadways achieving a given advance divided into mining technology (roadheader, explosives, mixed technology).

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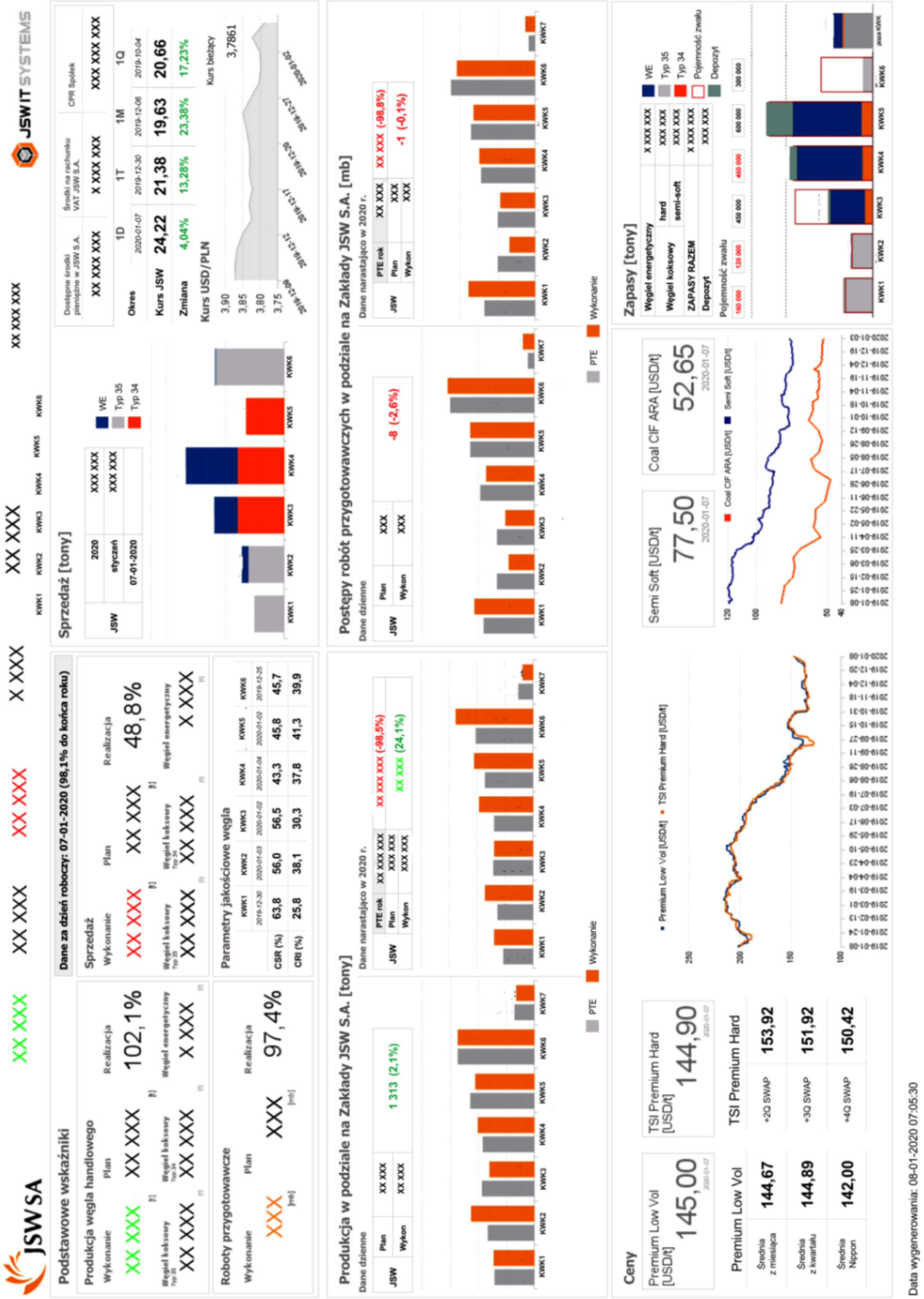

Fig. 3.23. Central Technology Data Server – Management Dashboard

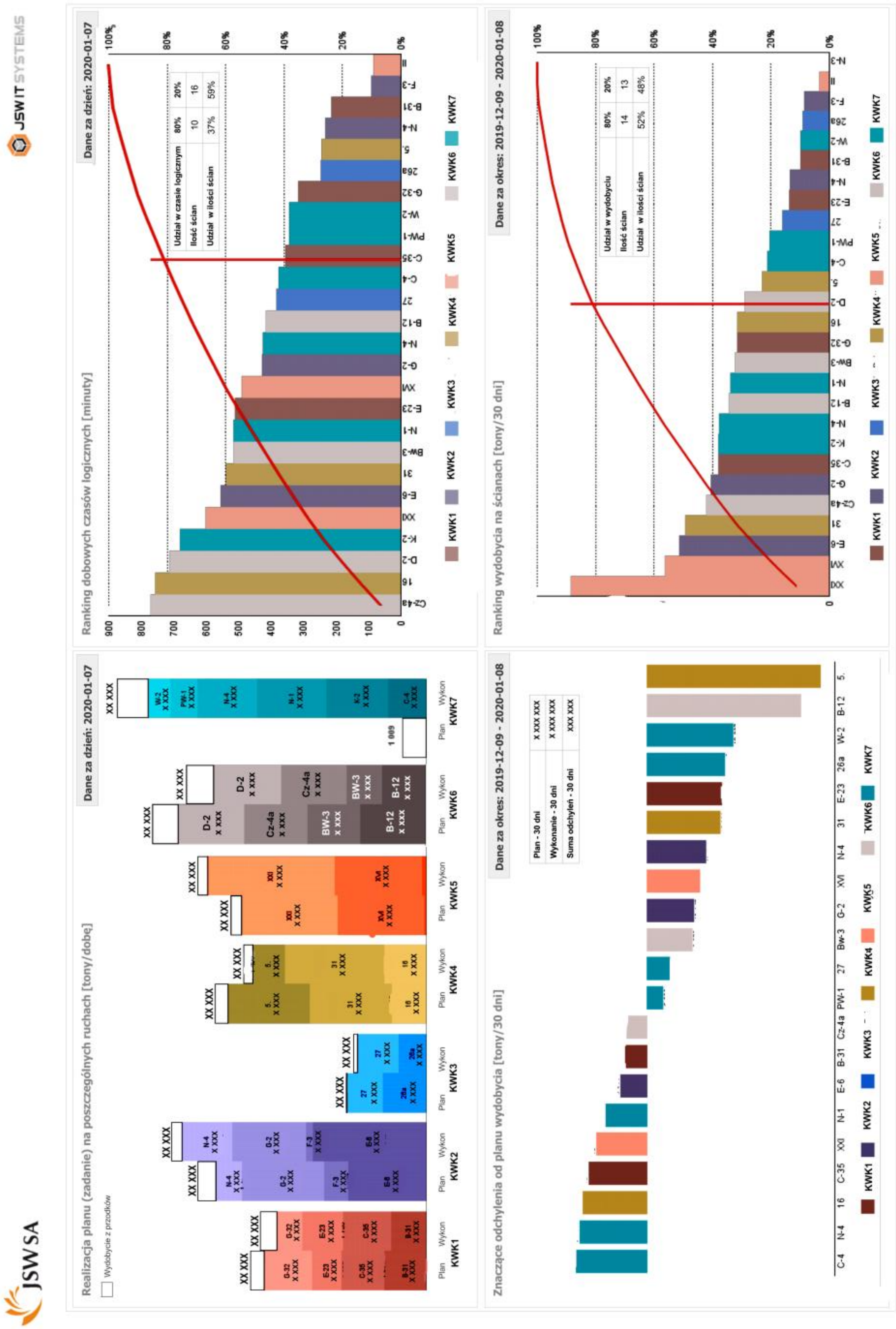

Fig. 3.24. Central Technology Data Server –Ranking Dashboard of Longwalls

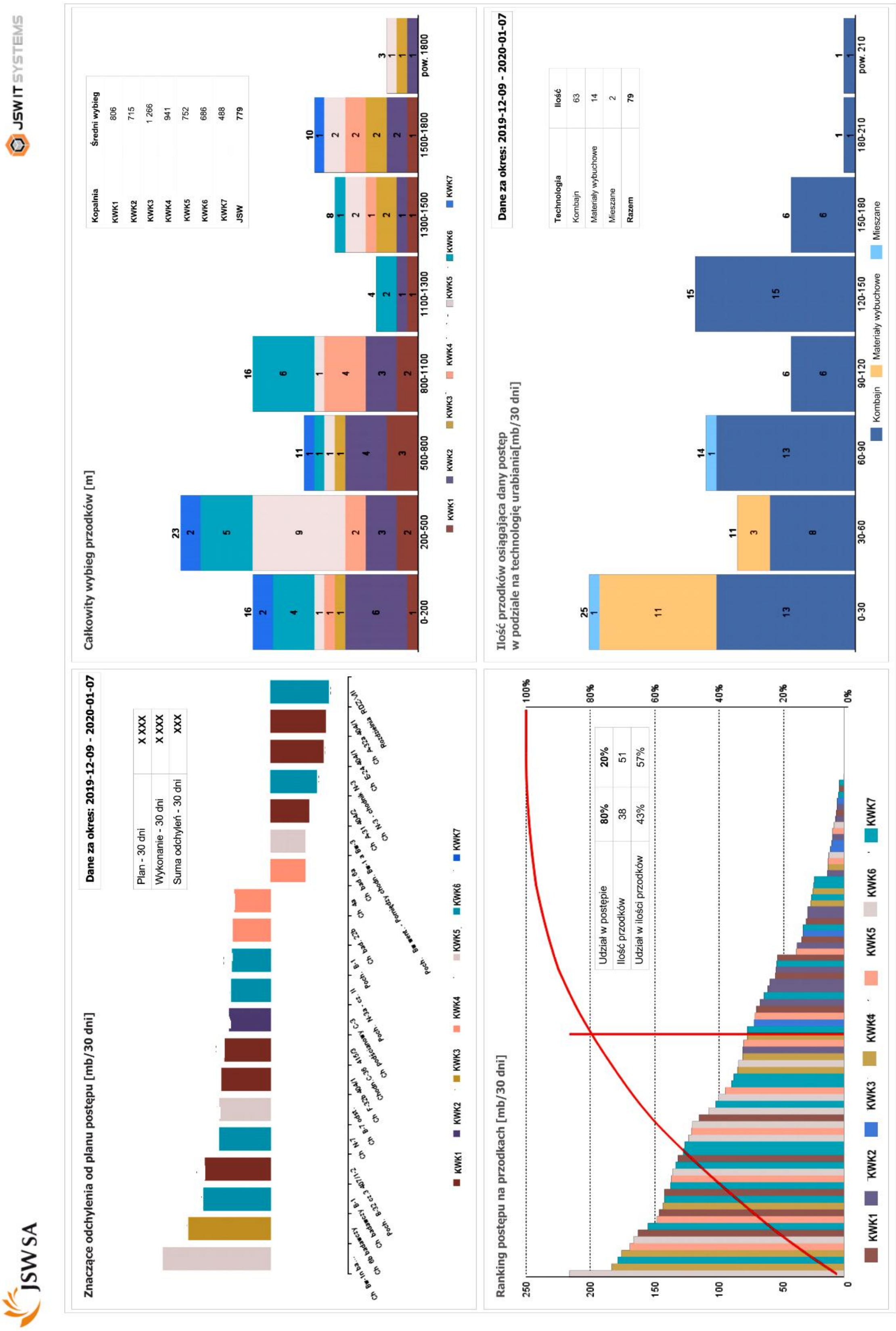

Fig. 3.25. Central Technological Data Server - Operational Ranking Dashboard of Roadways

3.4. The use of intelligent data processing techniques in mining

Making decisions in conditions of uncertainty is typical for the mining industry. The access to numerous data processing techniques, in the context of the existence of many areas of risk and optimization issues, clearly demonstrates the need to develop an environment supporting management processes in new ways.

The ability to learn and adapt is the basic determinant of intelligent decision support. The practical use of inductive reasoning methods to solve real problems requires domain experts to develop effective predictive models based on uncertain information. Intelligent decision support in the operating conditions of a mining plant should therefore be a combination of operational research being a source of optimization experiences and techniques (including artificial intelligence methods) enabling the discovery of knowledge from data.

The analytical part of the process of discovering knowledge from data present in the information systems of mining enterprises can be implemented in accordance with the CRISP-DM model (*Cross Industry Standard Process for Data Mining*), SEMMA (*Sample, Explore*, *Modify, Model and Assess*), DMAIC (*Define*, *Measure, Analyze*, *Improve*, *Control*), VCofDM (*Virtuous Cycle of Data Mining*) or a combination of stages specified in individual models (Table 3.1).

Basic stages of selected data mining models [Polak, 2014a]

Table 3.1.

CRISP-DM	SEMMA	VCofDM
1. Understanding business conditions	1. Sampling	1. Identifying business problems
2. Understanding data	2. Exploring	2. Transforming data into information
3. Data preparation	3. Manipulation	3. Taking action
4. Modeling	4. Modeling	4. Measuring and evaluating result
5. Evaluation	5. Assessment	
6. Implementation		

Data selection, cleaning, consolidation and transformation procedures should be tailored to specific tasks. The tasks also carry out the process of searching for answers to previously asked questions. However, what the organization actually wants to know is most often not clearly and permanently formulated. The construction of intelligent information systems should start with determining information requirements, understanding business conditions and assigning tasks for the process of discovering knowledge from data.

Data mining is a fundamental stage of the knowledge discovery process, which consists of complex research methods and techniques that enable the transition from data processing to knowledge discovery. The selection of techniques used individually or in combination is determined by the nature of the problem that needs to be solved. Most often, the choice of the method that will best cope with a specific data set and task (Table 3.2) is made through empirical tests. The data mining process is not a simple, routinely performed activity that can

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be automated, it requires interdisciplinary knowledge both in the field of data preparation, implementation of analytical tasks as well as the assessment and interpretation of results.

Selected tasks and research techniques in data mining [Polak, 2014a]

Table 3.2.

Tasks	Techniques
estimation and forecasting	visualizations on charts
classification and regression	statistical analyses
description (including density and correlation analysis)	artificial neural networks
grouping (cluster analysis and segmentation)	fuzzy inference rules
discovering patterns and rules (including associations, sequences)	Markov models
discovering characteristics	machine learning methods
singular point detection	support vector machines
detecting trends and deviations	Bayesian classifiers
time series analysis	trees and decision rules
text analysis	clustering algorithms
pattern search	genetic and evolutionary algorithms, swarm methods

In mining, the basic areas of application of intelligent data processing systems may be found in optimizing activities related to:

- classification of resources, design and closure of mines, economic evaluation of projects,
- modeling and development of the deposit, production scheduling,
- organization of production, selection of technical solutions,
- logistics, maintenance and diagnostics of the condition of machines and devices,
- early detection of threats, risk assessment, construction of simulation models,
- automation of controlling complex technological processes,
- budgeting and operational controlling,
- projection of future operating conditions, costs and production results.

The use of intelligent techniques in identified aspects of mining activities becomes more and more common. The implementation of intelligent data processing systems, in addition to the above-mentioned applications, may provide real support for other areas of mining activity, including in particular planning and optimization issues implemented using multi-scenario or multi-criteria analyses.

In Fig. 3.26 examples of results characterizing the course of coal mining in three longwall faces are presented. These results were placed on a unified plane of production efficiency and time. Then, the data sets were subjected to density analysis, which allowed for the visualization of their dispersion and location in space. The presented activity is an example of the practical use of a basic data mining technique - visualization on charts.

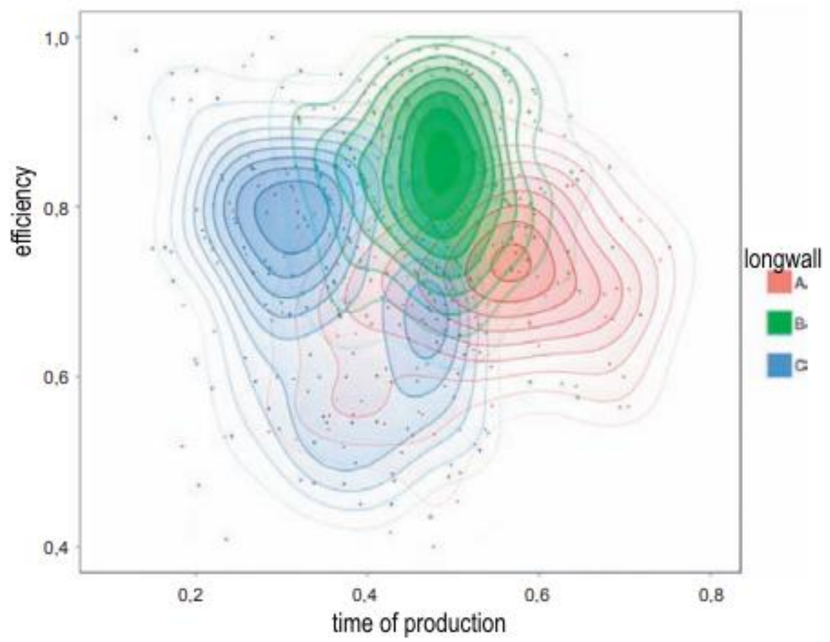

Fig. 3.26. Selected longwall systems analyzed in terms of key efficiency measures (effects of changes in work organization visible on the example of longwall C) [Polak, 2014a]

However, this method of exploration is subject to obvious limitations due to the maximum number of features (dimensions) in data mining. By adding further dimensions, including: downtime, failure, and other work, it is justified to classify and/or group observations using algorithmic data mining techniques, including: fuzzy inference rules, multilayer neural networks, support vector machines, k-means or nearest neighbor methods.

The practical use of this type of analysis may consist in determining patterns characterizing the production process and the results achieved in individual roadways. This can be achieved by using learning systems that map non-linear relationships between individual variables. Additional possibilities are provided by the use of the Monte Carlo method with a sampling procedure from distributions (Fig. 3.27).

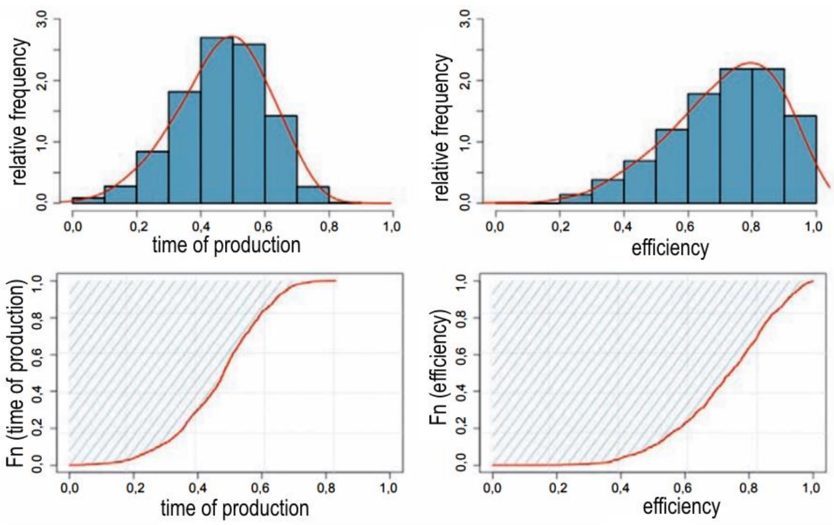

Fig. 3.27. Unified distribution function and histogram of working time and efficiency prepared collectively for longwall systems [Polak 2014a]

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The selection of important features of individual longwall faces becomes possible as a result of statistical analysis of generated combinations with a certainty of class assignment.

By analyzing historical data and current operational information, including: geological and mining conditions, events (e.g. occurrence of a failure), measurements carried out by control or telemetry systems (e.g. state of the mine atmosphere, shearer speed and cutting drum motor load) - it is possible to perform short- and long-term predictions of the production level. This may enable immediate actions to be taken to coordinate production tasks in order to stabilize the level and quality of extracted material.

Looking from the point of view of equipment life cycle management, the issues of multidimensional optimization of the total life cycle costs of a technical asset – LCC – are just as important. Generally, the cost-optimal point is a compromise on the axis of many directions of possible improvements and savings. Searching for it is a complicated process, which may be supported by the use of intelligent techniques. Estimation of losses related to, e.g. reduced availability, reparability, failure rate and performance of the purchased equipment, is possible, among others, by taking into account the impact of identified constraints on the unit cost of production (fixed and relatively fixed costs). However, increasing investment outlays enabling the acquisition of more effective solutions requires solid justification. They should be provided by the enterprise's information system, which performs the functions of recording and processing comprehensive data sets.

In relation to longwall systems, the need for ongoing improvement of production processes directly imposes the need to analyze production results and costs in terms of time, space and defined mining tasks (projects). The description of the geological and mining conditions, the equipment and technologies used, the method of organizing production, the number and qualifications of the crew, and the availability of infrastructure (including transport) enables to reveal hidden dependencies through the use of intelligent techniques. This allows not only to justify purchasing decisions, but above all to objectively predict the results and costs of future mining projects based on previously observed mine experiences, which can significantly improve planning processes.

3.5. Adaptation of key performance measures of the Total Productive Maintenance (TPM) strategy as the reporting key of the JSW Center for Advanced Data Analytics 4.0.

The share of fixed costs typical for the mining industry and the need to have an extensive machinery park oblige companies operating on the market to put continuous pressure on increasing productivity and reducing the costs of their operations. In practice, this means maintaining high technical efficiency and production efficiency of mining machines and equipment used in the production process. Achieving the above-mentioned goals requires absolute concentration on the selection of production means appropriate to the operating conditions, production plans and costs, as well as the optimization of their use and service processes.

TPM *(Total Productive Maintenance)* has been a relatively young management philosophy, developed since the 1970s. It involves maintenance services and operators in the continuous process of improving the production process through team activities aimed at maximizing the production potential of the company. The evolution and current directions of strategy development have been described in detail in the literature [Brzychczy, 2006; Polak, 2014b]. The subject of the TPM strategy, unlike TQM (*Total Quality Management*), is not directly related to the quality of the product, but the equipment – machines and devices necessary for its production.

Focusing attention on the process of using and servicing the basic means of production results in concentration on the causes of losses in terms of the efficiency of the use of production capabilities.

The TPM strategy is often perceived to have a par in relation to Lean Manufacturing. Its adaptation first of all directs all activities towards creating added value (product), which translates into generating profit for the company. Implementation of production in accordance with the TPM philosophy requires continuous improvement and concentration on activities enabling effective prevention in the long run, i.e. preventing any irregularities in place of previous corrective activities. This is achieved due to the full involvement of employees at all levels in multifunctional teams working to eliminate identified problems at the level of organizing production and service tasks. The implementation of the previously mentioned postulates, like the entire philosophy, requires a top-down approach.

Creating awareness and involvement in the process of continuous improvement should therefore start from the highest levels of management. For both operational employees and management staff, mechanisms for assessing and affirming results in the area of production and work efficiency must play an important role. They should constitute a basic element of an effective motivation system, aimed at achieving the intended results, and not only the implementation of the activities themselves.

In terms of preparing the reporting system for the Advanced Data Analytics Center (CZAD JSW 4.0.), it was extremely important to define measures and develop analysis methods that would provide measurable support in assessing the effectiveness of the use of basic mining machines and equipment applied in JSW SA mines. These measures should enable analysis of production results in the context of unified measures of work efficiency, which would enable, among others, efficient motivation of production crews and building a coherent, comprehensive knowledge base. In the longer term, key performance measures should constitute the basis for determining the scope of expected effects related to the implementation of various optimization activities, through dynamic estimation of equipment life cycle costs and unit production costs.

3.5.1. Analysis of significant conditions and functionality of current information systems in mining

Over recent years, a continuous development of technology has been observed, and thus an increase in the costs of equipment for excavations [Polak, 2014b]. As capital expenditure increases, the costs of replacing production capacity and equipment maintenance costs increase. Drastic declines in coal sales prices and persistently high mining costs require an increase in the profitability of assets held and changes in operating costs.

https://doi.org/10.32056/KOMAG/Monograph2024.2

The high share of fixed costs is currently the main barrier to mining efficiency. Their participation in total production costs varies in individual mines. On average, the level of fixed costs (including relatively fixed ones) is estimated at around 70%. Overcoming this barrier requires an increase in mining concentration, i.e. modernization of the mine model, including optimization of its key processes, such as: transporting the crew to the mine face, using highly efficient and reliable mining machines and equipment. However, these activities involve additional investment outlays that a significant part of the industry simply cannot afford. Reducing unit production costs in conditions of limited investments necessary to restore production capacity requires taking decisive steps to improve the efficiency of the use of existing equipment.

This goal can be achieved through an efficient motivation system that rewards efficiency in both production and safety. However, the functioning of efficiency improvement programs, the motivation system, the identification of gaps, disruptions and chronic losses occurring in the production process are not possible without effective mechanisms for measuring efficiency.

The longwall system is located directly at the beginning of the production chain; it largely determines production results, therefore in the research aspect it should be considered as the basic subject of attention. There are various systems and information channels in mines that enable to record the basic information about its operation. In a significant number of mines, there is a problem of integrating information recorded in individual information areas, including: reports on failures, exploitation advance, machine operating times, mining and geological conditions. This is partly due to the way in which responsibilities are directly delegated to individual, poorly connected departments. There is often a strong classification of information into important, used as part of cyclical processes, and information over which supervision has not been clearly and permanently formalized or covers a longer time horizon, using a different data source [Polak, 2014b].

This situation applies, among others, to shift reports from the longwall face. This information is typically available and used on an ongoing basis. However, the hard coal mining industry lacks permanent rules and mechanisms for their long-term analysis, resulting in the development of a uniform information standard. In fact, binding acceptance tests are carried out over a much longer period of time and constitute a much more reliable source of data, even though their detail is very limited. Production control in a shorter time horizon is most often carried out daily at the level of the entire plant. This is comparable and reliable information, but it does not make it possible to measure efficiency, determine the level of losses or identify their basic causes.

An important support for management staff is access to SCADA *(Supervisory Control And Data Acquisition)* systems. Unlike MES (*Manufacturing Execution System*) solutions, these systems enable tracking information in a short time horizon. Because they support operational control, the basic requirements for their functionality consortium online support for the dispatcher's work, both in terms of maintenance and control of safety parameters. Therefore, they do not have integrated tools enabling the analysis of collected data over a longer period of time and are usually characterized by limitations in the export and description of stored data.

The high share of fixed costs in the total costs of the mine speaks in favor of the presentation of key measures of the efficiency of longwall systems in the time dimension. Taking an example from best practices, it seems reasonable to apply elements of the TPM strategy used in the manufacturing industry, specifically the use of an indicator equivalent to OEE (*Overall Equipment Effectiveness*), which places all effectiveness measures on the timeline as a percentage. In this way, it is possible to identify both the time of creating added value (production) and the losses arising in this process. This approach can be extremely useful, bearing in mind the fact that in an underground mine, time can almost be directly equated with the cost incurred.

The focus on equipment productivity, typical of the TPM strategy, can certainly be applied to mines. However, the conditions characterizing mass production – including, among others: stationarity, a small number of random variables, limited influence of the environment - allow for meticulous planning and settlement of production tasks.

In the case of a mobile production system such as a longwall system, operating in extremely hostile and uncertain environmental conditions, these processes are extremely difficult, and often even impossible. Therefore, when scheduling or settling extraction from individual longwalls, a month is considered a safe settlement period. In the shorter term, production activities within the longwall faces are mutually coordinated in order to achieve the planned production parameters (including the quality of the commercial product) at the level of the entire plant.

When planning or settling production for a longwall, it is difficult to enforce the standard or even set it at the level of individual work shifts. If we set the partial, proportional values calculated from the monthly plan as the norm, it may turn out that on some days the performance was over 180%, and on others only 11% (Fig. 3.28). The daily use of the production capacity of mining machines is characterized by high variability over time.

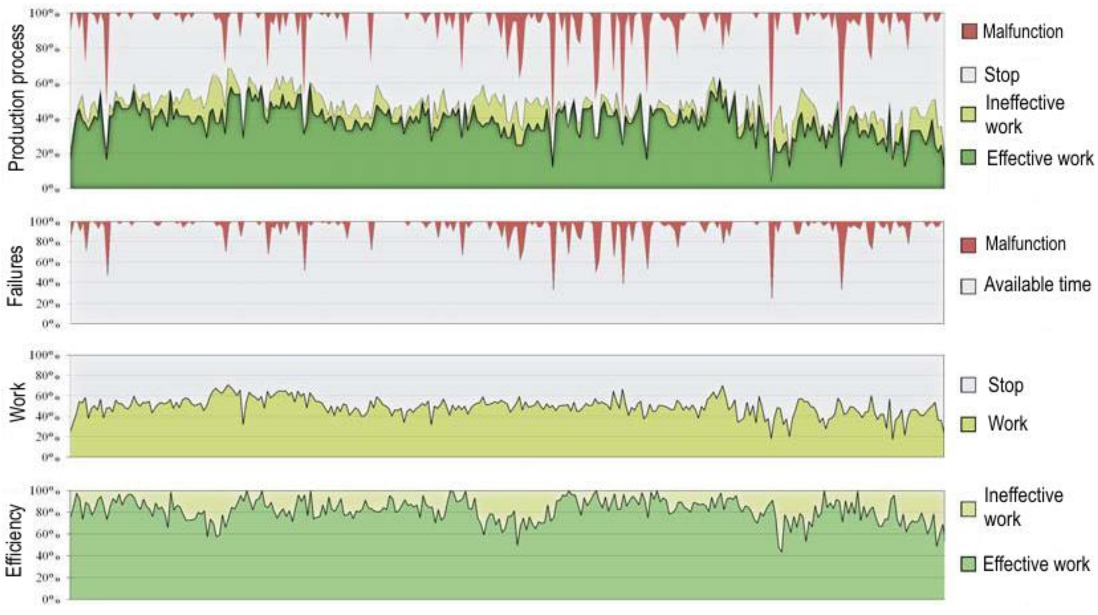


Fig. 3.28. Production flow for an exemplary longwall system [Polak, 2014b]

A degree of using the crew's time in the longwall face (TUD), observed in the mining industrry, changes in the scope from 30 to 90%, whereas the degree of the procedural use (PUD) – from 20 to 95%. The differences result, among others, from the method of production organiztion, an occurrence of interferences, limited in time, in a form of breakdowns, a deterioration of mining-and-geological conditions, a necessity of performing maintenance activities, which are indispensable for a realization of the following production tasks.

An optimization of processes of production means management in the mining industry, with use of the TPM philosophy, requires first of all a definition of the control and measurement system of efficiency concerning the use of equipment production potential. Thus, it is difficult to minimize losses, appearing in the production process without a proper and efficient system of their identification and assessment. The operational information, being some kind of a feedback, constitutes a basis for an assessment of undertaken activities. The lack of it renders it completely impossible to conduet an efficient management the means of production.

To control the determined, key efficiency indicators, it is necessary to be able to measure them and observe their changes in the function of undertaken activities (PDCA cycle – *Plan Do Check Act*).

3.5.2. Possibilities of adapting key TPM strategy effectiveness measures

Since the main subject of attention in the TPM philosophy is production equipment, the basic measures of the use of production potential are the indicator of overall equipment efficiency – OEE and installation (plant) – OPE (*Overall Plant Effectiveness*). Analysis of the basic causes of losses included in the OEE indicator allows, among others: optimal selection of equipment maintenance programs and improvement of production processes (e.g. Kaizen), which in turn increases total productivity, and thus improves the indicator. Importantly, the universal structure of the OEE indicator enables broadly understood benchmarking of mining units, production lines and systems or mines belonging to the capital group in the field of various production-related activities. It is also important to be able to compare the achieved results with global standards and norms, which in the long run result in an objectified assessment, leading to the adaptation of best practices following the example of the leaders of a given industry. The multi-stage structure of the OEE indicator enables the identification of the level of main chronic losses occurring in the production process. The value of the indicator determines how effectively the equipment and time allocated to production are used.

The OEE indicator includes the product of three key measures: Availability, Effectiveness Rate and Quality Rate:

- Availability is typically calculated as the ratio of operational time to scheduled working time. The basic dimension of availability losses is the time of unplanned production stoppage - downtime loss.
- Effectiveness Rate is determined by relating the current performance to the maximum achievable performance. Efficiency losses are defined as production Speed Loss.
- Quality Rate is calculated based on the number of products produced that meet quality requirements in relation to total production. Losses related to this element are described as Quality Losses.

Domestic and foreign literature widely describes attempts to adapt TPM elements to the specificity of mining. There is also a number of publications devoted to issues related to the assessment of effective working time and the efficiency of the production cycle carried out in longwall faces [Brzychczy, 2008; Kicki, 2011; Polak, 2014a].

The value of the OEE indicator is a measure of the added value *(Net Value Added)* created during scheduled work time, which is determined by the demand for the product (production plans). Therefore, the methodology for calculating the OEE indicator does not take into account losses related to planned downtime.

In the case of mining, the predominance of fixed costs (including maintenance of excavations, drainage, ventilation), the mechanics of the rock mass and the environment influencing the accelerated aging of technical facilities support the implementation of production tasks in a continuous manner. “Black” days, understood as mining days, are the basic period for carrying out production tasks. These typically involve two to four production shifts and one maintenance shift. The assignment of tasks for production shifts is flexible, as the work plan changes with the occurence of certain events or situations, e.g. unplanned shutdown of another longwall, the need to carry out maintenance work, or difficult mining conditions.

The process of mineral extraction in a longwall face includes both the advance of the longwall face and the performance of accompanying mining activities. During the time allocated for production, the following activities are carried out: ongoing maintenance of equipment (including checking the technical condition, start-up procedure) and a number of other activities enabling the maintenance of workings and ensuring continuity of production (including floor sampling, reconstruction or liquidation of longwall headings, disassembly of supports, conveyor advance, crushing of run-of-mine and unblocking of transport routes, rockfall and rock breaking). Due to safety reasons or technological limitations, a significant part of the work requires stopping the production. The time of work completion and downtime determines the present, available time that can be devoted to mining, which is a measure of technological and organizational readiness. The amount of this time is not subject to direct planning, its estimation is possible at the operational control level. At the same time, apart from the time of failure, it is difficult to clearly determine the cause of production stops. Detailed records of the time of activities and stops other than breakdowns are extremely cumbersome in practice.

While analyzing only the shearer's operating time, variable production efficiency can be noticed. This is mainly due to short stops (including difficulties in moving the supports, changing the position of the arms), procedural starts (including leveling the end of the longwall) and reduced advance resulting from the deterioration of mining and geological conditions (including the presence of waste rock, methane release, tightening of the powered roof support).

Ultimately, the quality of the carried out production can be considered, only as the exploitation within the seam limits. The level of losses in such a system reflects the share of roof and floor uplift together with rock fall in the total weight of extracted material.

All described information components can be obtained from currently operating information systems. Basically, their records boil down to determining: how many days in the analyzed time period were production days and isolating, along with determining the time share, the following states: failure, standstill and operation. Components reflecting the efficiency and quality of production can be estimated by analyzing the parameters of the longwalls, the advance and the weight of the excavated material over a specific period of time. It was decided to modify the typical structure of the OEE indicator by taking into account occupancy and specifying information about failures. The individual elements of the indicator are:

– occupancy – a measure of the planned use of calendar days,
– technical readiness – a measure of reliability and reparability, taking into account failure time,
– technological and organizational readiness - a measure of downtime and completion of other activities,
– efficiency - a measure of small stops and reductions in production "speed", determined by relation to the achievable and empirically determined maximum efficiency (in the CZAD JSW 4.0 analyses, the average value of production efficiency was assumed for the 10% of the best results),
– quality – a measure of added value creation (seam exploitation).

Fig. 3.29 uses a flow chart to present the efficiency index for the use of the longwall system, calculated according to the adopted methodology, aggregated for several longwalls. The data include longwalls extracted over two-year time period.

The proposed structure and the order of individual loss levels were determined by assessing the impact of changes in individual efficiency measures, i.e. verifying whether reducing losses at level n will result in a relatively proportional change in the duration of states at level n + 1. The order of taking into account technical and organizational readiness may raise some reservations. The adopted system results from both the method of recording the duration of the failure, as well as the lack of a clear correlation between the production time and the failure time in the long term.

The occurrence of a failure is an overarching random event, only to some extent dependent on aging processes and other factors occurring exclusively during production. In other words, completely stopping the longwall advance cannot be equated with achieving full technical readiness (eliminating failures). Additionally, the use of the adopted system is supported by the fact that, apart from downtime and maintenance time, the time of production stops to carry out the required work is almost directly dependent on the advance of the longwall, so with constant efficiency it is proportional to the production time.

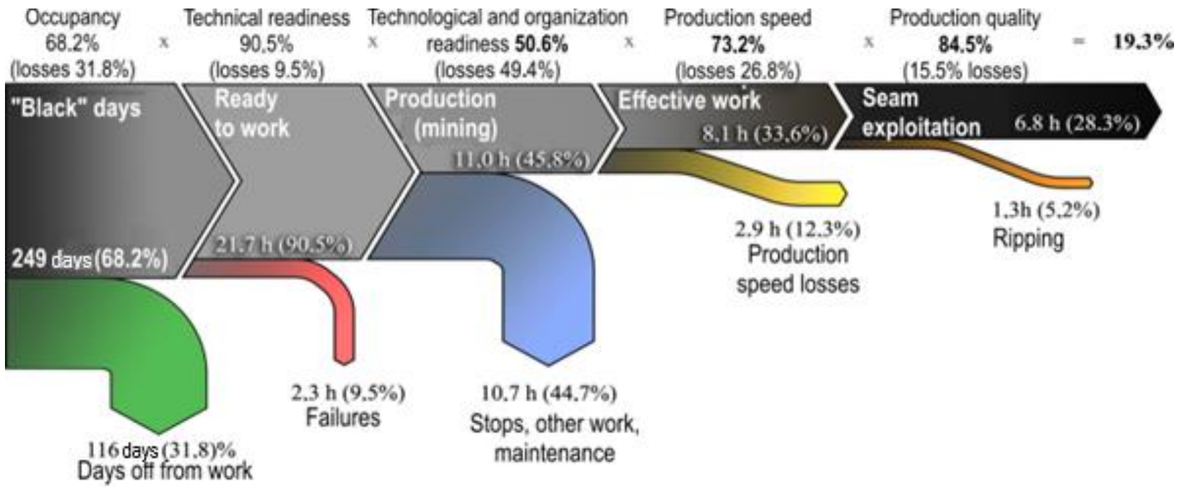


Fig. 3.29. Stream diagram showing direct production time losses [Polak, 2014b]

It should be noticed that mutual comparison of longwall faces, due to the highly diversified production potential, should always be performed on the basis of multidimensional analyses, taking into account all important features that may affect the achieved production results, including: the thickness of the seam, the severity of the conditions, the length of haulage routes and the degree of rock burst hazard.

3.5.3. Basic statistics characterizing the course of the exploitation process

Optimal production planning in mining is a real challenge in terms of risk management, cost analysis and profitability of new investments in the context of the market situation. Making decisions without access to certain information is inherent in the nature of mining activities. This applies to both natural conditions and operational parameters of newly purchased mining machines and equipment, such as availability, reliability, reparability, and total costs of maintenance.

Building durable and effective mechanisms for analyzing data from the longwall face is therefore extremely important, both at the level of ongoing optimization of the production process and knowledge management. Organizing and systematizing information provides the basis for empirical estimation of key performance indicators of the planned walls, and also plays an important role at the decision support stage.

The IT system implemented in 2018 at the JSW 4.0 Advanced Data Analytics Center optimizes the process of collecting and analyzing a wide range of data on means of production and automatically prepares statistics characterizing the operation of JSW SA mines.

The results of the analysis of data aggregated over time at the level of individual longwall faces (systems) are presented in Table 3.3. The analysis was carried out on the example of longwall faces with a total distance of over 10 km. As part of the research, approximately 1,000 production days were analyzed. Using the database, basic information about the longwalls was compiled and combined with reports on their advance, failures and readings from sensors monitored in SCADA systems.

Statistical indicators aggregated at the level of individual longwalls [Polak, 2014b]

Table 3.3.

Specification	Max.	Min.	Mean	Standard deviation	Coefficient of variation
Average failure time [h]	3.3	0.7	2.3	1.1	47.83%
Average parking time [h]	15.7	8.7	10.7	2.8	26.17%
Average working time [h], including:	12.0	7.6	11.0	1.8	16.36%
Average effective work time [h]	9.2	5.3	8.1	1.5	18.52%
Average time of ineffective work [h]	3.7	2.0	2.9	0.7	24.14%
MTTR [h]	3.3	1.6	2.7	0.7	25.93%
MTBF (for shearer operating time) [h]	18.1	9.6	13.2	3.5	26.52%
MTBF (for total time) [h]	55.3	17.2	20.7	15.8	76.33%
Advance per working hour [m]	0.49	0.43	0.49	0.03	6.12%
Mining per hour of work (gross) [Mg]	555.1	379.0	444.1	82.3	18.53%
Daily production on black days (gross) [Mg]	5,908.3	4,303.8	4,589.9	698.8	15.22%
Calendar time utilization [%]	69.6	67.2	68.2	1.0	1.47%
Technical readiness (availability) [%]	97.3	86.2	90.5	4.7	5.19%
Technological and organizational readiness [%]	57.8	32.7	50.6	10.0	19.76%
Production speed (efficiency) [%]	82.2	69.0	73.2	5.3	7.24%
Production quality [%]	85.3	83.6	84.5	0.6	0.71%

Analyzing the data in Table 3.3, it can be noticed that there are significant differences in the average failure time and the mean time-to-failure distribution index MTBF (*Mean Time Between Failures)* for individual systems. The relative production time is also subject to significant fluctuations, resulting mainly from the way work shifts are organized and the distance covered by the crew to the working face.

As observed, fluctuations in unit productivity are strongly related to the thickness of the wall and depend to a limited extent on its length. Observing the almost constant speed of advance of longwalls with different dimensions of the coal being mined, this is fully justified. Next, the previously calculated parameters were correlated at the level of individual production days. Correlations were made for normalized results characterizing the production process of various longwalls. In total, approximately 1000 observations (production days) were taken into account, the critical value of R for a two-sided test i = 0.01 was 0.082.

Apart from the obvious cause-and-effect relationships (Fig. 3.30), a negative correlation can be seen between technical and technological-organizational availability (rs = -0.32). This can be explained by the fact that during a failure, it is possible to perform additional activities that would normally require stopping the mining process. Similarly, in the analyzed data set there is a positive correlation between technical availability and production efficiency (rs = 0.23). Hence, it can be concluded that the occurrence of a failure temporarily limits both the mining time and has a negative impact on mining efficiency.

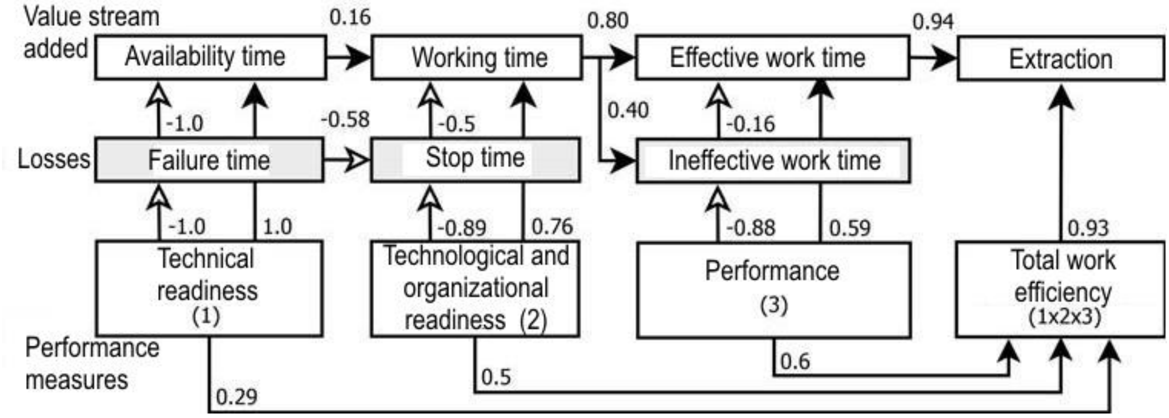


Fig. 3.30. Basic cause-and-effect relationships and their corresponding correlations [Polak, 2014b]

Next, the distribution of the set of observations recorded for individual longwalls was analyzed. It is difficult to clearly assign the type of distribution, but in most cases the shape of the distribution is close to normal or logarithmically normal. The logarithmically normal distribution can often be observed in the analysis of mining loads on belt conveyors. At a constant belt speed, disregarding its own resistance, this parameter changes linearly as a function of the amount of output, so it is an equivalent measure of the production level.

Figures 3.31 and 3.32 show ordered charts of absolute and relative efficiency measures, prepared for two extremely different longwall faces. The first case contains the extraction levels and durations of individual states, the second one contains the relative degrees of calculating the equipment use efficiency index. The shape of the distributions in Figures 3.31 and 3.32 is similar, but some characteristic shifts and rescaling can be noticed.

By comparing relative and absolute measures, one can notice the direct impact of the longwall parameters and conditions on the obtained production results. Despite the almost identical average value of the equipment utilization rate, longwall system A gives significantly better production results than system B.

This is largely due to the greater thickness of the seam and the less onerous mining and geological conditions, which in practice enable achieving and maintaining higher production efficiency.

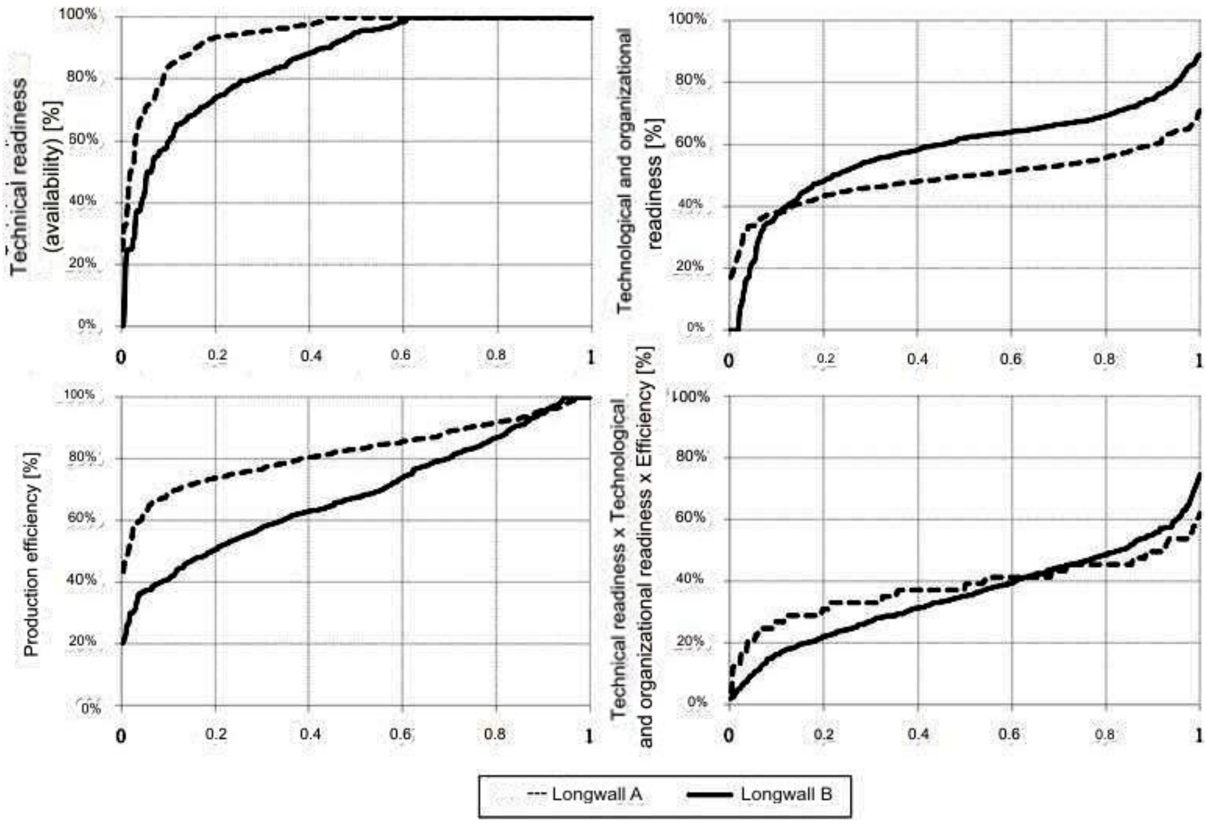


Fig. 3.31. Ordered chart of relative efficiency measures prepared for two different longwall faces (X-axis shows the share in the total number of production shifts) [Polak, 2014b]

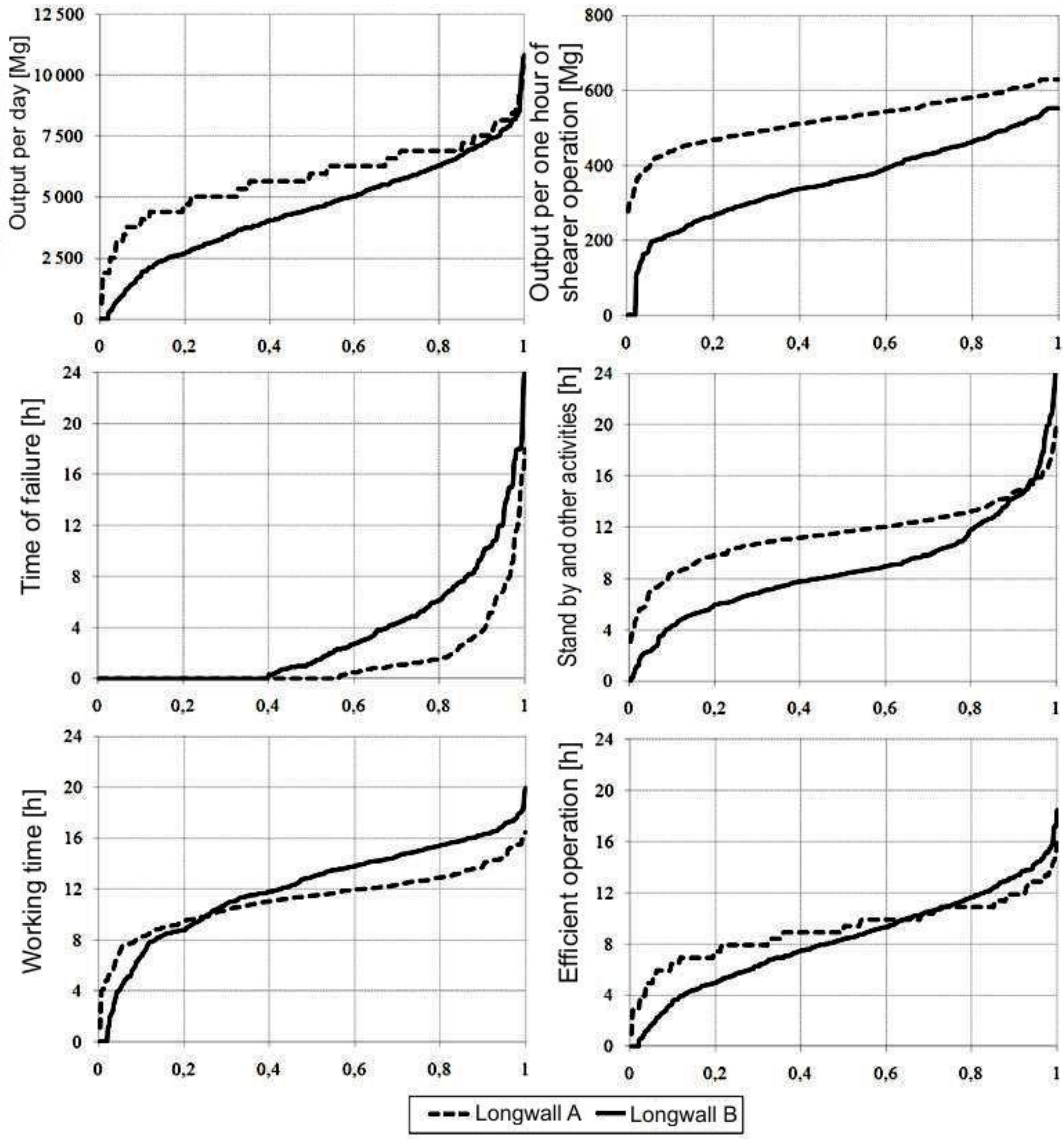
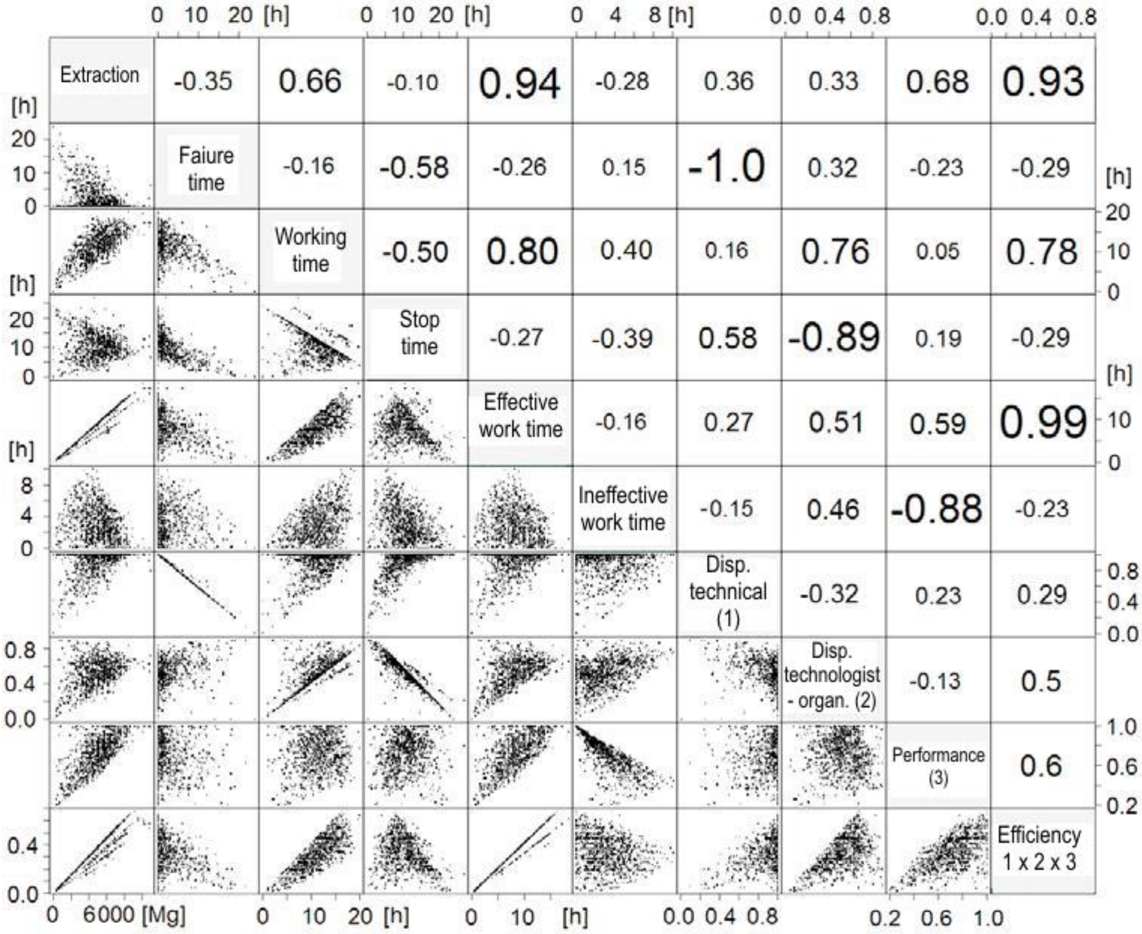


Fig. 3.32. Ordered chart of the level of extraction and the share of individual time periods prepared for two different longwall faces (the X-axis shows the share in the total number of production shifts) [Polak, 2014b]

It should be noted here that knowledge of the relationships described is needed both to identify and take into account regularities, as well as to make a full, reliable estimate of the economic effectiveness of future projects (Table 3.4).

Rank correlation coefficients of individual parameters [Polak, 2014b]

Table 3.4.



In 2018, Jastrzębska Spółka Węglowa implemented an IT system based on the PI system from OSIsoft, aimed at collecting and analyzing a wide range of data regarding means of production.

The data infrastructure is based on three layers of the system: data collection, processing and delivery and consists of four key elements:

- **PI Data Archive** – used to collect, organize and archive data and deliver it to users.
- **PI Asset Framework** – enabling clear definition of enterprise devices and organizational units in the system.
- **PI Event Frames** – organizing data according to key parameters, such as stop times, shifts, etc.
- **PI Notifications** – monitoring the collected data and alerting users if defined deviations from standards are detected.

As established during the implementation, an effective information system should implement the processes of recording and multidimensional structuring of the collected data (e.g. in accordance with the multidimensional OLAP model). The analysis of comprehensive databases makes it possible to reveal a number of seemingly hidden information.

The creation of this type of resources should enable the development of expert systems based on the mine's experience recorded in precisely defined environmental conditions, with a specific production organization system, technology used and selection of equipment [Kicki, 2011].

3.5.4 Mechanisms for analysing efficiency measures of longwall systems use

Due to the influence of random factors, certain cognitive problems are met while performing an analysis of time series and the full identification of correlations, especially non-linear or non-monotonic ones. When examining the interdependence of parameters, random factors and multiple connections distort the value of linear and rank correlation indices. Using the Kolmogorov-Smirnov test for the distribution function in individual quarters of the examined feature, it is possible to identify relationships to a significant extent. However, in the case of time series analysis, solving the problem requires developing an effective solution for eliminating local fluctuations in parameters characterizing the production process.

When developing data for the purposes of algorithming reports for the JSW 4.0 Center for Advanced Data Analytics, the following procedure was used to support the assessment of correlations and periodic trends in time series:

- Samples described with measures assigned to a given period (shift, day) were arranged according to the selected feature (in the case of time series analysis - time).
- Two parameters were selected and then summed, resulting in a cumulative course of the Y and X variables. Where X was selected as a parameter theoretically proportional to the analyzed value of Y, e.g. (shearer available time – operating time, shearer operating time - cutting).
- The points placed on the plane were approximated using the local approximation method using *Moving Weighted Least Squares* (MWLS) with an empirically selected degree of the polynomial, the number of nodes in the star and smoothing parameters.
- Differentiation of the obtained curve was performed.
- The obtained values and/or deviations from the proportional line are presented on a chart, with subsequent sample numbers on the X axis, resulting from the ranking carried out in point 1 (for time series – time unit).

In order to identify mutual dependencies, the described method was used to assess the shape of the distribution function, previously ordered according to the value of the selected parameter. Non-monotonic correlations could be captured on the derivative graph, while the test for compliance was performed on the cumulative graph with respect to the proportional line.

By using the MWLS approximation, significant limitations (periodicity, problems at the edges) of the default moving average used in similar cases were eliminated. Using a cumulative graph, a simple and transparent way of verifying the course of the curve approximating subsequent samples was provided, and the consistency of the total sums was ensured. By introducing the parameter X, which is proportional to Y by default, the need to apply additional transformations of the analyzed value in the event of more than one correlation is excluded. The method allowed for taking into account local disturbances and fluctuations while increasing the readability of the production processes.

In Fig. 3.33, using the previously described method, the course of basic efficiency parameters, including gross daily extraction, was determined.

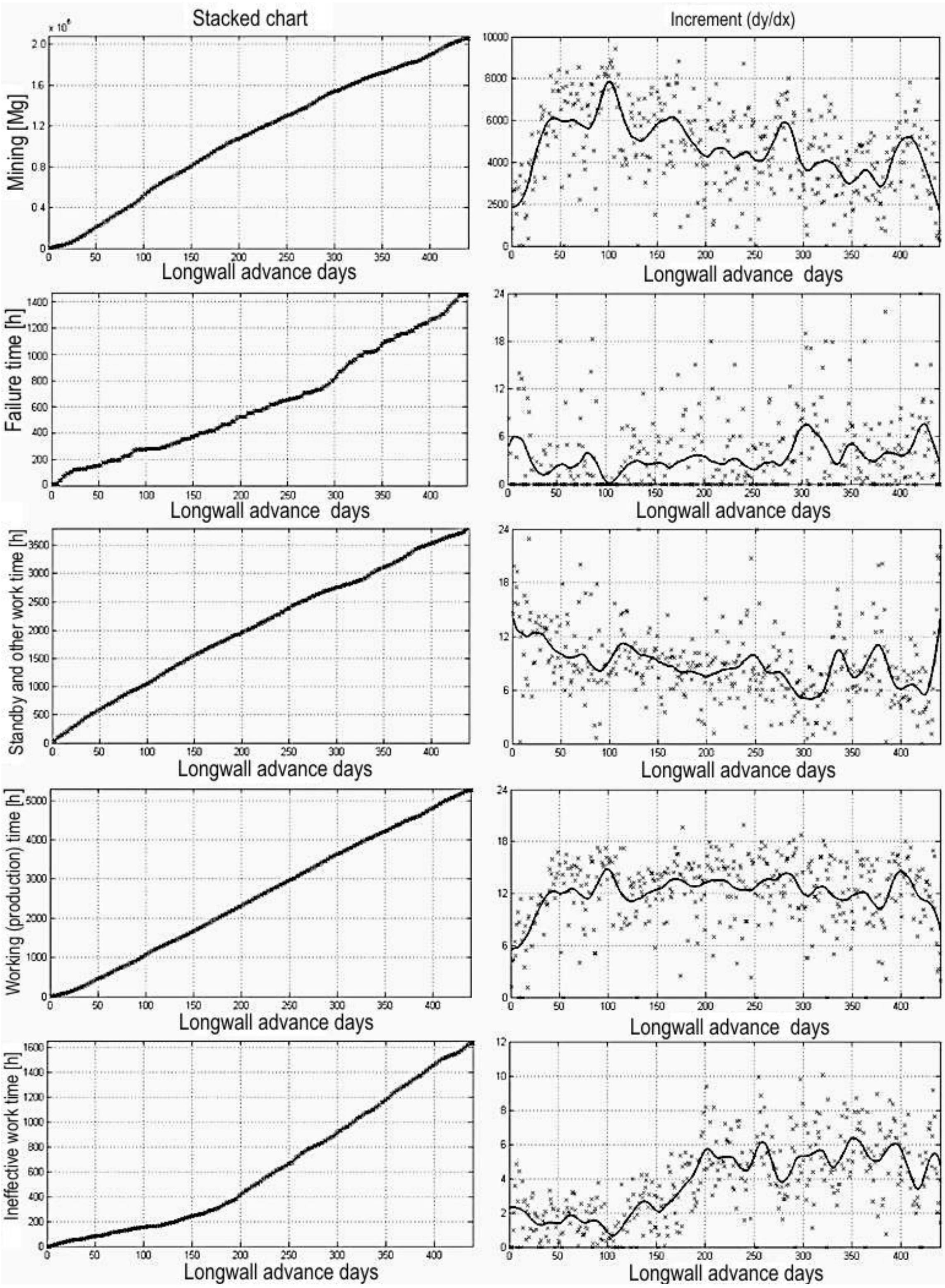


Fig. 3.33. Results of the application of the data processing procedure for the level of extraction and the share of individual time for an exemplary longwall face [Polak 2014b]

Fig. 3.34 shows the basic performance measures used to determine the overall equipment utilization rate, prepared for the same time period and longwall using the same method.

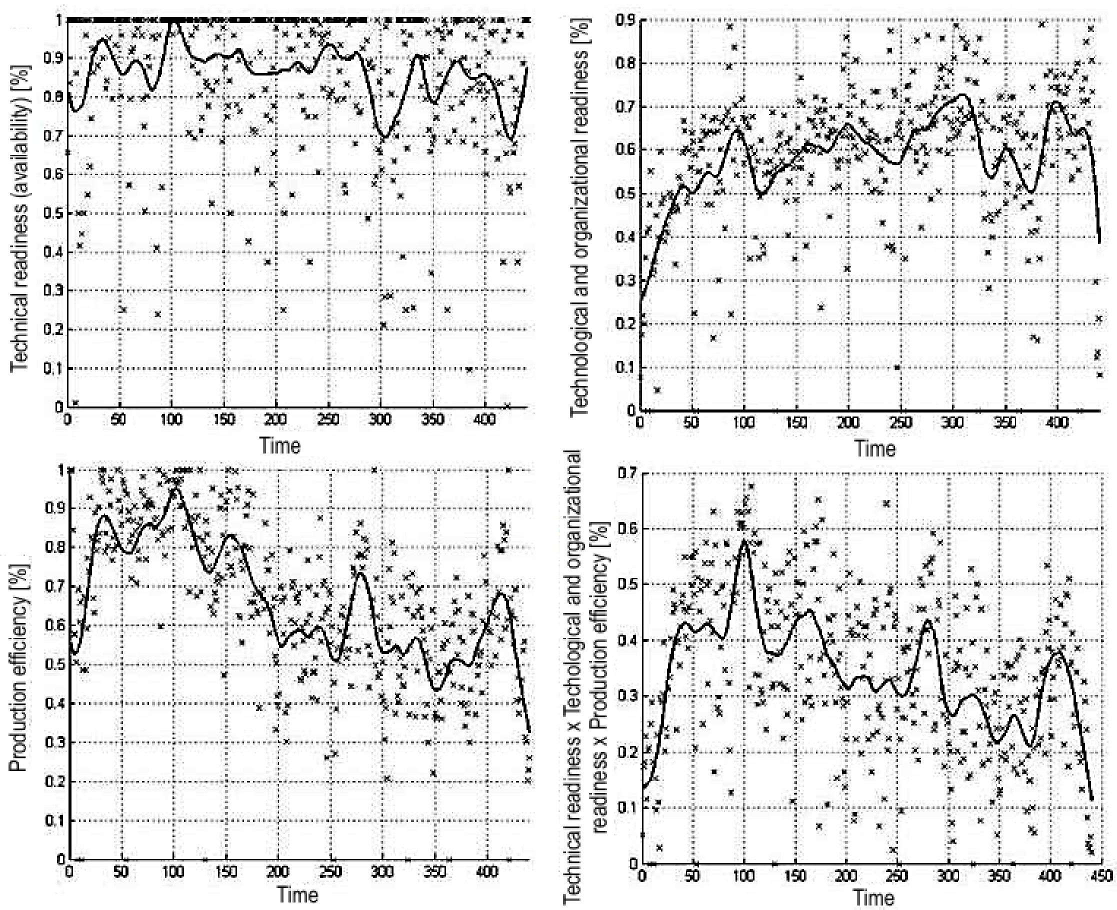


Fig. 3.34. Basic efficiency measures of an exemplary longwall face [Polak 2014b]

The decrease in unit production efficiency can be noticed both by observing the increase in ineffective working time (Fig. 3.33) and the decrease in production efficiency (Fig. 3.34). In this particular case, this factor is the main reason for limiting daily extraction. This variability as a function of time is visualized using the 3D graph in Fig. 3.35. The MWLS method was again used to approximate the plane.

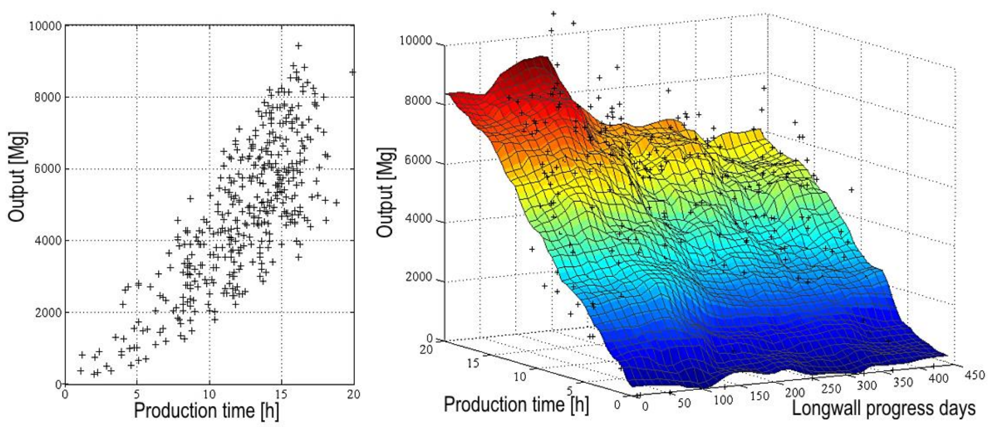


Fig. 3.35. Dependence of production time (shearer operation) and efficiency in subsequent days of longwall advance [Polak, 2014b]

Analyzing individual time intervals, one can notice a close correlation between extraction and operating time, which is justified given the limited impact of efficiency losses. It is also possible to observe a quite significant reduction in production efficiency for shorter shearer operation times.

This dependence can be explained by the increased share of permanent procedural losses, which are compensated by longer production time periods, which translates into a unit increase in efficiency. To a limited extent, it may also be a consequence of failures, the occurrence of which limits both the time and efficiency of production.

The described procedure allowed for a completely reliable calculation of the impact of the extraction level on the number and total duration of failures. As established on the basis of available data, reducing the level of extraction may reduce failure rates, but only in terms of time.

When converting the failure time into longwall advance or mining, the relative technical readiness rate deteriorates significantly (Fig. 3.36).

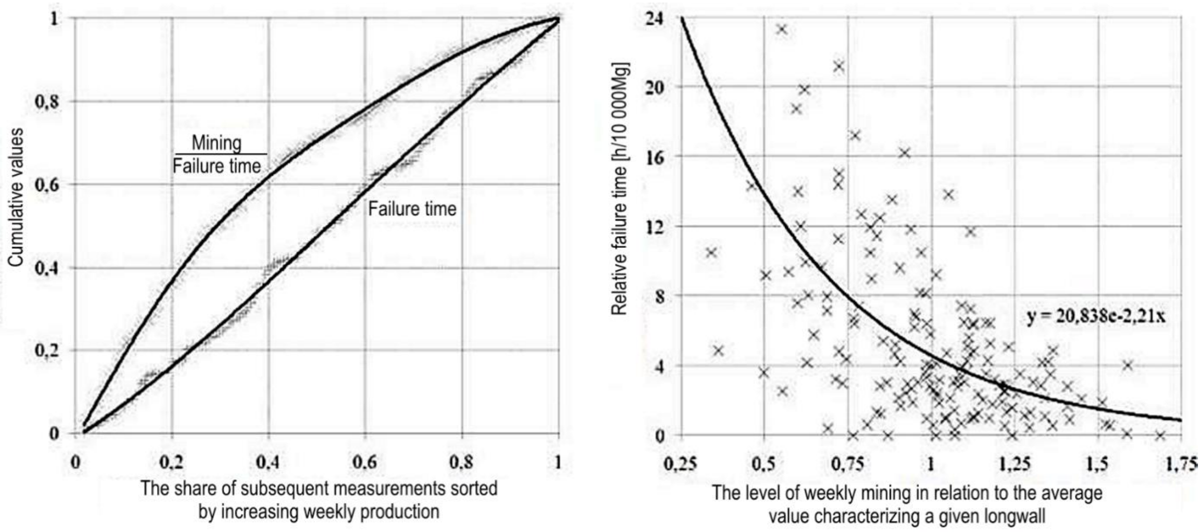


Fig. 3.36. Dependence of the relative failure time (converted to extraction) as a function of the extraction level [Polak, 2014b]

When performing the analysis, a weekly data aggregation period was used. Due to the fact that production is a secondary parameter in relation to availability (technical readiness), its value recorded in a shorter aggregation period may be directly limited by the occurrence of a failure.

As a consequence, this could lead to completely opposite conclusions. It is therefore important, when analyzing correlation, to determine the time horizon of phenomena and the interaction of isolated states of the system in the event of random events or other disturbances occurring in shorter periods of data recording.

In total, as part of the algorithmization of the reporting system for CZAD JSW 4.0, over 850 failures of mechanized systems were analyzed. In addition to calculating the time scope, these data were used to determine the distribution of the MTBF (*Mean Time Between Failures*) and the MTTR (*Mean Time To Repair*) (Fig. 3.37).

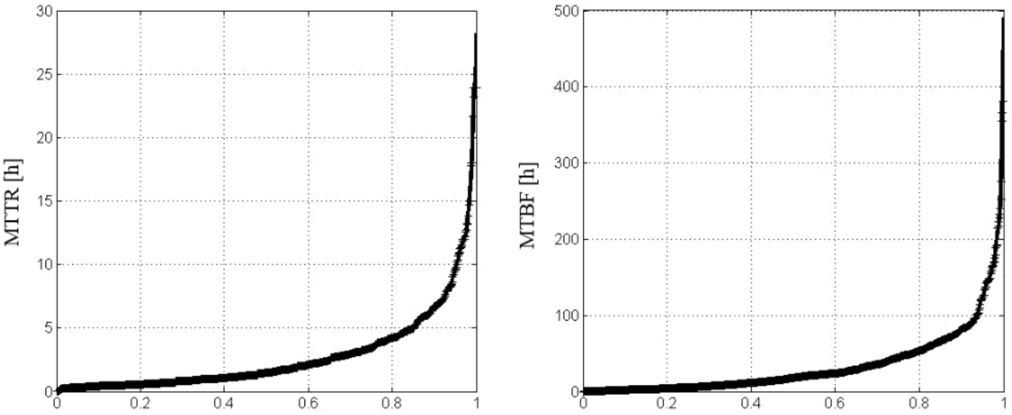


Fig. 3.37. Ordered chart of basic indicators of reliability and reparability - mean time between failures - MTBF and mean time to repair - MTTR (X-axis shows the share in the total number of production shifts) [Polak, 2014b]

When performing a basic analysis of the data, one can clearly notice the need to consider individual measures in at least two dimensions: time and longwall advance. Analysis of the failure as a function of time and advance, while limiting the level of extraction, allows drawing completely different conclusions in relation to the existing dependencies. The implementation of a significant part of the activities, the occurrence of difficult mining and geological conditions and the costs incurred are largely determined by the advance of the longwall. Treating the longwall as an undertaking, it is therefore reasonable to consider the variability of individual efficiency measures both as a function of time and the degree of its implementation, defined by the current advance of exploitation.

As stated during the algorithmization of the reporting system for CZAD JSW 4.0, most of the data subject to extended analytics are available in existing information systems and are subject to records. For example, by manually recording the breakdown time and fully remotely recording the shearer's operating time, the downtime can be calculated automatically based on the number and duration of work shifts. Similarly, the identification of geological conditions is already possible today using digital deposit models and profiling support systems. Data synergy in both directions is already possible today, because the scheduling process itself takes into account empirically confirmed indicators of achievable production levels in individual seams and operating conditions.

A separate issue at the analysis stage was the economic assessment of the efficiency of the equipment, i.e. supplementing the described structures with the costs of running the business. Taking into account expenses at the level of individual assignment units, such as a day or a working shift, requires a special approach. This is due to the need to eliminate natural discrepancies resulting from the method of assigning costs in relation to the current places and period of their occurrence.

3.6. Dynamic estimation of life cycle costs of basic means of production, mining machines and equipment as means of production management in the JSW 4.0 Center for Advanced Data Analytics

Life Cycle Cost Analysis (*LCCA)* is a tool supporting the determination of business-justified directions of action in the area of production and asset management of a mining company.

The use of this method as a decision-making criterion in terms of planned investments is particularly justified in the case of facilities or systems whose maintenance costs are many times higher than the purchase costs. Taking into account the relatively high costs of operation, energy and materials, this situation applies to many basic machines and devices used in mining. The use of calculations prepared by the manufacturer for this purpose is appropriate for technical facilities whose future operating conditions, their burdensomeness and intensity of operation are known and are not subject to significant differentiation.

For most of the basic machinery used in underground mining, this approach is too simplistic. This is evidenced by research conducted in the late 1990s [Polak 2015], where in over 50% of mines it was found that the costs of operating machines were more than twice as high as assumed by their manufacturer. This discrepancy supports estimating the costs of key facilities in a dynamic manner, with extensive use of own operational experience instead of simplified assumptions and hypothetical cost models. For this purpose, the use of key performance measures of the equipment management strategy focused on productivity (*TPM*, *Total Productive Maintenance*), seems to be the right solution. This provides a real opportunity to relate life cycle costs directly to the amount of work performed, and thus to estimate losses resulting from limitations in the level of production. When building systemic assumptions for the production process management in the JSW 4.0 Center for Advanced Data Analytics, it was inevitable to solve the dilemma: whether a dynamic estimate of life cycle costs, taking into account basic measures of production efficiency, can be a useful tool to support the decision-making process at the stage of planning, implementation and summary of investment plans related to using basic mining machines and equipment. In order to solve this problem, an attempt was made to develop detailed assumptions regarding the analytical model of cost settlement in JSW SA, and an example of calculation was presented, covering the life cycle of the key means of production of each hard coal mine, i.e. the longwall system.

3.6.1. Life cycle cost analysis of production means as a systemic tool to support the decision-making process in mining

Decisions in the area of production asset management are generally difficult and involve a high degree of risk. According to the proposed three-dimensional classification system, problems of a technical, organizational, normative-legal or economic nature can be distinguished.

When planning the life cycle of equipment, manufacturing companies are generally guided by economic aspects, narrowing the number of scenarios considered to those that meet technical and normative and legal requirements. Basically, four alternative decision criteria can be used for this purpose [Polak, 2015]:

– minimum Initial Cost Design (IC),
– minimum Running Cost Design (RC),
– minimum acquisition and maintenance costs (IC-RC – Reduction Design),
– minimum Life Cycle Costs Design Under Uncertain Circumstances.

Interest in LCC analysis as a decision support tool is still growing, as it is widely used in engineering practice and at the investment planning stage in many industries. The concept of life cycle itself is difficult to clearly define, as it appears in various forms, among others, in economics, project management, production management and research covering the impact of a product on the environment.

For the purposes of algorithming the reporting system for CZAD JSW 4.0, a definition was adopted in accordance with the EN 60300-3-3:2017 standard, which defines product life cycle cost accounting as "a process of economic analysis aimed at assessing the cost incurred throughout the product's life cycle or in part of this cycle", and the product life cycle as "the time interval from the creation of the product concept to its final use". This account may be a support instrument useful from the perspective of a manufacturer focusing on market aspects - Product *Life Cycle Costing* - as well as its potential buyer, who, using this method, mainly tries to estimate the total costs of alternative purchases and operating scenarios. In terms of the analysis of the said longwall system, it is both a product, an established technical system requiring maintenance, and a production installation implementing an undertaking related to the delivery of a specific product to the market (Table 3.5).

Various definitions of life cycle phases [Polak, 2015]

Table 3.5.

Equipment life cycle (TPM)	**Product life cycle (LCC)**	**Project life cycle**	**Operation with a longwall system**
Specification of needs	Concept and definition	Planning and formulation	Design and scheduling
Design, modification and purchase of equipment	Design, research and development		
Construction, installation and commissioning	Production and distribution	Preparation and initiation	Development operations, longwall roof support
Use and handling	Exploitation	Implementation	Field exploitation
Liquidation	Withdrawal	Completion and evaluation	Liquidation of the longwall

This dualism plays a fundamental role in the aspect of the approach described in the work, which focuses the buyer's attention on the product (enterprise assets) and unit production costs appropriate for the period of its ownership.

The life cycle cost analysis model proposed in this work aims to identify and minimize the total cost covering the design, development, production, operation and disposal of the product by analyzing alternative scenarios. It is also one of many life cycle cost analysis methods, a detailed review of which can be found in the work. An alternative concept described in the literature focuses the analysis process directly on the optimization of asset ownership costs, taking into account various facility operation scenarios. The identification of operating scenarios is particularly justified in the case of a complex production system such as a longwall system.

A number of different factors influence the technical object-man-environment plane (Fig. 3.38).

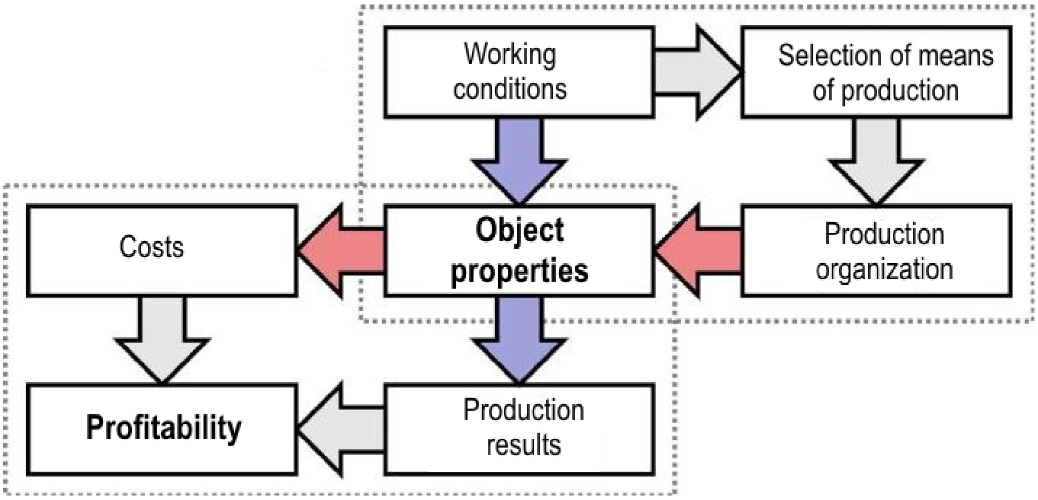


Fig. 3.38. A simplified illustration of a model mapping key aspects of the mining machines efficiency [Polak, 2015]

This means that the current level of ownership costs can be reliably estimated only on the basis of operational experience specific to environmental conditions and work organization methods. However, this type of approach limits the use of life cycle cost analysis to an ex-post assessment. According to the author, in relation to the basic means of production of mines, it is advisable to develop an intermediate solution in this respect, enabling the use of knowledge acquired through operational practice directly at the stage of making key investment and operational decisions.

Traditional life cycle costing in accordance with the EN 60300-3-3:2017 standard covers all phases of the facility's life cycle (pre-production, production, post-production). In the simplest terms, from the user's perspective, these costs can be expressed as the sum of the costs of purchasing, owning and liquidating the facility (formula 3.1) [Polak, 2015].

$$LCC = P + \sum_{j=1}^{n} U_j + L \tag{3.1}$$

Where:

n – operating time (usually years),
P – initiation cost (acquisition cost),
U_j – discounted maintenance costs specific to subsequent periods of operation,
L – liquidation cost.

An elementary stage of LCC analysis is the construction of an analytical cost model, its evaluation and development of operating process scenarios [Polak, 2015]. With reference to facilities directly forming the production line, in addition to basic maintenance costs, this means the need to estimate losses resulting from reduced quality parameters affecting, among others:

- ergonomics and work safety,
- production efficiency,
- availability (normative readiness to perform work),
- reliability – *Mean Time Between Failures* (*MTBF)*,
- reparability – *Mean Time To Recovery* (*MTTR)*,
- operability (ability to work in various conditions),
- compatibility (compliance with standards),
- service life.

The model should include all correlated drivers of explicit and latent costs, which may change, for example in terms of the technical properties of the facility. Using the example of a longwall system: the level of automation may have a significant impact on the number of crews, while the mining technology used may have a significant impact on the dimensions of longwall workings. Therefore, in order to guarantee the comparability of the estimates made, the qualification of costs should take into account both the costs of remuneration and development operations. Taking into account the often complicated relations between a facility and its surroundings, the boundary between eligible and ineligible costs is largely subject to subjective assessment.

Identifying the impact of individual factors on the life cycle costs of a facility is also the implementation of the postulates of the TPM strategy pillar - the so-called early equipment management (EEM). This direction can be described as the collection and use of available data and technologies at the stage of planning and construction of technological lines in order to obtain maximum reliability, ease of maintenance, operability and safety, while minimizing maintenance costs and losses related to the use of equipment. Life cycle cost analysis, as one of many cost accounting methods, can provide measurable support in the specification of detailed requirements for means of production and methods of implementing a production project, directly defining the objective function of a multidimensional optimization or one of its main constraints.

3.6.2. Life cycle of a longwall system

The longwall system is both an important cost element of the technological process and the first link in the production chain. This means that the course of its operation largely determines production results, which, with a high share of fixed costs, is directly reflected in the economic situation of the company. For management purposes, it is undoubtedly necessary to know the key performance measures characterizing individual longwall systems, as well as to determine the causes and costs of losses resulting from production disturbances or limitations.

One of the first activities carried out as part of a project related to raw material extraction is planning the mining process. This stage includes detailed identification of deposit conditions, modeling and optimization of longwall field parameters, and broadly understood optimization of the mining process. It is crucial considering the impact on subsequent effects related to the practical implementation of the initiated activities. With regard to basic means of production, what is primarily important is the proper selection of technologies and technical solutions that enable the implementation of production plans.

The longwall system is a complex system in which the mutual combination of machines and equipment and adaptation to the geological and mining conditions largely determine future production results and maintenance costs. Therefore, the decision to purchase or lease a longwall system is most often directly related to the implementation of specific, planned mining projects. The implementation schedule for these projects also imposes a series of maintenance activities such as longwall armament, liquidation and planned renovations.

The traditional method of estimating life cycle costs based on a strictly defined period of operation of the facility and fixed annual costs of its maintenance is not justified in the context of the dynamics of cost changes, intensity of the use process and the burdensome conditions characterizing subsequent phases of mining tasks (Fig. 3.39).

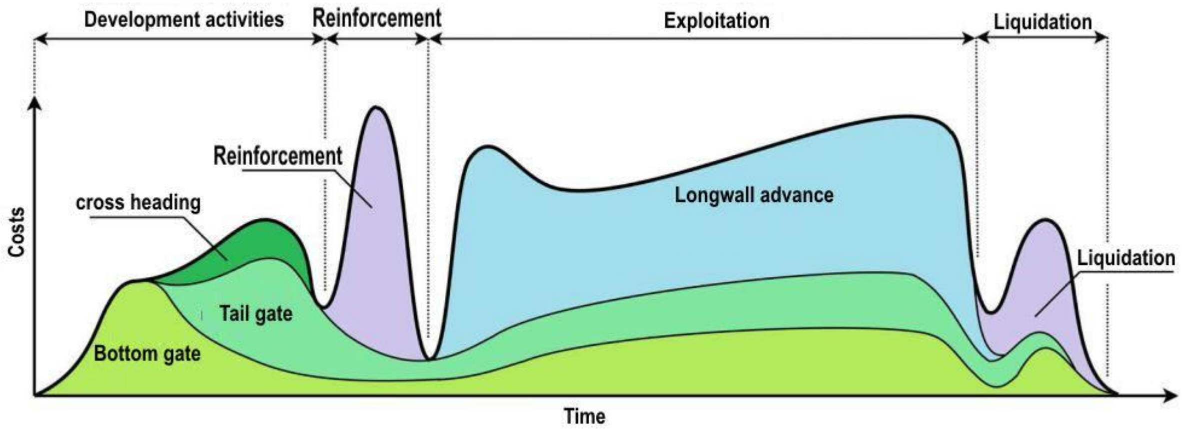


Fig. 3.39. Illustration of the costs incurred in individual phases of the implementation of a mining task using longwall mining technology [Polak, 2015]

Additional difficulties are generated by the need to clearly determine the age at which a facility will be withdrawn from operation. In practice, the decision whether to withdraw, renovate or modernize a longwall system depends on many individual factors and is most often not the result of a complete loss of the usability.

It is largely a consequence of the exploitation of prospective deposits, maintenance costs increasing with age, reduced reliability indicators and technological obsolescence, which make further exploitation of the equipment become economically unjustified. Therefore, it seems advisable to adopt an assumption that derives the period of operation of the longwall system from the time necessary to implement the mining projects considered for it. In this particular case, its life cycle will be characterized by a constant amount of extracted material, so the cost estimate will, to some extent, reflect the unit costs of extraction.

Using the proposed approach, comparability of cost accounting can be achieved, while losses resulting from, among others, underestimated operational properties of the facility, will be reflected in the costs incurred in conditions of limited production, and thus in an inherent increase in the time and costs of carrying out production tasks. The exception is the cost of current production losses in the form of raw materials not extracted due to the technology used or the selection of equipment, the extraction of which would have been possible using other technical means. This also applies to ripping that can be avoided by using other technical measures, and can be directly described by the technological and economic costs of transporting and storing waste rock. The application of the described assumptions seems to be an appropriate solution, especially taking into account alternative measures that assume direct inclusion in the calculation of an additional, generalized cost symbolizing the loss of production. Table 3.6 includes the basic categories of production losses along with the method of taking them into account in the dynamic cost model proposed in the work.

The main categories of production losses along with the method of their mapping in the cost model [Polak, 2015]

Table 3.6.

Production loss category	Mapping method
Delay in mining schedule	Shifting revenue over time (costs of a loan granted for the delay period with a value equal to the product of revenue and the share of fixed costs).
Reduction of production (rated capacity, availability, reparability, interruptions and stops in production, planned shutdowns)	The impact of fixed costs over time and costs of organizational readiness on the total costs of implementing a mining task (unit cost of production).
Exploitation above seam thickness (operability, production organization)	The cost of accelerated consumption of means of production. Cost of extraction, transport and management of waste rock.
Exploitation below seam thickness (operability, production organization)	Reducing the amount of raw material extracted in the task (impact on unit production costs).
Reduced efficiency of machines (utilization of rated capacity)	Cost of energy, technical wear and tear of the facility and consumables resulting from extended operating time. Costs of reducing production.
Reduced reliability, limited effectiveness of the service system	The cost of damage resulting from a failure. Costs of reducing production.
Durability, compatibility, ergonomics	Increased maintenance costs (renovations, materials, service). Costs of reducing production.

The dependence of the facility's operating time on the implementation of the adopted tasks is a criterion whose validity may raise some doubts. In the case at hand, however, this counteracts a situation where reduced equipment durability or reduced production properties result in decommissioning before the assigned tasks are completed, which calls into question the usefulness of comparisons based on traditional life cycle cost analysis over a well-defined time horizon. In the presented approach, objects with reduced durability will be characterized by a faster increase in costs and production losses with age and the amount of work performed. The use of this simplification is particularly justified from the perspective of an entrepreneur who invests in the purchase of means necessary to perform a specific job in the most economically effective way, while ensuring maximum employee safety and minimizing the impact on the natural environment. This approach also requires skillful mapping of aging and wear and tear processes, which are a function of many factors such as: durability of the object, time, environmental conditions, intensity of use, method of operation, amount of work performed (total advance, amount of extracted raw material, number of cuts). In the adopted

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model, the aging processes were reproduced by expenses for the purchase of materials and renovations, and for specific longwall conditions they are a function described in terms of time, operational status, operation advance and factors causing a sudden increase in load.

Considering that the total operating time of a longwall system is a relatively long period, dividing the life cycle into individual mining projects - characterized by relatively uniform implementation conditions - seems fully justified. In relation to the longwall system - an object that is almost constantly in motion due to the implementation of mining tasks, such an assignment allows both a reliable estimation of the total level of costs, as well as drawing conclusions in relation to individual mining experiences, especially in terms of the profitability of the undertaken projects.

3.6.3. Dynamic cost model of the longwall system life cycle

The purpose of building an analytical cost model is to isolate and dimension key operating parameters in the cost plane. The value of maintenance costs depends on many factors, for simplicity it can be assumed that they are appropriate for a given facility in the context of a specific mining task, conditions and course of its implementation. In such a case, the cost model may take the form of a multidimensional matrix. When creating the cost of ownership matrix during the longwall advance period, two dimensions were adopted: the cost structure and the operational states that the facility may be in, which are key from the perspective of costs and production efficiency (Fig. 3.40).

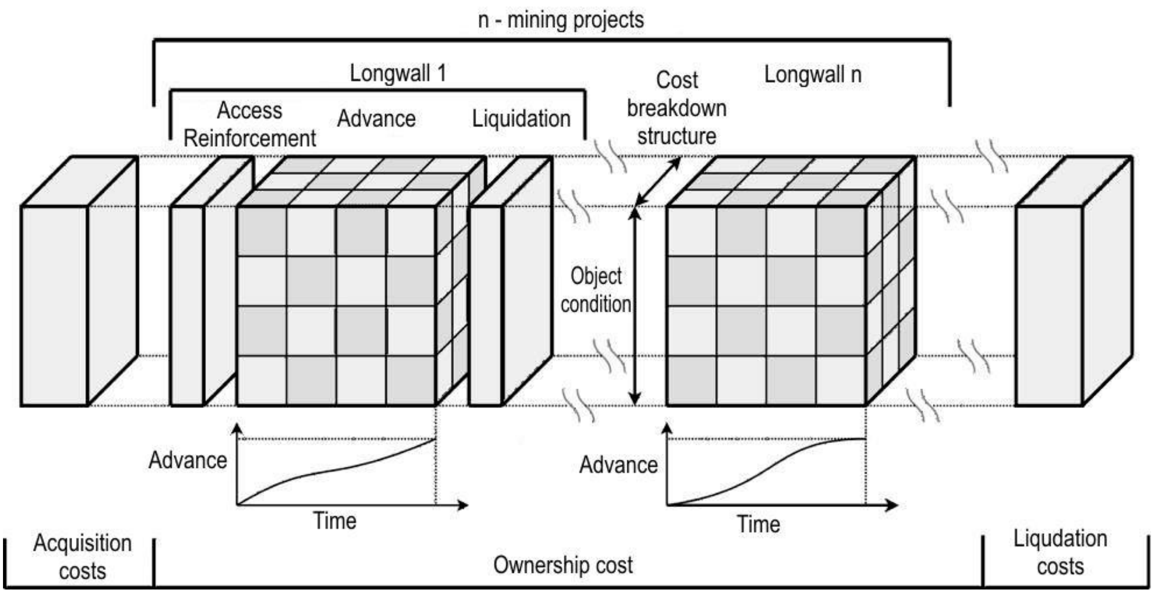

Fig. 3.40. Illustration of the adopted cost model [Polak 2015]

The proposed structure of operational states reflects the structure of the equipment utilization rate (*OEE - Overall Equipment Effectiveness*), the adaptation of this efficiency measure to the operating conditions of longwall systems was carried out in this monograph.

The procedure for building a cost matrix for mining projects requires the identification of key cost drivers. In relation to the longwall system, it may be: time, the status of the crew's stay at the face, the operating status of the system, occurrence of failures, advance of exploitation, increase in load due to deteriorated geological and mining conditions like seam partings. This enables the identification of work states characterized by a specific level of costs, relatively proportional to their duration. The breakdown of the total amount of costs according to the division structure into individual operational states can be carried out on the basis of computational and analytical models or as a result of an expert assessment. For the purposes of this work, the following procedure was developed and used, similar to the methods of measuring indirect costs in Activity Based Costing *(ABC)*:

1. For each condition, an analysis was made of what factors specific to that condition would increase costs (e.g. ineffective work condition – drives working without load, effective work condition – nominal load of the drives).
2. The impact of these factors on individual elements of the cost structure was estimated (e.g. service costs during production shifts).
3. Cumulative cost values were calculated, moving state-specific costs upwards according to the performance indicator breakdown structure.
4. The cost increase ratio relative to the parent states was calculated and verified.
5. Total costs were estimated assuming the duration of states appropriate for the analyzed project, their value and the structure of expenses were compared with real cost.
6. Based on the report from point 4 and information about the current, total costs of the project, alternative (adjusted) unit costs were calculated and interpretation of deviations was carried out.
7. The results were discussed in the context of other mining projects, and in special cases, an analysis of the method of assigning costs was carried out. Estimation of the unit cost matrix is also possible by using linear programming or constraint programming methods, assuming the cost K_{ij} as the decision variables and minimizing the error resulting from meeting a series of linear equations assigning a unit duration cost to each state as the objective function (formula 3.2) [Polak, 2015].

$$K_p = \sum_{i=1}^{n} \sum_{j=1}^{m} (S_{pi} \cdot K_{ij}) \tag{3.2}$$

Where:

p – project number,
i – number of operational states,
m – number of cost components,
K_p – total costs of the project p,
S_{pi} – total duration of the state – i during the implementation of the project – p,
K_{ij} – unit component – j of the cost of the duration of the state – i.

The system of equations applies only to homogeneous projects, in other cases it is necessary to take into account additional factors, such as: operating conditions, crew size, age of equipment, price level of services and materials. Determining the unit cost component of the state duration (K_{ij}) as a function of many variables is possible by means of mathematical programming, the use of statistical analysis methods or learning systems in the case of non-linear dependencies. The introduction of hypothetical cost drivers makes it possible to avoid distortions resulting from the method of recording costs, which does not reflect the current process of their creation over time. From this perspective, however, the implementation of each mining project requires an additional assessment of the impact on the technical wear and tear of the facility in order to properly assign renovation costs accumulated in the future.

3.6.4. Calculation of the life cycle costs of the analyzed longwall system

When carrying out an exemplary life cycle cost calculation, data describing the operation of one of the longwall systems analyzed in publication [Polak, 2015] were used. In order to estimate the total efficiency measure, individual operational states of the facility were isolated, maintaining the principles of constructing the OEE indicator. Data averaged for the entire period of longwall advance are presented in Table 3.7.

Key measures of operational efficiency of the analyzed longwall system [Polak, 2015]

Table 3.7.

<table>
<tr><th colspan="7" rowspan="2">Specification</th><th colspan="2">Time share</th></tr>
<tr><th>relative</th><th>cumulative</th></tr>
<tr><td rowspan="6">Stopover – day off (11 h 11 min)</td><td colspan="6">Production day (24 hours)</td><td>68.2%</td><td>68.2%</td></tr>
<tr><td>Stopover – service (4 h 53 min)</td><td colspan="5">Planned production (19 h 07 min)</td><td>79.7%</td><td>54.3%</td></tr>
<tr><td rowspan="4">Standby time (4 h 11 min)</td><td rowspan="4">Breakdown (3 h 19 min)</td><td colspan="4">Standby time (16 h 30 min)</td><td>86.2%</td><td>46.8%</td></tr>
<tr><td rowspan="3">Breaks and other work (4 h 30 min)</td><td colspan="3">Working time (12 h)</td><td>72.7%</td><td>34.0%</td></tr>
<tr><td rowspan="2">Ineffective work (3 h 44 min)</td><td colspan="2">Effective work (8 h 16 min)</td><td>68.9%</td><td>23.4%</td></tr>
<tr><td>Waste rock (1 h 40 min)</td><td>Coal (6 h 36 min)</td><td>79.9%</td><td>18.7%</td></tr>
</table>

Ultimately, the share of coal mining time with empirically determined nominal capacity was 18.7% of the total time. Since the state of failure and organizational readiness for work are largely independent, in order to maintain uniform principles of indicator construction, a division into the time of its occurrence during production shifts and planned shutdown was used. The sum of both values thus provides information about the total duration of the failure. Using the moving weighted least squares approximation - *MWLS* – and the techniques described in [Polak, 2014b], average durations of individual operational states were determined, appropriate for individual periods of longwall advance (Fig. 3.41).

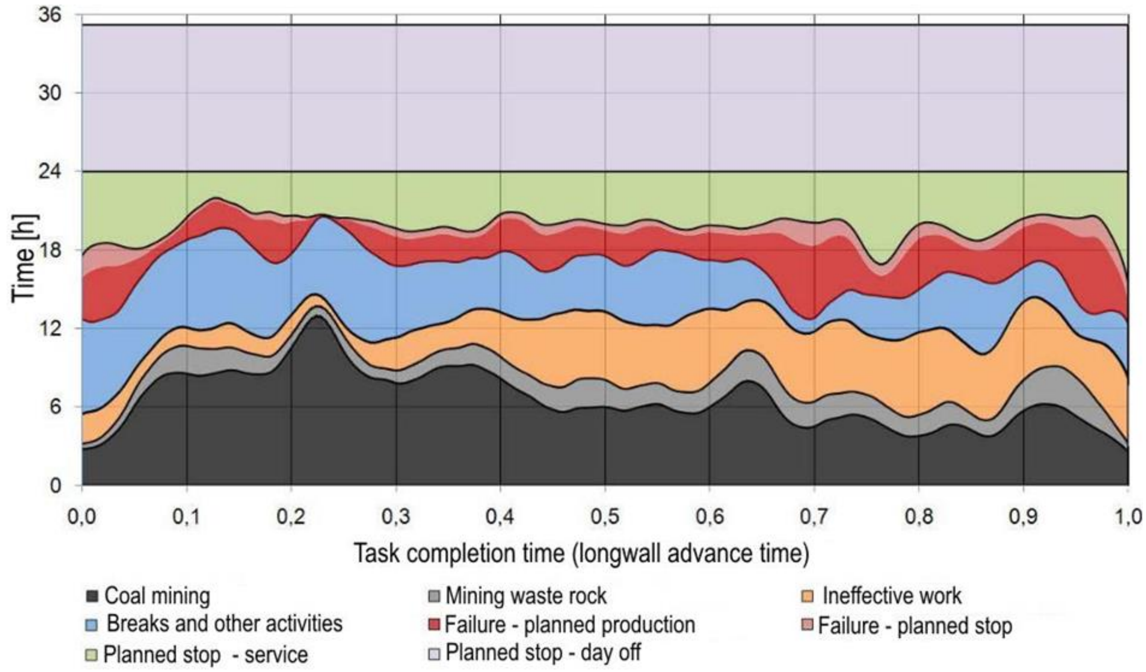

Fig. 3.41. Illustration of the production flow for subsequent days of the longwall advance [Polak, 2015]

The production flow chart presented above provides information on the high variability of key measures of the efficiency of equipment use over time, which is directly reflected in the level of production. An increase in ineffective work time directly indicates the occurrence of organizational, technical or natural factors that significantly limit the advance of exploitation. Although the presented analysis covers only the period of operation of one longwall face, this example can be used to evaluate alternative scenarios of the facility's operation. For this purpose, the following assumptions were made regarding the scenarios:

- Basic scenario - the duration of individual operational states is the average over the entire period of longwall advance (the task completion time remains unchanged).
- Pessimistic scenario - the duration of individual operational states appropriate for the period characterized by the highest unit production cost.
- Optimistic scenario - the duration of individual operational states appropriate for the period characterized by the lowest unit production cost.

Since the data characterizing extreme scenarios reflect long-term trends, analyzing individual cases allows for assessing the impact of the production process on the results of the total life cycle cost calculation of the facility. This impact is a key feature of implementing this estimation in a dynamic way.

In order to conduct life cycle costing, the following assumptions were made:

- the life cycle of the facility covers the period of implementation of 8 mining tasks (exemplary value),
- operational indicators (including MTBF, MTTR) do not deteriorate with age (the simplification results from the lack of data necessary to determine the variability of these parameters over time),

- no indexation of labor and material costs (due to the dynamics of changes in the market situation, no assumptions regarding cost changes were taken into account),
- fixed discount rate of 5%, annual costs of schedule delay amounting to 3.3% of the production value (due to the dynamics of changes in the market situation, an exemplary value of the discount rate was adopted, to determine the costs of schedule delay the share of fixed costs was assumed at the level of 66%),
- constant unit cost of the duration of the operating state during the longwall advance period determined on the basis of cost data covering the operation of the longwall field in accordance with the cost division structure (Table 3.8),
- fixed cost of purchase, transport and assembly as well as resales (liquidation) of equipment, fixed cost and implementation time of development activities, reinforcement and liquidation of the longwall (simplification results from the lack of data necessary to determine the variability of costs and working time),
- life cycle cost calculated using an analytical cost model for each of three scenarios of longwall advance, assuming different durations of eight basic operational states (Fig. 3.42).

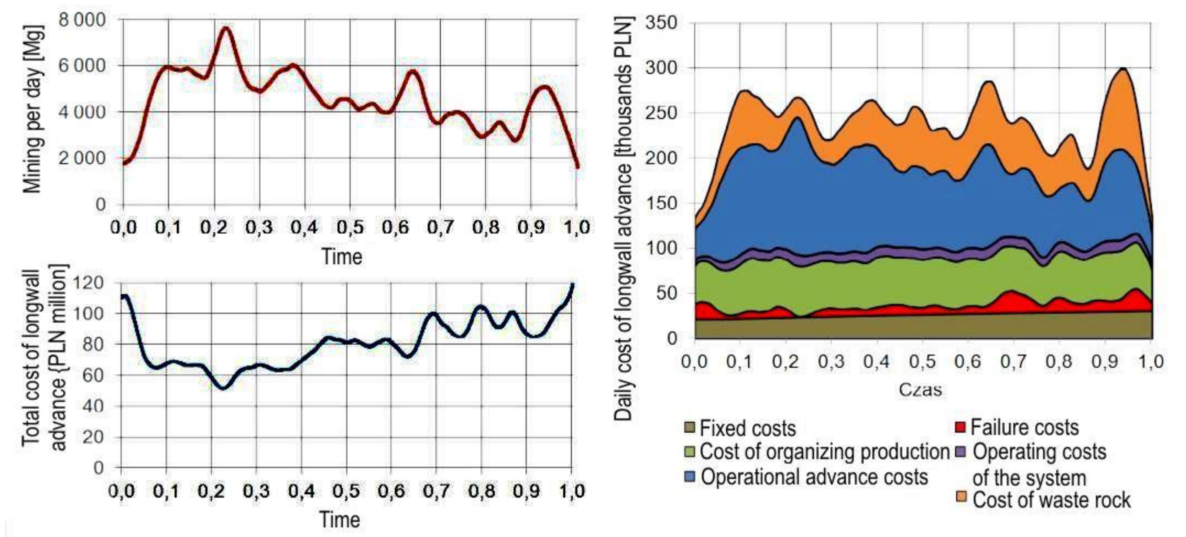

Fig. 3.42. The impact of the level of extraction on operating costs [Polak, 2015]

Calculating with the share of fixed costs at the level of approximately 11% and relatively fixed costs (organization of production shifts) at the level of 22%, the total cost characterizing the period of longwall advance was PLN 76,521 thousand PLN. Apart from approximately 30 days of the initial and final operation period, the local projection of the cost of implementing the task varied from 51,486 thousand PLN to 104,802 thousand PLN. With a relatively low share of fixed expenses, this projection shows high dynamics of changes (Fig. 3.42), especially since the data describe long-term trends.

The analyzed scenarios differed only in the course of production during the longwall advance, however, the cost of the pessimistic scenario was 65% higher than in the case of the optimistic scenario. Such significant variation in the results obtained based on current observations explains the need to use a dynamic life cycle cost model. In the event of additional delays related to the implementation of development activities, increased reinforcement time and removal of the longwall, a much greater diversity of results should be expected.

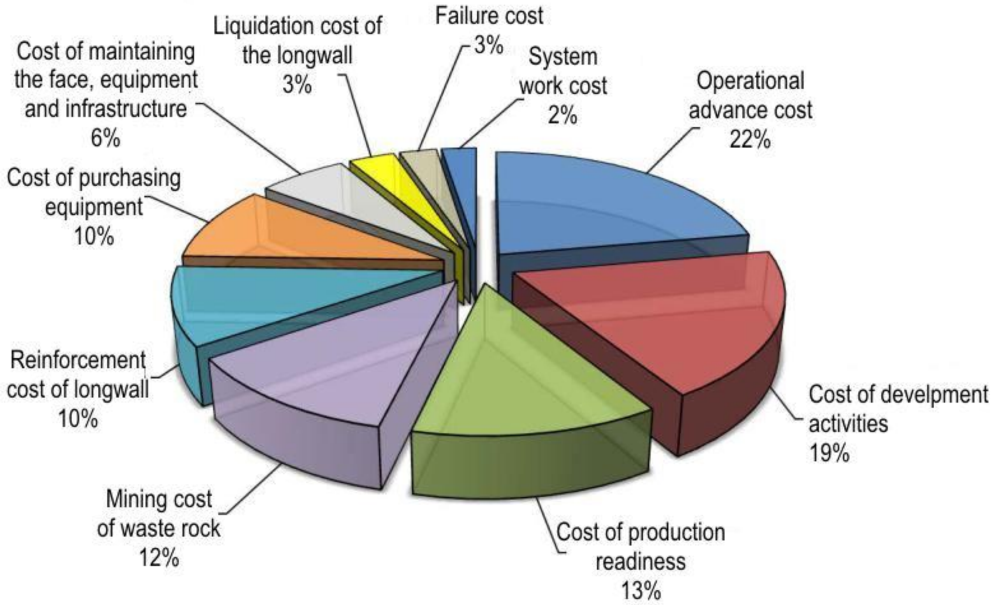

Fig. 3.43. Components of discounted life cycle costs for the base variant [Polak, 2015]

Fig. 3.43 shows the life cycle cost structure of the longwall system for the basic variant. It can be see, the purchase price is the sixth largest cost item and accounts for approximately 10% of the total life cycle cost. Therefore, adopting this value as the main decision criterion may raise justified doubts.

Analyzing extreme exploitation scenarios, the basic difference includes an increase in the share of: waste rock extraction costs (from 4 to 14%), failure costs (from 0.1 to 5%), fixed costs (from 4 to 9%) and production organization costs (from 10 to 16%). Fig. 3.44 presents the accumulation of costs over the equipment life cycle.

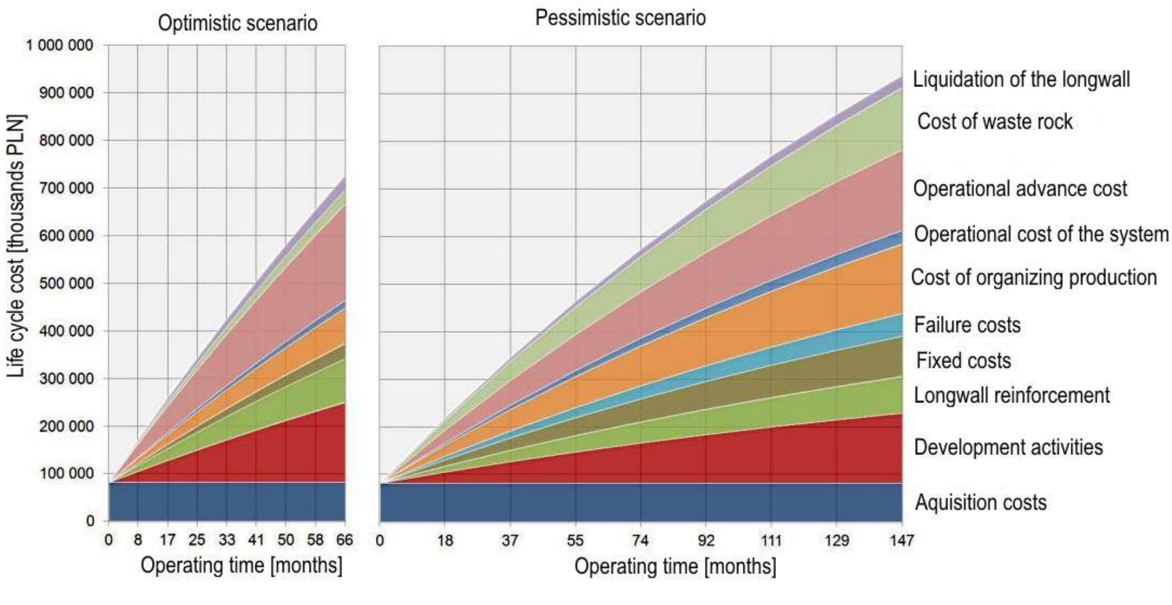

Fig. 3.44. The value of selected life cycle cost components of extreme operating scenarios [Polak, 2015]

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As shown, the costs characterizing the optimistic scenario increase much more dynamically as a function of time, but their final value is clearly lower. Therefore, making the aging processes dependent on the advance of use may lead to incorrect conclusions related to, among others: with the occurrence of failures - if the production rate is reduced, they will occur less frequently, which, however, will not reduce their total number in terms of the implementation of the entire task. The differences in the costs of acquisition, development activities, reinforcement, advance and removal of the longwall result from the discount rate. The share of fixed and relatively fixed costs in the total life cycle cost of the system was approximately 19%. However, taking into account losses due to production delays, halving the execution time of mining tasks allows for reducing the calculated cost of the facility's life cycle by approximately 30%. This leads to the conclusion that the content of waste rock in the gross output and the degree of utilization of the production potential are key factors related to the operating environment of longwall systems, having a decisive impact on the result of the economic calculation.

3.6.5. Performance measures card as a tool for assessing effectiveness and a means to optimize mining activities

As already mentioned, the JSW 4.0 Advanced Data Analytics Center is created by a team of JSW Group analysts, its primary goal is to optimize the Company's mining activities, increasing the productivity of the machines and devices used by increasing their efficiency and reducing operating costs.

As part of the CZAD JSW 4.0 analyses, data from:

– reports of maintenance services,
– systems for monitoring the operation of machines and devices and the location of the crew, i.e. ZEFIR, SAURON, EH, ARGUS, EMAC,
– BI systems – SAP BO, SZYK2, HPR.

Following the principle "you cannot manage what cannot be measured", CZAD JSW 4.0 has developed specific measurement techniques designed to provide information useful for decision-making, including:

– multidimensional analyses of geological, mining and production data of longwalls,
– efficiency reports on the operation of longwall systems and the company,
– selection of IT tools supporting data analysis.

In recent years, a number of scientific publications have been devoted to the topic of optimization of mining activities [Brzychczy, 2006; Kicki, 2013; Kicki, 2011; Dyczko, 2013; Polak, 2014a, b, c; Polak, 2016; Polak, 2016; Dyczko, 2023]. The interest in this topic should not be surprising, considering the specificity of the industry in which optimization should be an element of the continuous process of improving operational activities. Therefore, the implementation of even simplified assessment methods in the area of use of basic mining machines and equipment no longer seems only justified, but necessary.

As already mentioned above, as part of the implementation of modern data analysis, it was necessary to introduce new standards in CZAD JSW SA 4.0 regarding:

– IT/OT infrastructure,
– data exchange,
– Specification of Essential Procurement Terms for IT/OT software,
– conditions for access to dedicated networks.

The technique of using an efficiency measurement card as a basic tool enabling tracking, assessment and multidimensional analysis of the effectiveness of JSW SA's mechanized mining systems. It was first presented to the Company by the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in 2016, when they were developing strategic scenarios for JSW SA's exit from the crisis of 2014 - 2016. In 2018, optimized efficiency measurement cards were adopted by CZAD JSW 4.0 as the main measure for assessing the effectiveness of optimizing the Company's mining activities.

Initially, the functionality of the card was presented using the example of a longwall system, which is a series of cooperating machines and devices, including:

– powered roof supports,
– longwall shearer or plow,
– armoured face conveyor,
– beamstage loader,
– crushers,
– auxiliary devices.

In the course of algorithming the adopted method of reporting information in CZAD JSW 4.0, the potential range of applications of the described information tools was significantly expanded. At the same time monitoring of the operating parameters of key machines operated in all longwall and roadway workings has been extended by expanding the main fiber optic networks by approximately 170 km, implementing the Central Technological Data Server - central access to structured data generated in the production process and creating EDA automation departments at all JSW SA mines to maintain the monitored infrastructure (Fig. 3.45).

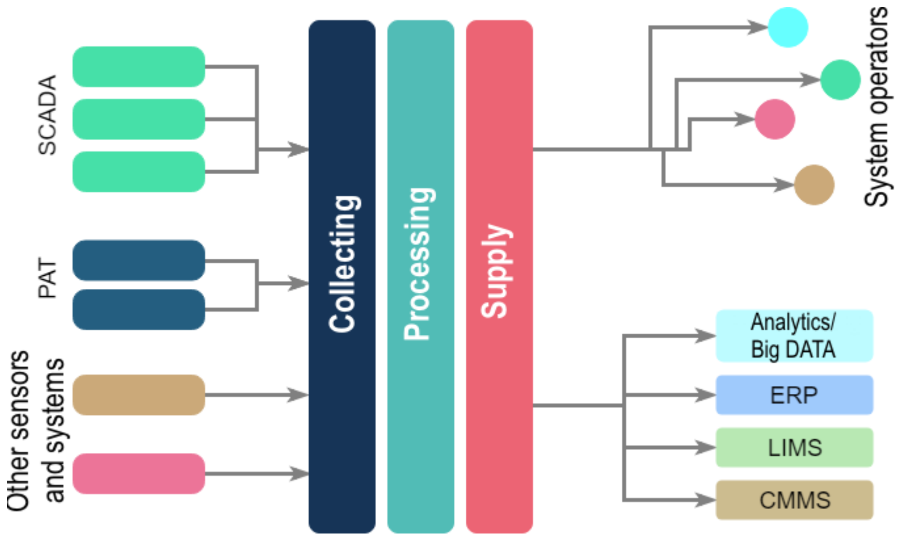


Fig. 3.45. Framework diagram of the data collection infrastructure implemented in CZAD JSW SA 4.0

The Central Technological Data Server operating in CZAD JSW 4.0, based on the PI system from OSIsoft, is the heart of the complex analytics of the built solution. Its task is to collect and analyze a wide spectrum of data regarding the JSW Group's means of production.

3.6.5.1. The concept of a card for measuring the efficiency of work of mechanized mining systems of JSW SA

The concept of assessing the operational efficiency of JSW SA's mechanized mining systems using an efficiency measurement card presented in the monograph is one of the unique and pioneer solutions for standardizing the reporting method implemented in the Polish mining industry.

Individual companies use a slightly different set of data, the differences also include their detail level, source and quality of data. This is partly due to the fact that, apart from a few cases, e.g. self-propelled mining machines used in KGHM PM SA, the industry does not implement methods supporting the management of machinery, based on pillars such as, among others, TPM (*Total Productive Mainlenance*).

The first JSW 4.0 Center for Advanced Data Analytics in the Polish mining industry was intended from the very beginning to be an element standardizing the reporting method of the JSW SA Group and supporting the business decision-making process in the Company. Fig. 3.46 shows the main data sources building CZAD JSW 4.0.

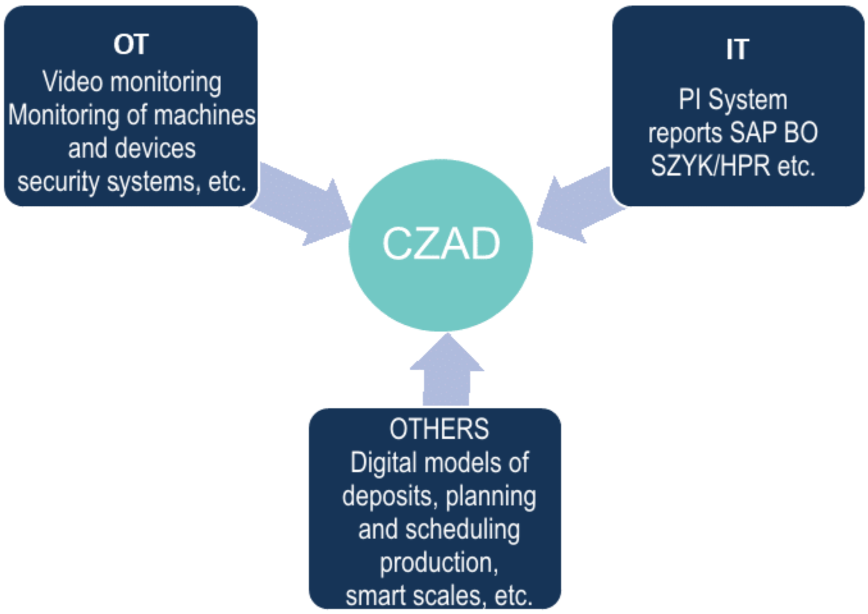


Fig. 3.46. Main data sources of the first Center for Advanced Data Analytics in the Polish mining industry, JSW 4.0

The analyses, reports and summaries generated in CZAD JSW 4.0, instead of the standard quantitative approach, focus on qualitative issues and the method of achieving the production result, thus identifying key stimulants and destimulants of the effective course of mining in accordance with the analysis methodology originally proposed by IGSMiE PAN consultants. To simplify things considerably, the following information, recorded periodically, should be specified in this regard:

- measurements recorded remotely or locally by various technical systems,
- shift and daily production reports,
- event (failure) registers,
- monthly operating costs,
- surveying and geological documents (including acceptance and geological profiles).

Specifically for the longwall system, this means recording:

- shift mining or advancement of the longwall face,
- daily or monthly operating time of the shearer,
- monthly operating costs by type and process with allocation according to the place of origin,
- incidents (failures and operational stops),
- surveying and geological measurements (monthly acceptance).

Subsequently, monthly data are most often analyzed, which allows for necessary corrections to be made, resulting from the natural limitations of ad hoc reports submitted by telephone and the fact that individual information has a different time allocation. This type of action allows for a generalized regression of costs and production results in the context of the equipment used, production organization and the burdensome working environment conditions, but it does not allow for a detailed classification and identification of the causes of individual losses.

The issue of registration and statistics of losses in accordance with the TPM strategy [Brzychczy, 2006; Kicki, 2011; Kicki, 2013; Polak, 2014a, b, c; Polak, 2016; Polak, 2016; Dyczko, 2023] points directly to the need to identify the level of sporadic losses - including: failures, and chronic losses - almost always present, recurring and highly dispersed in the organization. Marking the former is not a major problem, as it comes down to implementing and observing standardized rules for recording incidents. Determining the severity of repetitive losses is a much more complicated issue. Knowledge on this subject, like the losses themselves, is highly dispersed in the organization, and most often exists in the form of subjective beliefs and popular opinions.

To obtain a new value, it is necessary to create a synergy effect of data recorded in individual areas, including: operational control and maintenance, production reporting, accounting, while maintaining the most precise possible period of data assignment. In accordance with the "Garbage In - Garbage Out" principle, one of the most important activities of CZAD JSW 4.0 is initiating activities aimed at improving the quality of collected information. And participation in the development of tools, procedures, changes in the functioning systems and information channels resulting in reducing the information gap and improving the quality of recorded data - as shown in Fig. 3.47. The quality of information should be considered in the context of its main features, such as:

- accuracy,
- completeness,
- topicality,
- materiality,

– brevity,
– utility,
– availability,
– comparability,
– credibility.

The basic determinant of the effectiveness of any analytical methods used by CZAD JSW 4.0 is obtaining the required information that meets the given quality criteria (filling the information gap).

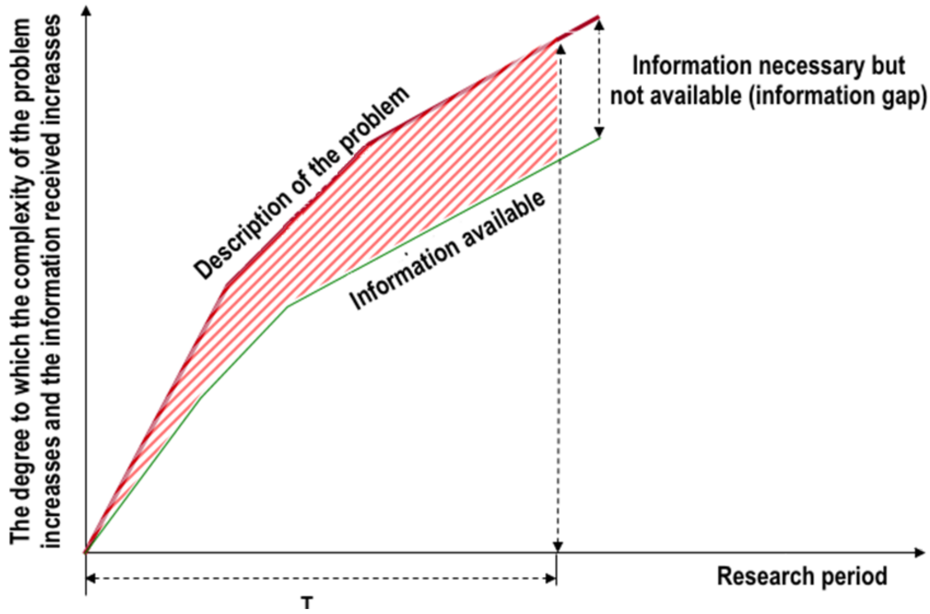


Fig. 3.47. Information gap in the quality of recorded data in IT/OT systems [Flakiewicz, 1991]

The decisive factor that distinguishes the JSW 4.0 Advanced Data Analysis Center from other organizational units of the Company is the conscious and purposeful use of advanced analytical methods in the assessment of the production process, including machine learning, implemented in the engineering process, based on data collected in IT systems.

The basic feature of "intelligent" methods should be the ability to effectively use experience and effectively condense information into its content.

The following types of applications include:

– broadly understood **data mining** - aimed at obtaining hidden knowledge, supporting decision-making processes by building reasoning systems enabling practical use of acquired experience,
– creating **domain systems** using simulation models enabling analysis of the operation of real systems or solving complex planning or optimization problems,
– creating **active systems** with the ability to learn and adapt, including technological process control systems, especially in conditions of lack of access to full information (fuzzy logic).

Having a knowledge base, in the form of a declarative set of facts that clearly describe past experiences, is a common element of all the above-mentioned applications.

Against this background, a work efficiency measurement card prepared in the form of a report should enable the decomposition of the economic efficiency of a mining project related to the use of equipment. In practice, this task comes down to multidimensional classification of the state in which an object is at a given time. This classification may correspond to various degrees of activity in terms of costs, as well as the natural chain of creating added value.

In order to assess mining systems, the following unified levels of description can be indicated:

- production availability (working days),
- technical and technological availability (failures and stoppages),
- organizational availability (temporary staffing of production shifts),
- stops during production shifts,
- idle work (working time without performing useful operations),
- production efficiency,
- production quality,
- product value,
- production cost.

An example structure allowing for a very precise classification of the condition of a longwall system is presented in Fig. 3.48. Using such a system in practice (Fig. 3.48) is quite troublesome, as the efficiency measurement should be possible to estimate on the basis of data that is commonly recorded in individual enterprises.

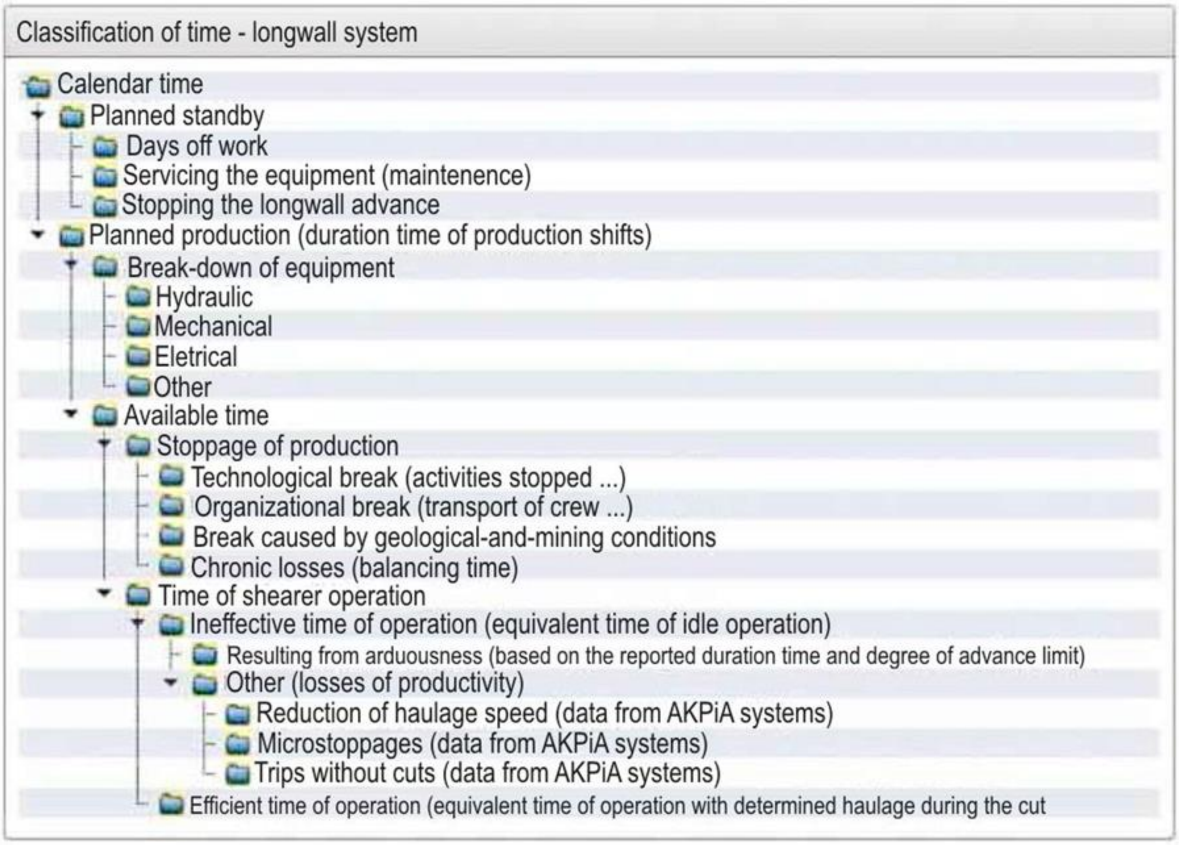


Fig. 3.48. Hierarchy of classification of the operating condition of a longwall system [Polak, 2016]

3.6.5.2. An example of an efficiency card for longwall systems in JSW SA

The longwall system is equipment located at the beginning of the production chain, therefore its uninterrupted and effective operation largely determines the profitability of the production of the entire mine. This facility is used continuously in an extremely unfavorable environment with varying degrees of nuisance, which generally has a significant impact on the course of its operation. At least some of the concerns related to the assessment of the efficiency of longwall systems result from the belief that individual faces and mines cannot be compared with each other due to specific differences. This statement is strongly justified, but it should be noted that comparisons cannot be made in a simplified and ill-considered way. An appropriate approach to assessing the operation of a longwall system should result in the identification of efficiency levels at which the comparison is meaningful or makes it possible to relate losses directly to the factors that cause them. A proposal for a multi-aspect system, dimensioned as a function of time, with a structure analogous to the OEE indicator *(Overall Equipment Effectiveness)*, together with a card for measuring the efficiency of the longwall system that modifies its structure, is presented in Table 3.8 [Polak, 2016].

A proposal for an efficiency measurement card prepared for a longwall System [Polak, 2016]

Table 3.8.

No.	Relative indicator (W1)	Absolute rate (W2)	Loss category (S)
1	Working days [%]	Working days [h] (average daily or days)	Non-working days
2	$\frac{\text{Time of mining days}}{\text{Time of working days}}$ [%]	Days of mining [h] (average daily or days)	Time of unplanned downtime resulting in production stoppage (supplemented with a Pareto chart of the reasons for stoppages)
3	$\frac{\text{Time of changes with cutting}}{\text{Time of days with cutting}}$ [%]	Production shifts time (daily) [h]	
4	$\frac{\text{Time spent by the crew during shifts with cutting}}{\text{Shift time with cutting}}$ [%]	Production crew readiness time (daily) [h]	Organizational downtime (chronic)
5	$\frac{\text{Availability time during shifts with cutting}}{\text{Time spent by the crew during shifts with cutting}}$ [%]	Time of readiness and availability for work (daily) [h]	Unplanned downtime resulting in production being suspended during a production shift
6	$\frac{\text{System operation time during shifts with cutting}}{\text{Availability time during shifts with cutting}}$ [%]	System operation time (daily)[h]	Standby time and work related to cutting
7	$\frac{\text{Cutting time during mining shifts}}{\text{System operation time during mining shifts}}$ [%]	Cutting time (daily) [h]	Operating time of the system without cutting (including technological breaks and other activities)
8	$\frac{\text{Advance}}{\text{Cutting time during shift with mining}}$ [m/h]	Roadway advance (daily) [m]	Production efficiency losses (micro-stops, reduced feed or take-off)

9	$\frac{\text{Gross Production}}{\text{Advance}}$ [Mg/m]	Extraction by department gross (daily) [Mg]	Performance losses resulting from, among others, from the thickness of the seam
10	$\frac{\text{Net extraction}}{\text{Gross extraction}}$ [%]	Extraction by department net (daily) [Mg]	Losses resulting from partings, seam disturbances and the mining technology used (e.g. floor top dressing)
11	Raw material value [PLN/Mg]	Department revenue (daily) [PLN]	The value of the mineral in the deposit exploited by the department
12	Unit cost for the department [PLN/Mg]	Department cost (daily) [PLN]	Operating cost in the department

The efficiency measures chart presented in Table 3.8, used in CZAD JSW 4.0 reporting, is simple in construction and can be fully prepared on the basis of data currently recorded by mining companies.

The first column of the metric (W1) contains relative measures ordered in the causal space, the subsequent product of which in lines 1-11 indicates values of the second column (W2). This procedure is intended to simplify the interpretation of the impact of individual efficiency measures on the final economic result (profitability) and to highlight frequent cases of correlation between individual efficiency measures. The third column of the metric is a place to insert appropriate comments and auxiliary charts, such as: a pareto chart, a correlation chart (including W1 and W2 for individual weeks of observation), or value distributions (including the achieved production efficiency). The measurements included in the card are:

- time classification (lines 1-7),
- performance measures (lines 8-9),
- quality measures (line 10),
- economic measures (lines 11-12).

Since the elements of the W2 column are the product of subsequent elements of the W1 column, with indicators No. 1-7 falling in the range <0, 1>, this results in a continuous loss of time, starting from the available calendar time and ending with the extraction time (which additionally allows for illustration in streaming graph). The time contained in the W2 column may cover any period, including quarter, month, week, average daily time or simply another dimensionless coefficient which, when divided by any of the W1 measures, allows its elimination. For example: the dimensionless coefficient W2 in line 7 divided by the measure W1 in line 1 and multiplied by 24 will provide information about the average mining time on working days. The product of the W1 indicators from lines 4,5,6,7,8 is equivalent to the average advance per hour of the work shift. The W1 coefficient in line 3 multiplied by the number of shifts in the existing work system (assuming their equal duration) will provide information on the average number of shifts with production on a working day. Thus, by providing 12 elementary pieces of information, it is possible to obtain many combinations, which can be traced according to a scenario from general to specific.

The proposed system of indicators supports the forecasting function. By changing one of the included parameters, one can directly assess how it will affect the final result.

For example, this allows us to answer the question: how much will the extraction time and daily advance increase if the crew transport time is shortened by 15 minutes, assuming that the remaining efficiency measures remain unchanged or that empirical or theoretical characteristics are used.

The tabular layout of the card allows for quick identification of the level of losses incurred in the space of twelve selected efficiency measures, enabling the analysis of subsequent indicators in a given column. When preparing a described card individually for each of the analyzed objects, the following fields may include:

– numerical value of the measure (very limited use),
– chart aggregated as a function of time - weekly or monthly.
– distribution of the population of measures appropriate for all analyzed objects (ordered chart) with a clear indication of the position of the analyzed case.

Experience related to the preparation and use of the described card indicates that the last two systems can be an extremely helpful tool, enabling an immediate assessment of the efficiency of production equipment in many parallel aspects, summarized by economic measures (lines 11 and 12). The compilation of analogous data in one line significantly speeds up the assessment of values, in particular: analysis of mutual correlation of subsequent measures and time trends for charts aggregated over time and instant analysis of the strengths and weaknesses of the analyzed object, in the case of using ordered charts with the value and position of the object in the group marked.

When using the card to evaluate many objects over a longer period of time, the observation of distributions (including distribution functions) of separate groups of observations that meet the given criteria is particularly useful. The described system allows for the direct identification of efficiency measures whose variability has a significant impact on the final result (including daily net extraction) and their distribution for mining projects carried out in specific geological, mining, organizational and technical conditions.

3.6.5.3. Complementary techniques for data analysis and visualization of results

An important supplement to the effectiveness measurement card should be a list of parameters related to the broadly understood nuisance of working conditions and charts of analytical importance. The basic types with the greatest descriptive usefulness include:

– chart of unit advance and or efficiency of mining,
– chart of advance and/or shift and daily production,
– distribution functions of daily values for various numbers of production shifts,
– values of individual observations as a function of mining time,
– chart of the duration of classified states,
– pie chart,
– chart aggregated for time,
– chart accumulated and ordered at the 24-hour level,
– 3D chart in the clock time - calendar time system,
– aggregated chart for clock time,

– chart of the duration of the mining cycle and breaks between subsequent cycles,
– box chart for subsequent periods,
– chart of relative and absolute performance measures,
– graph as a function of time,
– stream graph,
– heat map chart,
– graph of parallel values (so-called "fishing net"),
– mutual correlation chart for subsequent observations (including week),
– Pareto chart of the main causes of stops,
– distribution factor of MTBF times (Mean Time Between Failures) and MTTR (Mean Time To Repair),
– diagram of mining power and speed in the two-dimensional plane of the longwall (length, width),
– correlation chart of longwall production results within the mine, in particular in the case of common haulage and haulage routes.

Due to the number and diversity of methods of detailed data analysis, only selected examples of charts supporting the assessment of the course of use of the longwall system are presented in Figures 3.49 and 3.50 [Polak, 2016].

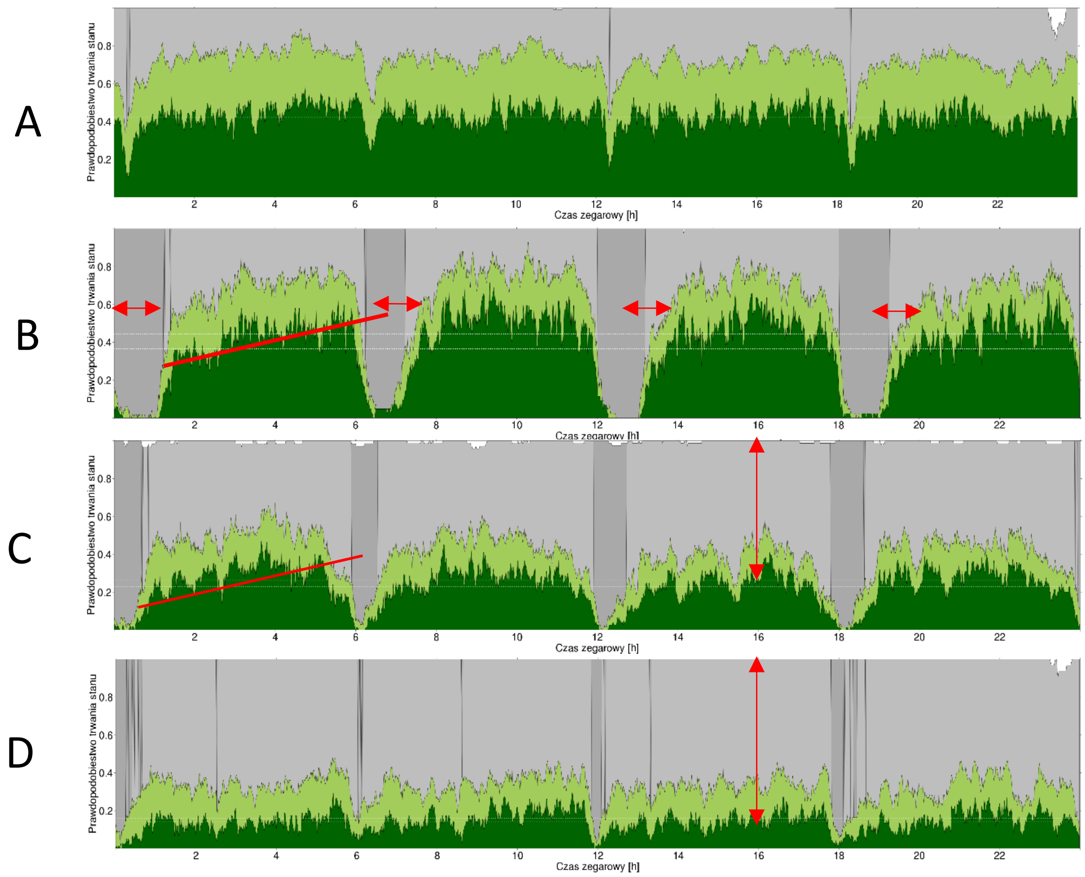


Fig. 3.49. Temporal characteristics of the use of the longwall system [Polak, 2016]

Fig. 3.49 a) contains a record of the operating status of the longwall system in the hourly time - calendar time system. This type of chart is extremely useful because it allows, at the first stage of analysis, to initially assess:

– method of organization and course of production (days off, days without production, total number of production shifts, average number of shifts with production),
– level of organizational losses (chronic, occurring between changes),
– occurrence of sporadic losses (failures and stoppages),
– approximate value and distribution of daily operating time of the longwall system,
– average duration of the production cycle and production breaks.

Further, by classifying time according to the states indicated in Fig. 3.30, an ordered graph can be drawn as shown in Fig. 3.49 b). The construction of the chart uses the efficiency measures previously described in the card and consists in cyclically accumulating successive efficiency measures aggregated for the day and arranging them according to value. This chart provides information similar to the distribution of individual efficiency measures, and their combination on one level allows, among others, to additionally identify the conditions in which sporadic losses occurred, including: whether it was a mining day and what part of the stoppage covered the whole day. It can be seen in the figure that not all shifts on working days that were characterized by no production have a reason for the stop given, the records of stops should be treated only as supplementary information. Fig. 3.49 c) shows a cross-section of production shifts aggregated as a function of time, which allows for the identification of chronic losses of an organizational nature (including crew changes).

Fig. 3.50 shows the variability of dynamic parameters, such as production efficiency (Fig. 3.50 a, b) and power consumed by the cutting drums (Fig. 3.50 c) of the selected longwall system. The data covers approximately 400 m of the advance and comes from the operation automation system and the strain gauge scale installed along the conveyor belt route. The shape of the efficiency distribution is similar to the Gaussian distribution with an average value of approximately 1300 Mg/h and a coefficient of variation of approximately 19%. Analogous graphs as in Fig. 3.50 c) can be made for parameters such as, among others: shearer feed speed or average work cycle time (detection of places where micro-stops occur).

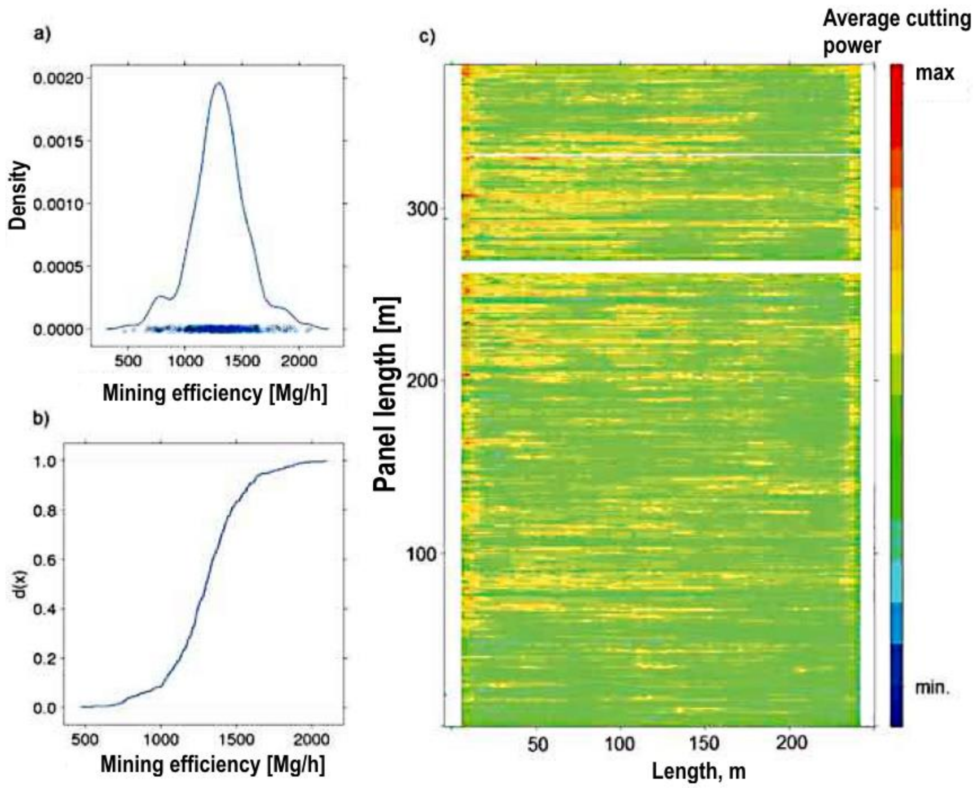
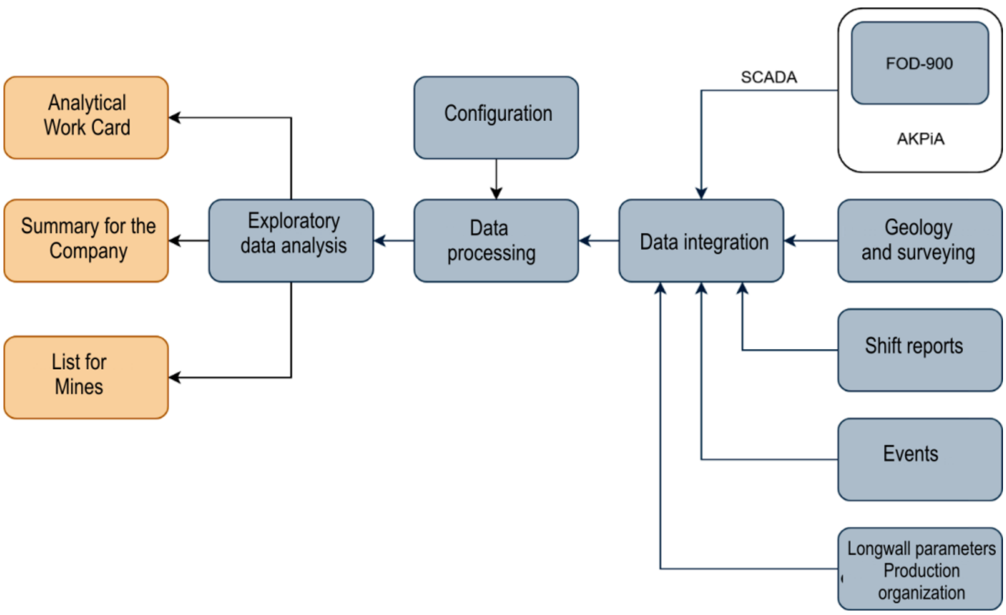


Fig. 3.50. Dynamic characteristics of the course of use of the longwall system:
a) density distribution of mining efficiency, b) distribution function of mining efficiency,
c) graph of average mining power as a function of length and longwall course [Polak, 2016]

The starting point for conducting a full-fledged analysis of the efficiency of mechanized mining systems is the proper decomposition of the added value creation chain, with direct addressing of individual categories of production and economic losses (Figures 3.51÷3.54).

a)



b)

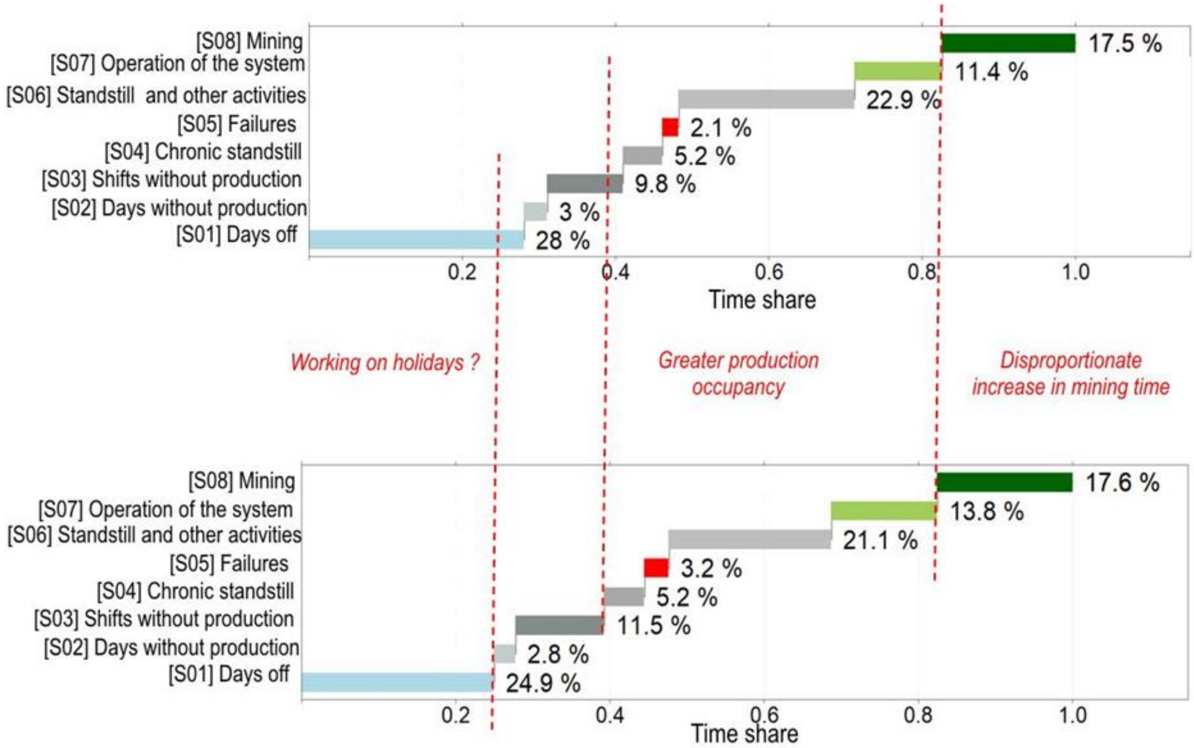


Fig. 3.51. Data sources (diagram above - a) along with the presentation of the results of work of longwall systems (b) – TIME SYSTEM

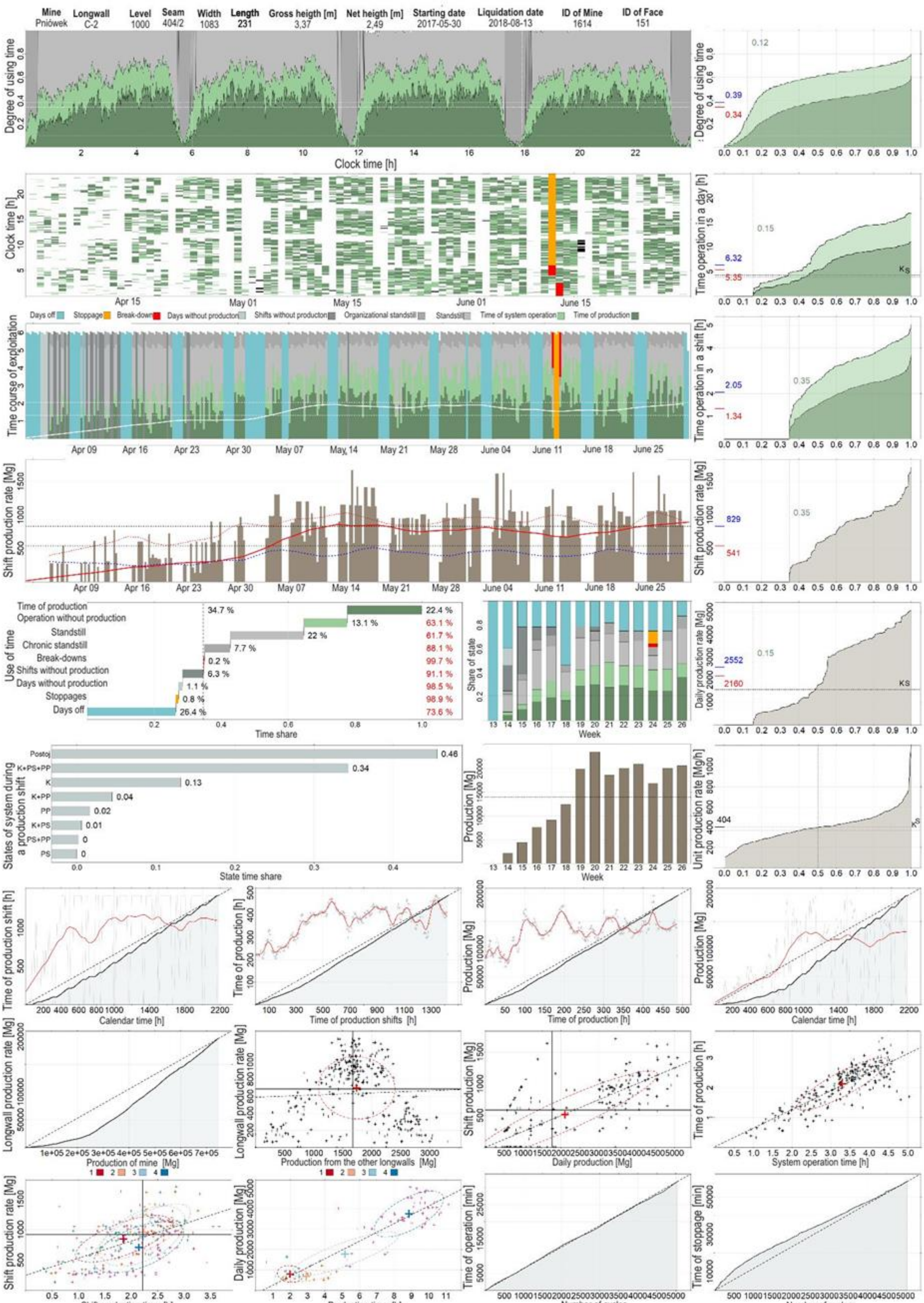


Fig. 3.52. Exemplary longwall systems efficiency

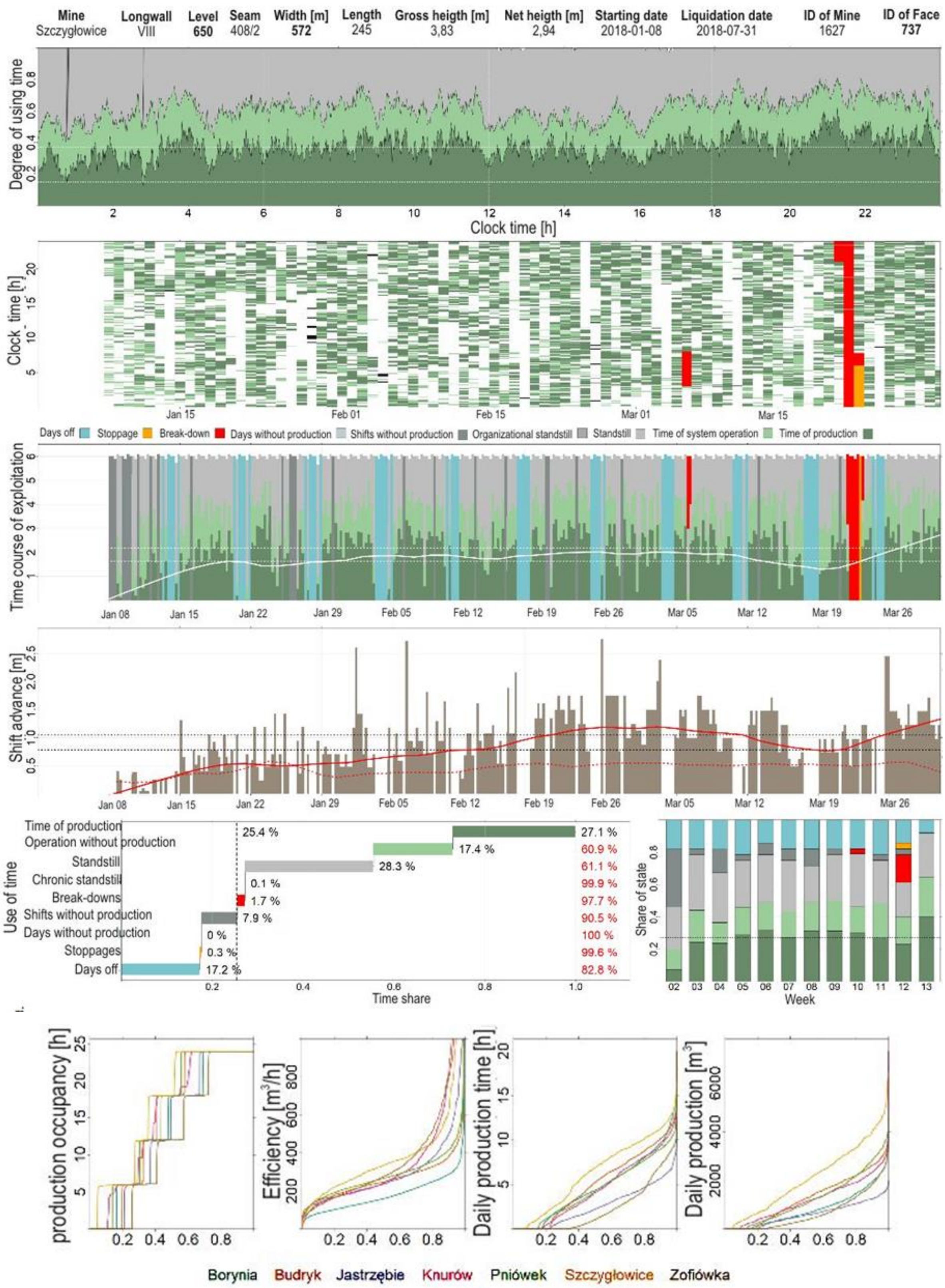


Fig. 3.53. Quarterly longwall management reports with performance charts - sample data

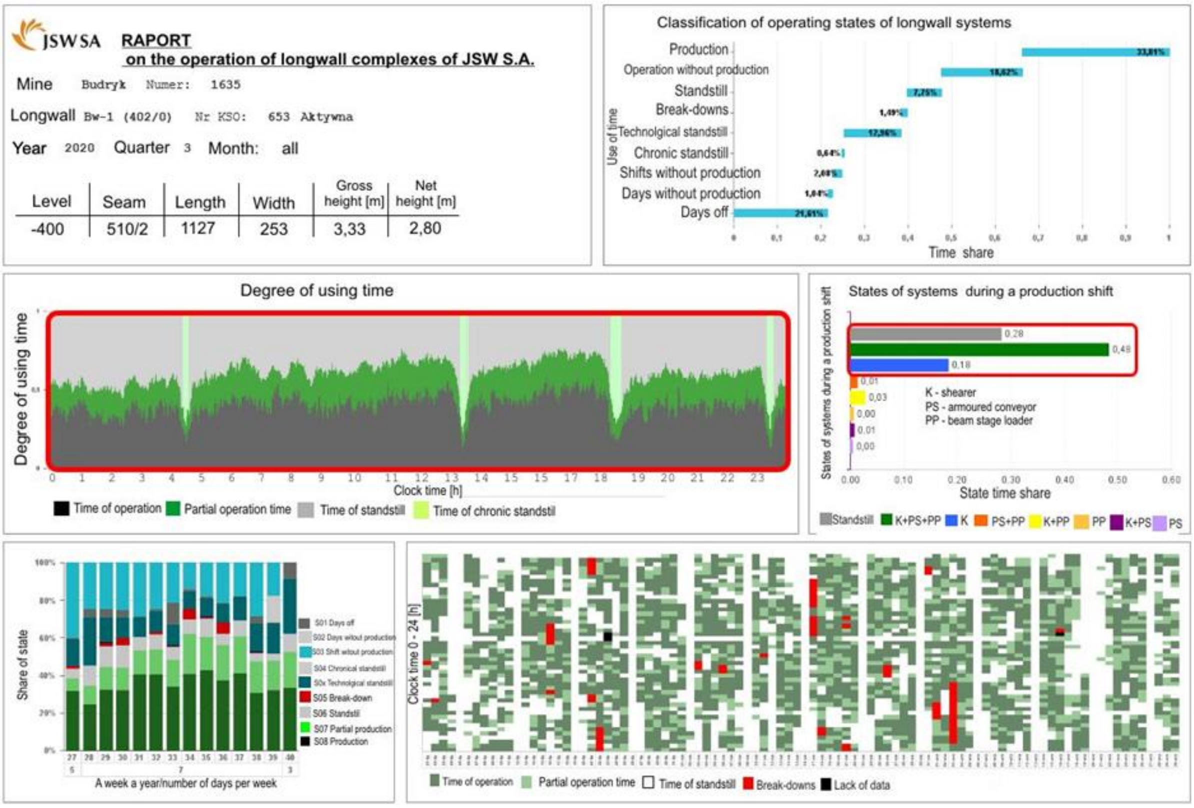


Fig. 3.54. Exemplary quarterly report on the operation of the BW-1 longwall at the Budryk coal mine

In Fig. 3.54, an effective work threshold of almost 34% with a small overlap between subsequent production shifts can be seen.

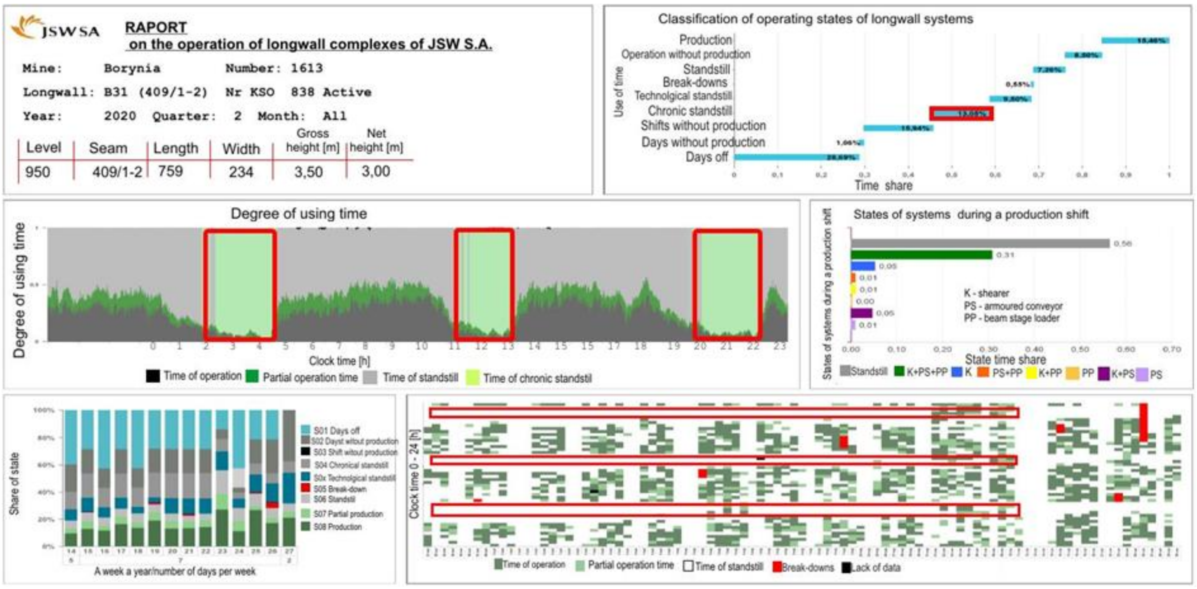


Fig. 3.55. Exempary quarterly report on the operation of the B-31 longwall in the Borynia coal mine with a clearly outlined operation of the system and the break between shifts related to methane restrictions (the B-31 longwall was conducted in a three-shift system)

Kopalnia	Ściana	Miesiąc	Liczba dni w raporcie	Dni robocze	Dni z wydobyciem	Zmiany z wydobyciem	Czas obłożony	Czas dyspozycyjny	Czas pracy kompleksu	Czas wydobycia	Postęp powierzchniowy [m²]	Wydobycie brutto [m³]	Wydobycie netto [m³]	Ranking obłożenie prod	Ranking czas wydobyci na zmianie	Ranking dobowy czas wydobycia	Ranking wydajność	Ranking Wydobycie netto	Koszt całkowity wydobycia 1 tony [zł/t]	Dni robocze [%]	Obłożenie prod. dni [%	Obłożenie zmian [%]	Dyspozycyjność org. [%	Dyspozycyjność techn. [%]	Praca kompleksu [%]	Urabianie [%]	Jednostkowy postęp pow. [m²/h]	Wysokość brutto ściany [m]	Uzysk objętościowy [%
Borynia	ściana B-31 (409/1-2)	1	30	20:17	20:17	18:41	14:34	10:28	7:04	3:35	485	1 631	1 452	1	1	22	5	11	55	85	100	92	78	72	68	51	136	3,36	89
Borynia	ściana C-35 (415/3)	1	31	18:49	18:49	17:05	13:35	8:28	4:47	4:02	438	1 179	1 021	1	7	17	17	15	76	78	100	91	80	62	57	84	108	2,69	87
Borynia	ściana E-23 (404/1 łg+łd)	1	31	19:20	19:20	15:05	13:55	8:10	5:28	3:51	286	772	686	1	17	15	22	23	102	81	100	78	92	59	67	71	74	2,70	89
Borynia	ściana G-32 (359/1 łg+łd)	1	31	18:46	18:46	18:35	17:23	13:34	9:24	5:52	775	1 550	1 232	1	3	8	20	14	61	78	100	99	94	78	69	62	132	2,00	80
Budryk	ściana B-12 (401/0)	1	31	18:48	18:48	18:37	13:56	11:00	7:35	5:22	713	1 797	1 547	1	2	12	13	7	78	78	100	99	75	79	69	71	133	2,52	86
Budryk	ściana Bw-3 (401/0)	1	31	18:13	18:13	15:30	12:04	9:31	7:28	4:43	407	1 021	749	1	14	10	25	21	122	76	100	85	78	79	79	63	86	2,51	73
Budryk	ściana Cz-4a (364/2)	1	31	18:11	18:11	17:36	16:05	13:02	9:09	7:22	1 122	2 210	1 739	1	5	1	19	5	69	76	100	97	91	81	70	80	152	1,97	79
Budryk	ściana D-2 (358/1)	1	31	18:14	17:28	13:59	12:10	9:03	7:15	4:53	671	1 650	1 315	23	21	4	16	12	93	76	96	80	87	74	80	67	137	2,46	80
Jastrzębie-Bzie	ściana 26a (510/1)	1	30	17:26	17:26	15:14	11:14	6:47	4:58	2:56	267	984	960	1	16	21	9	16	86	73	100	87	74	60	73	59	91	3,68	98
Jastrzębie-Bzie	ściana 27 (510/1)	1	30	18:15	18:15	13:03	11:13	6:09	3:51	2:36	312	859	712	1	23	20	15	22	75	76	100	72	86	55	63	68	120	2,75	83
Knurów	ściana 16 (361/0)	1	31	17:19	17:19	14:02	13:18	9:16	6:23	4:48	469	938	769	1	20	5	24	20	80	72	100	81	95	70	69	75	98	2,00	82
Knurów	ściana 31 (405/3)	1	31	18:08	18:08	16:36	15:54	12:32	8:25	6:09	675	2 493	2 222	1	12	3	8	2	61	76	100	92	96	79	67	73	110	3,69	89
Knurów	ściana 5. (504/0)	1	31	17:55	17:55	14:03	13:02	8:49	6:38	4:33	265	882	789	1	19	7	23	19	175	75	100	78	93	68	75	69	58	3,33	89
Pniówek	ściana C-4 (404/2)	1	30	18:51	18:51	16:51	13:08	9:52	5:44	3:49	572	1 865	1 453	1	10	18	6	10	108	79	100	89	78	75	58	67	150	3,26	78
Pniówek	ściana K-2 (363/0)	1	31	18:48	18:02	16:52	14:05	10:19	6:47	4:59	522	2 040	1 518	22	8	11	11	8	91	78	96	94	83	73	66	73	105	3,91	74
Pniówek	ściana N-1 (404/4)	1	31	18:50	18:50	17:29	15:29	11:17	7:31	5:25	737	1 792	1 556	1	6	9	14	6	66	78	100	93	89	73	67	72	136	2,43	87
Pniówek	ściana N-4 (404/1)	1	31	18:21	18:21	16:37	14:08	10:25	7:07	5:24	729	1 677	1 312	1	11	6	18	13	89	76	100	91	85	74	68	76	135	2,30	78
Pniówek	ściana PW-1 (358/1)	1	31	17:48	17:48	15:17	11:56	6:29	3:34	2:44	655	1 075	832	1	15	23	12	17	165	74	100	86	78	54	55	77	239	1,64	77
Pniówek	ściana W-2 (362/1)	1	31	17:50	17:50	12:59	10:35	6:44	4:26	2:56	229	508	394	1	24	19	26	25	373	74	100	73	82	64	66	66	78	2,22	77
Szczygłowice	ściana XVI (405/1)	1	31	17:50	17:50	16:52	14:13	10:53	6:58	4:42	543	1 988	1 760	1	8	14	7	4	90	74	100	95	84	77	64	68	116	3,66	89
Szczygłowice	ściana XVI (407/3)	1	23	17:51	17:51	14:43	11:29	8:43	4:10	1:32	291	871	810	1	18	26	1	18	92	74	100	82	78	76	48	37	191	2,99	93
Szczygłowice	ściana XXI (405/1)	1	31	17:28	17:28	15:43	14:17	9:05	6:20	4:31	603	2 236	2 116	1	13	13	2	3	36	73	100	90	91	64	70	71	134	3,71	95
Zofiówka	ściana E-6 (505/1)	1	31	17:15	14:55	13:11	12:13	8:28	5:06	3:17	468	1 532	1 485	24	22	16	3	9	54	72	86	88	93	69	60	64	143	3,27	97
Zofiówka	ściana F-3 (406/1)	1	31	17:02	10:04	8:19	6:53	3:19	2:20	1:21	211	364	243	26	25	24	21	26	205	71	59	83	83	48	70	58	157	1,72	67
Zofiówka	ściana G-2 (416/3)	1	31	17:40	17:40	17:40	16:35	12:58	11:32	7:06	890	2 492	2 296	1	4	2	10	1	36	74	100	100	94	78	89	62	125	2,80	92
Zofiówka	ściana N-4 (505/1)	1	31	16:50	14:31	7:32	5:53	2:25	1:44	1:01	112	493	442	25	26	25	4	24	168	70	86	52	78	41	72	59	110	4,41	90

Fig. 3.56. Quarterly reports on longwall construction in JSW SA mines – LONGWALL RANKING

The Longwall Ranking of JSW SA mines presented in Fig. 3.56 is created and analyzed in detail in the Center for Advanced Data Analytics (CZAD JSW 4.0), as a result of an advanced assessment of the best longwall faces of the Company's mines, which includes: work organization - mining shift ranking (availability); the number of technological downtimes along with the failure rate and operation of the complex - ranking of daily mining time (readiness for work); mining with surface advance (efficiency ranking) – efficiency. The mutual relationship of these indicators allows to determine which longwall performs best in the overall ranking.

The process of operating basic equipment used in mining is a constant search for optimal solutions, both in technical and organizational terms. Therefore, the correct identification of factors influencing the decline in the efficiency of basic production assets is crucial both in the context of reducing investment and operating costs, as well as from the perspective of increasing production and improving its quality.

Ubiquitous systems based on IT techniques currently allow for the recording and reporting of extremely extensive information structures, which contributes to the creation of information chaos. According to the authors, with the exception of people dealing strictly with data analysis processes, cyclical reporting of an extensive set of information for management purposes carries many risks. It may contribute to:

– "dilution" of the decision-making usefulness of important indicators,
– problems with cause-and-effect interpretation and combining information,
– deterioration of data quality (low utilization) and, as a result, loss of credibility.

The efficiency measurement card developed in CZAD JSW 4.0, although seemingly very simple, is a measurable support tool for identifying potential areas of improvement in the production process of the JSW mines. Its practical use since 2018 has made it possible to track and interpret in a standardized way the variability of individual measures of the efficiency of mining systems in terms of time, production units and structures, equipment used, work organization methods, natural conditions and occurring nuisances.

In 2018, the main assumptions for the operation of the JSW 4.0 Advanced Data Analytics Center were made. After obtaining the first results of the life cycle costs calculation of longwall systems, company decided to extend the target method of analysis to include transport and processing equipment, as well as fixed costs related to drainage, ventilation, maintenance of workings and distribution of utilities. It turned out that managing the life cycle of means of production used in mining by means of a dynamic analysis of all costs aggregated by them is a very effective control mechanism resulting in directing management processes to business aspects, and thus generating profit for the company [Dyczko, 2021; Dyczko, 2022a, b; Dyczko, 2023].

The presented method of assessing the management of means of production in JSW SA is the foundation of the JSW 4.0 Advanced Data Analytics Center research and analysis, forcing decision-makers to carefully interpret and reflect in the Company's cost model not only the technical properties of the equipment, but also, and perhaps above all, improvement of production organization and operating conditions. As it turned out, an accurate forecast of production costs requires CZAD JSW 4.0 to explore large amounts of empirical data, often using advanced processing techniques, all in order to prepare multi-variant cost projections that can be used by decision-makers for:

- assessment of ongoing and alternative investments,
- planning the costs of new projects,
- risk assessment of decisions made,
- identification of key factors affecting asset life cycle costs and production costs,
- optimization of the process of using and operating equipment,
- supervision over the efficiency of asset use (deviations from the plan),
- determining the economic life and durability of individual technical objects,
- comparison of existing production installations and mining projects,
- improving life cycle cost estimation methods by verifying assumptions regarding cost models, conditions and facility operation scenarios.

As research carried out at JSW has shown, one of the basic applications of LCC analysis in the mining industry may be the assessment of purchasing decisions, including the measurement of losses on investments in which the initial cost was the basic or only criterion for selecting the offer. However, it seems important to measure the effects of insufficient recognition of working conditions and, consequently, inappropriate selection of technical and technological solutions. Appropriate valuation of the risk associated with decisions made in conditions of uncertainty may be the only justification for the expenditure necessary to increase the available level of information.

Analyses currently conducted in CZAD JSW 4.0 show that the search for and continuous introduction of new technologies into mining, deteriorating mining and geological conditions, and the growing pressure to reduce operating costs have highlighted a new area of application of the LCC account in mining. It covers all activities related to the improvement of maintenance processes, optimization of the production process organization and technical assessment of the assets used.

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JSW is currently algorithming the system platform, which directly covers issues related to the operation of technical facilities, production engineering, logistics, geology and mining. Research on multi-criteria optimization in this area is particularly important in terms of mining concentration. The purchase of high-performance equipment most often involves the need to guarantee high utilization of production potential in order to balance the increased costs associated with its acquisition and maintenance. The erroneous belief that the mere introduction of new technologies or technical solutions will improve efficiency is often the cause of disappointment, especially in the economic dimension.

As shown by the work of entire teams of CZAD JSW 4.0 analysts, dynamic life cycle costing can be an essential support tool in the area of managing the production assets of mines. Its proper use has been proven to avoid costly mistakes and guarantees effective implementation of continuous improvement processes in the area of use and maintenance of key production resources.

Analyzing the current reporting system, it was found that there was a need to systematize the collected data by properly structuring it. For example, in relation to failure descriptions, it seems justified to introduce two levels of assignment to specific elements of longwall face equipment, including: shearer – control system, armoured face conveyor – drive. Next, it seems useful to add two levels of event description, e.g. activation of the lock - temperature exceeded and the need to assign it an appropriate category, e.g. mining, hydraulic, mechanical, electrical.

As a result of the data analysis, the basic information scope was determined in accordance with the OLAP model. In terms of facts (measurements), the basic elements are listed:

– work performed: advance, extraction, number of cycles, raw coal output,
– geological profile: partings, ripping depth, weight,
– duration of states: planned stop, breakdown (with detailed division into categories and type), standstill and other work, ineffective work, effective work,
– efficiency measures (calculated automatically): occupancy, technical readiness, technological and organizational readiness, production efficiency (speed), quality,
– assessment of the nuisance of conditions (according to an appropriate procedure),
– time and scope of additional work performed (according to the appropriate procedure),
– production limitation (the product of the time of occurrence and the degree of limitation).

The basic features (dimensions) of the cube are defined as:

– time: year, month, day, day of the week, assignment period,
– longwall: name, seam, level, department, width, length, thickness, dust hazards and methane, dimensions of roadways, floor and roof conditions, corrugations of the seam, seam disturbances (faults), partings, longwall inclination, driving conditions (e.g. longwall end), coal hardness, type of coal, commercial coal output, average calorific value, advance from the beginning of operation,

- organization: production day (y/n), number of shifts, duration of shifts, number of production shifts, duration of production shifts, length of transport routes, crew transport (length of the route on foot), crew number, number of employees,
- equipment: mining technology, manufacturer and type of equipment, mining speed and depth, type of control.

The OEE indicator is the result of three other sub-indicators:

- Availability – the ratio of the time planned for the task to the time that can actually be devoted to this task. Availability is reduced depending on the adopted method, by reinstallation and setting up machines.
- Utilization (efficiency) – the ratio of time available to current work. Utilization (performance) is lowered by losses in the speed of execution of operations.
- Quality – the ratio of good to total products.

The indicator is calculated according to the formula:

$$\text{OEE} = \text{Availability x Utilization x Quality.}$$

World Class OEE – International research shows that world-class manufacturers achieve OEE rates of 85% or more. And it is a component of the parameters:

- Availability: 90.0% Efficiency: 95.0% Quality: 99.9%. Which, after applying the above formula 90.0% x 95.0% x 99.9%, allows to obtain the above-mentioned 85%. The average OEE for typical production plants is approximately 60%.
- Automation of OEE determination – The pursuit of continuous improvement of OEE causes many plants to move away from manual recording and calculation of performance factors to the use of specialized IT systems for production. Processing signals automatically collected from the production process (e.g. from PLC controllers) regarding the current condition of machines, their efficiency, causes of downtime or micro-downtime affects the reliability of determining OEE and other KPIs. This makes it possible to monitor the efficiency of equipment and production processes in real time and report them for any period and in any time any context (e.g. line, machine, product, shift, employee).
- In the maintenance of production plants, an important aspect is the use of tools related to the concept of TPM - Total Productivity Maintenance (Global Maintenance Management). The measure of the effectiveness of implementing TPM initiatives is the OEE index.

We live in the information age. Every day we deal with larger and larger data sets, the analysis of which requires the implementation of dedicated tools. At the same time, it is a fact that the value of information decreases over time – Fig. 3.57.

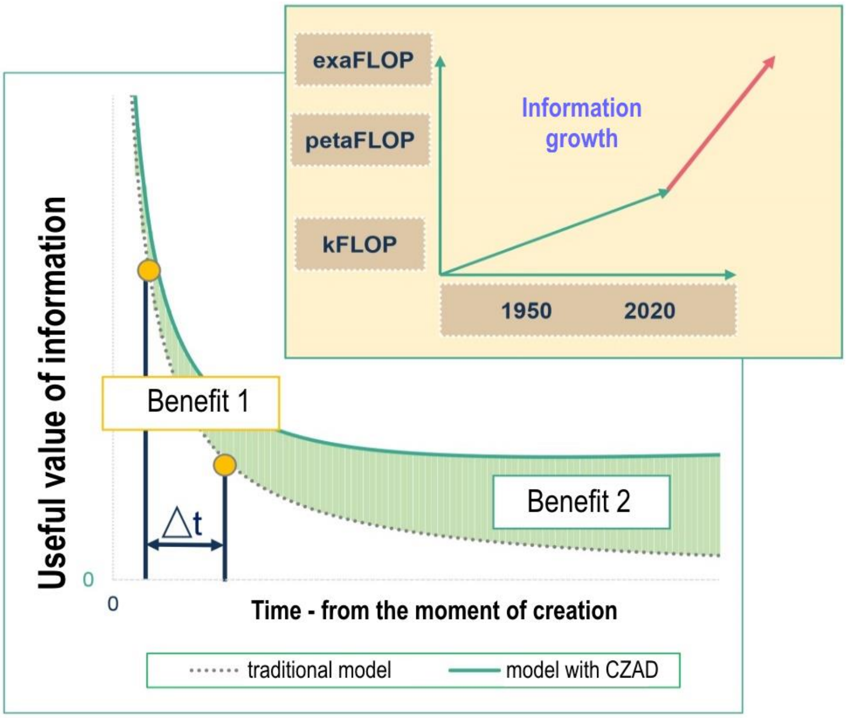

Fig. 3.57. Useful value of information

The earlier we obtain information, the more useful it is in the organization. This is the first type of benefit highlighted in Fig. 3.57 **(Benefit 1**). This benefit occurs mainly in the action or reaction period of the information life. **Benefit 2** results from **more effective use of information** during the reactionary and historical periods of its life. This benefit results from the use of advanced and multidimensional data analyses, as well as operating on large historical data sets, including Big Data. The CZAD vision envisages achieving the above-mentioned types of benefits.

Large enterprises use many specialized IT systems, which can be divided into the following categories:

– ERP systems, e.g. mySAP – used to record and settle costs of the serviced business area,
– EAM/CMMS asset management systems - support for maintenance management,
– SCADA industrial automation systems - supervising the technological or production process,
– specialized "industry" systems remained, e.g. APO BDG.

In practice, for every real process there are data that are saved in the above-mentioned systems. With a few exceptions, the analysis of process indicators is carried out on the basis of data from one source system, which does not allow the use of the synergy potential that can be achieved by combining data from many systems. Tools dedicated to this type of applications are Business Intelligence (BI) systems.

Therefore, multidimensional data analyses involve combining and processing data and information about processes taking place in the organization into new knowledge, presented in various information sections.

The developed JSW Group Strategy for 2017÷2030 included a number of activities to optimize costs in all JSW SA mines. The strategy assumed a gradual reduction of mining cash cost (MCC) mainly due to the implementation of activities constituting the JSW 4.0 Smart Mine in terms of high IT/OT maintenance standards and the implementation of the EFFICIENCY Program – Fig. 3.58.

Fig. 3.58. JSW Group strategy for 2017÷2030 [Ozon, 2019]

Concluding this chapter of the monograph, attention should be paid to the fact that one of the basic problems related to the lasting and efficient functioning of the JSW 4.0 Advanced Data Analysis Center within the Organization is the issue of creating, sharing, storing and making available documentation constituting knowledge resources obtained by CZAD JSW 4.0.

The author recommends creating an environment for group work that will constitute an internal knowledge base in the organization, serving, among others, documenting research work, sharing analysis results and summarizing initiatives conducted by CZAD.

This environment may additionally constitute a "gate" providing external entities with data, information and knowledge about the functioning and course of processes in the Organization and the results of research work. It can also be a place for co-creating documentation with external entities, providing ongoing opinions on the results of ongoing work and initiatives while strictly controlling access to data.

An additional advantage of the environment may be integration with the task management module (*workflow*), in order to, among others, coordinate tasks entrusted to individual members of CZAD.

Acquired experience shows, that the role of the described environment can be performed by Atlassian software, widely used in IT Confluence and Atlassian Jira.

One of the key decisions related to the functioning of CZAD in the future is the choice of environment for the implementation of data processing and analysis processes.

Currently, free environments are widely used, including: R, Python, giving access to thousands of dedicated packages and libraries supporting data science processes, including machine learning. These environments are characterized by high capabilities and flexibility, access to them is possible via Jupyter Notebook-type interfaces, which facilitate the sharing of results and promote a broader understanding of the analytical process being implemented. It should be emphasized, however, that the use of the tools described requires having at least basic programming skills.

The second category of tools are commercial solutions such as: SPSS, SAS, Matlab, Statistica. These are generally easier-to-use solutions, but due to their multitude and the cost of licenses, access to staff well trained in the use of a given type of software (with the exception of the Matlab environment present in almost all universities) may be a significant problem.

In the above situation, also in the case of choosing commercial solutions, it is worth considering the benefits of **parallel use of free software,** such as:

- ease of obtaining trained staff (IT specialists, mathematicians) and quick implementation of their work,
- possible integration with commercial solutions,
- no license costs, no functional limitations related to the product or the license held,
- the possibility of making selected research issues available to communities specializing in data analysis - with direct and quick use of the proposed best solutions,
- possibility of implementation on corporate cloud computing platforms.

The decisive factor that distinguishes Advanced Data Analysis CENTERS from other organizational units should be the conscious and purposeful use of advanced analytical methods, including artificial intelligence and machine learning, implemented in the engineering process, based on data collected in IT systems.

4. JSW SA production line management system with an aim of stabilizing and improving the quality of output and maximizing economic effects based on demand and quality of the exploited raw material – its role and importance in implementation of the idea of SMART MINE JSW 4.0

Artur Dyczko

The effective implementation of new market strategies poses new challenges to mining companies, the implementation of which requires precise instruments for assessing their activities at the level of mines, processing plants, coking plants and steelworks. These instruments are deposit, technological and economic parameters, which, together with safety margins determining the percentage level of reserves of each parameter, shape the profitability of undertaken projects.

The heuristic technical architecture of the JSW SA production line management system developed by the author allows analyzing the profitability of the production process on a drawn-out calculation basis on the level of mines, processing plants and coking plants of the mining group of the largest European producer of coal for metallurgical purposes.

In the mining part, the built system is an element of the production planning and scheduling system enabling control of the entire technological chain of the JSW SA Group, i.e. in all areas covering the entire coal-coke process. The system was built in 2018÷2020 and included the creation of a central geological database and feeding it with data from 250 surface boreholes, 1,440 underground boreholes, over 14,670 heading profiles, 24,000 qualitative samples, 100 main faults and 150 local faults. The final effect of the design work was the creation of spatial, structural and qualitative models of the deposit exploited in JSW SA mines and the construction of strategic production schedules until 2030, along with a model of 700 kilometers of designed roadway workings and 480 mining longwalls, including 50 types of roadway workings linings and 25 algorithms of production limitations.

The chapter presents the assumptions for designing the IT architecture of a system for deposit modeling and mining production scheduling, implemented in JSW SA mines in 2016÷2020. The development and use of the system was important from the perspective of achieving the primary goal **of the QUALITY PROGRAM,** which is an integral part of building the idea of **the JSW INTELLIGENT MINE 4.0**. i.e. increasing the efficiency of managing the quality of the deposit and commercial product. As a result of its implementation, many barriers in the functioning of information systems were overcome, a coherent architecture of the information system was developed and implemented, resulting in the standardization of data recording and processing activities using the so-called "computational intelligence" methods, which allowed to extract useful and understandable knowledge from the data, supporting decision-making, at the level of strategic, tactical and operational planning. Currently, in JSW SA, this knowledge is the basic resource of the company, which determines the possibility of intelligent functioning in the changing mining, geological and business situation.

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4.1. Strategy and Policy for managing the production line of the coal-coke group in terms of examining the quality of the exploited deposit and produced coke

The update of the JSW Group's business strategy, prepared since the beginning of 2020, the aim of which was to ensure, above all, the safety and continuity of the production, led to the adoption of the necessary regulations in the Company to prevent mines from being filled with stored coal above the level safe for the operation of the mining plant and to secure its own strategic storage sites, so that if necessary (e.g. when rail traffic stops due to the pandemic), it was possible to deposit safely coal extracted by mines when mine storage sites were dangerously close to 75% filling. All these activities carried out in the field of production volume optimization: ongoing analysis and monitoring of production capacity, testing and forecasting of quality and sales opportunities based on the demand of the internal and external markets (export and domestic sales), together with the establishment of a new Quality Management Office, contributed to the decision adopted by The Management Board "Product quality strategy for the JSW Group for 2020÷2030" and "Quality management policy for deposit and product testing in the JSW Group" enabling to ensure the desired level of quality parameters of coking coal and steam coal, as well as the rules for forecasting the level of seam coal quality parameters – Fig. 4.1.

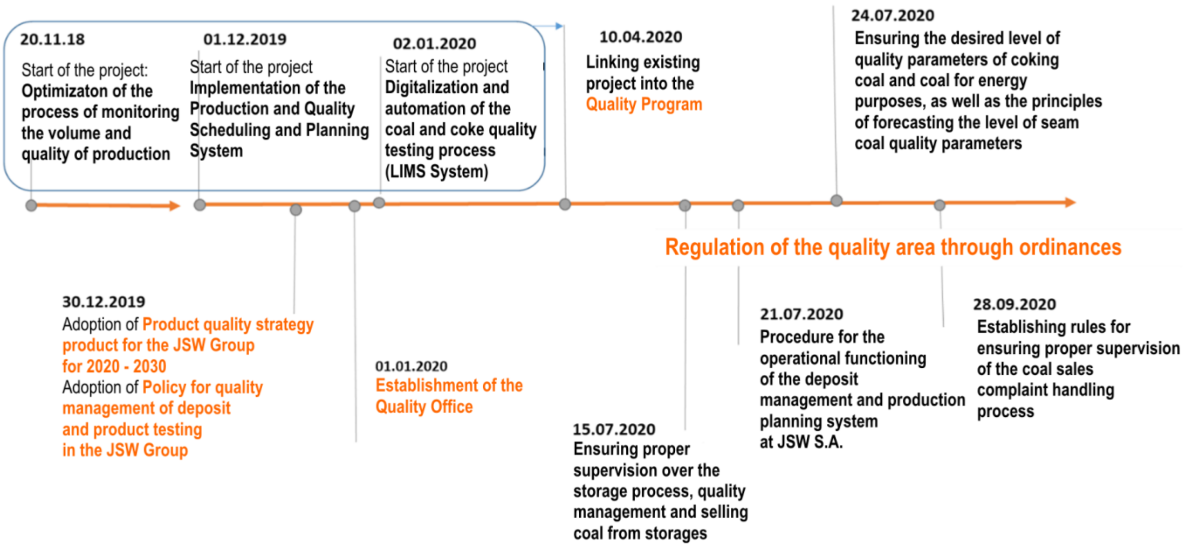

Fig. 4.1. Schedule for the construction of proactive production control and stabilization of commercial coal parameters in the JSW Group

Research shows that only by correlating forecasts in terms of demand (the expected volume and quality of the product depend on the business cycle) and supply (mining volume), i.e. production and planned investments enabling the implementation of the assumed production plans, it is possible to achieve the greatest economic effect in the period of price increases, while at the same time cost control enabling staying above the break-even point during economic downturns [Dyczko, 2021, 2022a].

That is why a holistic approach to issues related to the correct planning of production volume, quality and demand based on monitoring of all important operational indicators related to the production process is so important. Currently, mining companies lack systems enabling such an approach, and that is why it was proposed to build a production planning and accounting system driven by demand, and especially the quality of extracted coal, in the entire JSW Capital Group, which integrated previously dispersed domain systems using SOA architecture [Dyczko, 2022a].

The construction of the system concept began with organizing the quality management area, taking into account the results of scientific research [Dyczko, 2020; 2021; 2022a], which confirm that the implementation and operation of a quality management system brings many benefits. Internal benefits include: ongoing quality monitoring, predictability of production quality, improvement of operational efficiency, orderliness of activities in the organization, involvement of employees in shaping the quality of the product or service, economic benefits, supervision and improvement of processes in the organization, assignment of authorizations and responsibilities to appropriate employees, motivation for improvement and innovative activities, better and faster document and information flow, improved communication within the organization, fewer complaints and greater employee motivation. External benefits include, among others: increasing the quality of manufactured goods and services provided, increasing external customer satisfaction, standardization of procedures towards customers, changing the company's image - shaping the pro-quality orientation of the organization, increasing sensitivity to customer expectations, easier access to the local and international market. It should also be emphasized that a quality certificate builds credibility and trust in the organization, confirms the organization's development, and is often a condition for participation in business negotiations.

Jastrzębska Spółka Węglowa SA, which produces coking coal, has been conducting research on the implementation of a management system based on demand and quality (SPPJ) for several years. The primary goal of the company is to increase the efficiency of management of deposit quality recognition and product quality. This may be made possible by a comprehensive approach to the quality management process, according to which monitoring and supervision of product quality should take place at every stage of production in order to increase the production potential and stabilize the coal quality.

4.2. System for deposit modeling and production scheduling in JSW Capital Group as the foundation of the heuristic architecture of the "QUALITY PROGRAM"

The new strategy of the JSW Capital Group has defined goals for key areas of responsibility in order to, on the one hand, limit the risks and business challenges associated with them, and, on the other hand, to maximize opportunities resulting from socio-economic changes.

A key element of JSW's business strategy is the implementation of the "**QUALITY PROGRAM**", which includes a number of activities enabling modeling of deposits and production schedules, as well as ongoing monitoring and supervision of production quality, including:

- geological databases of 6 mines were built and organized,

- IT tools for scheduling and modeling of these mines were implemented,
- geological models were prepared for strategic deposits, resource areas and mining levels of all JSW SA mines,
- strategic production schedules related to deposit models were created,
- a central database aggregating deposit models and production schedules was built at the level of the JSW SA Management Board Office,
- a central strategic scheduling model was created enabling the merging of mine schedules at the level of the JSW Management Board Office.

Much effort was devoted to selecting and training appropriate employees in the surveying and geological departments of all JSW mines. Sufficient to say that for the purpose of building the system, the Company signed appropriate agreements with the Silesian University of Technology and the AGH University of Science and Technology, employing seventeen young mining geologists, and managing, among others, an entire science club dealing with geostatistics and modeling of parameters describing the quality of hard coal at the Department of Deposit and Mining Geology at the AGH University of Science and Technology in Krakow.

The construction of the Teams was accompanied by an equally complex process of equipping the staff with modern IT systems and measuring instruments used to obtain data for deposit modeling, automation of measurement processes and data visualization. For this purpose, the project of "Intelligent Scales" and "Neuron Analyzers" was launched, which enabled continuous control of the quantity and quality of mined coal transported by conveyors to processing plants.

Before conducting research on the development and implementation of a system for deposit modeling and production scheduling, the Group's IT environment consisted of the Geolisp and ArchiDeMeS systems, which were used to map individual seams in the exploited and planned deposit (this was nothing more than building 2D models for individual coal seams). In turn, in the area of production planning, the CAD environment was used (through AutoCAD overlays) and in the area of production scheduling, Excel sheets with the THPR module of the SZYK2 system were used. The SZYK System is an Integrated Mine Management Support System, the second generation of which - SZYK2 - has been using the latest achievements of world computer science since the beginning of the 21st century [Łukaszczyk, 2018, 2019]. THPR module is used to create and control mining plans, schedules and advance of development activities, and allows for the recording of elementary data on ongoing and planned mining operations [Puzik, 2012]. In practice, deposit management and scheduling of its exploitation were carried out with little support from IT systems.

Most activities related to production management and scheduling were performed in **a dispersed manner** in non-system tools (.dwg, .xls files without the possibility of automatic data exchange or even file import) at the level of individual mining plants. The vast majority of activities were carried out manually **and decentralized**. For this reason, it was important to conduct research and take actions **to capture the entire process of deposit modeling and production scheduling in centralized IT tools.**

Fig. 4.2 shows the architecture of deposit management and production scheduling at JSW SA - before the introduction of dedicated IT systems.

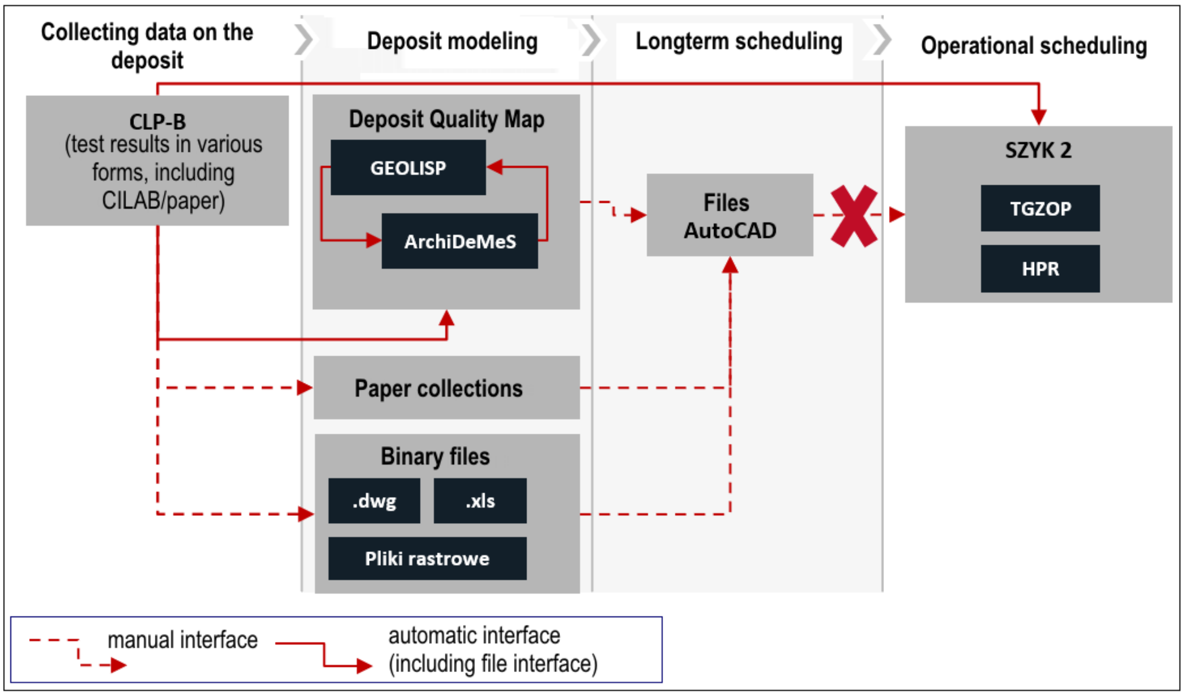

Fig. 4.2. Architecture of deposit management and production scheduling at JSW SA – before the introduction of the deposit modeling and production scheduling system

JSW carried out the process of implementing a software for geological modeling – MineScape, and for production planning and scheduling - Deswik. In its final form, MineScape was to partially replace deposit modeling and provide approved models of structural and quality parameters of the deposit in individual group mining plants directly to the Deswik platform. In turn, the Deswik system was to download data from the MineScape system and process it in the form used by the SZYK system - just like other IT systems in the group. The implementation of the production modeling and scheduling system allowed the geological department of all mines to switch from analog maps to digital maps. The systems allow for precise forecasting and control of production quality.

The first system - a **deposit modeling system** - enables the development of a digital, spatial geological model of the deposit with the ability to use a selected database to manage geological data and make it available to other IT tools. **The geological deposit model created in the system** is understood as a digital, geological model of the mineral deposit describing the location of the deposit, its geometry and spatial differentiation of the mineral quality. The purpose of geological modeling of the deposit is to determine as precisely as possible the geological structure of the deposit and the quantity and quality of the mineral within the mining area. The deposit model is the basis for all activities related to the creation of mining plans and their optimization from the point of view of the group's economic calculation. The subject of geological modeling may be, to a selected extent, physical properties of the overburden as well as the rock mass surrounding the coal seams. The model can also be enriched with information complementing the full picture of the geological situation of the deposit, such as, for example, results of hydrogeological observations. The geological model of the deposit is created primarily on the basis of geological observations made both on the earth's surface and in mining excavations. Therefore, great emphasis was placed on activities aimed at digitizing source materials and collecting them in a geological database. It is worth noting that an indispensable element of the geological modeling process is also the geological interpretation of the collected data performed by an experienced geologist. For the needs of developing and implementing the system the following assumptions were made:

– a digital deposit model is a qualitatively new way of analyzing the geological structure of a deposit, using source information (currently existing in analogue form or in the form of scans, including geological borehole cards) as well as collected in 2D seam map system and operating under the control of GEOLISP and ArchiDeMeS software,
– Ultimately, the digital model of the deposit should support the activities of the geological department related to designing and conducting geological works and interpreting and documenting the geological structure of the deposit,
– the most important goal of maintaining a digital deposit model is its significance from the viewpoint of the Group's production goals: it is intended to be the basis for new solutions in the area of mining design and mining and production planning.

In turn, the second system – Deswik **production planning and scheduling software,** allows, among others, for creating integrated schedules for longwalls and access and preparatory works, reporting and creating quantitative and qualitative forecasts. The system also allows for graphical visualization of plans and schedules along with charts, solids and surfaces as well as their animations in 3D. Deswik imports data from the spatial model and allows you to build optimal production schedules, anticipating various scenarios.

The systems were implemented at workstations in the Group Management Office and in six mining departments, and the project covered 10 deposits and 90 seams - a total of over 580.3 million tonnes of operable resources. Due to the implementation of the system for **deposit modeling and production planning and scheduling,** the following activities were carried out:

– geological databases for individual mining sections were built and organized,
– IT tools for scheduling and modeling in mining sections were implemented,
– geological models were made for strategic deposits, resource areas and mining levels of all mines/sections,
– strategic production schedules were created related to deposit models in six sections,
– a database was built, aggregating deposit models and production schedules at the level of the Group Management Office,
– an operational model of strategic scheduling was created, enabling the merging of schedules at the level of the Group Management Office.

Many studies in the field of geological modeling of deposits have been described in the literature, including [Kokesz, 1992; Sermet, 2017; Mielimąka, 1991; Borowicz, 2014; Naworyta, 2016; Mucha, 2017; Wasilewska-Błaszczyk, 2014; Probierz, 2000, 2004, 2007; Marcisz, 2017, 2021; Probierz, 2017] and mining production scheduling, among others [Dyczko, 2014; Dzedzej, 2008, 2013; Gumiński, 2014; Serafin, 2007; Grzesica, 2014; Szot, 2010; Kijanka, 2017]. However, the system implemented by JSW SA described in this monograph is a new solution, encompassing the entire process related to deposit modeling and production scheduling in centralized IT tools. It is an original solution that has not yet been used in mining practice. It is an expression of the JSW Group's comprehensive approach to quality, according to which monitoring and supervision of product quality should take place at every stage of production in order to increase production potential and stabilize coal quality.

4.3. Technical architecture of the production line management system of the JSW group in the light of global experience in the development of computerization of the mining sector

IT tools used to design and plan mining production appeared on the market around the same time, significantly influencing the quality of the mining and processing activity [Kaiser, 2002].

The first software packages supporting the exploitation of mineral resources appeared in the 1970s, and the main catalyst for their development was the pressure of gold producers to look for effective tools to minimize losses related to the identification, documentation and extraction of excessively depleted material - the average gold prices on the stock exchanges did not exceed USD 50 per ounce at that time.

The tools created at that time were developed both by the mining companies themselves and by research centers, whose employees quickly became creators of innovative products, which in the competitive market quickly turned into commercial software, often more functional than that built inside the mining companies [Kapageridis, 2005].

Ultimately, in the early 1980s, most global corporations abandoned their own research projects aimed at building IT tools supporting the process of planning and scheduling mining production in favor of the rapidly developing commercial market. Over the last decades, we have witnessed the continuous development of mining production planning systems, and it is safe to say that it is impossible to find a mining company that does not use engineering software in some form. Particular advance in the field of deposit modeling and the use of IT tools in the mining process is visible in deep mines of precious metal ore deposits, where many companies obtained the first direct benefit from the use of these tools by reusing information that was previously considered useless. The driving force behind the advance taking place before our eyes is 3D modeling, which has recently become an extremely important tool opening new directions of development. In deep precious metal mines in southern Africa, geophysical techniques are used to conduct practical planning and management of mining production [Campbell, 1994; De Wet, 1994; Pretorius, 1987, 1994, 2003].

4.3.1. Description of the technical architecture of the system built at JSW SA

The technical architecture of the **MineScape** and **Deswik** systems is partly based on the client-server architecture. The systems are based on centrally processed databases. For both systems, the central database is a reference, not a source of transaction data for current work - this data is processed locally. The architecture diagram is shown in Fig. 4.3. The server part, in addition to the Geological Database (GDB) and data sources (*Deswik FM - Deswik File Manager, which is a Document Management System* solution), includes the Deswik license server. The entire infrastructure is subject to standard mechanisms of JSW SA IT systems, i.e. workstation security policies and archiving and high availability policies for solutions installed in the virtual environment.

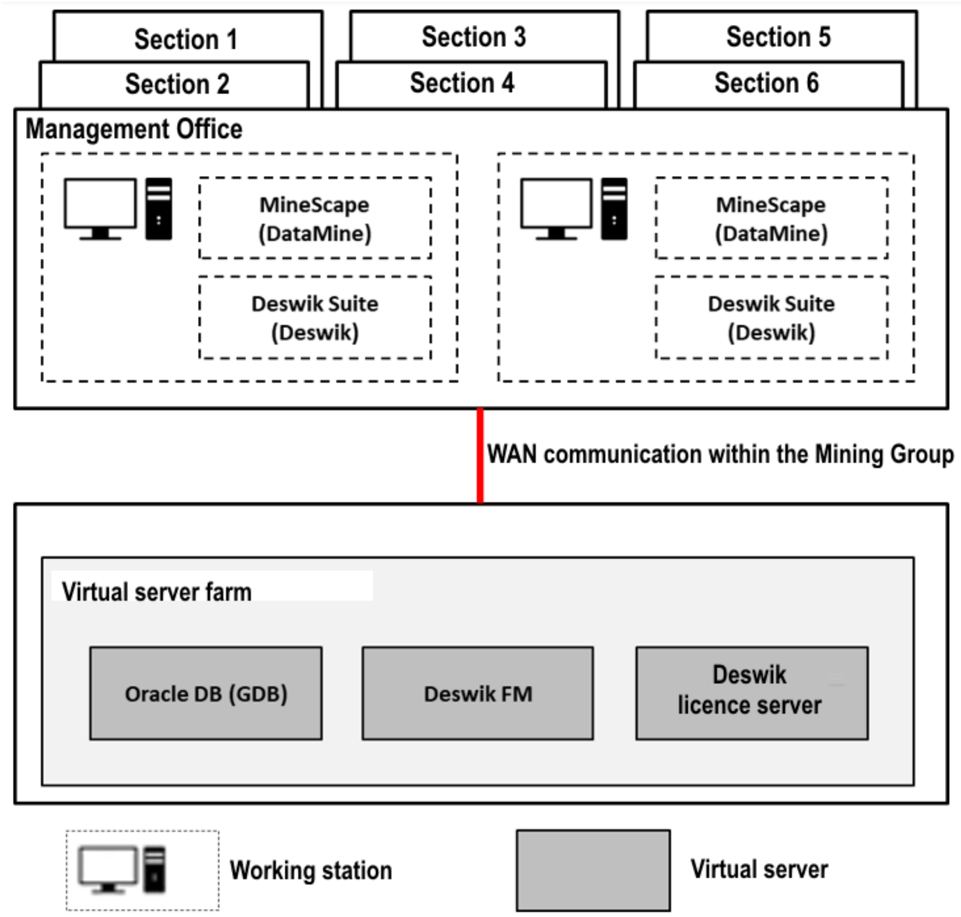

Fig. 4.3. Diagram of the physical architecture of the solution

MineScape system is characterized by a fully integrated architecture of modules enabling modeling of the geological structure of selected mining seams and quality parameters. MineScape also has the feature of a multi-user environment when working with graphical data, which allows to save changes to one file at the same time. MineScape has the ability to share projects stored on the GDB server. It is also possible to share projects stored on local drives of individual workstations, but due to security policy restrictions, this functionality has been blocked. The GDB database is created on a virtual server and the designs of individual mine sections are stored there.

Deswik system consists of five modules: the Deswik.CAD module, the Deswik.SCHED module, the Deswik.IS module, the Deswik.ADVUGC module and the Deswik.FM module. The interconnections of the modules are shown in Fig. 4.4. The connections in the figure are divided into connections related to license management (blue) and connections related to data exchange between modules (red). The role of the license server is to verify the user using individual modules in the Deswik system.

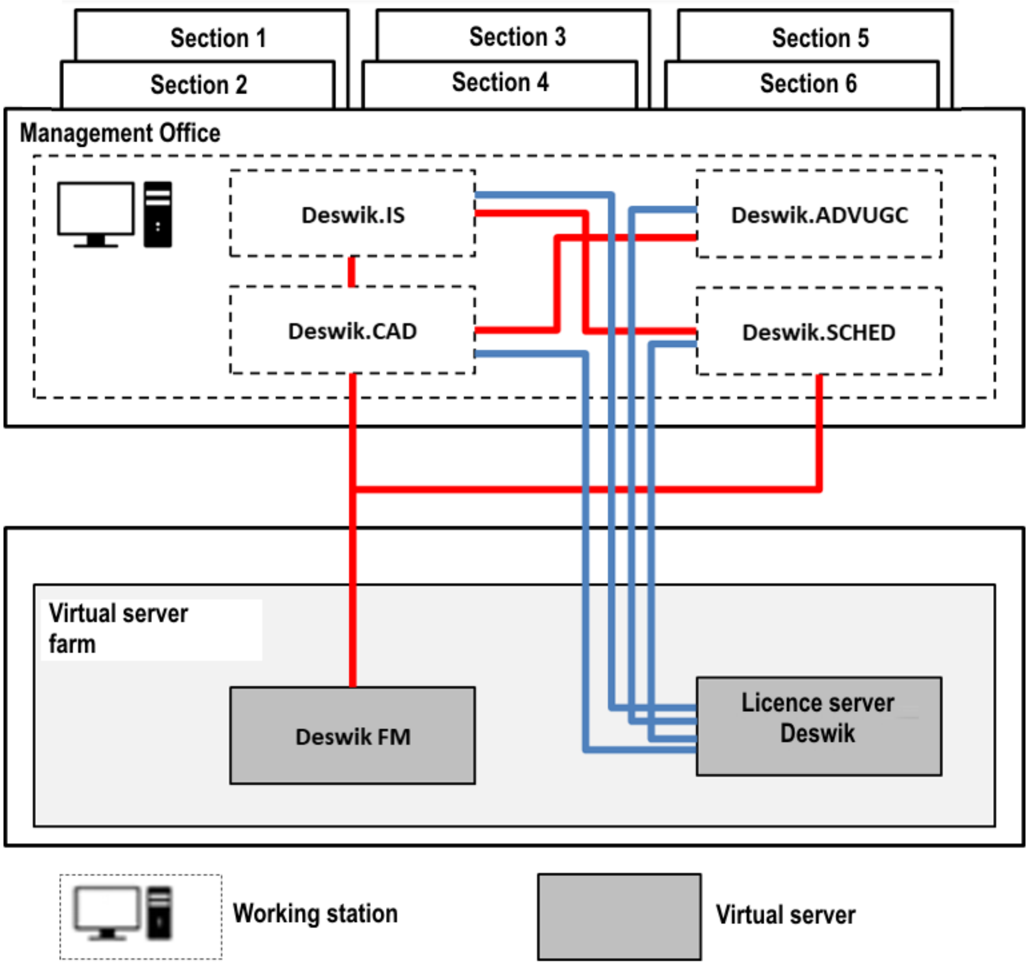

Fig. 4.4. Deswik system architecture diagram

Deswik.CAD module provides a three-dimensional design platform. Using this module, data drawn from other sources can be handled as a part of further deposit design or to make appropriate changes and edits to the seams, as well as to introduce additional attributes or metadata helpful in developing the schedule in the Deswik.SCHED module. In turn, the Deswik.SCHED module is used to create long-term schedules while maintaining dependencies and features corresponding to the individual nature of mining sections. This module sets priorities and limits related to the availability of resources used in the mining process. Deswik.SCHED is linked to the Deswik.CAD module through the Deswik.IS module, from which it downloads data about individual seams and workings. Then, based on this data, a mining schedule is designed for each individual section. The Deswik.IS module provides direct integration of the Deswik.CAD 3D design environment with the Gantt-based Deswik.Sched (as an intermediary module). This module defines complex mining processes, as well as auxiliary tasks, such as reinforcement or liquidation. The module provides feedback in the form of a visualized schedule, which is updated on an ongoing basis. The next module - Deswik.ADVUGC - is used to support design within Deswik.CAD in terms of automating the creation of design lines and assigning attributes to individual seams/excavations as part of the designed schedule for a given section.

The Deswik.FM module is integrated with Deswik.CAD and Deswik.SCHED, which store files within Deswik.FM and enable their use from the Management Office level to create collective reports on planned extraction schedules for a given period. Deswik.FM can be described as a document repository. The module is used to manage file versions and access to them within set restrictions. It also determines the current status and shows the history of selected files.

4.3.2. MineScape and Deswik system installation and configuration settings

Modern design aid packages have countless algorithms, from the simplest to the most complex. From the moment of geological work to the moment of transport of the excavated material, the integrated system of algorithms ensures the possibility of continuous calculation of deposit resources, monitoring the condition of excavations and many others, with the constant availability of a friendly graphical environment. The presence of algorithms and their complexity allows to control the time needed to achieve the intended modeling goals [Kapageridis, 2005].

Creating mining plans is a linear process. Information from boreholes and geodetic data is collected to determine the structure and conduct quality analysis of the reservoir. The collected data is then used to create a geological model of the structure and quality of the deposit and to determine its resources based on mining constraints. Mining planning uses information from geological modeling to design three-dimensional blocks of a size that allows production scheduling. The quantity and quality of minerals in individual blocks is estimated, and then - taking into account mining restrictions - a production schedule is created. Optimizing the developed schedule usually requires creating several alternative production scenarios. If the production process is efficient, integrated and linear, the amount of time needed to develop a single scenario will be reduced. Additionally, this process should be repeated when new geological information becomes available. This is to ensure that the assumptions of the created plan will reflect the current conditions in the deposit. The inaccuracy of geological models may result in errors in subsequent steps of mining planning, which in turn may result in an unexpected increase in costs and a decrease in revenues from mining activities [Wilkinson, 2010].

In case of a MineScape system implemented in JSW SA, the database server parameters are as follows:

- Operating system: Centos 7,
- CPU: 4 x 3GHz,
- RAM: 16GB.

MineScape system uses Oracle version Oracle 12c Standard Edition 12.2.0.1 and the client is OracleSE212c_12.2.0.1_x64_client. The MineScape project server is configured as follows:

- Operating system: Windows server 2012 R2,
- CPU: 2 x2.93GHz,
- RAM: 4,00GB,
- HDD: 2 x 50GB.

Version 6.0.2466 with the continuous update option (Continuous Delivery) has been installed on the project server. As part of the configuration work, the following ports were opened for the project server:

- 21554 – for MineScape Design File service,
- 24568 – for MineScape Design File Monitor service,
- 24567 – for MineScape Monitor service.

As part of the configuration of the GDB database on Oracle, one database was created for all users, divided into GDB projects for each of the sections participating in the project. The MineScape project server was launched on a virtual server and made available to all users of the MineScape system. On each of the computers used for particular section, the local disks of the workstations have a "TEMP" directory available for storing temporary files. The Oracle database and MineScape project servers have been connected to the Mining Group's corporate network, user authorization is carried out in accordance with the Group's corporate security policy and is managed by the Group's IT unit.

In the case of the Deswik system, the following parameters have been recommended for the workstation:

- Operating system: 64-bit version of Windows 7 SP1, Windows 8.1 or Windows 10,
- CPU: Quad Core 3GHz,
- RAM: 32GB,
- Video card: 2GB Video Card,
- .NET Framework: 4.6.x or higher,
- Visual C++ libraries:
  - 2010, 64-bit, version 10.0.30319 or higher,
  - 2012, 64-bit, version 11.0.61030 or higher,
  - 2013, 64-bit, version 12.0.21005 or higher,
  - 2015, 64-bit, version 14.0.23026 or higher.

Moreover, for communication with the Deswik.FM server it is necessary to provide a gigabit network, and the file server should use fast drives (SAS or SSD). The requirements for the license server are as follows:

- Operating system: Windows 2012 R2 Server or higher (64-bit only),
- CPU: Dual Core 2.5GHz,
- RAM: 2GB,
- .NET Framework: 4.6.x or higher.

4.4. Integration of the JSW production line management system with the Group's business systems

Currently, mining design programs are becoming more and more dynamic both in terms of modeling and visualization. It is nothing extraordinary to simulate, for example, the movement of mining machines, during which a series of optimized (motion-related) patterns is followed. These diagrams combined in a 3D environment and visualized in appropriate time synchronization give an almost real picture of the mineral extraction process. The toolkit is used to freely move objects in various ways, making the program environment fully interactive [Kapageridis, 2005].

Geological and mining software, taking advantage of the dynamic development of information technologies, is subject to changes typical for the entire industry, which in relation to the area of applications in the mining industry means the following trends:

- concentration of the potential of companies providing software for the mining industry,
- expanding the scope of activities covered by computer support – developing new algorithms for modeling and optimizing selected processes, implementing new IT technologies, creating new IT tools,
- integration of the proposed solutions - replacing tools supporting "isle" processes with comprehensive solutions supporting documentation, analysis and optimization of the entire value creation chain in a mining company,
- avalanche growth of increasingly diverse data collected and processed in specialized, dedicated programs,
- construction of IT environments aiming to manage the processing of specialized data to ensure the smoothness and security of digital computer support at the scale of the mining corporation served.

Production management in a mine, as in any enterprise, is in fact a continuous decision-making process in which emerging problems are resolved [Dyczko, 2009].

In the conditions of a mine and the management of the mining process, the phase of preparing the decision to start mining is crucial for its rationality and accuracy. It means collecting the necessary information about the nature of the selected deposit, factors limiting the exploitation, the cost side of the technological process being implemented. In other words, the entire information process must be subject to INTEGRATION.

4.4.1. Integration of the MineScape system with the IT infrastructure of the JSW Group

One of the stages of implementing the MineScape system was its integration with the IT systems operating in the Mining Group. The system had to be integrated with three systems: Geolisp, ArchiDeMeS and Deswik.

A dedicated *Menu function was created* in the **Geolisp program**, enabling the dumping of information from heading profiles and selected longwall profiles necessary for building a stratigraphic model in MineScape. This function allows to export the necessary data in the form of two .csv files (coordinates and lithology) in a fixed format that enables to load this data into the GDB database tables (Borehole Coordinates and Lithology and Stratigraphy, respectively). When loaded into the GDB database, data are subject to standard verification processes and are treated as boreholes in the database. The remaining required data (e.g. 3D topography isolines, 3D geodetic points, fault traces, thin-outs, splits, washout zones, etc.) are imported using standard mechanisms, previewing and/or importing data from the AutoCAD format. The MineScape system exports data to the Geolisp system also via the AutoCAD format. This applies to data that are derived from the model and are required for visualization purposes in seam and level maps. These include, among others: isolines of the roof, floor and thickness, as well as traces of modeled faults.

With regard to **ArchiDeMeS, it should be emphasized that the current practice in the Group's mines consisted in manually entering analysis results, received in paper or electronic form (using e-mail), into an MS Excel file, or in exporting data from the ArchiDeMeS program to a text file** and further processing to obtain the desired data format. The GDB database is the target repository of data from coal quality analyses verified and approved by geologists. A validation dictionary was also created, the purpose of which was the final verification of the values of quality parameters.

Therefore, the procedure, including the use of the ArchiDeMeS database, consisted of the following steps:

- providing by company Y an SQL script that unloads the indicated data from the database structure into a text file with a defined format,
- loading data into XLS format,
- checking and approval of the resulting data by a geologist,
- loading qualitative data into GDB.

Due to the high degree of complexity of the procedure and the emerging data redundancy between the ArchiDeMeS and MineScape (GDB) systems, it was necessary to switch the method of storing qualitative geological data (borehole information, furrow tests, underground observations) to the GDB system. The processing of quality data obtained for the geological model in consultation with the research laboratory was simplified by integrating of the MineScape system with the LIMS (*Laboratory Information Management System)* class system supporting the quality management processes of deposit and product testing, laboratory operation and distribution of deposit and product testing results in the Mining Group.

Deswik system has an interface that allows to import data from the geological model of the MineScape system. With the update of the MineScape software, it is possible to export the model to the format indicated by Deswik (GoCAD), which ensures the transfer of data from the MineScape geological model directly to the Deswik format (data required by the Group on the structure and quality of the deposit). In terms of model data, for the purposes of design and operation scheduling, the MineScape system enables the preparation and sharing of a stratigraphic model in the standard MineScape - Stratmodel format.

4.4.2. Integration of the Deswik system with the IT infrastructure of the JSW Group

In the Table 4.1. it was presented, to which systems the Deswik production scheduling system had to be integrated. In addition to the list of systems, the table below contains business areas (covered by a given integration), target software (integrated with Deswik software) and a description of activities in the scope of individual integrations.

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Deswik software integration

Table 4.1.

Business area	Software	Description of activities within the Deswik integration
Production planning	THPR	• configuring the schedule report to match the required inputs, • examining the option of direct import into the THPR system, • determining the requirements regarding the process and preparing data for importing current production results from external sources (such as the SZYK database or measurement data),
Geology	MineScape	n/a
Surveying, geology	AutoCAD	• development of a process map for importing geological and surveying data from existing AutoCAD files, • developing a process map for exporting drawings with mining projects to existing AutoCAD files,
	Subsidence	• configuring the schedule report to match the required inputs, • configuration of the Deswik.CAD report for exporting design coordinates of longwall workings (blocks),
Control	Hyperion	• configuring the schedule report to match the required inputs,
Ventilation	Aero	• configuring the schedule report to match the required inputs, • examining the results of importing ventilation modelling for display in software,
Geophysics	Hestia	• configuring the schedule report to match the required inputs, • examining the results of importing rock burst occurrence points for display in software.

The presented technical architecture of the developed solution is supported by two systems – MineScape, used for deposit modeling, and Deswik, enabling production planning and scheduling in a multi-plant mining enterprise.

The developed IT architecture allowed for the real implementation of a system for managing and planning mining production at JSW SA.

In the developed data model, the system is based on two sources - the Geological Database (GDB) and Deswik FM. The physical architecture presents a simplified client-server model in which there are no complicated interfaces due to the low level of transaction activity. The entire solution is based on software installed on workstations and the server part providing access to data (application logic is implemented by client software).

The presented architecture is simple and accessible to users, and has been successfully implemented in all mines of the JSW Group.

Designing mining and preparatory excavations in 3D space, based on a geological model of the deposit describing both its structure and quality, has been carried out at JSW SA for three years. The created operating variants are analyzed in any time period due to the possibility of selecting any work calendar. It can be, for example, a monthly calendar divided into days, an annual calendar divided into months, but also a daily calendar, a five-year calendar, a twenty-year calendar, until the mine resources are exhausted. Due to the constant updates of information in the database and the possibility of its quick use and modification, the design process (both in the case of access, development and operational activities) is improved and accelerated many times compared to traditional methods, enabling:

- planning (short- and long-term) operation and technical design,
- designing access, development and operational activities,
- execution of the schedule of planned works.

The built model allows automatic calculation of the quantity and quality of excavated material and waste rock in selected time intervals, and after completing the simulation, a forecast is automatically generated for all parameters related to the extraction project, such as: quantity of excavated material, amount of waste rock, quality parameters, etc.

4.5. The current and target state of the production line management system, based on demand and the quality of the production process

The analysis of the current state of quality management in JSW SA allowed to draw the conclusion that in practice the potential of IT systems was used to a small extent. Most activities related to production management and scheduling were performed in a non-standardized manner, often using spreadsheets, without the possibility of automatic data exchange, at the level of individual mining plants of the Group. Planning was carried out in a manual and decentralized manner, with data aggregation taking place only at the very end of the process. This made it impossible to conduct this process quickly and to respond to changing market conditions or the macroeconomic environment on an ongoing basis. With such a process, it was impossible to create scenarios to select the most effective solution [Kopacz, 2018; Dyczko, 2021].

Currently, quality data at JSW SA is processed in many systems. The group has, among others, data on resources, production plans and quality plans, parameters controlling production processes affecting product quality, readings from production and production quality monitoring systems, and the results of quality tests. In many cases, this data were not recorded and archived in an organized or systematic way. They were also not unified or synchronized. It should be emphasized that quality data come from different sources and have different nature, recording frequency (unit readings or continuous readings) and a non-unified data model (planning data, data from unit readings, data from continuous readings, data parameters controlling production processes, data of contracts, results of quality tests, etc.).

Therefore, **there were grounds for building an appropriate management system in the JSW Capital Group,** which would allow, among others, for building a coherent data model, centralization, comprehensive computerization of the deposit and product quality management processes, orchestration of the quality data acquisition and analysis process. This would translate directly into an increase in the quality and efficiency of qualitative research and its accompanying processes, such as collecting, storing, processing, sharing data, etc. in the full production cycle.

Currently, only some of the elements of the Management System based on demand and quality have been implemented, work is still ongoing on the practical and effective implementation of the remaining parts of the system. This **chapter describes the current and target state of SPPJ**.

The basic principle of running a business should be based on reactions to the changing market environment, especially in times of major economic fluctuations. The desire to introduce changes and the desire to catch up with the market may result in downplaying the issue of preparing appropriate corporate architecture and IT architecture. JSW SA, striving to prepare a lasting foundation for its operations, developed not only an operational model specifying general requirements for the integration and standardization of individual business units, but also a corporate architecture design including, among others: quality management process, which is correlated with the planned directions of development [Kopacz, 2019; Dyczko, 2021, 2022b].

This architecture indicates key processes for the company's operations and data integrating the main forms of activity, which allowed the foundation of the business to be digitized, thus treating the management system based on demand and quality as the basic element of management.

The management system based on demand and quality covers the following key business areas implemented in the Capital Group:

- quality management area,
- planning and scheduling area,
- coal mining and processing area,
- coke production area,
- trade and logistics area (coal and coke).

In all the business areas defined above, the prepared SPPJ architecture concept adopts a uniform approach to defining the system architecture, based on the following components:

- source data (e.g. samples, sensors, scales, analyzers),
- business process support systems,
- integration,
- Central Quality Management System,

– data repository,
– analysis and reporting (Business Intelligence).

The proposed SPPJ architecture assumes the use of data from currently applied IT systems supporting key operational processes, primarily ERP systems and systems containing data on resources (3D Deposit Model System) integrated with the production planning and scheduling system (Production Planning System), as well as implemented systems for monitoring of production processes, and their full integration is planned to be performed using microservices.

Additionally, full integration with the currently implemented system for comprehensive support for laboratory processes in quality testing is assumed, both for solid fuels (coal), coke, and other elements subject to quality testing processes (LIMS System - Laboratory Information Management System). The developed concept of SPPJ architecture [Kicki, 2011; Dyczko, 2021] assumed that it would be necessary to prepare, implement and integrate the following additional components in individual business areas - presented in Table 4.2.

Components in individual business areas

Table 4.2.

Area	Component
Quality management	Quality Integrator
	Central Repository of Qualitative Data (CRDJ)
Planning and scheduling	Production Planning Integrator
	Central Repository of Planning Data
Coal mining and processing Coke production	Production Data Integrator
Trade and logistics (coal and coke)	Trade and Logistics Data Integrator
	Warehouse Quality Map

The aim of implementing SPPJ is to effectively manage production processes in the JSW Group, including the quality of the product in the form of coking coal and coke, which will translate into maximizing the margin obtained from the sale of products and reducing operating costs related to the optimization of production processes for products of the required quality level. In Fig. 4.5 a map of the SPPJ architecture layers is presented along with marked components in business areas [Dyczko, 2020, 2021, 2022a].

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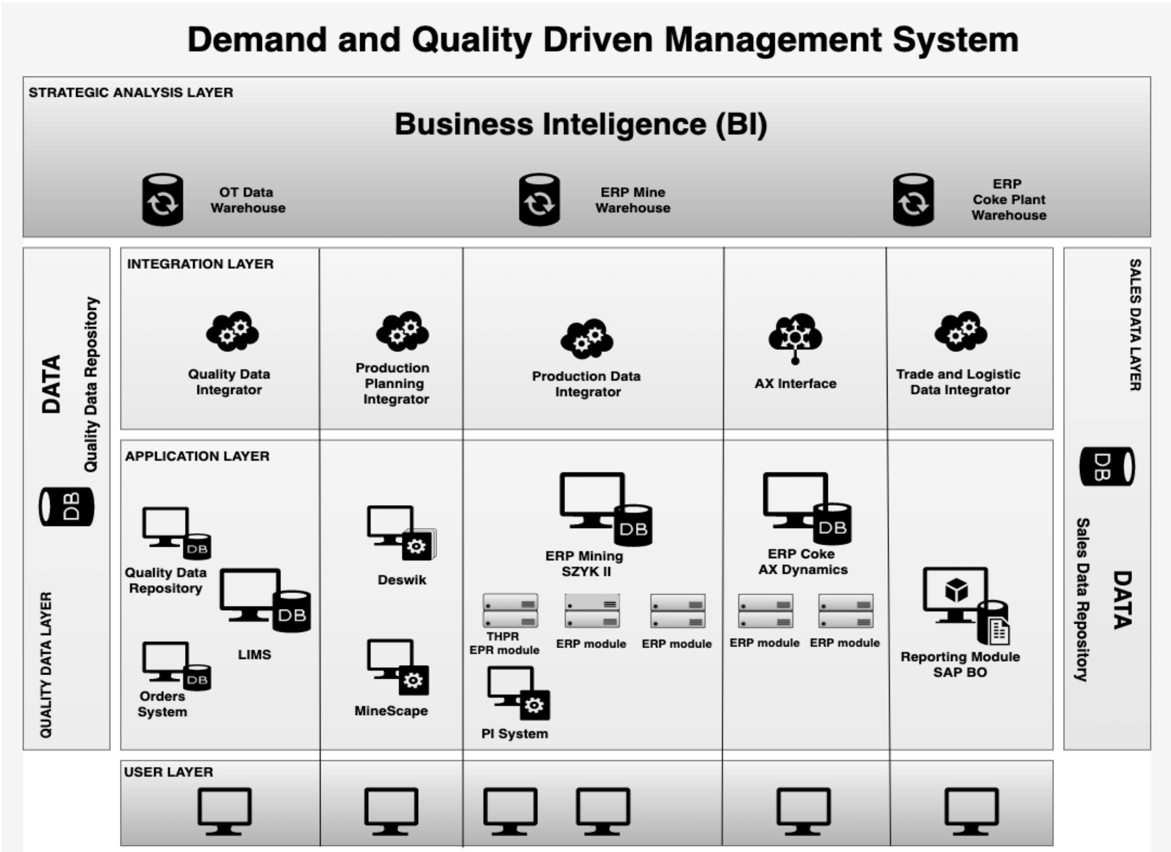

Fig. 4.5. Map of SPPJ architecture layers with components - target state

It was assumed that SPPJ will be used primarily by the management and employees of the Quality Office, Production Office and Trade Office, as well as by employees of other operational offices responsible for supporting planning processes and production management from the point of view of its quality [Dyczko, 2021, 2022a].

4.6. Construction of the architecture of the JSW Capital Group's production management system based on demand and quality using the service-oriented architecture (SOA) paradigm

In recent years, changes in software architecture have tried to keep up with the rapidly increasing level of complexity of IT systems. However, due to the pace of this growth, traditional patterns were unable to cope with current challenges. There is a need to quickly respond to new business requirements, expectations for further reduction of IT costs and, above all, the needs related to rapid integration and absorption of new business areas [Erickson, 2009]. Service-oriented architecture emerged as a new architectural solution [Perrey, 2003] separating the application layer from the user of network services. This solution enables easy integration of the functionality of various systems without making major changes to these systems. Due to its flexibility, this approach has been widely recognized by many scientists and practitioners as appropriate for implementation in organizations [Niknejad, 2018]. However, during its development, this architecture was repeatedly criticized due to doubts about its real value [Dorman, 2007].

Service-oriented architecture introduces the concept of integrating various systems using separate services and dividing application functionality into services. The main characteristics of the services include [Erl, 2014]:

– service interface - contains information about communication rules, input and output data and methods provided by a given network service,
– description of the service - contains only basic information about the service, apart from the provided contract. It completely hides how a given functionality is implemented,
– usage logic - services contain divided logic among themselves, when the logic is divided, the created functionality can be easily reused,
– autonomy - each service is autonomous, and the service's responsibility is limited to the functionality it provides,
– stateless - minimizes resource use by not storing information about the client or previously performed operations,
– discoverability - services created for use in distributed systems are supplemented with metadata with which they can be effectively detected and interpreted,
– composition - they can consist of several functionalities implemented by other services, i.e. create complex services that divide the task among themselves.

It is clear from existing definitions and models that service-oriented architecture is commonly viewed as the architecture or way of building and orchestrating an organization's information infrastructure. As such, SOA is not a technology in itself: rather, it is a way to organize the flow of data or integrate other technologies to perform a number of other tasks. This naturally leads to the problem of multiple SOA definitions, as many relatively similar service structures are possible. Many definitions of SOA also indicate that the arrangement and relationships between services should be loosely coupled rather than tightly. This allows services to be tailored to your needs and implemented on demand, without the need of building a predetermined structure.

The analysis of research conducted in the field of mining data processing has shown that there are limitations (barriers) in data exchange related to the client-server architecture, so far commonly used in the Polish mining industry. The solution to this problem was the use of SOA architecture, which improves data integration processes [Kosydor, 2020].

Software development methods are constantly changing, including changing the architectural paradigm. These changes have been made in part to help cope with higher levels of software complexity and in part to enable rapid and painless integration of applications using parts, components or services.

Service-oriented architecture enables the design of systems that provide services to other applications through published and discoverable interfaces, and a space where these services can be invoked over the network. An application of a service-oriented architecture using network technologies and services means taking advantage of a way of building applications that allows reducing maintenance and development costs as well as mitigating implementation risks [Service Oriented Architecture (SOA) A New Paradigm to Implement Dynamic E-business Solution].

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One of the components of SOA is the service registry. The use of SOA technology in a closed enterprise network architecture limits the use of developing SOA solutions such as service discoverability in favor of using the Registry of services already defined by the entrepreneur in the central Service Registry or distributed in service registries in individual departments of the consortium [Endrei, 2004].

4.7. Quality management area – functional assumptions

The quality management area includes the following components, the first two of which are currently operational:

- LIMS (Laboratory Information Management System), i.e. the central system supporting qualitative research processes,
- Central Registry of Quality Orders (CRZJ),
- Quality Integrator – understood as an integration layer/set of interfaces connecting the new LIMS system with other elements of the IT/OT architecture in the Capital Group,
- Central Repository of Qualitative Data (CRDJ).

The target architecture of the integrated components will allow for full digitalization and orchestration of the data transfer process, both when ordering the qualitative tests and when returning the obtained test results.

4.7.1. LIMS - Laboratory Information Management System

The LIMS system is a new system that comprehensively supports the work of the JSW Group laboratory. It supports the registration, entry, archiving of laboratory results and their analysis.

The scope of implementation includes the digitization of laboratory service processes in the administrative area and supporting processes, as well as integration with measuring devices. The system will ultimately be used to manage laboratory work and all types of qualitative tests performed in the main laboratory.

Qualitative research is to be conducted in the following laboratories:

- solid fuel laboratory,
- gas and dust sampling laboratory,
- coke laboratory,
- environmental protection and work environment laboratory,
- microbiological and genetic laboratory.

The LIMS system is intended to replace the currently used IT system, which in its current functional scope is only used to support qualitative tests of coal samples.

4.7.2. Central Register of Quality Orders

The reason for building the Central Register of Quality Orders was the fact that the JSW Group currently does not have a unified process for preparing and monitoring quality test orders. The processes of preparing orders, ordering tests and processing test results are often manual or semi-automatic. Test results for coal samples are recorded electronically in the laboratory system and transferred directly, electronically, from the IT system to the analytical and reporting system. For other types of qualitative samples, test results are transferred manually via batch files. There is also no unified model for assigning unique identifiers to various types of quality samples, except for coal samples, for which unique identifiers are assigned in the appropriate module of the ERP system. For other types, no unified method of assigning identifiers is often used. The scope of operation of the Central Register of Quality Orders includes:

- covering all types of qualitative samples, i.e. coal, gas, dust, working environment, coke samples, etc.,
- ensuring automatic two-way integration between CRZJ and the LIMS system, ensuring the possibility of eliminating paper document circulation,
- ensuring the possibility of parameterization and management of Registers, Dictionaries, Catalogs of qualitative research (e.g. by sample types and functional groups of research) with the ability to automate the selection of necessary parameters when generating an order,
- ensuring the possibility of presenting operational and cost parameters related to ordering tests for various types and scopes of quality tests,
- ensuring the ability to generate unique numbering of qualitative samples (when creating a qualitative test order) and sample identifier,
- ensuring integration with marking systems / assigning samples, e.g. barcodes / QR codes, to increase work efficiency and control over the completeness of samples and quality tests performed,
- ensuring online monitoring of the order status, fulfillment of sample criteria, test implementation status and expected test completion date,
- ensuring integration with CRDJ.

4.7.3. Integrator of the Qualitative Data area

The Quality Integrator is responsible for ensuring automatic integration of all input and output data to/from the LIMS system. The implementation and integration of a LIMS solution is intended to ensure full implementation of the electronic flow of data regarding the sample and qualitative testing: from generating and registering the order, through the processes of performing qualitative testing, to preparing and sharing a report with test results. A quality integrator is understood as a set of interfaces connecting individual elements of the quality management system architecture. The key supported processes and main functional requirements include:

- preparation and implementation of a uniform data model for the quality area,
- covering all types of qualitative samples, i.e. coal, gas, dust, working environment, coke samples, etc.,
- ensuring automatic integration of all input and output data to/from the LIMS system,
- covering the scope of integration of all customer service processes in the areas of: Price Lists and Quoting, Management of Contract Parameters, Customer Monitoring, Complaints,

- elimination of paper document circulation between units in the Capital Group in the full scope of sample circulation (orders, sampling, marking and sample coding, sample registry, status preview, approval of test results and authorization, test reports, etc.),
- ensuring integration in the exchange of data from Registers, Dictionaries, Research Catalogs,
- ensuring integration enabling the use and transmission of unique numbering of quality samples,
- ensuring integration with generation and marking systems (including assigning samples, e.g. barcodes /QR codes and reading them) in order to increase work efficiency and control over the completeness of samples and quality tests performed,
- ensuring online monitoring of the order status, fulfillment of sample criteria, test implementation status and expected test completion date,
- exchange of information about the test status of a given sample, activities on the sample and sample test results between all systems,
- ensuring access to sample test results immediately after the test is performed,
- ensuring automatic transfer and storage of data on tests performed and results obtained in the Central Repository of Qualitaty Data,
- ensuring integration and automatic transfer and storage of data on tests performed and results obtained to the Central Repository of Quality Data, the Central Quality Management System and the analytical and reporting system.

4.7.4. Central Repository of Qualitative Data

The Central Repository of Qualitative Data (CRDJ) is to be the place where qualitative data will be sent and then collected. The main task of the CRDJ will be to collect and store individual types of data in a unified repository and synchronize them with other operational and quality data. CRDJ will feed the Central Quality Management System and/or the analytical and reporting system as a basic and uniform source of quality data.

The functional scope of CRDJ includes:

- covering the scope of data processing of all types of data collected in the full range of so-called processes "from the deposit to the sea", i.e. in the areas of quality management, production planning and scheduling, monitoring of coal and coke production processes as well as commercial and logistics processes,
- ultimately: collecting and processing data not only for planning and monitoring, but also for controlling and optimizing production processes,
- ensuring data supply from individual functional areas, i.e. Quality Integrator, Production Planning Integrator, Production Data Integrator (both for coal and coke production), Trade and Logistics Data Integrator (both for coal and coke),
- ensuring integration with the Central Quality Management System and/or the analytical and reporting system as a uniform data source,
- the possibility of adopting a hybrid service-oriented architecture, using as components technological solutions currently used in the Group (SAP Business Objects/MS Reporting Services/PI Systems), integrating them using microservices,

- orchestration of integration between CRZJ and the LIMS system, ensuring the possibility of eliminating paper document circulation in the full scope of sample circulation while maintaining the possibility of displaying/printing prepared orders, marking and sample coding, sample register, status preview, etc.

4.8. Scope of required integration of the production line management system based on demand and quality of the production process

The most important task for effective enterprise architecture is the definition of processes, data, technologies and interfaces (also for users), so that all key resources and their complements are optimally used. In order to prepare the target system architecture, a Master Data Model was implemented as a link between the business and technical layers, due to which a uniform approach to data and related processes was achieved, treating it as an element of a broader data management strategy. The master data model ensures consistent data from each key business area of the company, eliminates the creation of duplicates and guarantees the availability of critical data, while ensuring easy integration with data warehouses, analytical systems and transaction systems. In order to achieve specific data orchestration, a model of the required integration and data flow between key processes was prepared, i.e.:

- exploration of the deposit,
- coal mining,
- coal processing,
- coal sales,
- coke production,
- coke sales.

In order to illustrate the processes that the system must perform, as well as to organize data exchange between individual components, a data flow and integration diagram was prepared (Fig. 4.6). This allows you to illustrate the network of connections between individual system components and their functions.

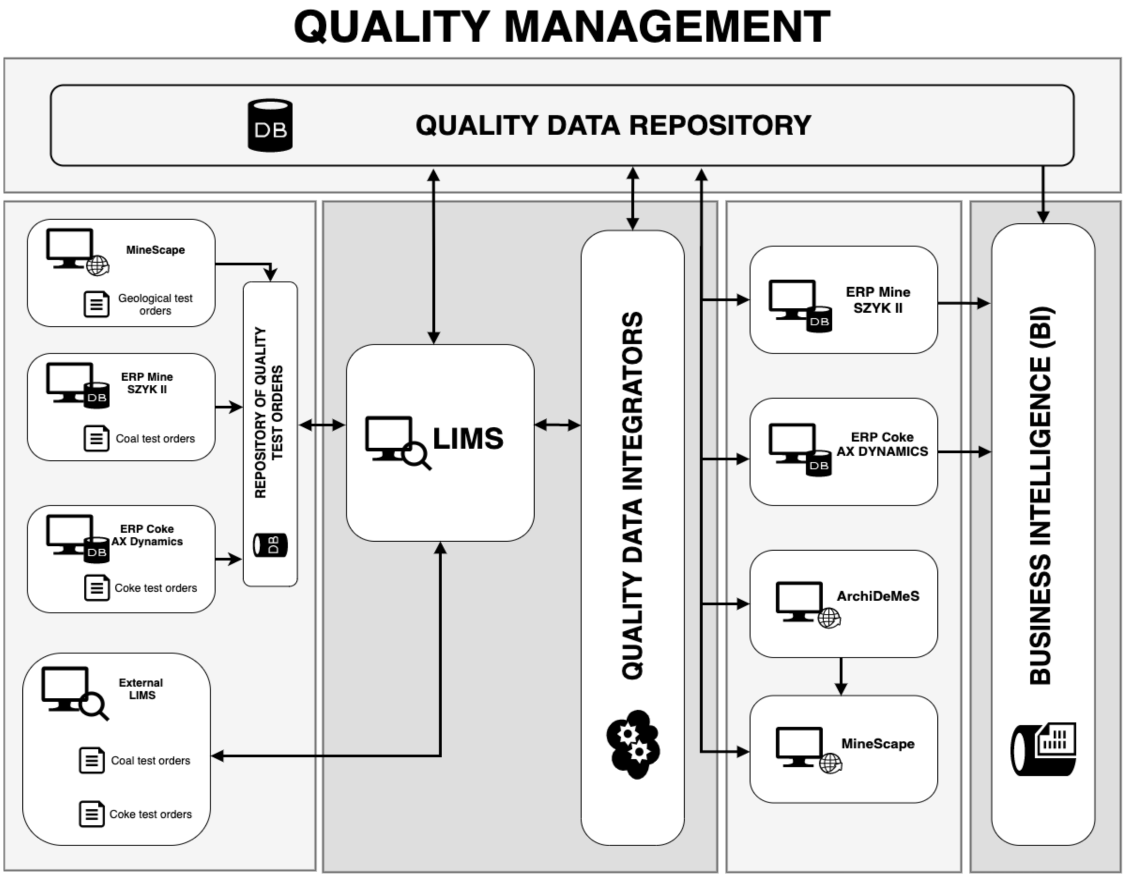

Fig. 4.6. Scope of required integrations in the area of quality management

Due to the adopted master data model, it was necessary to define the scope of required integrations in the area of quality management between individual system components. The definition of requirements concerned the indication of the source component for data, data processing components and the scope of their use. Due to this approach, data entered in one component system is available in all connected components, so there is no need to duplicate them, and it also enables simultaneous use of data. The described action also ensures data consistency, which reduces the risk of errors and duplicates. Well-designed integration facilitates access to individual system components because SSO (Single Sign On) technology can be used, due to which the user after logging in to any of the system components can have access to the entire system. The key interfaces between the elements of the SPPJ architecture in the area of quality management, required for design and implementation, are presented in Table 4.3.

Scope of required integrations in the area of quality management

Table 4.3.

Component 1	Component 2	Component 3	Description
Central Register of Quality Orders	Quality Integrator	LIMS system	Qualitative research orders
LIMS system	Quality Integrator	*3D Deposit Maps, Production Planning System*	Deposit test results for geological tests
LIMS system	Quality Integrator	ERP	Test results of coal production samples
LIMS system	Quality Integrator	ERP	Test results of coke production samples
LIMS system	Quality Integrator	Central Repository of Qualitative Data	Data on qualitative test orders and obtained test results
LIMS system	Quality Integrator	Central Quality Management System	Complete data on resource, production and product quality management
Central Repository of Qualitative Data	Central Quality Management System	SAP Business Object	Statistics and reporting of the quality management process in the Capital Group
Central Repository of Qualitative Data	Central Quality Management System	MS Reporting Services	Statistics and reporting of the quality management process in the Capital Group

It was assumed that within the **planning and scheduling area** it is justified to implement the following two components: Production Planning Integrator and the Central Planning Data Repository. The target architecture of the components will enable the integration of production planning and mining work scheduling processes, assuming the possibility of dynamic updating of plans, simulations and creation of many variants with the creation of current Quality Plans, based on the same data source - based on a geological model of the deposit, describing the structural and qualitative features of extracted minerals, maintained in the 3D Deposit Map system and the Production Planning system. This approach will also eliminate the duality of entering identical data between the Production Planning system and the ERP system module in the Group.

In **the area of coal mining and processing and coke production,** a Production Data Integrator was developed to ensure automatic integration of all data collected from infrastructure sensors and IT/OT systems in the production processes: mining, processing and

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coking. In order to enable proactive planning of supply quality and product quality management in trade and logistics processes, the assumption was made to implement the following SPPJ architecture components **in the area of trade and logistics (coal and coke**): Trade and Logistics Data Integrator and Warehouse Quality Map. Such solutions will allow for appropriate balancing and management of product streams adequate to the quality requirements of a given recipient - on the one hand flowing continuously from the Processing Plants, and on the other hand from the Warehouses (heaps).

4.9. Implementation of individual components of the production line management system based on demand and the quality of the production process

The implementation of SPPJ at JSW SA requires huge outlays and the involvement of many resources. It is a long-term, very complicated process in organizational, financial and technical terms, requiring the involvement of both the management, employees and stakeholders of the JSW Group. Due to the very wide scope of implementation, this monograph shows one of its stages - namely, determining priorities for the implementation of individual components.

The MoSCoW prioritization method was used in the research, which involves hierarchizing the required functionalities so as to implement first those that will bring the greatest business benefits. It is often used in management, business analysis, project management, as well as in software development processes.

MoSCoW itself comes from the first letters of the four priority categories described in A Guide to the Business Analysis Body of Knowledge:

- M – MUST: an essential requirement that must be met in the final solution, is often treated as a criterion for implementation success,
- S – SHOULD: high priority requirement, but not necessary to be delivered in the first stage of implementation,
- C – COULD: desired requirement, implemented if time and resources permit,
- W – WON'T: a requirement that will not be implemented in a given implementation, but may be considered in the future.

The analysis began with an inventory of all systems in the planned implementation area, while identifying overlapping functionalities or gaps in the coverage of business processes with IT systems. This allowed to limit the number of systems used and support the creation of a master data model. Then, the leaders of individual areas were identified, including: coal production, deposit exploration and quality management. Based on surveys, interviews and workshops conducted with leaders, the target areas of the system were identified, as well as key activities to be implemented. The following classes of priorities for implementing individual architecture components were adopted in the research:

- **urgent priority** (must) - a component necessary for implementation in connection with other implementation projects currently underway or critical from the point of view of the quality and availability of information used for quality management processes.

The component must be implemented and integrated independently of other elements to enable automation of key processes.

- **high priority** (should) – a component important from the point of view of processing key information in quality management processes. The component should be implemented to improve processes and improve the quality of information.
- **medium priority** (could) – a component whose implementation complements and improves the SPPJ architecture. The decision to implement the component may be postponed to a later period in case of budget constraints or lack of organizational or implementation capabilities.

Due to the wide scope of the project, the necessary involvement of key employees, and high costs, the definition of low priority components was abandoned. The final prioritization was agreed with stakeholders as part of the implementation of the "Quality Program", taking into account the following factors:

- criticality for achieving the assumed goal, i.e. the ability to manage the enterprise based on planning in accordance with demand and product quality,
- costs of implementing individual activities launching expected functionalities,
- time needed for implementation,
- the state of advancement of projects already launched that have an impact on or are part of the system.

The adopted analysis method indicated a number of requirements of urgent priority, and the lack of a clear, standardized justification did not allow for ranking the activities currently indicated for implementation first. Therefore, it was decided to indicate the critical path for the implementation of the system enabling the launch of the full quality management process. Table 4.4 presents a list of activities for the implementation of a given component in individual business areas and the corresponding priority.

Results of prioritizing the implementation of individual components

Table 4.4.

Area	Action on a given component	Priority	Critical path
Quality management area	Implementation of the LIMS System;	Urgent	YES
	Ensuring integration within the Quality Integrator (LIMS – Quality Integrator – SPPJ – SAP BO);	Urgent	YES
	Implementation of the Central Register of Quality Orders;	Urgent	
	Construction and implementation of the Central Repository of Qualitative Data (CRDJ);	High	YES
	Implementation of SPPJ in the field of Quality Management, in the form of analytical and reporting functionality;	Urgent	

Planning and scheduling area	Implementation of the Production Planning Integrator between the Production Planning system and ERP; enabling the generation of Production Plans based on data from the Production Planning system;	Urgent	YES
	Construction of the Central Repository of Planning Data (CRDP);	High	
	Implementation of SPPJ in the field of Planning and Scheduling, enabling automatic generation of Quality Plans in SPPJ based on data from the Production Planning system, in the form of analytical and reporting functionality;	Urgent	
	Construction of the Resource Planning module outside the ERP system and changes in the Production Resources Planning module;	Medium	
Area of coal mining and processing and coke production	Implementation and launch of automatic scales and analyzers at key points in the coal production line;	High	
	Implementation and launch of automatic scales and analyzers at key points in the coke production line;	Medium	YES
	Expansion of the Central Repository of Quality Data to include the area of monitoring production processes and production balancing;	Urgent	
	Implementation of SPPJ in the area of coal mining and processing and coke production, in the form of analytical and reporting functionality;	Urgent	
Trade and logistics area	Implementation and launch of automatic sampling plants and analyzers in the area of coal trade and logistics;	High	
	Implementation and launch of automatic sampling plants and analyzers in the area of coke trade and logistics;	Medium	
	Implementation of the Warehouse Quality Maps functionality;	High	
	Ensuring integration within the Trade Data Integrator and coal logistics;	Medium	
	Ensuring integration within the Trade Data Integrator and coke logistics;	Medium	
	Expansion of the Central Repository of Quality Data to include the area of Trade and Logistics;	Urgent	
	Implementation of SPPJ in the area of Trade and logistics, in the form of analytical and reporting functionality.	Urgent	

4.10. The use of parameterized interpolators in modeling the geometry of coal deposits and the distribution of quality parameters implemented in the JSW system

Data for the MineScape system come from both tests of drill cores in surface boreholes, but also from tests performed in mining excavations. Geology departments of mines conduct ongoing sampling in accordance with internal regulations and the guidelines of the Polish standard PN-G-04501:1998. Rig samples are taken from headings and core samples from drill boreholes. The sampling grid is designed so that the obtained qualitative information presents the most accurate distribution of quality parameters in exploitation fields [Sosnowski, 2021]. Data from the analyses are collected in the GDB geological database (Table 4.5).

Coal quality parameters collected in a geological database

Table 4.5.

Unit name	**Symbol**	**Unit measures**
moisture	W^a	[%]
ash content/air-dry condition	A^a	[%]
volatile matter content/air-dry state	V^a	[%]
sintering ability according to Rogi	RI	-
coal swelling indicator	SI	-
contraction	a	[%]
dilatation	b	[%]
total sulfur content	S_t^a	[%]
phosphorus content	P^a	[%]
chlorine content	Cl^a	[%]
calorific value	Q_i^a	[kJ/kg]
ash content/dry state	A^d	[%]
total sulfur content	S_t^d	[%]
volatile parts content	V^{daf}	[%]
coal type		-
current density	d_r^a	[g/cm^3]
apparent density	d_a^a	[g/cm^3]
coke reactivity index towards carbon dioxide	CRI	[%]
coke strength index by reactivity	CSR	[%]
random reflectivity of vitrinite	R_o	[%]
vitrinite content	V_t	[%vol]
liptinite content	L	[%vol]
inertinite content	I	[%vol]
mineral content	M	[%vol]

The database is loaded with data stored in the ArchiDeMes system, originating primarily from analyses performed by CLP-B (central laboratory) (Fig. 4.7). When loaded into GDB, this data are verified according to user-defined rules. The collected information on coal quality is assigned to appropriate deposits found in geological holes or mining excavation profiling.

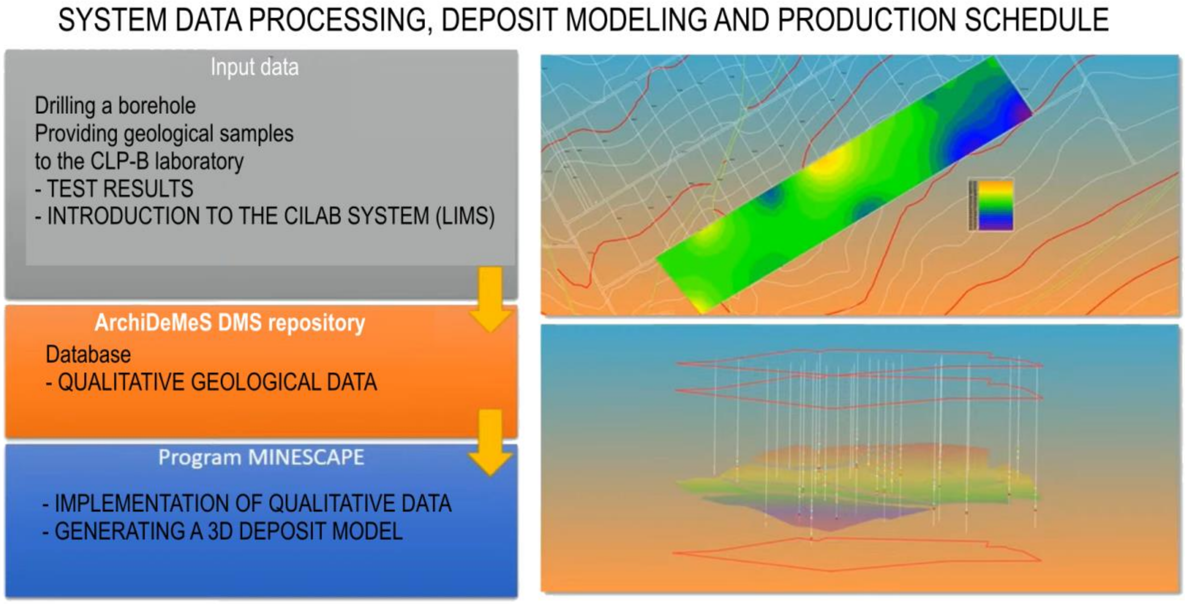

Fig. 4.7. Data processing process in the deposit modeling system [Saganiak, 2021]

The coal quality model is created as a result of interpolation of point findings of individual quality parameters obtained from analyses of samples taken from boreholes or sampling of mining excavations. It was assumed that the key parameters from the point of view of product quality obtained from enriched samples (with ash content less than 9%) would be modeled. At the stage of preparing data for modeling, for each of the individual quality statements, the values of quality parameters were averaged within the full thickness of the seam or the thickness of the gate (if it covered more than one seam).

For individual quality parameters there were selected interpolators - mathematical procedures that, based on point quality statements, calculate the predicted values of the analyzed parameters in the nodes of the mesh model. Individual interpolators differ significantly in terms of input data requirements, the range of parameters allowing to control the interpolation performed, and the nature of the resulting model surfaces (Fig. 4.8).

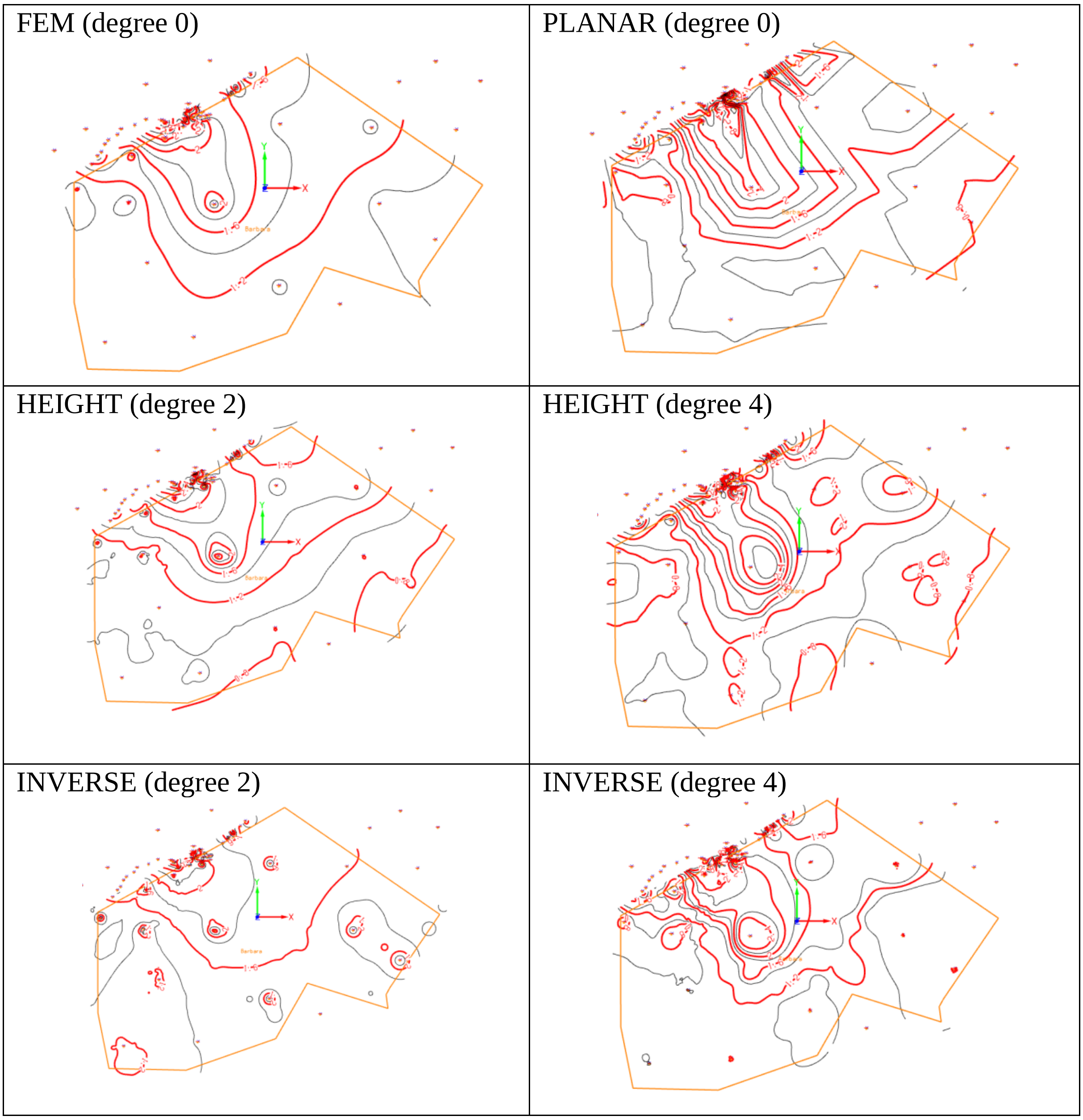

Fig. 4.8. Comparison of quality isolinear maps developed on the basis of grids calculated while using different interpolators

The selection of an appropriate interpolator of model quality parameters is also important for the economic assessment of the planned operation [Kopacz, 2020]. In modeling the quality of deposits exploited by JSW SA mines, Inverse Distance Weighting, and Height interpolators were primarily used. The tools used also allow for geostatistical interpolation (ordinary linear kriging) of the tested coal quality parameters.

Geostatistical interpolation called kriging [Cressie, 1990] is used when we assume that the variation in the value of a deposit parameter contains random and non-random components, and that the structure of such variation can be described using a function called a semivariogram, which illustrates the dependence of the average variation of a specific parameter on the mean distances between measurement points.

Kriging method as an interpolation procedure can only be used when there is enough data to construct a semivariogram, which is only possible in more advanced stages of deposit exploration [Nieć, 2012]. This procedure also requires an analysis of the variability of each quality parameter in each of the modeled seams, which is why it is currently used only in special cases (Fig. 4.9).

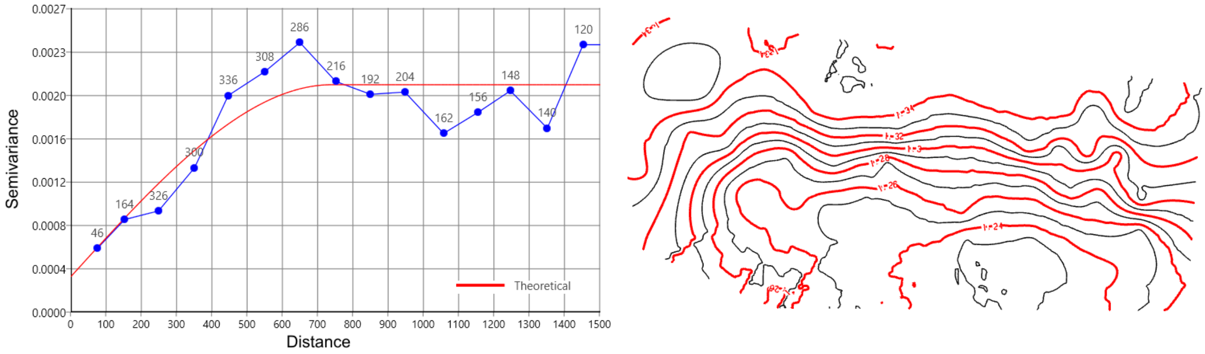

Fig. 4.9. Empirical and theoretical semivariogram and isolinear map, developed on the basis of the kriging procedure for the random reflectivity of vitrinite in a selected seam

Interpolation enables to fill the entire model space with predicted values of quality parameters. They become an element of the three-dimensional model of the deposit and can be the subject of visualization in the form of maps, cross-sections or spatial projections (Fig. 4.10).

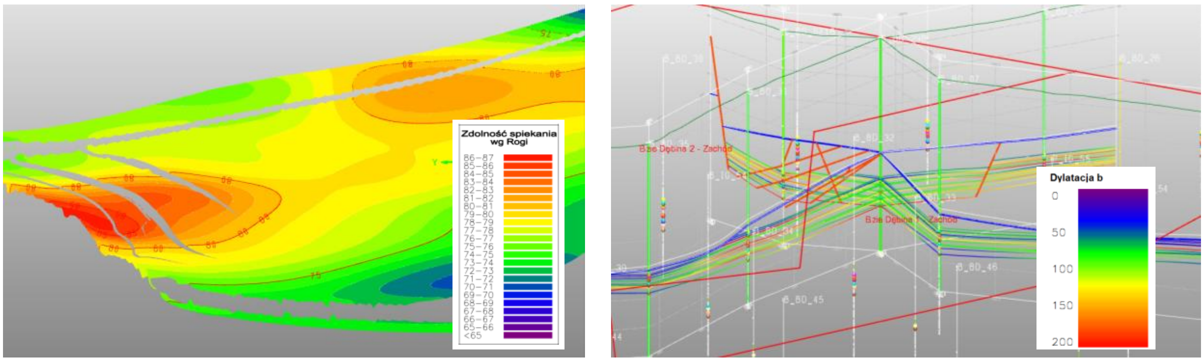

Fig. 4.10. Sintering capacity according to Rogi and dilatation on the spatial projection of the floor surface of the selected seam and cross-sections through the deposit [Jamroży, 2019]

The technological classification of coal types used in Poland, in the field of coking coals, takes into account the content of volatile matter V^{daf}, dilatation b, coal swelling index SI and sintering ability according to Rogi RI. Coal type is not a numerical value, so it cannot be interpolated like other quality parameters. In the implemented solution, depending on the users' needs, it can be interpreted and modeled in two ways:

– as a class defined for a given sampling point and seam, interpolated between individual statements using the Polygon interpolator,
– as the value calculated at each point of the model grid resulting from the combination of the parameters V^{daf}, b, SI and RI.

In the first approach, coal type data at the analysis point is used to plot the point's "zones of influence." The coal type at a given point in the model is assigned based on the closest statement. The second approach is based on expression surfaces defined in the MineScape software, taking into account four quality parameters defining the type of coal at a point. The result is smooth transitions between individual types of coal in the model space (Fig. 4.11).

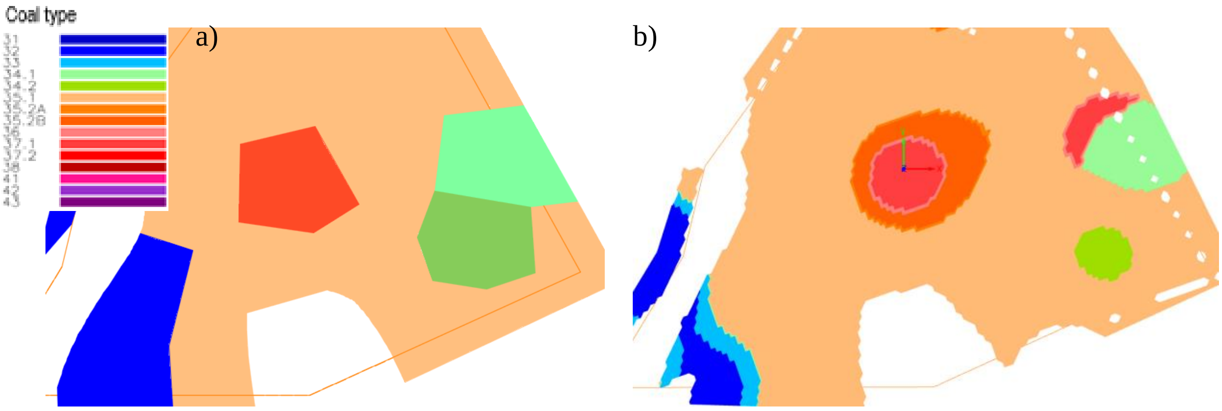

Fig. 4.11. Interpretations of the type of coal in the seam made with the Polygon interpolator (a) and by taking into account four qualitative parameters defining the type of coal at each grid point (b)

4.10.1. Determining the quality of coal deposits designed for exploitation based on a digital model of a hard coal deposit

The mineral quality model allows for not only the planning of exploitation in relation to the expected quality parameters of the product, but also facilitates activities related to the protection and recording of deposit resources. Resource reports prepared according to Polish or international standards may include selected quality parameters or their combinations (Fig. 4.12).

SEAM	COAL_TYPE 32.2	33	34.1	34.2	35.1	35.2A	35.2B	37.1	Total amount
362/1				2 393	7 898				10 290
362/2		1 370		1 572	14 417				17 358
363/1			311	5 587	10 565				16 463
401				343	22 032			489	22 864
402/1				773	12 835				13 608
403/1				403	26 868				27 271
403/2				1 208	22 282				23 490
404/1				81	29 316	893			30 290
404/2					6 083				6 083
404/3					19 150				19 150
404/4	401	1 088		122	16 706		1 047	271	19 635
405/1				70	43 858			980	44 908
Total amount	401	2 458	311	12 552	232 007	893	1 047	1 739	251 409

Fig. 4.12. An exemplary report from a deposit model with the division of coal resources in the deposit into individual seams and types of coal

Deswik solutions used at JSW SA apply a digital deposit model to plan the production of commercial coal with the desired quality parameters. Geological information collected in the GDB database and modeled in the MineScape program, among others, in terms of mineral quality, is updated monthly and transferred to production preparation departments, which allows for ongoing updates of production plans. The main challenge currently faced by JSW SA mines in terms of product quality is to provide contractors with coal from which coke with stable parameters will be produced. Some mines are also faced with requirements to limit coal production for energy purposes and at the same time maximize coal production for coking purposes [Owczarek, 2021].

During the project, requirements were defined for key elements of quality testing processes in order to standardize the qualitative testing process - establishing the Testing Quality Standard (Fig. 4.13).

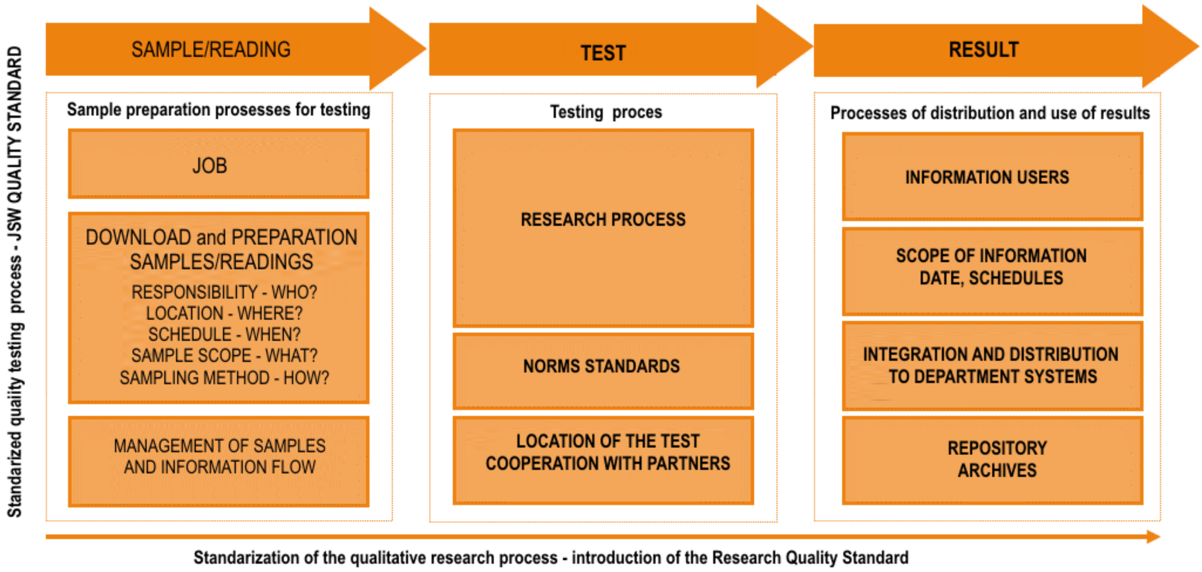

Fig. 4.13. Requirements for key elements of the quality testing process

The condition for obtaining high-quality blast furnace coke is the good and stable quality of the feed coal from which it is produced. The feedstock for coke production is composed of several types of coals with compatible coking properties. Some of these coals are the so-called base, while others act as refining and slimming ingredients. The process of shaping the quality of coal input for coking begins when coal is extracted in mines and enriched in processing plants, and then the process is continued in coking plants [Ozga-Blaschke, 2010]. The utility value of coal sent to the coking process depends on many quality parameters; processing of coking coal processes allow to influence mainly the moisture and ash content [Blaschke, 2009].

At the stage of designing mining excavations, the layout of development and operational excavations is adapted primarily to the constraints related to the structure of the deposit, in particular to tectonic disturbances (main faults, seam folds). At this stage, primarily the structural model of the deposit is used, the mineral quality model provides a background and a possible indication of the location and orientation of the mining longwalls (Fig. 4.14).

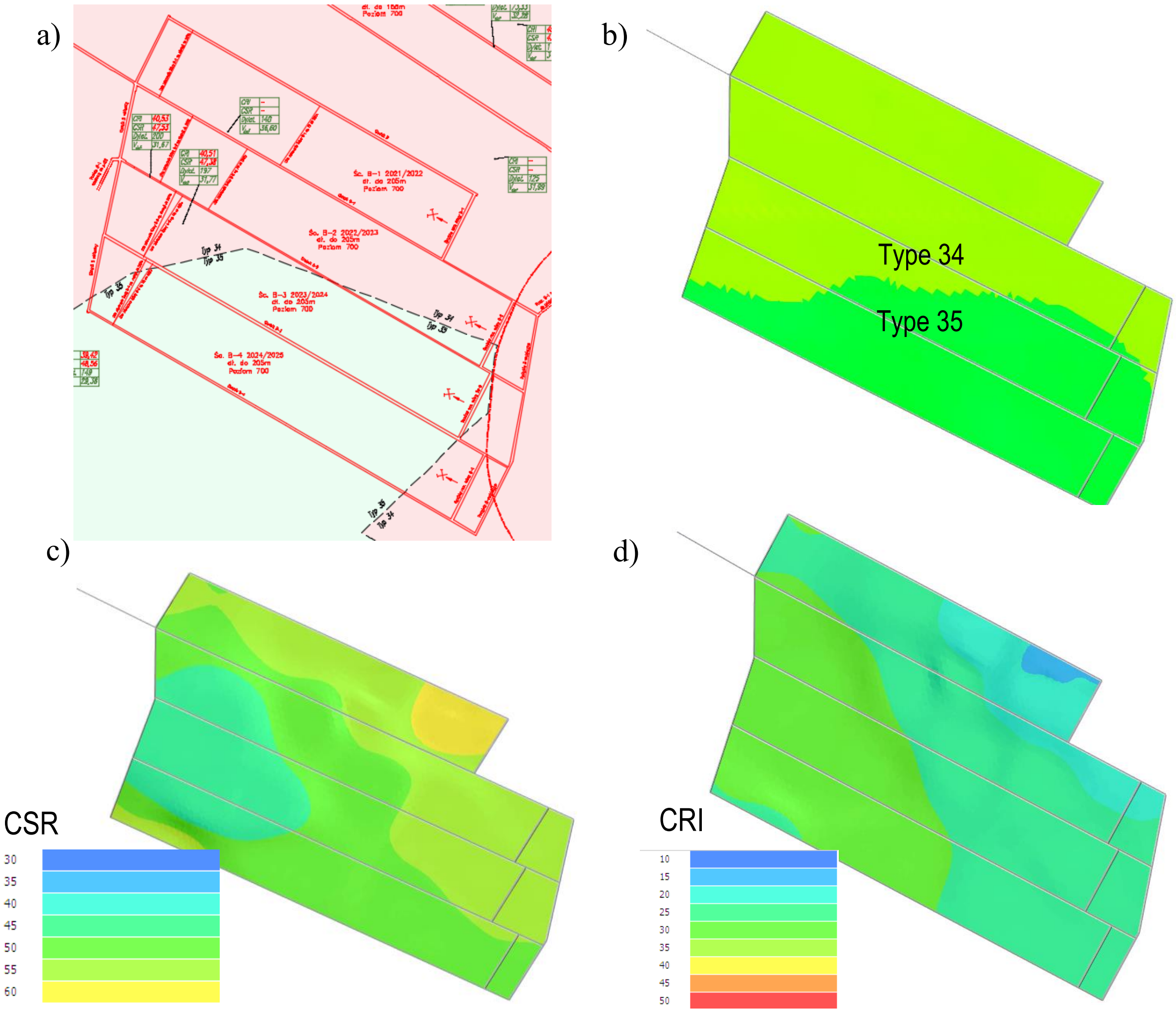

Fig. 4.14. Comparison of coal types according to the seam map (a) and deposit model (b), distribution of CSR (c) and CRI (d) indicator values in the selected exploitation field [Owczarek, 2020]

The bodies of the designed workings are divided evenly into sections of the length 25 m. For each of such sections, the average values of quality parameters are read from the deposit model (Fig. 4.15). The volumes of excavations divided this way become the tasks of the mining work schedule.

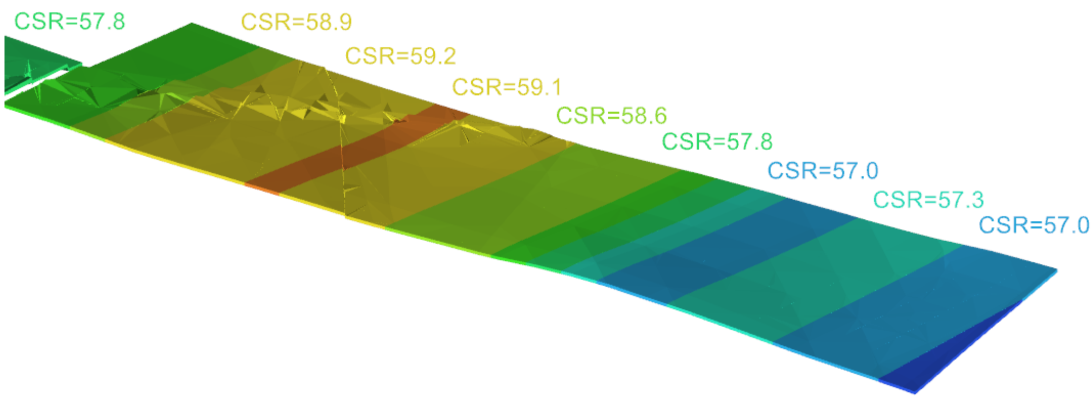

Fig. 4.15. CSR values [%] in the tasks of the selected longwall cut by two faults

4.10.2. Application of the mineral quality model for long- and short-term planning to determine the quality of excavated material

At the stage of scheduling mining works, tasks are distributed in time taking into account production goals and limitations related to the availability of production resources and geological and mining conditions. Schedules are visualized primarily on Gantt charts, which, depending on needs, can display various types of production and quality data. The Deswik.Sched tool also allows to constantly view the average parameters of individual longwalls and summary production data for the entire project in individual reporting periods of the schedule (Fig. 4.16).

The greatest opportunities for planning the quality of produced coal exist at the long-term (strategic) planning stage. Analysis of the coal quality of individual longwalls allows iterative indication of the optimal sequence of exploitation and advance in terms of stabilizing the product quality at the optimal level for the mine and the expected level of extraction while maintaining the conditions resulting from the mining technology used [Lewandowski, 2021].

Exploitation planning using detailed qualitative information from the deposit model enables to identify groups of seams and walls whose excessive exploitation may be a threat to the stabilization of product quality. The simultaneous exploitation of lower quality longwalls with better quality longwalls allows for better use of the deposit resources without a negative impact on the quality of the product (Fig. 4.17).

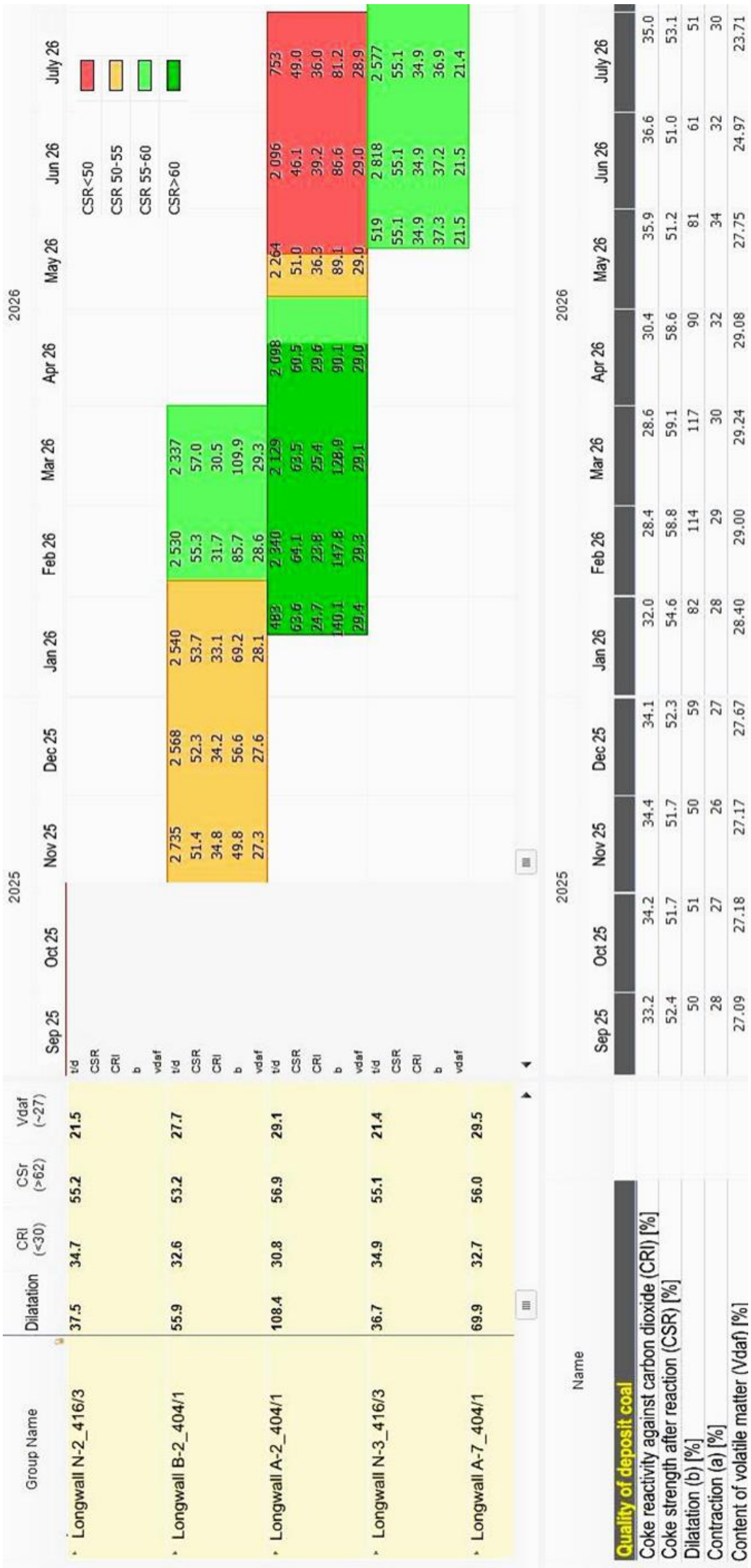

Fig. 4.16. An exemplary Gantt chart with task coloring adjusted to the value of the CSR index [%], average values of quality parameters in longwalls and the resulting quality parameters of coal output in individual periods

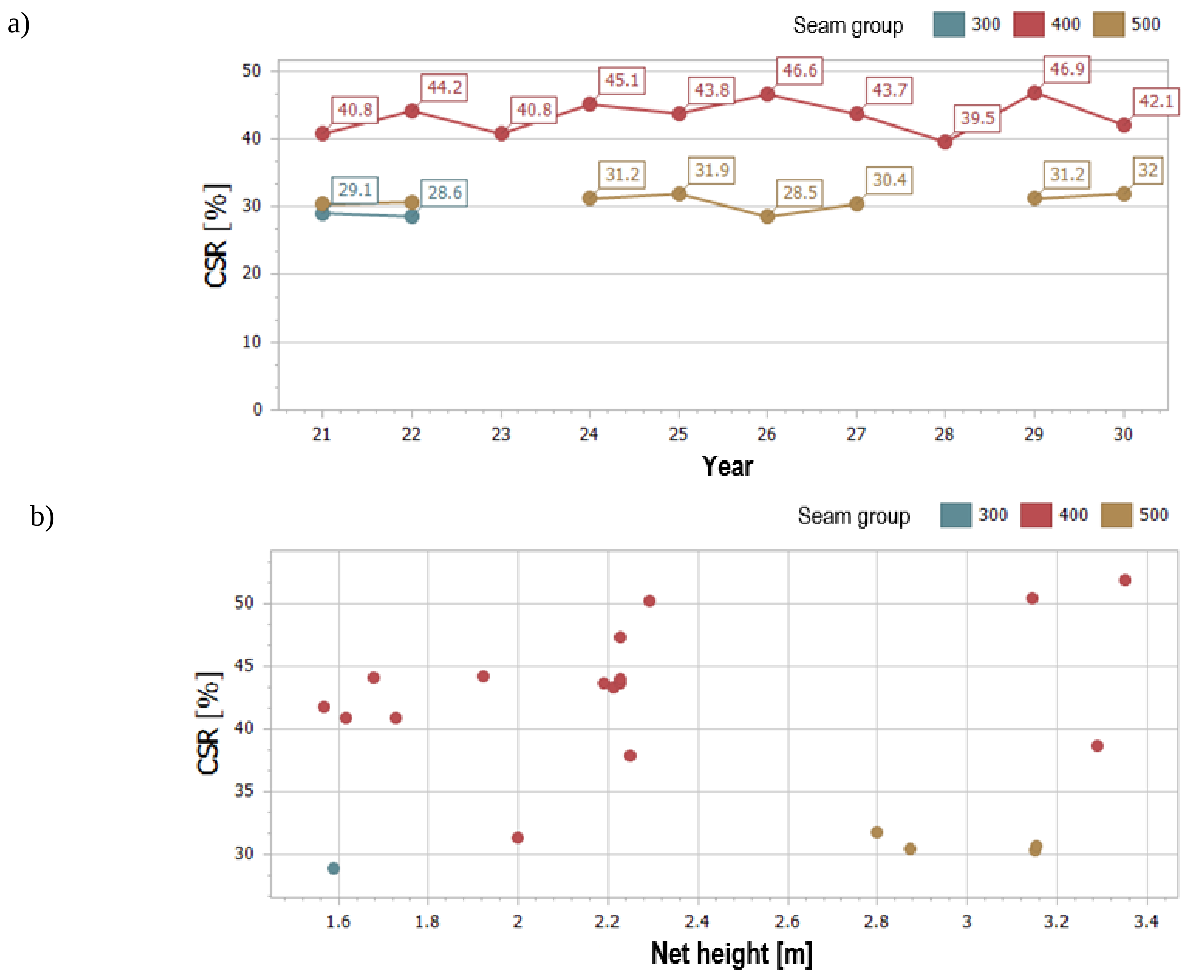

Fig. 4.17. Coal quality in groups of seams in individual years of operation (a) and in individual longwalls in relation to their net height (b)

In mining plants that have technological solutions enabling selective extraction and hauling of mined material, solutions are also used to predict the quality of individual mined streams. In particular, solutions are used to direct the run-of-mine stream by dividing the excavated material underground and directing it to a selected technological line [Owczarek, 2021]. In combination with underground and surface raw coal bunkers, the solution used allows for planning the proper mixing of coal from individual technological lines and obtaining the expected quality parameters of coal sent to the processing plant (Fig. 4.18).

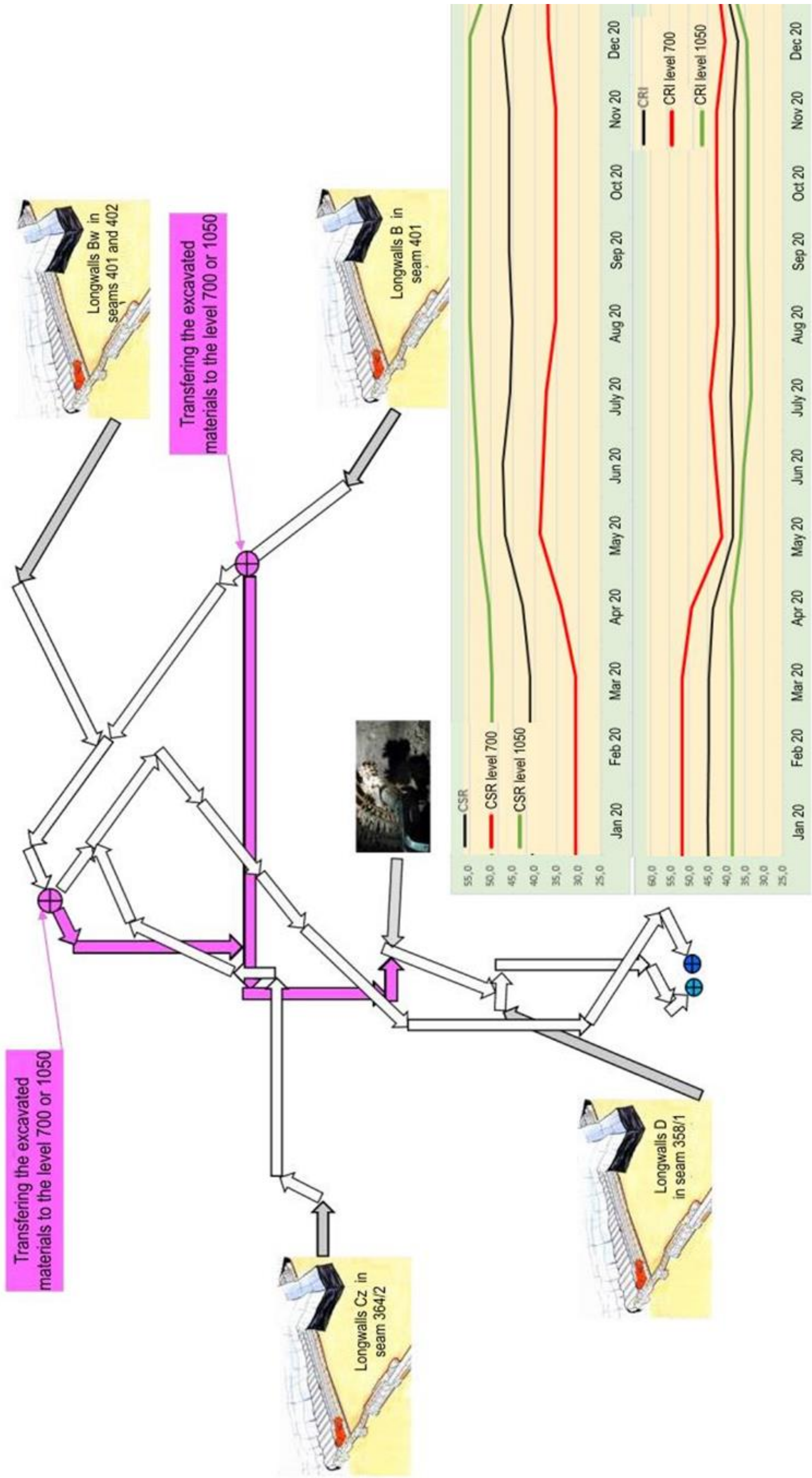

Fig. 4.18. Diagram of the main haulage of the "Budryk" coal mine with the possibility of directing the mined stream and a chart of changes in CSR and CRI indicators on individual technological lines [Owczarek, 2021]

The company has taken steps to increase the production and sales of coking coal with stable and desirable quality parameters, including: through the development of the coking coal resource base and the related access to new deposits and new mining levels. These activities, combined with the advanceive computerization of the entire production chain, including: deposit modeling, forecasting and ongoing monitoring and supervision of product quality allowed us to significantly stabilize and, in some cases, also improve the quality of coal output sent to processing plants (Fig. 4.19).

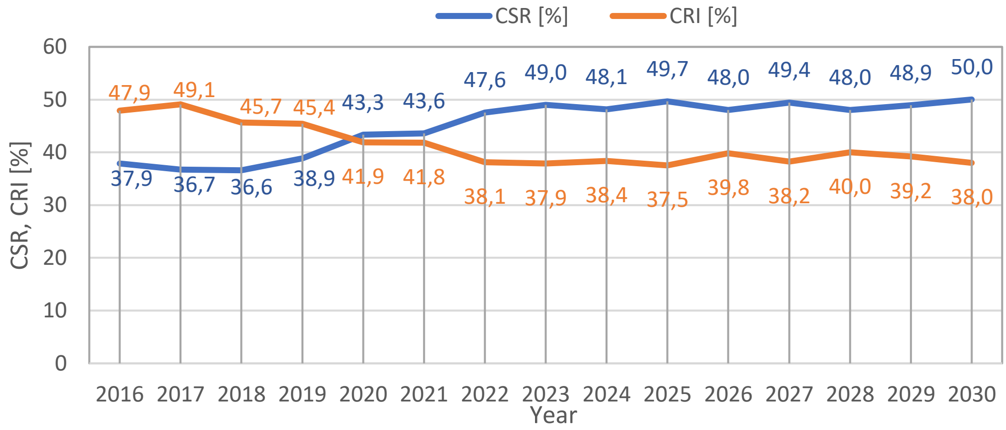

Fig. 4.19. Improvement and stabilization of CRI and CSR indicators [%] of deposit coal in the years 2016÷2030 in a selected JSW SA mine. Years 2016-2021 - performance estimated on the basis of longwall run schedules, years 2021-2030 - forecast based on the deposit model

The digitization of geological data has improved the work of geologists in the processing of geological data, both those describing the structure and quality of the deposit. Changes in the quality of the deposit, their current trends and long-term forecasts are regularly analyzed by mine teams for forecasting the quality of seam coal. Deposit models and mining simulations based on them in terms of coal quality are currently an important source of management data.

In short-term planning, when some walls are in operation and preparatory excavations for subsequent walls have already been completed, the possibilities of quality control may be limited [Burczyk, 2021]. However, constant monitoring of production allows in many cases to respond quickly and in accordance with mining practice (Fig. 4.20) and to stabilize the quality at the expected level.

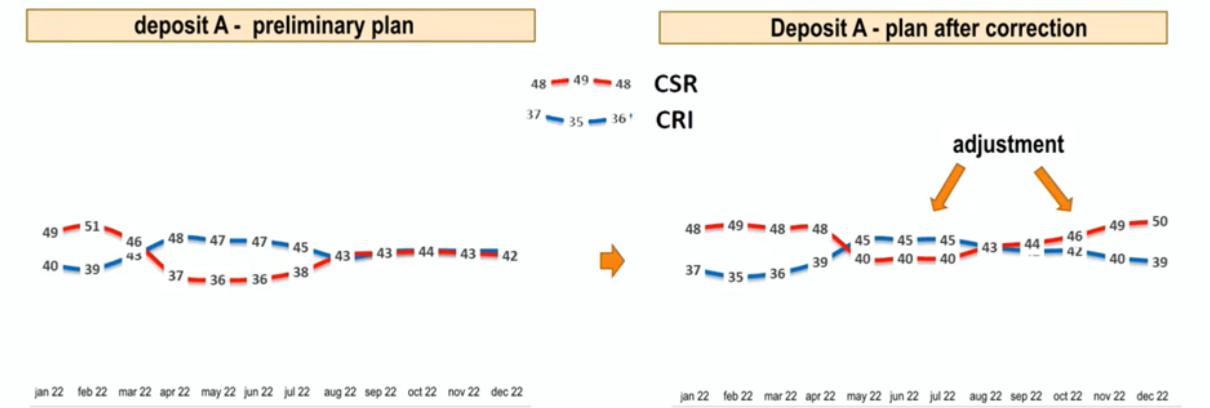

Fig. 4.20. An example of correction of a short-term operation schedule in terms of product quality [Burczyk, 2021]

The IT system designed for implementation was aimed primarily at improving and making the Company's planning processes in the mining area more flexible by optimizing the quantity and quality of extracted coal, stabilizing the quality parameters of the mined material and adapting production to the changing market situation.

4.11. Effects of implementing a system for modeling coal quality parameters and operation planning in terms of product quality at JSW SA

The factors that triggered the implementation process of the discussed system were the changing economic situation on the coking coal market and the need to increase production efficiency. As a result of the actions taken, two key documents were developed that shape this area at JSW SA: "**Product quality strategy**" and " **Deposit and product quality management policy**". The second document specified, among others: strategic projects in the area of quality management. Strategic projects were then defined in the technological sphere and included in **the documentation regarding technological solutions of the entire JSW SA -** they were also part of the overall IT strategy of JSW SA. The development of these three documents resulted from the need to reduce the risk of business challenges faced by the company and, on the other hand, to maximize the chances of further development of the company. For this purpose, two key areas were distinguished: **operational management** and **planning and scheduling**. The second key area included projects to create a digital deposit model and modern production scheduling integrated at the company level based on a three-dimensional deposit model.

Implementation of IT solutions is a complex process and has been repeatedly analyzed in scientific research. The most common software implementation model in large enterprises is the cascade model, which was defined by Royce [Royce, 1970]. This model was then modified and extended for use in large-scale enterprises [Petersen, 2009]. Virtually all implementations in the Polish mining industry were carried out based on the cascade model. It should be emphasized that many of them failed or were completed exceeding the deadline and increasing the costs of their implementation. Already in the 1990s analyses of software implementations led to the identification of the problem in the form of "the factors that distinguish successes and failures ..." [Herbaleb, 1994]. Over time, factors of this type have become a tool for assessing the software implementation itself. During software implementation, there may be factors that make it difficult to implement. The results of scientific research on the implementation of IT solutions in the Polish mining industry [Krawczyk, 2019] indicated that there are many examples of the so-called implementation barriers. By implementation barrier we mean the occurrence of such limitations and obstacles during implementation that cause partial or complete threat to its realisation. Therefore, before implementation, actions were taken to reduce the barriers identified in the Polish mining industry, which are: skills, communication, human resources, technological, organizational, interoperability and software usability [Krawczyk, 2019]. Therefore, even before the system was implemented, a number of actions were taken to limit the possibility of problems occurring during implementation.

The defined required functional scope of the system was achieved by conducting an advanced component selection process, during which these components were tested and assessed by JSW SA employees [Dyczko, 2021]. This allowed to reduce the software usability barrier.

Reducing the skill barrier was achieved using two methods. The first method involved selecting the most committed employees among those who knew the individual areas best and improving their qualifications by organizing a series of training courses for them conducted in the surveying and geological departments of all JSW SA mines. The second method involved cooperation under an agreement with the AGH University of Science and Technology, due to which seventeen new employees - young mining geologists - were hired. As part of the cooperation, all members of the scientific group dealing with geostatistics and modeling of parameters describing the quality of hard coal at the Department of Deposit and Mining Geology at the AGH University of Science and Technology in Krakow started working at JSW SA. This agreement also increased the level of available resources for implementation, thus significantly limiting the possibility of a reserve barrier.

Reducing the technological barrier was achieved through a complex process of equipping the staff with measuring instruments used to obtain data for deposit modeling and modern IT systems enabling the automation of measurement processes and data visualization. For this purpose, projects were launched to implement "Intelligent scales and neuron analyzers" that allow for continuous control of the quantity and quality of extracted coal transported by conveyors to coal processing plants. Technological limitations in terms of processing large amounts of data were also analyzed [Kosydor, 2020]. The analyses showed that the ICT infrastructure at JSW SA required additional investments due to the large amounts of data collected during the system's operation.

The organizational barrier was reduced by establishing a quality team whose task was to analyze data and make strategic and current decisions regarding mining operations with broad powers of intervention in the field of stopping and resuming mining in any field of any JSW SA mine. Due to this JSW introduced a uniform and coherent model for planning mining operations and quality forecasting, which improved the creation of short and long-term production plans as regards of stabilizing the quality of the final product [Burczyk, 2021].

Currently, work is still being carried out related to the optimization and automation of activities in the system for modeling coal quality parameters. Analyzing the effects of the two-year operation of the system at this stage, the following achievements and changes can be distinguished:

- procedures related to product quality management were prepared and implemented at JSW SA,
- geological databases of six mines were built and organized,
- IT tools for deposit scheduling and modeling were implemented,
- geological models were prepared for strategic deposits, resource zones and mining levels of all JSW SA mines,
- strategic production schedules related to deposit models were created,
- a central strategic scheduling model was created enabling the integration of mine schedules at the level of the JSW SA Management Board Office,
- the basis for building a central database aggregating deposit models and production schedules was created at the level of the Management Board Office of JSW SA using a spatial database [Krawczyk, 2018].

Due to the implemented system, employees of JSW SA mines can create exploitation variants that are analyzed in any time period, due to the possibility of selecting any work calendar. In the result of the constant updating of information in the database and the possibility of its quick use and modification, the design process (both in the case of access, development and operational activities) are improved and accelerated many times compared to traditional methods, which allow:

- planning (short- and long-term) operation and technical design,
- designing access, development and operational activities,
- execution of the schedule of planned activities.

The built digital deposit quality model allows for automatic calculation of the quantity and quality of extracted material and waste rock in selected time intervals, and after completing the simulation, a forecast is automatically generated for all parameters related to the extraction project, such as: quantity of extracted material, amount of waste rock, quality parameters, etc.

The implementation and integration of qualitative research processes, digital recognition of deposit coal and its parameters, allowed for the introduction of proactive production control and obtaining increased, stable parameters of commercial coal. Due to the implementation and integration of systems in the area of quality management, there is now a possibility of:

- modeling of production management and forecasting and its key parameters, to achieve a stable level of production quality for coking coal recipients and coke producers;
- planning and management of development operations and extraction to obtain and maintain the required levels of physicochemical parameters of the product;
- implementation of selective mining by controlling the quantity and quality of extracted material - introducing control of extracted material with various parameters and the process of selective enrichment;
- separation of product streams in terms of their quality, based on established key quality parameters and market demand, in order to maximize sales prices - in 2020, price increases were achieved for coals supplied to strategic suppliers due to maintaining a stable level of coking parameters of the produced coking coal;
- elimination of purchases of low-phosphorus coal from outside the JSW Group.

The implementation effects, achieved due to the computerization and automation of deposit and product quality management processes, led to the stabilization of key contract parameters and enabled an increase in prices obtained in the case of key customers. Digitalization and automation of the collection of quality data throughout the entire production cycle also enabled ongoing monitoring and management of complaint handling processes in order to minimize their financial impact.

After implementing the system for deposit modeling and production planning and scheduling, an estimate was made of the possible financial benefits being the return on investments and design activities carried out so far, as well as operational activities carried out by the company's Quality Office, made by the Author of this chapter on the basis of hypothetical negotiated price changes in the execution of the contract with a key recipient, and the result reaching up to several million euros. The estimate was made based on the results of international market analyses conducted by globalCOAL (globalCOAL, 2021), containing data on current and predicted coal prices, market factors and energy trends.

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5. Mobile telecommunications in underground coal mines

Kazimierz Miśkiewicz, Antoni Wojaczek

5.1. General thoughts

This chapter partially uses the material contained in the author's monograph Miśkiewicz K., Wojaczek A.: Radiocommunication in underground mines. Silesian University of Technology Publishing House, Gliwice 2020 [Miśkiewicz, 2020].

Mobile telecommunications should be understood as the possibility of voice communication and data transmission with mobile workstations. Such positions include mobile machines commonly used in underground mines (electric locomotives, floor-mounted railways, suspended railways, self-propelled machines). Mobile telecommunications are also used by people who do not have permanent workstations (e.g. supervisors) who perform work on road haulage and transport of materials. This type of telecommunication is also commonly used in all cage and skip shafts.

In underground mines, there are practically the following possibilities for implementing mobile telecommunications:

- use of infrastructure containing AP access nodes (access points) connected with fiber optic cables (sometimes copper),
- use of infrastructure containing AP access nodes (access points) connected by radio links,
- use of infrastructure built from radiating cables or using existing shaft infrastructure (supporting ropes and compensating hoisting machines).

Access nodes should be arranged so that their coverage areas overlap. Fig. 5.1 shows a network of access nodes located in the mine, connected with each other by a copper cable and connected to the mine's telecommunications network. Each TM mobile terminal can, via an access node (usually the closest one), communicate (voice, data transmission) with another mobile terminal or other device in the mine's telecommunications network (telephone, server). Access nodes can also measure the parameters of the signal received from mobile terminals and enable zone or precise localization of terminals.

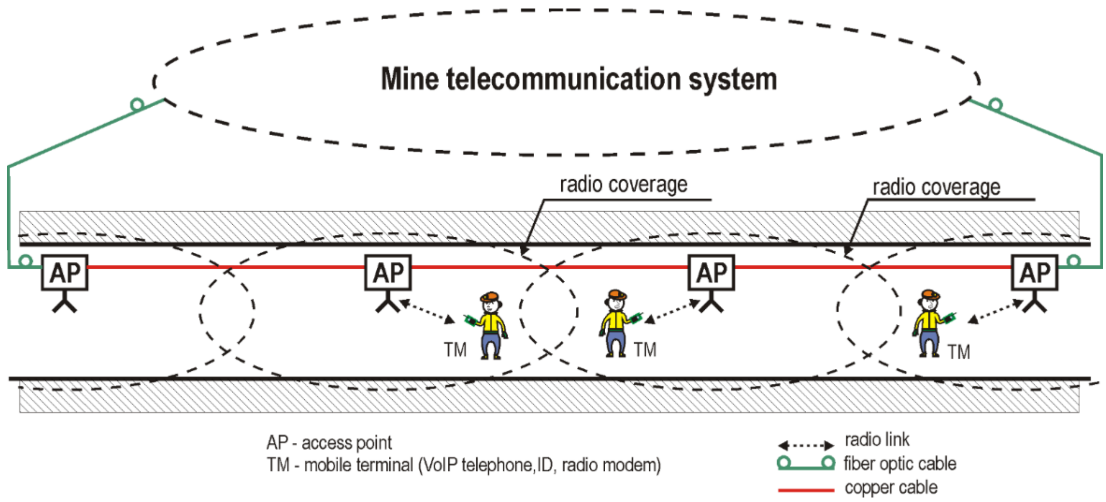

Fig. 5.1. Wired access network with copper cables

The radio link uses Wi-Fi protocols (according to the 802.11 family of standards) in the 2.4 GHz band [Gast 2003], ZigBee in the 2,4 GHz band (according to the 802.15.4 standard), DECT in the 1880 - 1900 MHz band according to the standard (ETSI EN 300 175), and sometimes proprietary protocols in the ISM 868 MHz band. Cables connecting individual access nodes use Ethernet protocols (according to the 802.3 standard) with a throughput of 10 Mb/s, 100 Mb/s, and sometimes protocols based on the RS485 standard. In the case of the Ethernet protocol, it is important to limit the length of the copper cable (standard up to 100 m). In the case of the RS485 standard, the catalog limitation of 1200 m is irrelevant because it is greater than the radio transmission range (in the case of free propagation) in the excavation.

Fig. 5.2 shows a network of access nodes located in the mine, connected with each other by a fiber-optic cable and connected to the mine's telecommunications network. In the case of fiber optic cables, their maximum length (between AP access points) may be several hundred meters and results only from the radio transmission range in the excavation.

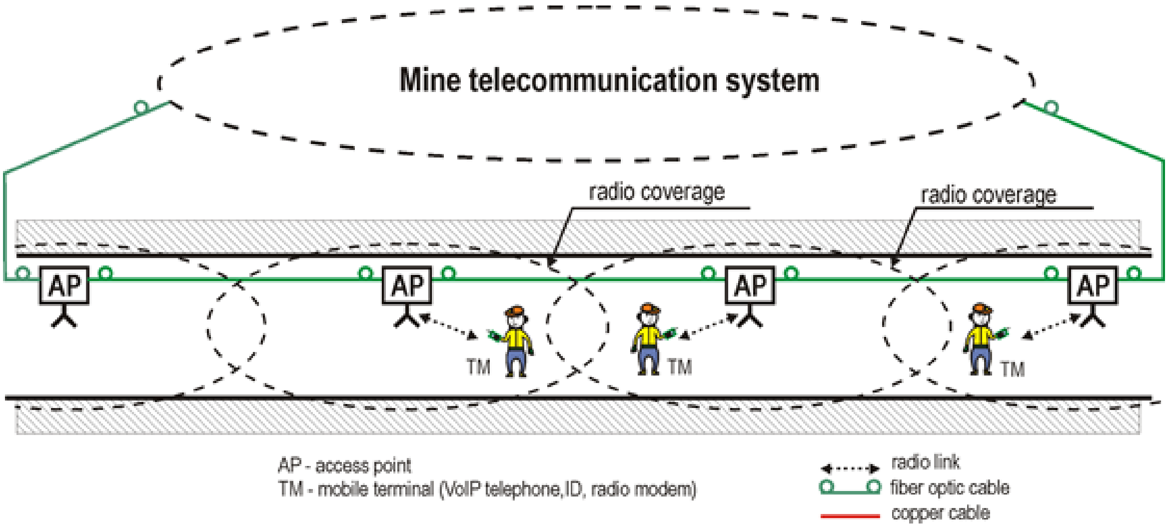

Fig. 5.2. Wired access network with fiber optic cables

Fig. 5.3 shows an access network in which nodes are connected to each other by radio links.

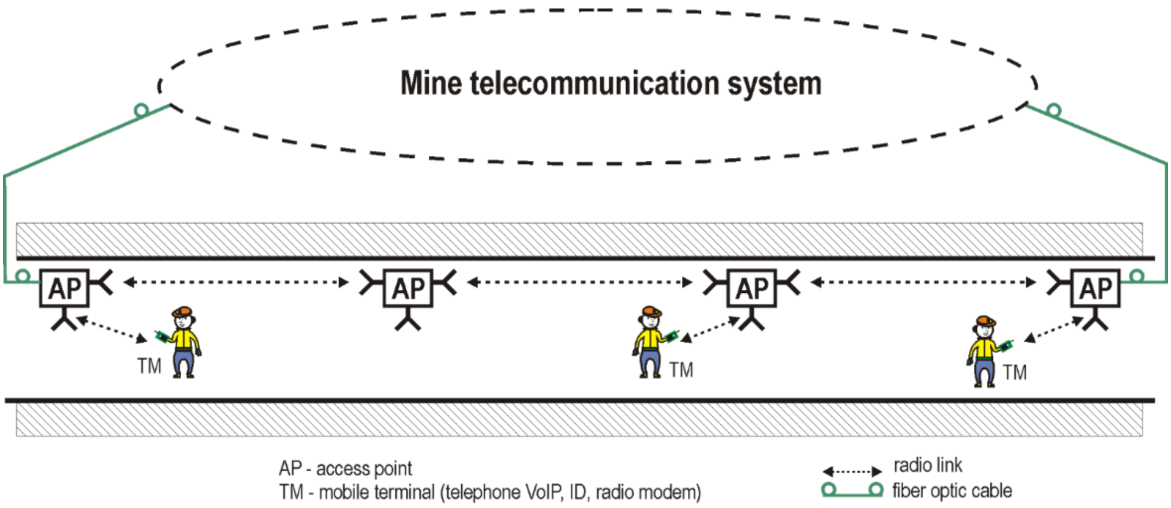

Fig. 5.3. Wired access network with radio links

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It should be noted that all AP access points in wired access networks presented in Figures 5.2 and 5.3 require guaranteed power supply (mains and battery), which is a significant problem in underground conditions. In methane mines, there is an additional requirement for the intrinsic safety of this power supply, due to the fact that audio communication is particularly necessary when the mains power supply is turned off by the gasometric system.

The radiating cable is a coaxial cable with a "leaky" outer conductor, which makes it a kind of "antenna" providing radio coverage in the workings where it is installed, as well as in the immediate vicinity. Fig. 5.4 shows the infrastructure for mobile radio communications using a radiating cable. The signal transmitted by the mobile terminal on the frequency f_u is transmitted via a radiating cable to the RP repeater. There, its frequency is changed and as a signal with frequency f_d it is fed into the radiating wire and can be received by all mobile terminals with the set receiver frequency f_d.

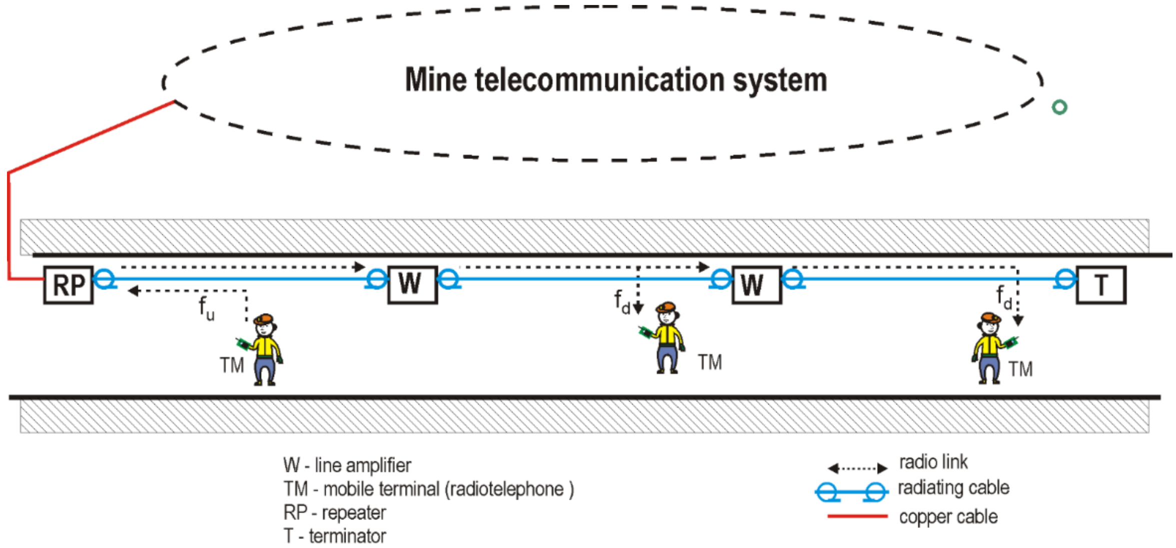


Fig. 5.4. Telecommunications infrastructure with radiating cable

Due to the attenuation of the radio signal, line amplifiers are installed in the radiating cable at intervals of 300÷500 m to amplify the radio signal in both directions, and at the end of the radiating cable a terminator is installed, whose impedance is equal to the wave impedance of the radiating cable.

As already mentioned, a very important issue for the network of access points is their power supply method and the implementation of battery backup to ensure the functioning of the radio communication system in the event of planned or unplanned power outage from the mine's power grid. Information about the lack of mains voltage and battery operation should be sent to the radiocommunication system administrator, triggering an alarm.

Fig. 5.5 shows a network of access points with individual power supply. Each AP access point has its own separate power supply. The battery backup can be in the power supply or in the access point. The problem may be supplying 230 V mains voltage to each power supply, which will sometimes require the installation of a transformer unit (a device containing a 500/230 V or 1000/230 V transformer).

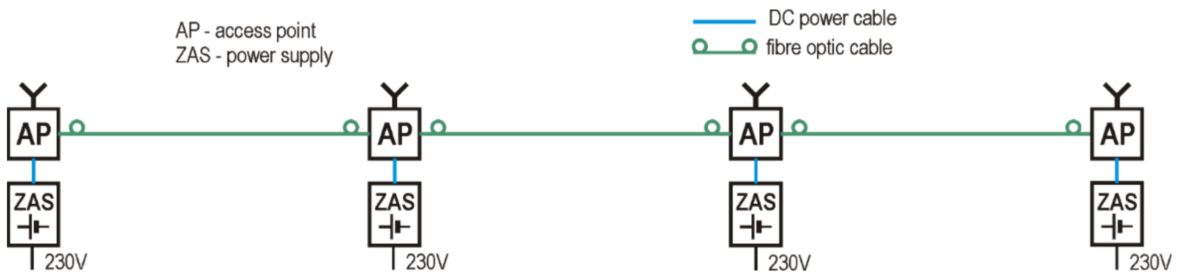


Fig. 5.5. A network of access points with individual power supply

To reduce the number of power supplies, group power supply for access points is used (one power supply for several AP points). When connecting AP access points with optical fibers, you can use hybrid (also called composite) cables, which contain both optical fibers for transmission and copper wires for power (Fig. 5.6) or external DC power cables (Fig. 5.7).

Fig. 5.6. Network of access points with group power supply via hybrid cable

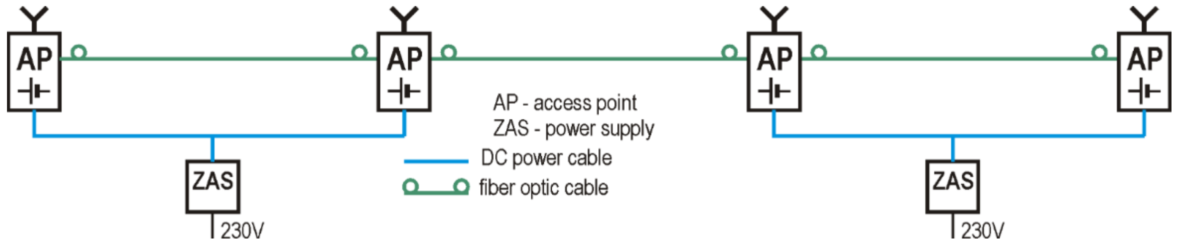


Fig. 5.7. A network of access points with group power supply via an external cable

In the case of a cable network, the copper wires of the cable can be used for both data transmission and power supply. A solution called PoE is used in Ethernet networks. Fig. 5.8 shows an example of group power supply with copper cable.

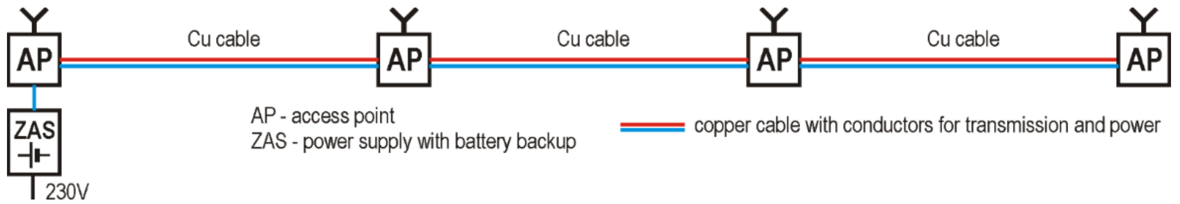


Fig. 5.8. A network of access points with group power supply via copper cable and battery backup in the power supply

In the case of group power supply, battery backup can be used in the power supply (Fig. 5.8) or in access nodes (dispersed battery backup), as shown in Fig. 5.9.

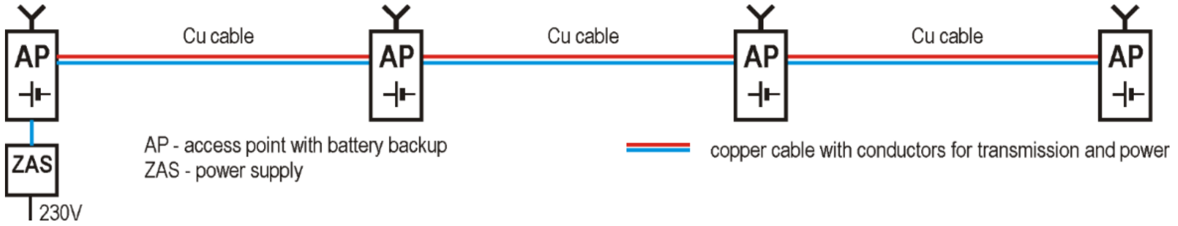


Fig. 5.9. A network of access nodes with group power supply via copper cable and dispersed battery backup

It should be noted that all elements of the access network must be adapted to work in the environment of underground mines, i.e. have an appropriate degree of housing protection (at least IP54), and in the case of methane mines, they should be explosion-proof.

Examples of systems with access nodes are the following solutions [Miśkiewicz, 2020]:

- ImPact system by MineSite using the 802.11 protocol. The system offered by HASO uses NS40A, HAP-4 access points, HAP-1/RP repeater and mobile terminals (MP70 VoIP phones).
- ATUT system using the 802.11 protocol. The system uses access points with fiber optic link and radio link.
- The RWCS system developed by SEVITEL for the room-and-pillar mining system for copper deposits. The system includes battery-powered access points (with autonomous backup time 1 month) creating a mesh network, using the proprietary protocol in frequency band 868 MHz.

5.2. Construction and properties of the radiating cable

The radiating wire is a coaxial wire of special construction in which there are two modes of electromagnetic wave propagation [Martin, 1975]:

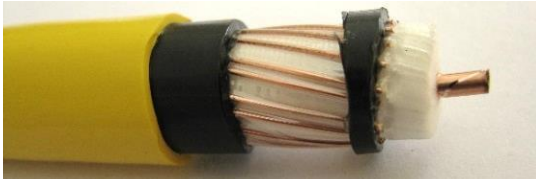
- **coaxial mode,** associated with the electromagnetic wave between the inner and outer conductors of a coaxial cable,
- **single-wire mode,** related to the electromagnetic wave between the external conductor of the coaxial cable and the surrounding rock mass.

In the radiating wire, mutual conversion between both modes occurs, which makes it possible to obtain radio coverage in workings with the radiating cable installed.

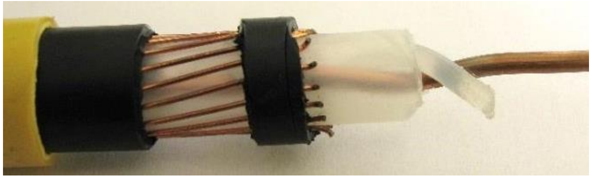
The radiating cable contains the following structural elements:

- internal conductor, copper, most often made in the form of a wire, tube, or cord (especially for a flexible cable - Fig. 5.10 c),
- insulation made of solid, foamed plastic (Fig. 5.10 a) or air-dielectric insulation (e.g. a plastic pipe adjacent to the outer conductor, supplemented with a spiral element holding the inner conductor in the middle of the pipe - Fig. 5.10 b),
- external conductor in the form of a braid of wires with an appropriately low optical density (Fig. 5.10) or a tape wrap with appropriate perforations (e.g. Fig. 5.11 a); sometimes the outer conductor of the copper tape is corrugated to increase the flexibility of the cable (Fig. 5.11 b),

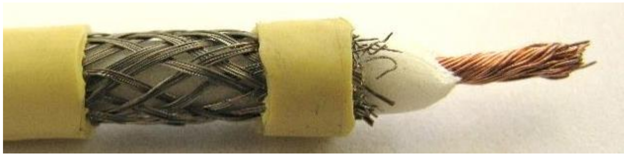
- a plastic coating (e.g. black polyethylene) providing protection against moisture in the radiating cable medium,
- an external protective sheath (e.g. yellow polyvinyl chloride, approximately 1,2 mm thick), ensuring the fire resistance of the radiating cable.



a) VLFC-IS cable

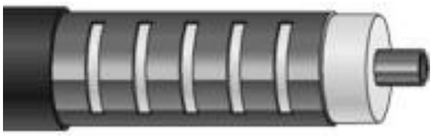


b) FLFC3529 cable



c) YnWGDek 50-1,63/4,8 cable

Fig. 5.10. Radiating cables with low density wire braiding



a) RLK cable

b) RCF cable

Fig. 5.11. Radiating cables with slots manufactured by RFS (Radio Frequency Systems) [RFS]

Sometimes the coating and protective cover are one integrated layer. The properties of a radiating wire are described by two types of parameters:

- transmission parameters (wave impedance Z_f unit wave attenuation α),
- coupling parameters (coupling loss α_c).

Definitions of the transmission parameters of radiating cables are presented in many publications [Miśkiewicz, 2010; Miśkiewicz, 2018] and will not be discussed here.

5.3. Examples of radiating cables

Table 5.1 shows the electrical parameters of radiating cables used in the Polish mining industry (FLEXCOM, MCA 1000, SmartCom systems). Radiating cables for various applications (e.g. for building infrastructure for trunking systems, mobile telephony, as well as wireless networks according to the IEEE 801.11 standard in tunnels, underground garages, building interiors, etc.) are produced by many manufacturers, e.g.: ANDREW, RFS, NK CABLES, Kabelwerk Eupen AG.

Selected parameters of radiating cables with an external braided cable

Table 5.1.

Parameter	FLFC3529 (FLEXCOM)	VLFC-IS (MCA 1000)	RNG-500 (SmartCom)
Internal conductor diameter	2.3 mm	2.3 mm	2.3 mm
Insulation	polyethylene-air	foamed polyethylene	foamed polyethylene
Structure of the external conductor	16 wires of 0.6 mm diameter		
Outer diameter	15.5 mm	15.5 mm	15.5 mm
Unit resistance of the internal conductor	4.23 W/ km	< 4.5 W/ km	4.5 W/ km
Unit resistance of the external conductor	4 W/km	< 4.1 W/ km	4.2 W/ km
Unit wave attenuation for f=160 MHz**	4.3 dB /100 m*	4.3 dB /100 m	4.3 dB /100 m
Wave impedance	75 W	75 ± 3 W	75 ± 3 W
Unit inductance	300 nH /m	300 nH /m	300 nH /m
Unit capacity	51 pF /m	51.2 pF /m	51 pF /m

Comments:

* for this type of radiating cable, the MRS company provides the unit attenuation for a fabrication section with a length of 350 m and a frequency of 175 MHz,

** unit attenuation is also given for other frequencies.

5.4. Organization of radio channels and frequency bands used

Radiating wire radio communication systems use **analog devices** (radiotelephones with frequency modulation) as well as **digital systems** in the VHF and UHF bands.

5.4.1. Frequencies used in radiating wire systems

The frequency ranges used in these systems depend on the equipment used (radiotelephones) and formal restrictions, such as the frequency allocation table [KTPCz, 2022] or the need to obtain a radio permit [PTEL, 2022]. The following frequency ranges are used in existing solutions:

– VHF range (dispatch systems) – 150÷159 MHz band (from the base station), 165÷174 MHz band (towards the base station),
– UHF range (trunked systems) – 410÷420 MHz band (towards the base station) 420÷430 MHz band (from the base station),
– mobile telephony systems – 890÷915 MHz band (towards the base station), 935÷960 MHz band (from the base station).

Radiating wire can also be used to transmit other signals such as:

– video signals from cameras in 6 MHz channels, e.g. in the 20÷120 MHz band,
– broadband digital data transmission signals (Ethernet over Leaky).

In the case of broadband data transmission, the radiating cable network is then similar to that providing Internet access services over a cable television network. The standard for data transmission in cable television networks is called DOCSIS *(Data Over Cable Service Interface Specification)* and is described in Recommendation J122 developed by ITU-T [J122]. There are known solutions for radiocommunication systems with a radiating cable using Ethernet over Leaky [Waye, 2007; Varis]. In the Ethernet over Leaky system by Mining Radio Systems additional bands are used:

– 220÷232 MHz for 2 streams from the base station (6 MHz, 30 Mbit/s),
– 18÷42 MHz for 6 streams to the base station (3,2 MHz, 10 Mbit/s).

If a radiating cable is used for audio communication, there are the following options for organizing the radio channel:

– **conventional** system, also called **dispatcher system**, using half-duplex [Wodzyński, 1978],
– **trunked** system [Wesołowski, 2003].

The spectrum to be used is divided into frequency channels separately for the transmission direction to the base station (downward direction) and the transmission direction from the base station (upward direction). The width of the channels depends on the inter-channel spacing in the radios used.

In a **conventional system**, one of the available frequency channels is permanently assigned to each user group. To service each channel, a repeater is installed in the base station).

In the **trunked system** [Hołubowicz, 1996; Wesołowski, 2003] there are a number of frequency channels available, one of which is the control channel. The number of channels may be less than the number of user groups. Channel assignment to individual users is done dynamically as needed, except when all channels are busy. In trunked systems, a mechanism to shorten the duration of calls can be used to limit the situation when the system cannot serve the user because all channels are busy. The functioning of a trunked system requires the definition of appropriate procedures and transmission protocols for system management purposes. Can distinguish:

– analog trunking systems:
    - corporate with proprietary protocol; an example is the EDACS network developed in Ericsson company,
    - open, which enables the production of equipment that meets the requirements of the standard by various companies; an example is the MTP 1327 standard developed by British Radiocommunications Agency,
– digital trunking systems, such as:
    - TETRA system *(TErrestrial TRunked RAdio)*,
    - DMR system.

In the MPT 1327 system, the signaling channel carries out digital transmission with MSK modulation (FFSK), with a symbol rate of 1,200 baud, using the Dynamic Framelength Slotted ALOHA protocol [Zieliński, 2009]. The base station of a trunked system sends messages periodically with an interval containing a certain number of time slots. Responses from mobile stations (radiotelephones) may be transmitted in time slots. In each mobile station, the time slot

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number for reply transmission is random. The protocol used enables data transmission between mobile stations and the base station in one common channel. A description of the MPT 1327 system can be found in the literature [Hołubowicz, 1996; Wesołowski, 2003]. The MPT 1327 system was used in KGHM Polska Miedź under the name DOTRA [Miśkiewicz, 2010].

The TETRA digital trunking system was developed by ETSI. In Poland, TETRA systems use 25 kHz frequency channels in the "up" (410÷420 MHz) and "down" (420÷430 MHz) bands. Each frequency channel uses 4 time slots (approximately 14 ms) for the simultaneous transmission of 4 speech or data channels with an interleaved control channel. A general description of the TETRA system can be found in the literature [Wesołowski, 2003].

DMR trunking system uses several 12,5 kHz frequency channels with two 30 ms time slots [ETSI 102361-4]. One time slot of the selected frequency channel serves as a control channel. There are also proprietary intermediate solutions between the conventional and trunked systems, called pseudo-trunking, extended pseudo-trunking (developed by Hytera [HYTERA XPT]) or Capacity plus (developed by Motorola [Motorola].

5.4.2. Voice services in radiotelephone systems

A number of radiotelephones are used in a radiotelephony system. Such a system enables the following types of voice services:

– individual calls, also known as private calls,
– group calls,
– broadcast connections.

Individual calls allow you to talk between two radios. The other radios cannot hear this conversation. Fig. 5.12c) shows an example of an individual connection between radios marked in green. The radios involved in the connection occupy a transmission channel (e.g. frequency) that cannot be used by other users.

Group calling allows you to conduct a conversation within a certain group of users. In conventional analog systems, frequency channels are assigned to individual groups. Fig. 5.12b) shows an example of a radio connection to a group of radios marked in blue. Broadcast connections allow you to connect to all users, as shown in Fig. 5.12a).

In digital systems, as well as in trunked systems, additional voice services related to queue management and priority consideration are possible.

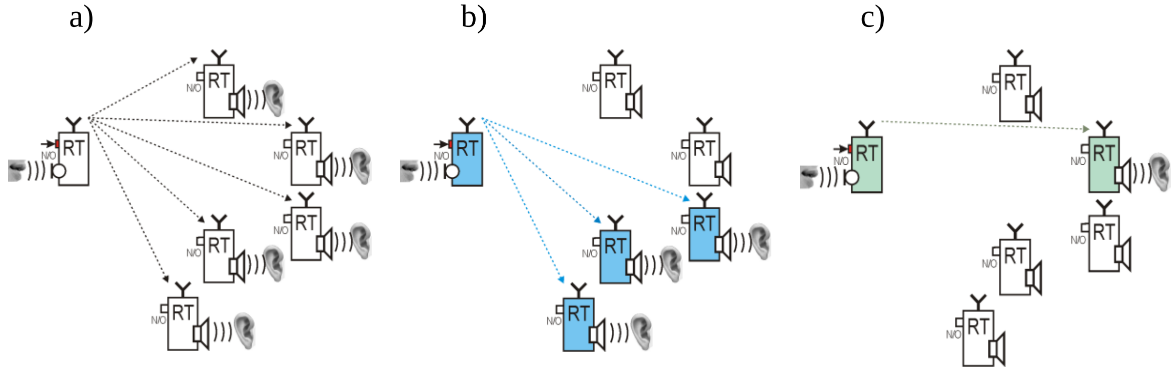

Fig. 5.12. Basic methods of providing voice services in radiotelephone communication systems: a) broadcast, b) group, c) private (individual)

5.5. Analog systems

The simplest organization of radiotelephone communication involves the use of single-frequency simplex radiotelephones. The concept **of simplex** means that the transmission between radiotelephones can take place in both directions, but not simultaneously, i.e. the radiotelephone can work as a transmitter or as a receiver, and transmission in both directions takes place in the same frequency channel [Kettelring, 2004]. The radio's operating mode is switched using the transmit/receive button (N/O), often referred to as PTT. The radio's operating mode (N/O) can also be switched using a signal from the microphone (VOX function). If the microphone signal level is greater than the set threshold, the radio switches to transmitting. Two or more radios using a common frequency channel cannot operate simultaneously as transmitters.

Fig. 5.13 shows an example of a network of three radios operating on a channel with frequency f_1. Both the transmitter (Tx) and receiver (Rx) use the same frequency channel. Radio 1 transmits, and the speakers of radios 2 and 3 hear what the user says into the microphone of radio 1. In this way, a group of users with radios set to a common frequency channel hear each other.

This type of radio communication using analog radiotelephones is used, among others, in the unprotected 446 MHz band, in which eight channels have been allocated in the range of 446÷446.1 MHz with an inter-channel spacing of 12,5 kHz.

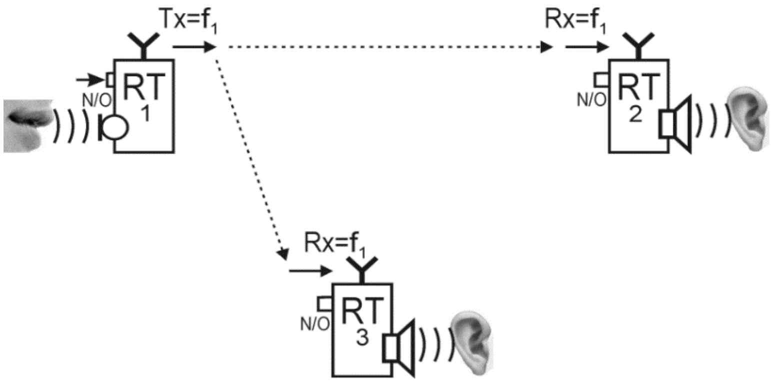

Fig. 5.13. Illustration of the operation of radiotelephones in a single-frequency simplex system

In radiotelephony communications, special tones with a frequency lower than 300 Hz can be used, called CTCSS *(Continuous Tone Coded Squelch System)*. There are 38 CTCSS tones in the range of 67÷250 Hz. If the transmitting radio transmits a voice signal with CTCSS tone No. n_1, only radios with CTCSS tone n_1 set will emit voice acoustic signal, and other radios without the CTCSS tone set or with a different CTCSS tone set will have the voice channel blocked. This way you can limit the number of radios receiving your radio call. Fig. 5.14 shows the operation of radios using CTCSS tones.

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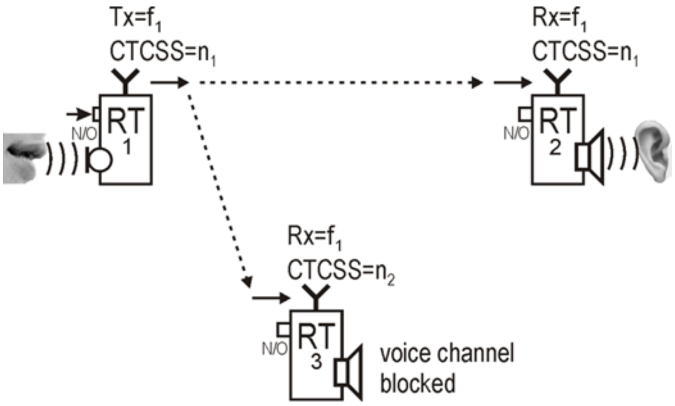

Fig. 5.14. Illustration of radio operation in a single-frequency simplex system using CTCSS tones

Sometimes a CTCSS tone is called a subchannel. This name is misleading because conducting a conversation using the CTCSS tone causes the frequency channel to be occupied and another user cannot use this frequency channel by setting a different CTCSS tone number. A single-frequency system is difficult to adapt to work with lines containing a radiating cable and amplifying devices that would have to amplify the radio signal in both directions in the same frequency channel. The exception is the GABI-98 rescue radio communication system, in which the gain direction is set by the base radio [Miśkiewicz, 2010].

To build radiocommunication system with a longer range, radiotelephones adapted to work with a repeater are used, in which transmitters and receivers use channels of different frequencies, and transmission in both directions cannot take place at the same time. This way of working is called **semi - duplex** [Kettelring, 2004]. The transmitter of each radiotelephone uses a channel with frequency f_u and the receiver uses a channel with frequency f_d. Half-duplex radios require a pair of frequency channels. In half-duplex systems, the frequency channel is often considered to be the pair of channels necessary for transmission to and from the repeater.

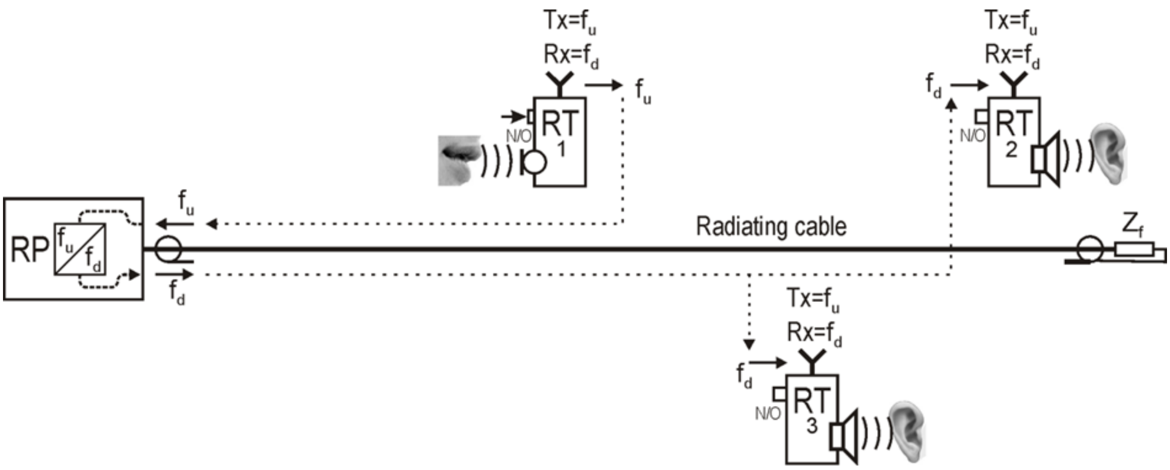

Fig. 5.15. An example of a single-channel, half-duplex radio communication system using a radiating cable

Fig. 5.15 shows an example of implementing a radiotelephone communication system using a radiating cable. Pressing the N/O button on the RT1 radio will transmit a signal on the f_u frequency. This signal enters the radiating cable and is then transmitted to the RP converter. In the converter, the signal from the channel with frequency f_u is converted to the channel with frequency f_d and transmitted to the radiating cable. The signal from the channel with frequency f_d is emitted outside the radiating wire and is received by radiotelephones RT2 and RT3.

If one channel is not enough to support radiotelephone communication, a larger number of repeaters should be used (one repeater for each channel). The converters are mounted in a suitable rack. Each repeater has an Rx input tuned to the appropriate frequency and a Tx output (transmitter) supporting the appropriate frequency channel. All inputs and outputs are connected to the radiating cable via the head. The head provides:

- mutual separation of the outputs of individual converters,
- separation of transmitting and receiving frequency channels using band-pass filters.

Fig. 5.16 shows an example of a two-channel, half-duplex radiotelephony system using a radiating wire. The RT1 radio transmits on the f_{1u} frequency. The RT1 radio signal is received by the RP1 repeater. At frequency f_{1d} it is transmitted to the radiating wire and then received by the RT3 radiotelephone. Communication between the RT2 radiotelephone and the RT4 radiotelephone takes place in a similar way via the RP2 repeater. The presented system allows for handling two calls simultaneously using two frequency channels. Individual frequency channels can be assigned to specific user groups in the mine, e.g. channel 1 - shaft department, channel 2 - transport department, channel 3 - power-mechanical department.

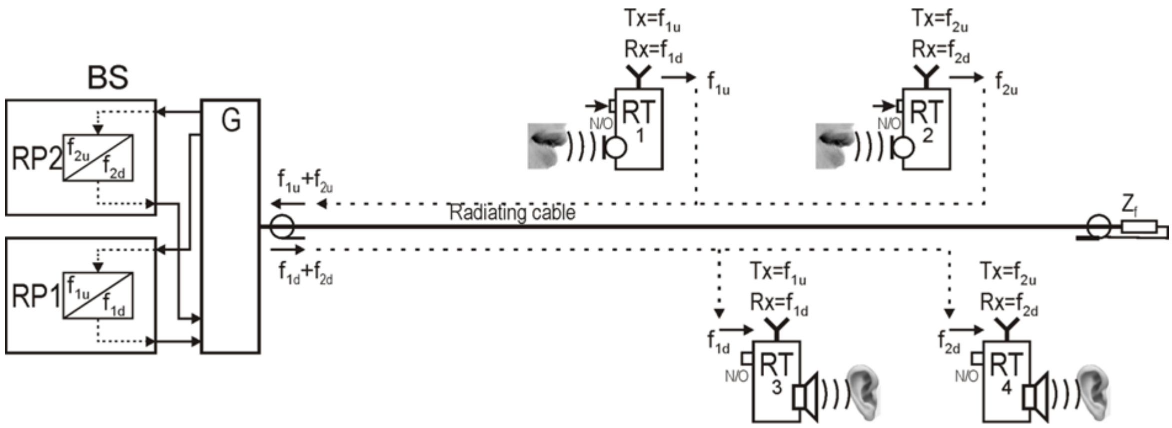

Fig. 5.16. An example of a two-channel, half-duplex radio communication system using a radiating cable

Radiating wire systems can also use CTCSS signaling for selective calling.

5.6. Digital systems

Two standards for the digital implementation of voice services that are used in radiating cable systems in mining will be briefly discussed:

- **DMR** standard,
- **TETRA** standard**.**

The DMR standard has been developed by ETSI in the form of a series of standards [ETSI 102361]. DMR standards have been developed for three levels:

– level I, intended for simplex digital radiotelephone communication in direct mode (without infrastructure) in the unprotected 446 MHz band (446.1÷446.2 MHz) using a radio transmitter power of 0.5 W,
– level II, intended for half-duplex digital dispatcher radiotelephone communication using repeaters licensed VHF bands (136÷174 MHz) and UHF (400÷470 MHz),
– level III, intended for trunked digital radiotelephone communications using repeaters in the licensed VHF bands (136÷174 MHz) and UHF (400÷470 MHz).

DMR radiotelephony communication is characterized by the following properties:

– frequency channels with a channel spacing of 12.5 kHz,
– two time slots with a duration of 30 ms were created in each frequency channel, due to which one frequency channel can be used to simultaneously transmit two calls at the same time,
– a frame transmitted in a time slot (burst) lasts 27.5 ms and contains 216 bits of data (compressed voice) and 48 bits for synchronization and internal signaling,
– digital voice is compressed with the AMBE+2 codec to a bit rate of 9.6 kbps,
– the digital signal is transmitted with four-valued phase modulation 4-PSK.

Fig. 5.17 shows the temporal structure of slots in DMR systems. Each 30 ms time slot contains a 27.5 ms frame *(burst)*. In the frequency channel directed towards the base station between the frames of individual slots there is a guard gap of 2.5 ms, while in the frequency channel directed from the base station between the frames of time slots there is an administration channel CACH *(Common Announcement Channel)* 2.5 ms long.

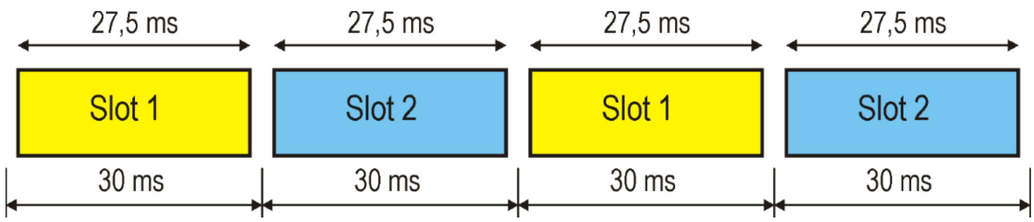

Fig. 5.17. Time structure of transmission in the DMR system

Fig. 5.18 shows the structure of a DMR time slot frame. The frame contains two 108 bits of data or compressed voice (AMBE+2 codec), with 48 bits inside for synchronization or signaling purposes. Signaling bits enable the implementation of many advanced services, such as pseudo-trunking or various calling modes.

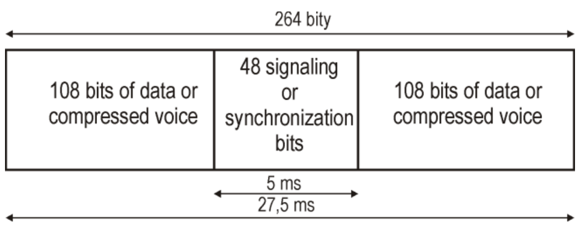

Fig. 5.18. Construction of the DMR system frame

The DMR system results in better spectrum utilization compared to analog systems, because two independent conversations can be conducted simultaneously in one 12,5 kHz frequency channel. The radio's transmitter does not transmit continuously, but only during its designated time slot (not the entire time, only 27.5 ms [ETSI 102361-1]), which corresponds to transmitting 45% of the time and saves energy from the radio's battery.

Fig. 5.19 shows an illustration of two independent simplex conversations in direct mode. Radiotelephones are set to a common frequency channel for transmitting and receiving. Radio RT1 transmits in time slot 1 and radio RT2 receives in time slot 1. Radio RT3 transmits in time slot 2 and radio RT4 receives in time slot 2.

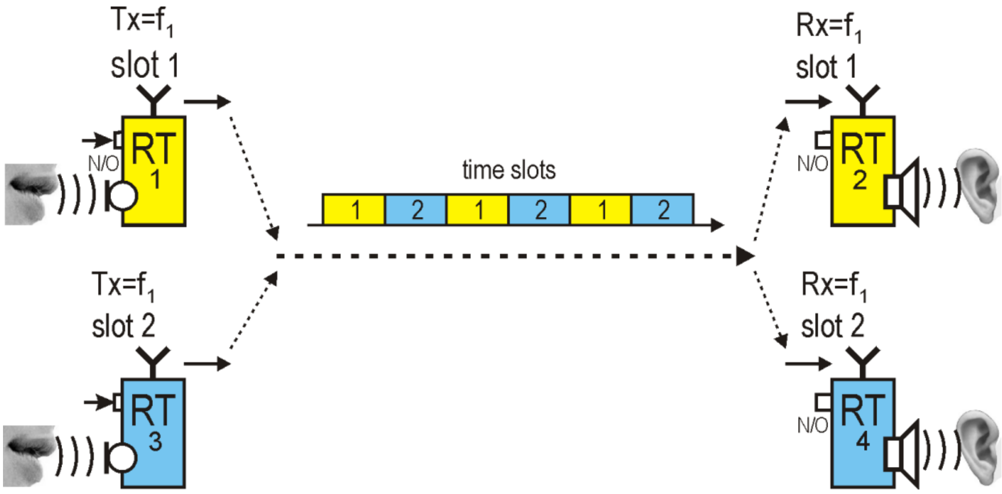

Fig. 5.19. Illustration of the operation of a simplex DMR communication system in direct mode

Operation in direct mode takes place without the use of a radiating cable and a base station. The range for this type of mode depends on the frequencies used and the propagation conditions in mining workings. If it is necessary to obtain a larger communication range, a radiating cable and a base station containing one or several repeaters are used.

Fig. 5.20 shows an example of a communications system with a radiating cable and a base station containing 1 repeater. In this type of system, two conversations can be conducted on a common frequency channel.

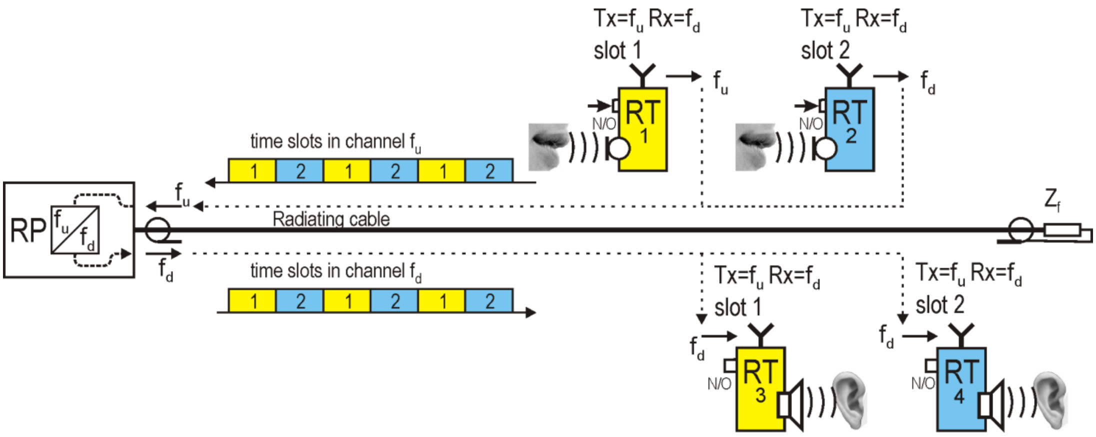

Fig. 5.20. Illustration of the operation of the communication system with DMR radios with an RP repeater and a radiating cable

In situations where two channels are insufficient, a larger number of repeaters can be installed in the base station, each of which supports two time slots. The converters are connected to the radiating cable via the head. They can be connected via an Ethernet computer network to the VoIP card of a telecommunications server, enabling the radios to be connected to subscribers of the company's telephone network. Fig. 5.21 shows an example of a DMR radiotelephone communication system with two repeaters and a connection to a telecommunications server via an Ethernet network. On the first frequency channel, a conversation is carried out from radiotelephone RT1 to RT6 (yellow - first time slot) and from radiotelephone RT2 to RT7 (blue - second time slot). On the second frequency channel, there is a call from the RT3 radiotelephone to RT5 (green - first time slot) and a call from the RT4 radiotelephone to the T telephone via a VoIP link and a telecommunications server (orange - second time slot).

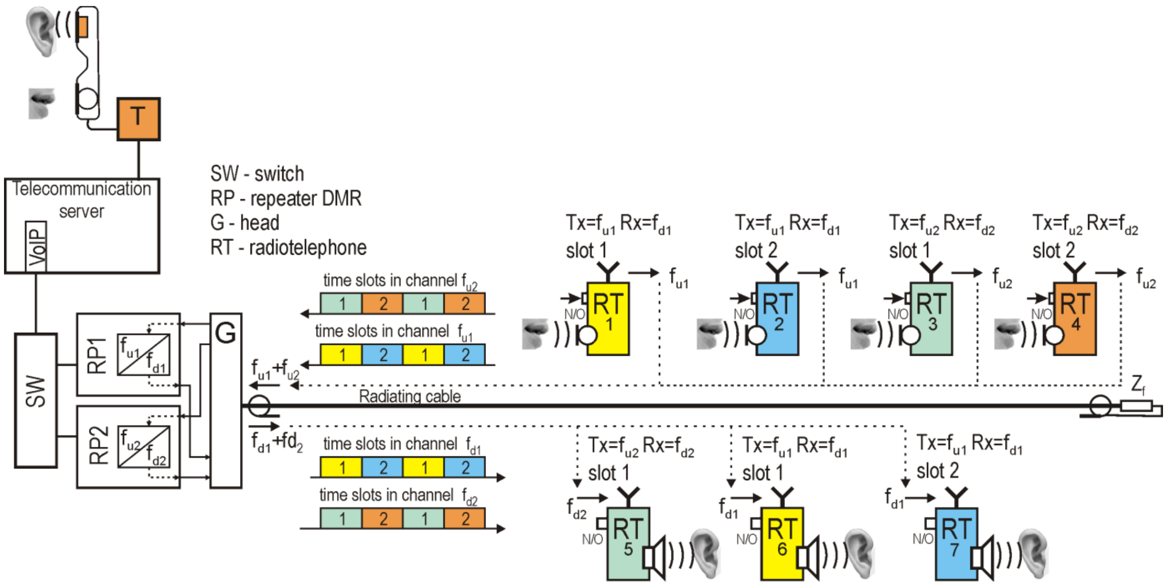

Fig. 5.21. Illustration of the operation of a DMR communication system with a radiating cable, two RP repeaters and a connection to a telecommunications server

The assignment of individual frequency channels and time slots in the DMR system can be done in two ways:

– statically, i.e. each talk group is assigned a frequency channel and a timeslot; it is a conventional (dispatching) system; the assignment takes place when configuring individual radios; this operating mode is defined at the Tier II level of the ETSI 102361 standard,
– dynamically, i.e. the frequency channel and slot are assigned for a given conversation; it is a trunked system. One of channels (frequency + slot) is the so-called a control channel not used for call transmission; the control channel is used to allocate a frequency channel and a slot for carrying out a conversation; this operating mode is defined at Tier III level of ETSI 102361.

Dla To obtain a trunked system, equipment (radiotelephones and repeaters) and a radio controller supporting trunking are necessary. A trunked system allows for better use of frequency channels, but requires more advanced (and more expensive) equipment.

The proprietary intermediate solutions have also been developed. Hytera has developed:

– pseudo-trunking,
– extended pseudo-trunking (XPT).

Pseudo-trunking refers to the allocation of a free time slot within a set frequency channel. A given frequency channel can be assigned to several user groups. All radios set to a common frequency channel listen to both time slots. If a user of any group presses the N/O button, the first free time slot will be occupied and all radios belonging to the selected group will receive the signal from the radio with the N/O button pressed. If a radio from another group presses the N/O button at the same time, it will occupy the other slot for the conversation. The user of the next group from the same frequency channel will not be able to call anyone because both time slots are occupied.

Extended XPT pseudo-trunking involves repeaters transmitting system status information on each frequency and time slot via a beacon, thereby informing radios of the availability of individual channels and time slots. The radios can switch to an available channel to begin communicating. This allows different users from specific groups to gain access to a free frequency channel and time slot of the communication channel without being assigned to a specific channel and time slot as in the case of conventional DMR Tier II solutions.

In the pseudo-trunking and extended pseudo-trunking systems, there is no queuing or priority management mechanism.

Motorola has developed several pseudo-trunking versions, of which the **Capacity Plus system** [Motorola] is used in mining. In this system, repeaters of all channels are connected via an internal LAN network to a radio controller (computer with appropriate software). All base station repeaters send information in the administration channel on which frequency channel and in which time slot the so-called resting channel. A new radio call takes place on the idle channel, and another free channel becomes the idle channel unless all channels are occupied.

In **trunked systems**, the simultaneous number of calls is greater due to dynamic channel allocation. If all channels are allocated, each incoming connection request is queued and completed as soon as channels become available in FIFO (*First in First Out*) order. Priorities can be set for individual connections so that connections with higher priority are immediately connected. The use of both pseudo-trunking and extended pseudo-trunking requires the use of hardware (repeaters and radios) and software that supports such functionality.

5.7. Wide area network of radiating cables

The radiating cable has a relatively high specific attenuation in the range of frequencies used (e.g. 4.3 dB /100 m, e.g. for FLFC3529, VLFC-IS cables - Table 5.1), which limits the length of the radiating cable to several hundred meters (usually 500 m). To obtain radio coverage in the most important workings of deep mines, it is necessary to install many kilometers of radiating cables, use many devices that amplify radio signals (including power supply systems), as well as splitters to build a branched network of radiating cables. Such a system can also be expanded with additional functions, such as narrowband or broadband data transmission.

A telecommunications system with a radiating cable installed in a typical mine consists of the following elements:

– base station (BS) containing (analog version): head, repeaters (RP), radio modems (RM), telephone interfaces (RICK), system modems (CMTS),
– repeaters (W),
– splitters (R),
– terminators (T),
– power couplers (PC) with power supplies (Z),
– radio modems (RM) and cable modems (MK).

Fig. 5.22 shows an example of a block diagram of a radiating wire radio communication system. The presented system enables:

– conducting two independent radiotelephone conversations simultaneously with using analog radiotelephones,
– possibility of connection between the radiotelephone and any subscriber of the telephone exchange on both channels,
– slow data transmission between mobile radio modems or those connected to the radiating cable and the radio modem in the base station (e.g. 9600 b/s),
– broadband data transmission between cable modems, and CMTS system modem.

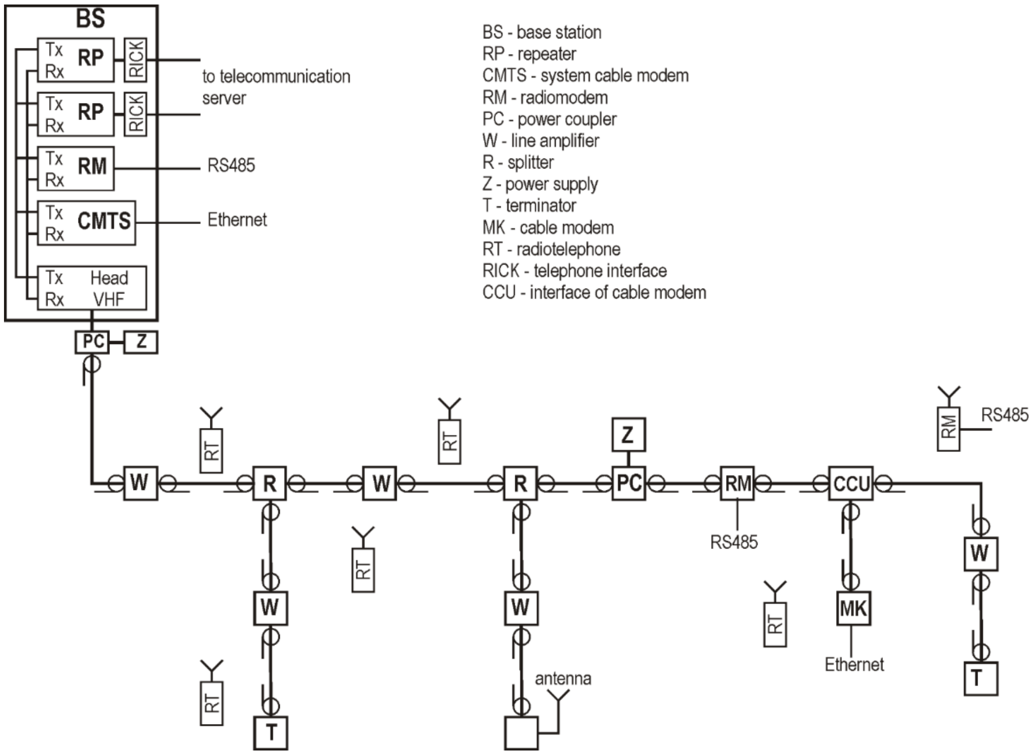

Fig. 5.22. An example of a radiocommunication system with a wide network of radiating cables

During transmission, the radio signal from the RT radio enters the radiating cable and is transmitted "upwards" to the base station (usually located on the surface in control rooms), and is amplified in subsequent repeaters. In the base station repeater (RP), the radio signal is shifted to the "down" band and is transmitted to the radiating wire. In individual repeaters, it is amplified and at the same time radiated outside and received by radios set to reception.

The RICK telephone interface allows you to connect your radio with a telephone exchange subscriber and conduct a conversation. Radio modems occupy an assigned frequency channel and allow data transmission in both directions. Cable modems enable broadband data transmission.

5.7.1. Line amplifiers

The signal in the radiating wire is transmitted in two directions (in different frequency bands for each direction). To amplify the radio signal in such a case, it is necessary to use **a line amplifier**, i.e. a device that amplifies the radio signal in both directions. Fig. 5.23 shows a simplified block diagram of the line amplifier. It contains two amplifiers that amplify the signal in both directions. Input and output band-pass filters work with the amplifiers. Amplifiers have the ability to adjust the gain. This regulation can be manual (setting the appropriate gain after completing the system installation) or automatic, using a pilot signal.

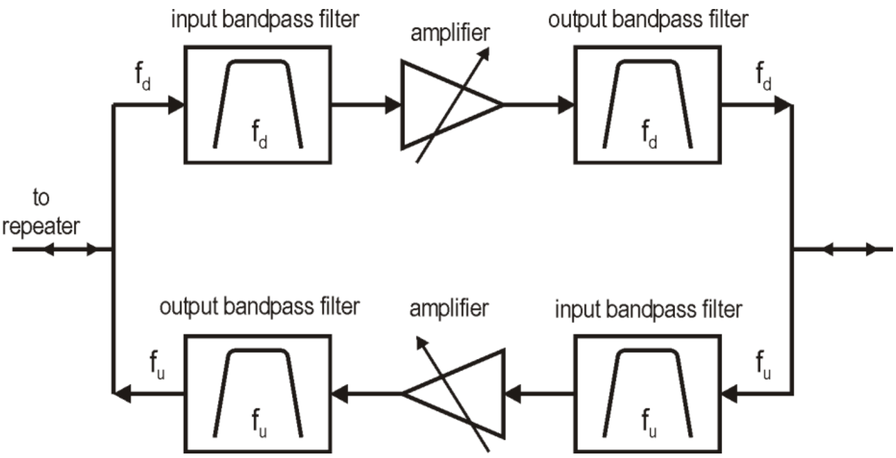

Fig. 5.23. Simplified block diagram of the line amplifier

When a radiating cable is used for broadband data transmission, the number of amplifying branches is greater. Fig. 5.24 shows examples of repeaters from TRANZTEL and PBE (*Pyott Boone Electronics)* used in JSW SA mines.

a) WLB-IS b) BDA-4 hybrid

Fig. 5.24. Examples of repeaters from companies: a) TRANZTEL, b) PBE [TRANZTEL, PBE]

5.7.2. Splitters

The need to ensure radio communication in the complex system of mine workings necessitates the use of branching radiating cables. Such branching requires maintaining the

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conditions for matching the wave impedance of the cable. To maintain wave matching in such cases, splitters are used, which enable:

– transmission of the radio signal from the base station to all branches of the radiating cable (outputs) with appropriate power division,
– transmission of a radio signal from individual outputs to the base station,
– transferring DC power between input and individual splitter outputs.

The terms "input" and "output" of the splitter should be treated conventionally and refer to the transmission of a radio signal from the base station. Splitters can be passive or active devices (i.e. they can contain signal amplifiers). In the case of a passive splitter, the power supplied to the input is not less than the sum of the power at the outputs (when loaded with impedance Z_f). This means that in the case of a double splitter, the output power is no more than 0.5 of the input power and then the splitter attenuation is no less than 3 dB (usually 3.5÷6 dB). In the case of a lossless triple splitter, there can be found attenuations of 3 dB for one branch and 6 dB for the remaining branches. Real splitters have higher attenuation than lossless ones. Fig. 5.25 shows examples of splitters from TRANZTEL and PBE.

a) VBU1-IS

b) BU2

Fig. 5.25. Examples of splitters: a) double by TRANZTEL, b) triple by PBE [TRANZTEL, PBE]

5.7.3. Terminators

Each section of radiating cable should be loaded (terminated) with a wave impedance to avoid signal reflection from the impedance mismatch at the end of the cable, resulting in a standing wave and local signal dropouts. This ending is the terminator. Electrically, a terminator is a series connection of a resistor (with a resistance equal to the wave impedance of the radiating cable, 75 W for systems operating in the UHF range and 50 W for systems operating in the VHF range) and a capacitor eliminating the flow of direct current from the power source through the terminator. As an ending of the radiating cable ensuring wave matching can also act a properly selected antenna.

Fig. 5.26 shows examples of terminators from TRANZTEL and PBE. Terminators from some companies (e.g. PBE) include a pilot tone generator. The generator produces a signal with a fixed frequency (e.g. 175 MHz) and a set level. The pilot signal is used to adjust the gain of the repeaters.

a) VTB-IS

b) TB

Fig. 5.26. Examples of terminators: a) VTB-IS by TRANZTEL, b) TB by PBE [TRANZTEL, PBE]

5.7.4. Power couplers

Amplifiers used in radiocommunication systems with a radiating cable are active elements that require DC power supply. To reduce the number of power supplies, several amplifiers are powered from one power supply, introducing direct voltage into the radiating cable via the power coupler.

Power coupler PC1 (the diagram of which is shown in Fig. 5.28) has two functions:

- introduces DC voltage from the power supply to the radiating cable, causing slight attenuation of the carrier signal in the cable line,
- divides the radiating cable (with a capacitor) into separate power supply zones of different power supplies to prevent parallel connection of different power supplies (which is particularly important in intrinsically safe systems).

Fig. 5.27 shows a view of the power couplers used at JSW SA.

a) VPCD-IS

b) PC

Fig. 5.27. Examples of power couplers: a) VPCD-IS by TRANZTEL, b) PC by PBE [TRANZTEL, PBE]

5.7.5. Power supply for repeaters

A number of elements are incorporated into the radiating cable to enable the operation of the radiocommunication system. Some of these components (e.g. repeaters) require DC power. The power supply is most often provided by introducing direct voltage from the power supply into the radiating cable through a power coupler. Individual devices that require power draw power from the radiating cable. The radiating cable is then used both to transmit the carrier signal and to power the devices with direct current. The flow of direct current in the radiating cable causes voltage drops and therefore the voltage at the terminals of individual devices is lower than the output voltage of the power supply. The radiating cable installation should be designed and constructed in such a way that the voltage at the terminals of each device (requiring DC power supply) is greater than the minimum voltage supplying the device U_{zmin}.

Typically, a radiating cable installation is divided into sections powered by separate power supplies. Individual sections are separated by capacitors, which are in power couplers, so that individual power supplies are not connected in parallel.

In the case of intrinsically safe installations, separation of individual sections is necessary and for this purpose three series-connected capacitors with a voltage class of at least 1500 V are used. Fig. 5.28 shows an example of a diagram of a radiocommunication system with a radiating cable of the MCA 1000 type, highlighting the elements important for powering individual devices.

The power supply to the radiating cable is provided by the power coupler (PC1 – Fig. 5.28). The coupler has a capacitance separating the individual power supply zones, as well as a small inductance blocking the flow of the carrier signal to the power supply. In line amplifiers (W) there is a DC bypass (series inductances and parallel capacitance) to pass the supply voltage to the next section of radiating cable. Similar workarounds also exist in other components, such as splitters (R). The terminators (T) contain a resistor with a value corresponding to the wave impedance of the radiating cable, connected in series with the capacitor so that the terminator does not constitute a receiver for direct current (this would be an unnecessary loss of power).

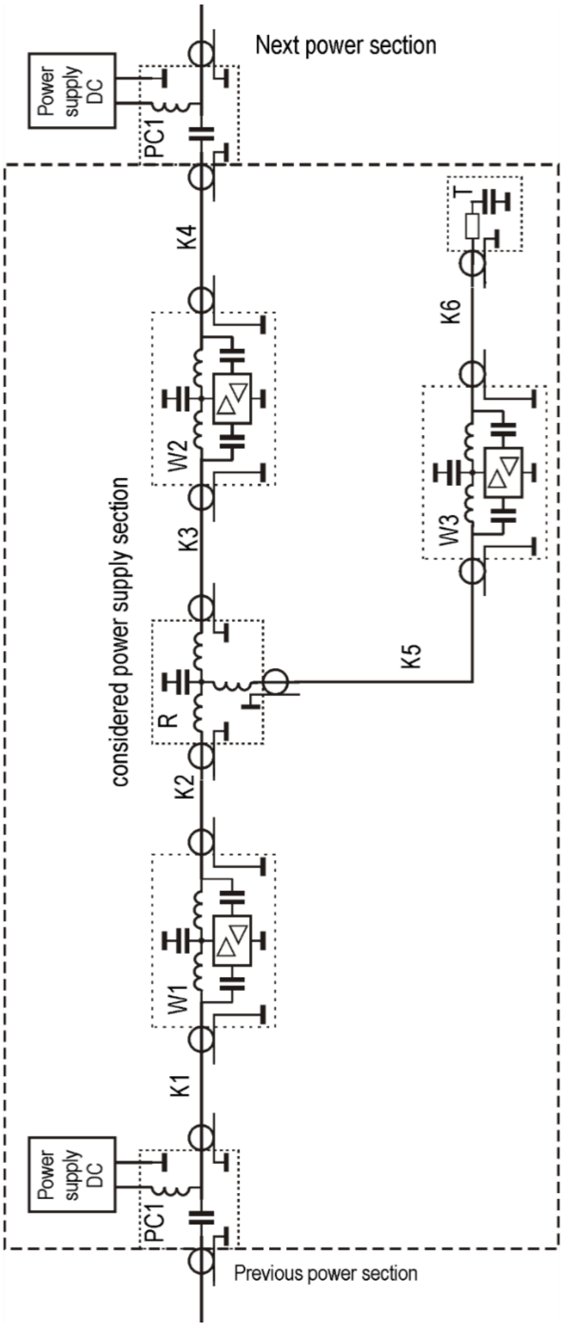

Fig. 5.28. An example of a power supply system for one section of a radiating cable

The proper operation of a radio communication system using a radiating cable depends on the correct power supply of the repeaters. The direct current flowing in the radiating cable causes voltage drops, which reduces the voltage supplying individual amplifiers. The supply voltage of individual repeaters should not be less than the minimum voltage for a given repeater type. The correctness of the power supply system should be analyzed at the design stage of the radiating cable radio communication system. Details of the analysis of the power supply system are given in the literature [Miśkiewicz, 2010].

The power supply for active elements (mainly repeaters) should have battery backup, which will ensure the functioning of the system in the event of a lack of voltage in the power grid supplying these power supplies, which often occurs in underground mines. The battery backup time depends on the functions of the radio communication system with a radiating cable. Battery backup can be implemented in two ways:

– centralized (one battery built into the DC power supply or UPS power supply),
– distributed (power supply without batteries, while batteries are installed in any device requiring power).

For the proper operation of the radio communication system, it is important to monitor the status of the power supply system and provide the system administrator with information about the battery operation of the power system via the radio communication system or an external data transmission system (e.g. UTS, FOD-900, etc.) and appropriate visualization software.

5.7.6. Base station for analog systems

Schemat The block diagram of the base station (for analog systems) is shown in Fig. 5.29. The base station is an element containing repeaters for each speech channel.

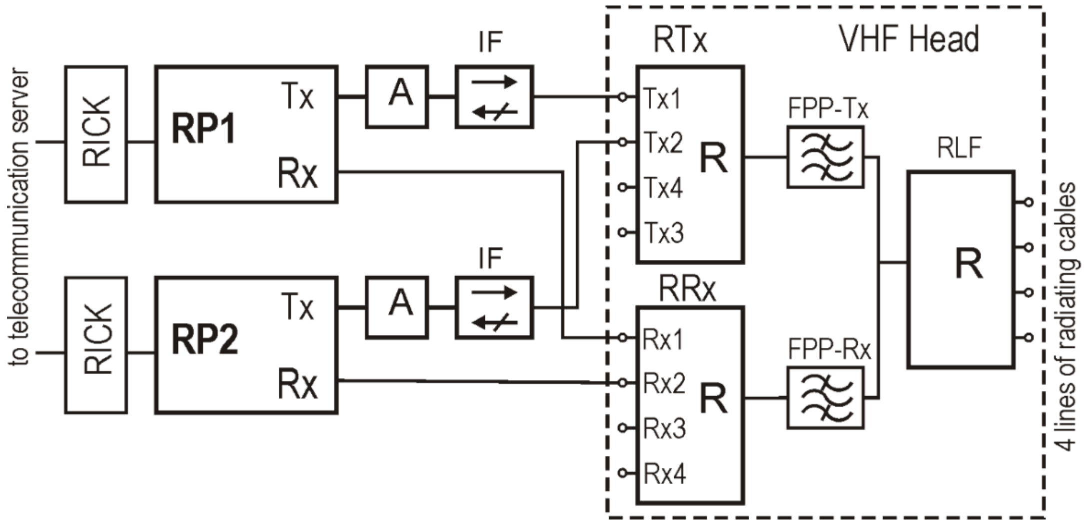

Fig. 5.29. Block diagram of a base station for a two-channel radiocommunication system with a radiating cable, operating in a dispatcher system

Repeater RP consists of a pair of radios connected to each other by an interface sometimes called RICK *(Repeater Interface Communication Kit)*. One of the radios is permanently switched to receive, and the other is prepared for transmission. If the signal level at the antenna input of this telephone is higher than the squelch level, the receiver is activated and the signal is transmitted to the transmitter. As a result, the acoustic signal received by the receiver is transmitted on a different carrier frequency by the transmitter and fed to the radiating cables. The repeater may consist of two properly configured radios (the solution used in the FLEXCOM system) or it may be a separate device (e.g. the FR-3100 repeater from ICOM in the MCA-1000 system shown in Fig. 5.32) [Miśkiewicz, 2010].

The RICK interface can be used to connect a voice channel to a telephone exchange. Then the user of the radiotelephone (equipped with a keyboard) can dial the telephone exchange subscriber's number and talk to him. Conducting this type of conversation is a bit troublesome because the radiotelephone user activates the transmission using the N/O (transmit/receive) button, while the radio's RT (transmission) is activated via the RICK interface based on the measurement of the acoustic signal level coming from the telephone exchange, which requires some discipline in the telephone exchange subscriber's conversation.

Dialing information can be transmitted from the radio to the RICK interface using various methods, depending on the functional capabilities of the radio and the RICK interface. An example The RICK interface is the 48-MAX type Interconnected Repeater Panel (Fig. 5.32).

Attenuator (6 dB /50 W) and a ferrite IF insulator are connected to the antenna output of the RT radio transmitter. The ferrite insulator is a four-terminal network that allows energy to flow in one direction (with low attenuation below 1 dB) and absorbs energy transmitted in the other direction [Szóstka, 2008]. Fig. 5.30 shows an example of an I2111A ferrite insulator by Sinclair. A ferrite insulator is used to limit the interaction between radio transmitters.

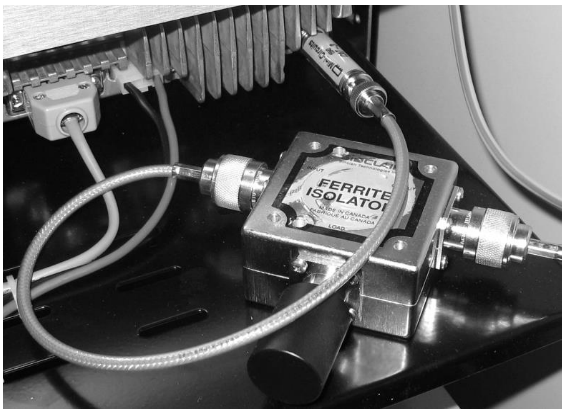

Fig. 5.30. Ferrite insulator type I2111A from Sinclair

The second basic element in the base station is the head-end coupler. In the base station, it performs the following functions:

– receives radio signals from all transmitters of channel repeaters (terminals Tx1 - Txn), sums them and distributes them, e.g. to four radiating cable line,
– receives radio signals with max. four lines of radiating cable, sums them up and distributes them to individual receivers RT on terminals Rx1 – Rxn.

Sygnały The output signals from the RT radios are fed to the RTx splitter in the head, which sums the signals from the individual radios, limiting the crosstalk of signal from each radio to the others and ensuring wave matching. After summing, the signal passes through an FPP- Tx band-pass filter tuned to the downstream band of the system and then to the RLF splitter, which branches the signal onto four radiating wires. The signal from the radio transmitters does not pass through the FPP-Rx filter to the repeater receivers because it lies outside the passband of these filters.

The "upstream" signal from individual radiating cables (Fig. 5.29) is summed in the RLF splitter and fed to the FPP- Tx and FPP- Rx band-pass filters. The part of the signal (in terms of spectrum) that contains signals from mobile radios comes only through the FPP- Rx filter and, after branching, is fed to radio receivers (Rx) serving individual channels. The head is often a passive system that does not require power. Fig. 5.31 shows the view of the head of the MCA 1000 system, and Fig. 5.32 shows the views of the base station of the MCA 1000 system.

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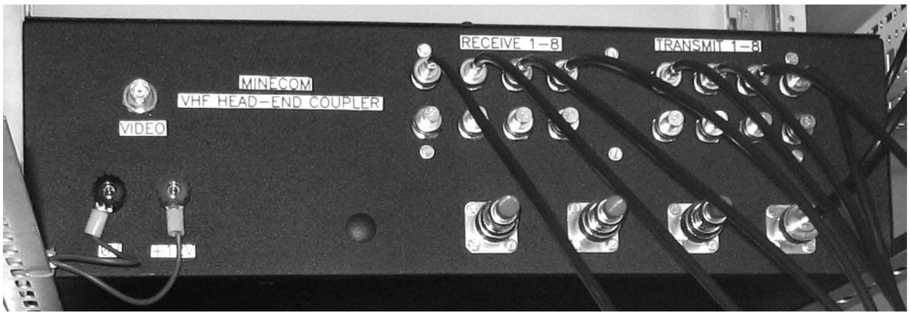

Fig. 5.31. Rear view of the base station head (MCA 1000 system). The top terminals are for connecting radios (receiving and transmitting), and the bottom terminals are for connecting the four lines of radiating cable

Fig. 5.32. View of the base station of the MCA 1000 system. Visible are: four ICOM repeaters, head (top), 48-MAX interface from ZETRON (bottom)

5.7.7. Adjusting the amplifier gain

The gain of the repeater should compensate for the attenuation introduced by individual sections of the radiating cable, or by other elements, such as splitters. Fixed amplifier gain can cause problems due to signal levels being too low or too high.

Fig. 5.33 c) shows the course of the signal level from the base station as a function of the distance x, when the wave attenuation of individual sections is equal to the "downstream" gain of the repeater. When the radiating cable sections are shorter than those resulting from the amplifier loss, signal levels increase, which may lead to amplifier clipping (Fig. 5.33 b). If the radiating cable sections are longer than those resulting from the gain of the repeater, the signal level decreases, which will reduce the radio range (Fig. 5.33 a).

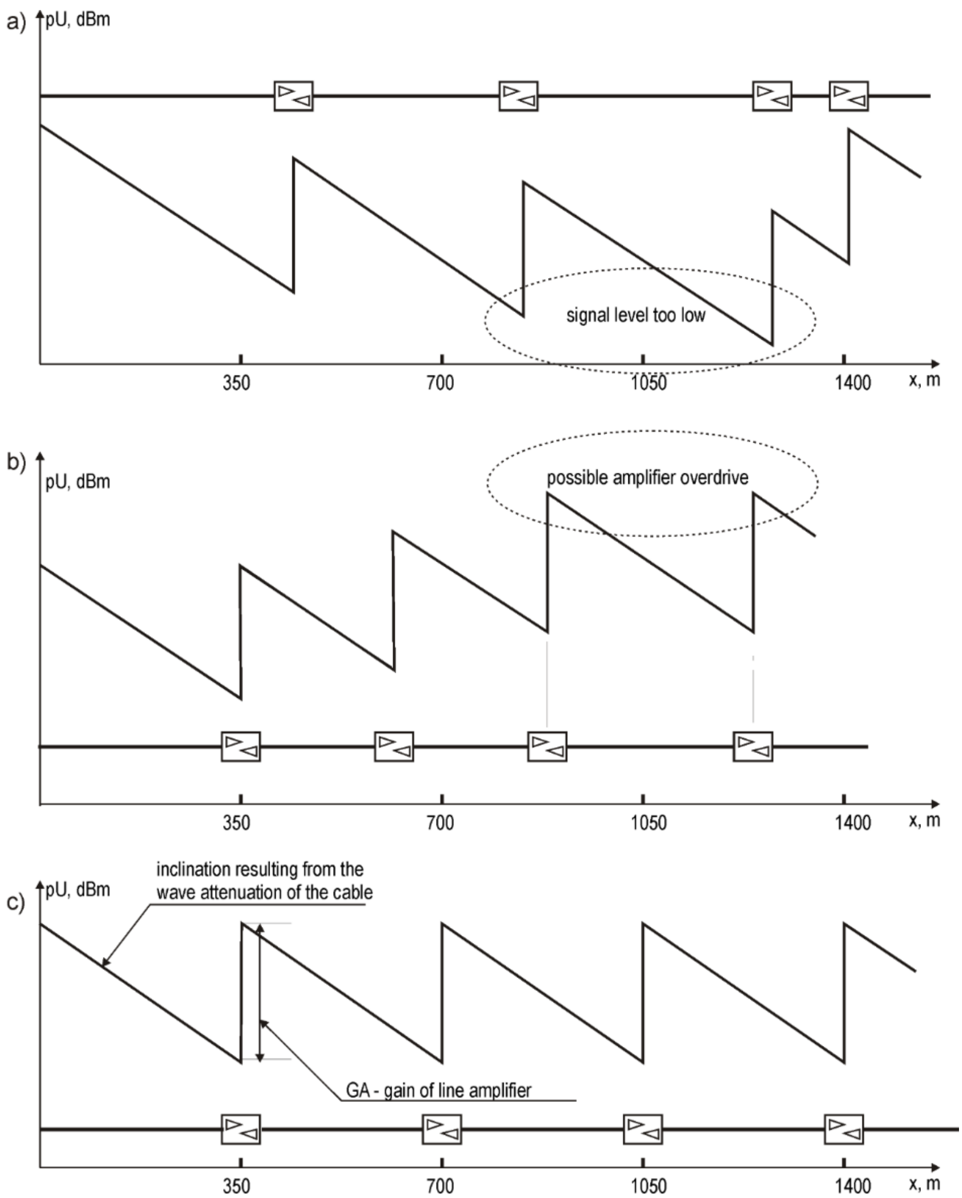

Fig. 5.33. Waveforms of the signal level in the radiating cable (direction from the base station) as a function of the distance, with constant gain of the repeater: a) for too long cable sections, b) for too short cable sections, c) for properly selected radiating cable sections

A better solution is to be able to adjust the amplifier gain. The following solutions are possible:

– manual adjustment of the amplifier gain (jumper, switch); the correct gain setting is assessed by measuring the signal level from the base station (after pressing the u N/O button on the radio) or by observing the diodes signaling the correct signal level from the base stationej,
– use of amplifiers with automatic gain control (AGC),
– the use of amplifiers with gain regulated by a pilot signal.

An amplifier with automatic gain control is characterized by the fact that whenever the input voltage level exceeds a certain value, the output voltage level is constant, practically independent of the input voltage level (the higher the input voltage level, the lower the amplifier gain). Fig. 5.34 shows the signal level (from the base station) as a function of distance using a repeater with a gain of 24 dB and an output voltage level of +10 dBm.

If a pilot signal is used, the pilot (a generator not modulated by any signal) can be installed either in the base station or in the furthest repeater. Then the automatic gain control system selectively measures only the pilot signal.

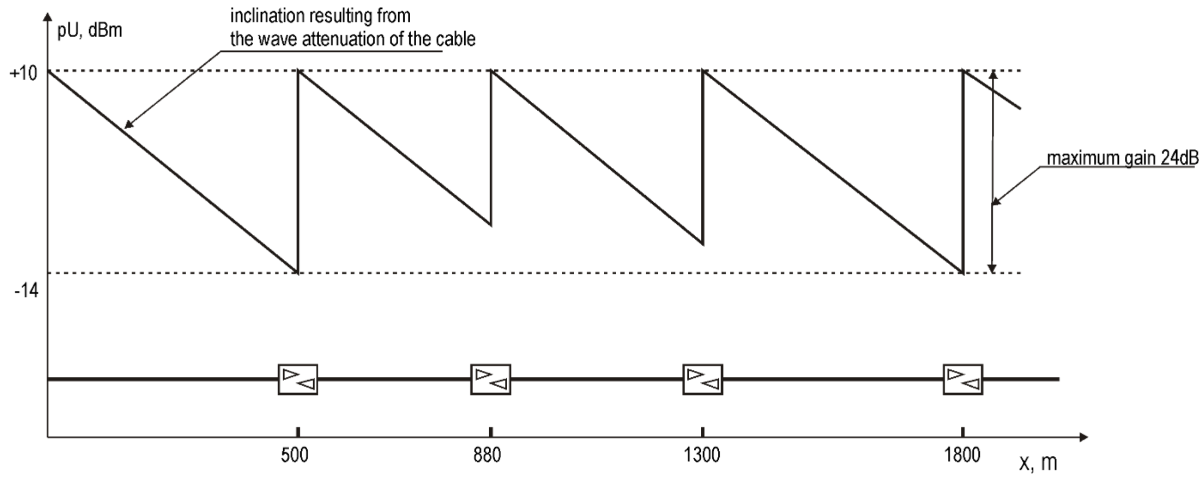

Fig. 5.34. Waveforms of the signal level in the radiating cable (direction from the base station) as a function of distance using an amplifier with the AGC function with a gain of 24 dB and an output voltage level of +10 dBm

In the case of automatic gain control in radio communication systems, there is a cascade connection of amplifiers with automatic gain control. Fig. 5.35 shows a simplified block diagram of the downlink path for a chain connection of three repeaters. The output signal of the amplifier is fed to the detector D, and the output signal from the detector is compared with the set value. The difference in the signals through the filter controls the gain of the amplifier.

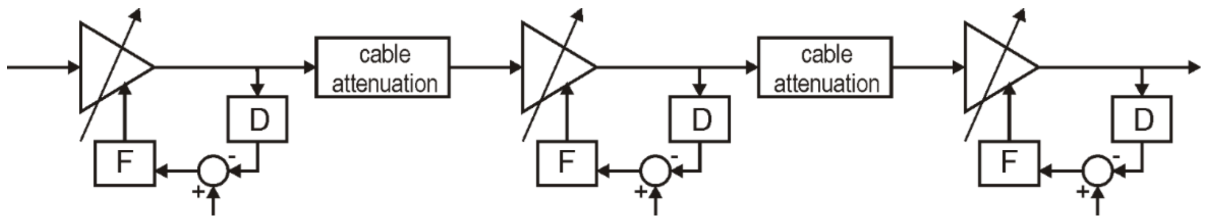

Fig. 5.35. Simplified block diagram of a chain connection of repeaters

In some solutions (e.g. MULTICOM 2.1), the pilot signal generated in the terminator is used to adjust the gain of the amplifiers in the repeater.

The analysis of the control properties of the chain connection of repeaters was carried out by Farjow [Farjow, 2009]. He proposed using the signals of three pilots in the path from the base station and introducing amplifier gain adjustments in both directions and correction of the amplifiers' frequency characteristics in both directions. This type of solution has been used, among others, in newer versions of the MULTICOM system by PBE.

5.8. Conventional radiocommunication systems with a radiating cable in mining

Conventional analog radiating wire radio systems used in mining have the structure shown in Fig. 5.22. The following systems are used in underground mines, among others:

- FLEXCOM by Mining Radio System,
- MULTICOM by Mining Radio System,
- MCA 1000 by Tranztel,
- BeckerCom by Becker Mining Systems,
- SmartComm by VARIS Mine Technologies.

A detailed description of these systems is presented in the monograph [Miśkiewicz, 2010].

5.9. Digital radiocommunication systems with radiating cable in mining

New solutions of radio communication systems with a radiating cable use digital radios operating in the DMR standard. TRANZTEL has developed a digital radio communication system with the MCA1000digi radiating cable. The view of the system's base station is shown in Fig. 5.36.

The base station contains two RD985S repeaters from HYTERA, a head, a 24-port switch (not visible in the drawing) and a power supply system with an overcurrent protection panel. RD985S repeaters can support both digital DMR (Tier II layer with the ability to support extended XPT trunking) and analog radios. The network of radiating cables (amplifiers, splitters, terminators, power couplers) is practically the same as the MCA1000 analog system from TRANZTEL. In mines at risk of coal dust and/or methane explosions, the MCA 1000 digi system uses intrinsically safe HYTERA radios, types PD795IS, PD715IS and TTR-100, with the I M1 Ex ia I marking. Fig. 5.37 shows examples of intrinsically safe HYTERA radios, type PD795IS (with display), PD715IS (without display) and TTR-100 (with display). Selected manipulation elements are described for the PD795IS phone, such as the power switch with volume control, channel selection knob, N/O (PTT) button. The PD715IS and PD795IS radios can operate in the following modes:

- conventional analog or trunked analog MPT1327,
- conventional DMR (Tier II) or trunked DMR (Tier III),
- extended pseudo-trunked XPT.

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Fig. 5.36. View of the base station of the MCA1000 digi system from TRANZTEL

Fig. 5.37. View of the PD795IS, PD715Ex, TTR-100 digital radios from HYTERA

If the system is installed in a methane mine, the network of radiating cables must be intrinsically safe, separated from the base station by an intrinsically safe barrier, users should use intrinsically safe radios (I M1 Ex ia I), and the base station must be installed on the surface or underground in a working with an explosion hazard category "a".

The MCA-1000 digi system can be supplemented with a connection to a telecommunications server equipped with a VoIP card (telephone exchange) and a connection to the dispatcher console. The block diagram of the MCA-1000 digi system is shown in Fig. 5.38.

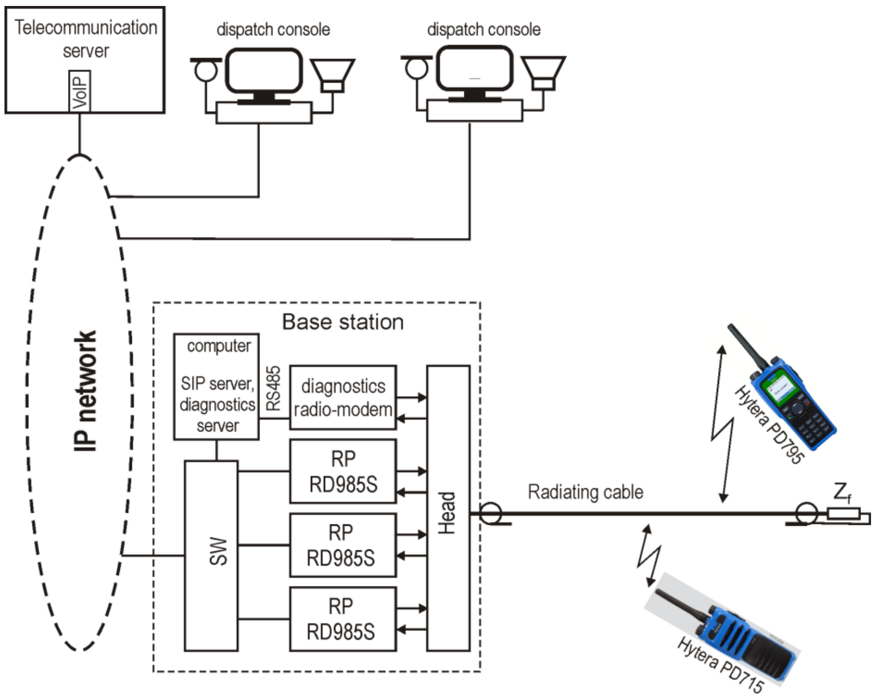

Fig. 5.38. Block diagram of the MCA-1000digi radio communication system

The set of RD985S repeaters is supplemented with a radio modem receiving diagnostic signals from individual repeaters. The modem transmits diagnostic signals to the computer via RS485. The repeaters are connected to the SW switch via Ethernet links. The computer has a SIP server installed to handle voice calls with a VoIP card of the telecommunications server. Dispatcher consoles (a computer equipped with a microphone and loudspeaker) can be connected to the SW switch via a computer network, enabling, among other things, the dispatcher's voice calls to radiotelephones.

A modification of the MCA-1000 digi system called the SCS 1000 digi Shaft Communication System can be used for communication between the driver of the skip hoisting machine, the crew in the mining vessel (cage, skip) and the staff of signal stations at shaft bottom and shaft top. In the SCS-1000 digi system, due to the nature of his work (both hands are occupied), the hoisting machine driver is equipped with a stationary radiotelephone with an external microphone and a foot-operated PTT button. System users can use DMR radios (Tier II level).

Emitech together with PBE (Pyott Boone Electronics) offers a radio communication system with a radiating cable called MULTICOM for mines in several versions. This is a system using DMR repeaters and DMR radios by Motorola. It uses pseudo-trunking with the trade name Capacity Plus. Fig. 5.39 shows the block diagram of the MULTICOM 2.1 system with the extension of dispatcher communication under the trade name SmartPTT.

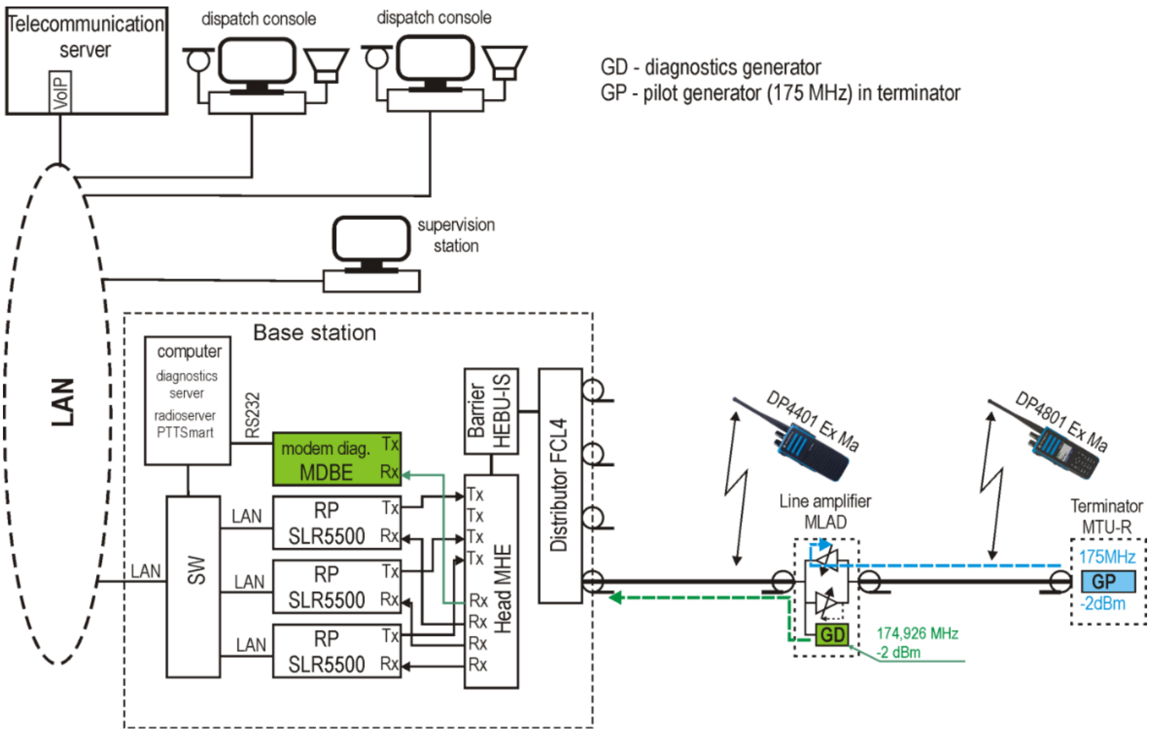

Fig. 5.39. Block diagram of the station part of the MULTICOM 2.1 system

The MULTICOM 2.1 system uses SLR5500 repeaters by Motorola. In methane mines, intrinsically safe Motorola radios of the type DP4401 Ex Ma (without display) and DP4801 Ex Ma (with display) with the marking I M1 Ex ia Ma are used as mobile terminals. In the base station, SLR5500 DMR repeaters and an MDBE diagnostic modem are connected to the head.

The MULTICOM 2.1 system can be supplemented with the SmartPTT platform, which contains dispatcher consoles and performs dispatcher radio communication functions. To operate the SmartPTT platform, the base station has a control computer with software to support dispatcher communications (radio server SmartPTT). The control and diagnostic computers are connected via an RS232 link to the modem.

The DMR repeaters and the control computer are connected to the SW switch, creating an internal LAN network to which the dispatch consoles and the supervisory station are connected. The dispatcher's console is a computer equipped with a microphone and speakers enabling voice communication between the dispatcher and radios in various configurations. In addition, the dispatcher can send short text messages from the console to the radios requesting confirmation. By connecting the base station via a computer network to the VoIP card of the telecommunications server and supplementing the control computer software with a SIP Interconnect license, you can get automatic connection between radiotelephones and subscribers of the company's telephone network. It is also possible to use a telephone interface and connect the base station to a telecommunications server using a DC subscriber link.

In the underground part of the MULTICOM 2.1 system, a number of elements are used to provide power to the repeaters, branching of the radiating cable, terminating the radiating cable with wave impedance and amplifying the radio signal in both directions. A characteristic feature of the MULTICOM 2.1 system is the "up" regulation of the amplifier gain by pilot signal. The MTU-R terminator contains a pilot signal generator with a frequency of 175 MHz and a level of -2 dBm. The "up" amplifier gain in the repeater is adjusted to obtain a pilot signal level at the amplifier output of -2 dBm (blue line in Fig. 5.39). For the "down" radio signal, a typical AGC system is used so that the output signal level does not exceed the set value, as shown in Fig. 5.34.

DMR digital radio communication systems can be configured with additional functions that increase operational safety, such as:

- Lone Worker,
- Man Down,
- alarm button operation,
- function of sending short text messages with confirmation of reception (Job Ticketing),
- signaling the absence of a radiotelephone in the system's radio range.

The **lone worker** function means that the radio detects the lack of activity of the employee in operating the radio. In the event of inactivity, the radio emits an acoustic warning signal at programmed intervals, and the user must press any button on the radio after hearing it. If the user fails to respond to the warning signal, the system assigns Emergency Status to the radio, which is visible on the dispatch console in the form of optical and acoustic signals.

The Man Down function means that in the event of the radio being immobile (detected by the internal accelerometer) for a specified period of time or the radio being tilted beyond the set limit position (fall), the system assigns the radio to an **emergency status for a set period of time**, which causes optical and acoustic signaling on the dispatch console and activation of the microphone ("*hot mic*") enabling the dispatcher to listen to the radio's surroundings.

Pressing the **alarm button** on the radio gives the radio **an emergency status**, which causes optical and acoustic signals on the dispatcher's console and activates the microphone allowing the dispatcher to listen to the radio's surroundings.

The dispatcher can send **a short text message to one user or a group of users**. The radiotelephone user is obliged to confirm reception of the message. This makes it possible for the dispatcher to send commands with confirmation of execution. Dispatch consoles provide the following functions:

- all types of calls - individual, group, conference, broadcast,
- caller identification (ID number displayed),
- intercom between dispatchers,
- keyboard for selecting the called subscriber 's number,
- receiving emergency calls for the "lone worker" function,
- checking the presence of the radio in the radio network,
- sound calling the subscriber – call alert,
- locking / unlocking the radio,
- remote radio listening.

5.10. Radio communication systems with radiating cable at JSW SA

In order to improve the transport of materials and people in underground workings, in 2018, JSW SA decided to modernize and significantly expand the radio communication systems used so far using a radiating cable. Until then, individual JSW SA mines operated analog radio systems of the FLEXCOM or MULTICOM type by EMITECH, MCA1000 by TRANZTEL and, to a limited extent, a radio communication system with a radiating cable of the BECKERCOM type, provided as an auxiliary communication device for drivers of suspended railways by BECKER installed in some of JSW SA's mines. In 2018, the total length of the radiating cable installed in the workings in all JSW SA mines was approximately 110 km. This was definitely insufficient for the rapidly developing wheeled transport (battery locomotives) and, above all, suspended railways. The modernization of radio communication systems using radiating cables consisted primarily in replacing the previously used analog radio communication systems and a significant expansion (by over 200 km) of the network of radiating cables in underground workings and shafts.

Table 5.2 shows the characteristics of radiating cable radio communication systems in individual mines. The type of communication system used, the approximate length of radiating cables installed and the estimated number and type of radiotelephones used were specified.

https://doi.org/10.32056/KOMAG/Monograph2024.2

Characteristics of radio systems with a radiating cable in JSW SA mines (as of second quarter of 2022)

Table 5.2.

Mine	System type	Length of cable in workings [km]	Number of radios	Notes, radio type
Coal Mine Pniówek	MCA1000digi	60	270	PD795IS, PD715Ex
Coal Mine Knurów-Szczygłowice, Knurów Section	MCA1000digi	52	80	
Coal Mine Knurów-Szczygłowice, Szczygłowice Section	MCA1000digi	32	50	
Coal Mine Borynia-Zofiówka, Borynia Section	MULTICOM 2.1	36	70	DP 4401, DP4801
Coal Mine Borynia-Zofiówka, Zofiówka Section	MULTICOM 2.1	60	80	
Coal Mine Budryk	MULTICOM 2.1	60	50	
Coal Mine Jastrzębie-Bzie	MULTICOM 2.1	12	40	
	Total	**312 km**	**640 pcs.**	

In all JSW SA mines (except Knurów Section), the base stations of the radio system are installed above ground in the telephone exchange or plant control room. They can therefore use the uninterrupted power supply available in these rooms. In this case, mines usually operate one base station with several repeaters installed.

Since up to four lines of radiating cable can be connected to the head of the base station, the MULTICOM radio communication system is operated in two shafts in Zofiówka Section, and in three shafts in Borynia Section and Coal Mine Budryk.

In the remaining mines (Pniówek, Szczygłowice, Bzie), the radio communication system is operated in one shaft.

Knurów Section operates two base stations of the radio system, which are located in workings with a methane explosion hazard level of "a", on the shafts bottoms of levels 650 and 850. They do not have a guaranteed power supply and in the event of a power failure in the power grid, radio communication does not function at these levels. At level 850, it is used by drivers of wired and battery electric traction. At level 650, the radio system is used in suspended diesel railways. In this mine, radio communication in the shaft using the MCA1000 digi system is not possible. In shaft communication, the mine uses the ECHO radio system, which uses the lifting ropes of hoisting machines to transmit a radio signal.

MCA1000digi and MULTICOM 2.1 radio systems usually support 4 channels in the following configuration:

– One (or two) channels for supervisors. Supervisors can then use the radios with keyboard, which enables contact via the company-wide telephone communication system. In these radios, it is also possible to change channels at will, which facilitates contact with supervisors and other technical services communicating with transport managers at individual levels. In sporadic cases, these radios are also used by other services, e.g. ventilation units while performing specific works in trenches or transport roadways, as well as by rescuers from rescue teams.

- One channel for the shaft department using radiotelephones without keyboard, with a separate channel for these services.
- Two (or three) channels for transport departments. To ensure greater safety, separate channels are used for each mining level of the mine. Independent channels are also assigned to individual operators of road transport (battery traction) and transport using suspended railways. These services use radiotelephones without keyboards. These radios are specially programmed for these departments.

In each JSW SA mine, radio communication systems with a radiating cable are used on at least two levels. In several mines (e.g. Zofiówka, Budryk, Szczygłowice) even at three mining levels. This fact justifies the length of the installed radiation cable (Table 5.2) in individual mines.

Telecommunications systems with radiating cables used in JSW SA mines contain up to several hundred repeaters. To ensure proper operation of the entire system, the status of individual repeaters is monitored. Fig. 5.40 shows an example of the MULTICOM system diagnostics board.

The board contains a schematic arrangement of workings in which the radiating cable is installed, the arrangement of repeaters, power supplies, identification gates, power couplers and terminators with a pilot signal generator. For each amplifier, the supply voltage value and the pilot signal level are provided. Red indicates an error in data transmission from a given repeater.

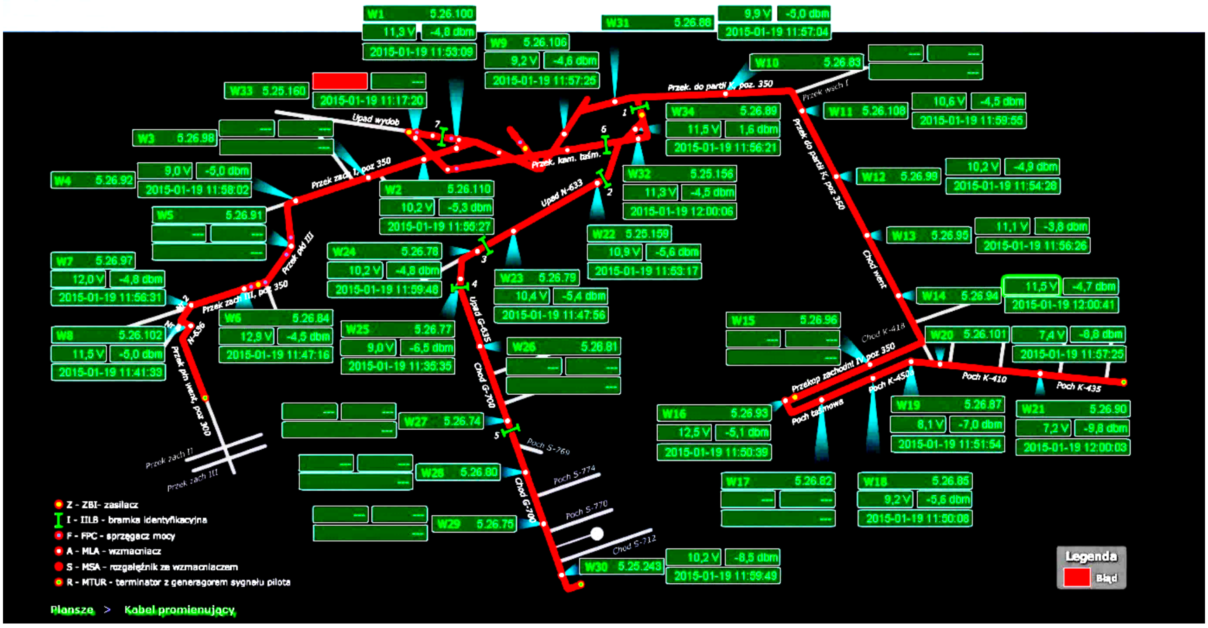

Fig. 5.40. Example of the MULTICOM 2.1 system diagnostic screen

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6. Fiber optic telecommunication networks in underground coal mines

Kazimierz Miśkiewicz, Antoni Wojaczek

6.1. Signs

In this chapter, the following notations are used in block diagrams:

SW	– switch, both managed and unmanaged
Nport	– serial port server allowing you to connect RS485, RS422, RS232 ports to a network with the TCP/IP protocol
IoLogic	– a measurement module that allows you to connect digital inputs and outputs (binary) to a network with the TCP/IP protocol
Fo	– single-mode fiber optic connection, multimode (with two fibers), also bidirectional with one fiber (WDM BiDi) without distinction of bit rate
FE	– computer network connection 10Base-TX, 100Base-TX, 1000Base-TX without distinction of bit rate
ZAS	– power supply
Mon	– monitor
komp	– computer
klaw	– keyboard
SEP	– separator between non-intrinsically safe and intrinsically safe teletransmission port (FE, RS)
MC	– media converter between the FE and Fo port regardless of bit rate and protocols
Tx	– transmitter
Rx	– receiver
100Base-TX	– transmission standard in copper cables with a bit rate of 100 Mb/s
1000Base-TX	– transmission standard in copper cables with a bit rate of 1000 Mb/s
100Base-EX	– transmission standard in fiber optic cables with a bit rate of 100 Mb/s
1000Base-LX	– transmission standard in fiber optic cables with a bit rate of 1000 Mb/s
Ka	– camera with analog output (composite video)
KIP	– camera with digital output.

The explosion-proof status is highlighted in color in the device block diagrams as follows:

- blue color – **intrinsically safe** device, intrinsically safe circuit (both ia and ib level protection),
- green color – **inherently safe** optical fiber(s) and ports,
- yellow color – implementation of explosion protection for devices of group I, category M2 (usually flameproof enclosure),
- white color – device of ordinary construction.

6.2. Introduction

The basic transmission medium in underground coal mines are symmetrical copper mining telecommunications cables with conductors with a diameter of 0.8 mm. The vast majority of these types of cables are used in telephone communication systems, alarm systems, slow data transmission (usually binary) and gasometric, seismological and seismoacoustic systems, performing the role of transmitting useful signals and remotely powering subscriber (end) devices. Symmetrical cables are characterized by a relatively high specific wave attenuation in the supra-acoustic frequency range (Fig. 6.1) [Wojaczek, 2014]. For a frequency of 2 MHz and a cable length of 10 km, the wave attenuation will be 110 dB, which seriously limits the transmission range even when using broadband modems.

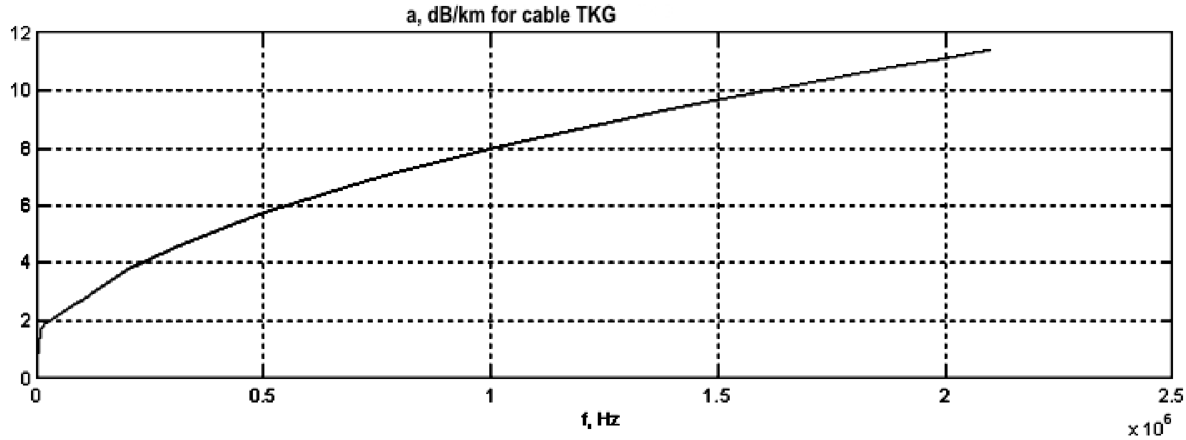

Fig. 6.1. Dependence of the unit wave attenuation of a symmetrical TKG cable on the frequency in the supra-acoustic frequency range [Wojaczek, 2014]

Currently fiber optic cables are increasingly used for data transmission in mine telecommunications networks. Fiber optic technology is a relatively young field of technology. Its origins, in its modern form, date back to the 1970 s. Charles Kao and George Hockham showed that it is possible to produce optical fiber with attenuation below 20 dB/km from high-purity glass. Cornig Glass produced optical fiber with an attenuation of 20 dB/km. We managed to construct light sources (LED and laser) with wavelengths of 850 nm, 1300 nm and 1550 nm. Further refinement of the technology enabled the production of single-mode optical fiber. Fiber optic connection technology and a number of accessories (joints, distribution boxes, media converters) were also developed. The first practical application of fiber optic technology was the construction (in 1977) of a fiber optic cable connecting two telephone exchanges in Turin. In Poland, work on optical fiber technology (in the field of research and production of optical fibers) began in the 1970s at the Maria Curie-Skłodowska University.

The introduction of fiber optic technology to underground mines required solving the following problems:

- Developing the design and launching the production of fiber optic cables intended for use in underground mines. Cables should have the following properties:
  - Flame retardant outer covering or cover.

- Equipping cables intended for installation in vertical and strongly inclined workings (above 45°) with armor made of round steel wires with an anti-twist helix.
- The filling medium does not contain gel due to the possibility of dust adhesion during repairs and installation of cables in distribution boxes and other termination elements.

– Availability of fiber optic equipment intended for operation in environmental conditions of underground mines, including: spaces at risk of methane and coal dust explosions (housing protection level at least IP54).
– Determining the permissible parameters of optoelectronic transmitters so that the light stream escaping from a damaged optical fiber does not cause an explosion of methane or coal dust.
– Developing a standard harmonized with the ATEX directive regarding the protection of devices and transmission systems using optical radiation.
– Organizing laboratories and certification bodies for testing and assessment of devices using optical radiation intended for use in potentially explosive atmospheres.

6.3. Explosion-proof construction of devices used in fiber optic networks of methane mines

The use of fiber optic technology requires defining a possible method of initiating a gas (dust) explosion by optical radiation and determining the conditions for the safe use of fiber optic technology in potentially explosive atmospheres.

The most common mechanism of ignition of an explosive gas (dust) mixture is shown in Fig. 6.2. In an explosive atmosphere, the optical fiber may be damaged and the light from the optical fiber falling on the absorber grain (e.g. coal dust) will heat it to such a temperature that it will cause a gas explosion.

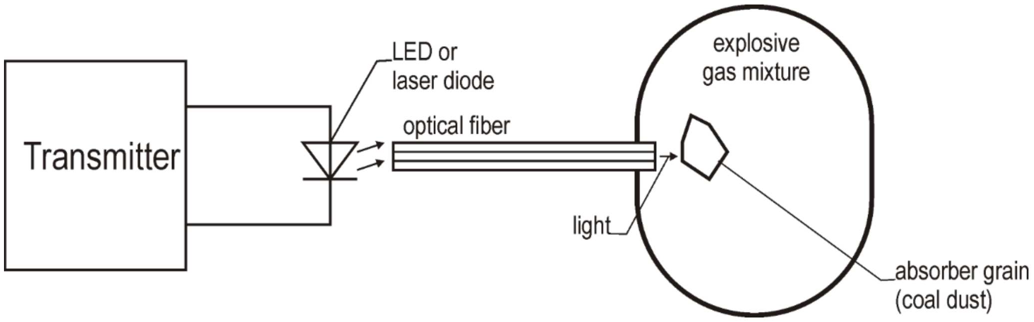

Fig. 6.2. Illustration of the mechanism of initiating a gas explosion using fiber optic technology

The standard [PN-EN 60079-28] presents three methods of explosion protection to prevent methane ignition when using fiber optic technology in potentially explosive atmospheres:

– inherently safe optical radiation – type of protection **op is**,
– protected optical radiation – type of protection **op pr**,
– optical system with interlock – type of protection **op sh**.

W In fiber optic networks used in methane mines, *Ex op is* protection is most often used. In optical transmitters with this type of protection, the electrical power supplied to optical sources (LED diode, laser diode) must be limited by appropriate voltage and/or current limiters to a value at which the optical power that can be radiated from the optical fiber does not exceed safe values specified in the standard [PN-EN 60079-28]. For group I devices, the continuous wave optical power is limited to 150 mW.

Ex op pr protection requires the entire optical fiber installation to be covered in such a way as to prevent the light ray from escaping into the potentially explosive atmosphere. For example, it may be the armor of an optocommunication cable along the entire length of the fiber optic cable located in an explosive atmosphere, or the use of an additional protective pipe (e.g. conduit) of an unarmored fiber optic cable.

Ex op sh protection is that if the optical fiber is damaged and optical radiation escapes into open space, the transmitter will be turned off in a time shorter than the ignition delay time. Cable damage detection is performed by detecting the lack of transmission in the control fibers.

The ATEX Directive [ATEX] introduced the division of explosion-proof equipment into two groups:

- group I – explosion-proof devices intended for use in underground mine workings and parts of surface installations at risk of the presence of mine gas (mainly methane) or flammable dust (coal),
- group II – explosion-proof device intended for use in other places at risk of explosive atmospheres (except underground mine workings).

There are two categories for group I devices:

- **category M1**, covering devices equipped with explosion protection measures ensuring **a very high level of protection**,
- **category M2**, covering devices equipped with explosion protection measures ensuring **a high level of protection**.

The categories relate to the security level of devices EPL *(Equipment Protection Level)* contractually defining the reliability of the protection used [PN-EN 60079-0]. Two levels of EPL have been defined for mining:

- Ma – for devices that have a "**very high**" level of protection,
- Mb – for devices that have (only) a "**high**" level of protection.

Category M1 devices must have an EPL of Ma and category M2 devices must have an EPL of Mb.

M1 category devices can operate at any methane concentration. M2 category devices must be turned off if the permissible methane concentration is exceeded (2% CH_4 or less depending on the measurement site). The automatic methane measurement system deals with switching off M2 category devices [Cierpisz, 2007].

Devices used in mine fiber optic networks also have an electrical part (except for fiber optic distribution frames). For this reason, other methods of implementing explosion-proof construction are also used in these devices [Miśkiewicz, 2018]:

- flameproof enclosure with "d" marking,
- increased safety with "e" marking,
- intrinsically safe devices and circuits marked "ia", "ib",

https://doi.org/10.32056/KOMAG/Monograph2024.2

– encapsulation of devices marked "ma", "mb".

The flameproof enclosure allows you to place virtually any standard electrical devices inside and also enables the installation of any cameras, monitors, indicators or measuring instruments in the cover with a transparent window.

Explosion-proof devices must be marked on the nameplate and in the documentation containing information about the type of intrinsically safe construction. A full description of the marking method is included in the standards from the PN-EN 60079 series, as well as in the literature [Miśkiewicz, 2018]. The marking includes, among others:

a. device group (I for mining),
b. device categories (M1 or M2 for mining),
c. Ex symbol indicating the use of at least one type of explosion-proof construction,
d. symbol(s) of the explosion-proof structure used (e.g. d – flameproof enclosure, e – increased safety; ma, mb – encapsulation; ia, ib – intrinsic safety; op is – inherently safe optical radiation, etc.),
e. gas explosion group symbol (I for methane and coal dust),
f. EPL level (Ma, Mb for mining).

The interpretation of the marking of explosion-proof equipment will be explained using the following examples:

– **I M1 Ex ia I Ma** – device of group I, category M1, intrinsically safe ia protection level for gases of group I (methane) and EPL Ma level. The device can operate at any methane concentration.
– **I M1 Ex ia op is I Ma** – – device of group I, category M1, intrinsically safe with protection level ia , with inherently safe fiber optic port, for gases of group I (methane) and EPL level Ma. The device can operate at any methane concentration.
– **I (M1) [Ex op is Ma] I** – device of ordinary construction with an optical port that is inherently safe for gases of group I (methane) and EPL Ma level. The marking in brackets applies only to parts of the device. The device is intended for installation in safe room. It may be a part of a device with a different type of explosion protection, e.g. it may be placed in a flameproof enclosure.
– **I M2 (M1) Ex d [ia op is Ma] I Mb** – device of group I of category M2 in flameproof enclosure for gases of group I (methane) and EPL Mb level. If the methane concentration exceeds the permissible value (2% or less depending on the installation location), the device's power must be turned off by the methane measurement system. Signage in the bracket applies only to the part of the device that is intrinsically safe with protection level ia, and the inherently safe fiber optic port. This part can operate at any methane concentration if it is equipped with an internal intrinsically safe power supply with battery backup with protection level ia.

In **M1 category devices,** an explosion-proof design with the marking **ia, ma, op is** may be used. The use of other explosion-proof construction methods results in the device is classified as M2.

6.4. Fiber optic cables for mine telecommunications networks

Optical fibers with an outer diameter of 125 μm are used to produce fiber optic cables:

- multimode gradient with a core diameter of 50 μm (marking G50 or 50/125),
- multimode gradient with a core diameter of 62.5 μm (marking G62.5 or 62,5/125),
- single-mode with a core diameter of approximately 8÷9 μm:
  - with unshifted dispersion (J marking),
  - with non-shifted dispersion with increased bending resistance (marking Ja, Jb),
  - with non-zero dispersion (marking Jn).

The most important transmission parameters of fibers used to produce fiber optic cables by TELE-FONIKA Kable SA are shown in Table 6.1.

Selected transmission parameters of optical fibers [TF-KABLE]

Table 6.1.

Parameter	**Wavelength**	**Unit**	**J**	**Ja, Jb**	**Jn**	**G50**	**G62.5**
Attenuation	850 nm	dB/km				≤2.6	≤2.9
	1310 nm		≤0.35	≤0.35		≤0.6	≤0.7
	1550 nm		≤0.22	≤0.22	≤0.2		
Bandwidth	850 nm	MHz·km				>500	>200
	1300 nm					>500	>500

The specific type of fiber optic cable installed in a mine depends on its application. In this case, the following should be taken into account primarily:

- installation location,
- installation technique,
- transmission distance.

Taking these factors into account, you should pay attention to the following basic elements:

- central supporting element,
- optical fiber,
- a tube protecting the fibers,
- seal,
- reinforcement,
- outer sheath.

As can be seen from Table 6.1. Single-mode fibers have low attenuation, making them suitable for transmission over longer distances. The lowest attenuation occurs at certain light wavelengths - the so-called transmission windows: 1310 nm (2nd transmission window) and 1550 nm (3rd transmission window). Single-mode fibers enable transmission with a bit rate of Tb/s.

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Gradient fiber optics usually use wavelengths of 850 nm and 1300 nm. Mode dispersion in gradient fibers limits the transmission rate. The most important transmission parameter of these optical fibers is the bandwidth expressed as the product of length and frequency (MHz·km), which means that the longer the optical fiber, the lower the maximum possible bit rate.

Depending on their design and application, fiber optic cables can be divided into three basic groups:

- internal cables – used inside buildings, e.g. in control rooms and switchboards server rooms,
- external cables – for installation in the ground, cable ducts, shafts and in horizontal underground workings; in these cases, self-supporting, and armored cables are most often used,
- universal cables - they can be used in both indoor and outdoor installations.

This chapter presents examples of fiber optic cables designed and manufactured specifically for underground mines. Fig. 6.3 shows a cross-section of the YOTKGtsFoyn cable.

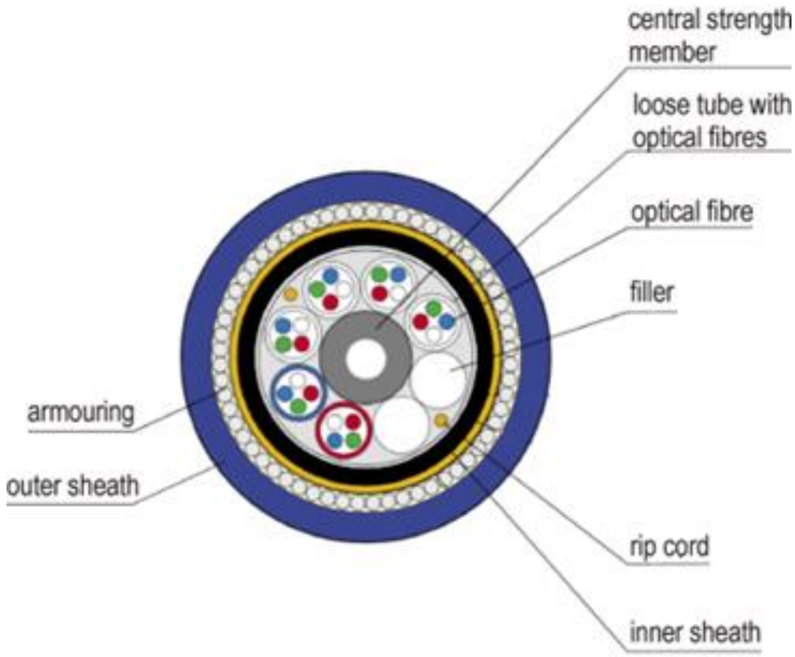

Fig. 6.3. Cross-section of the YOTKGtsFoyn cable

It is an optical telecommunications mining cable (OTKG), tube (loose tube) with a dry core seal (ts), with a PVC coating (Y), armored with round steel wires (Fo), with a flame-retardant PVC outer sheath (yn). According to the catalog, it may contain up to 72 optical fibers.

The first tube is red, it is the so-called counter tube (from which the numbering of individual tubes begins), the second tube next to it is blue. This is the so-called directional tube, defining the numbering direction of the remaining tubes. A 0.2 mm thick dry moisture barrier is placed longitudinally on the center of the cable, protecting the center of the OTKG cable against moisture ingress into the cable. This is the so-called swelling tape, i.e. a tape that expands under the influence of moisture and seals the damaged area.

An example of a flexible mining optocommunication cable, without armor, with flexible coatings made of materials with a high oxygen index, adapted to particularly difficult operating conditions, type ZW-(QG) GNOTKSdD 6J, is shown in Fig. 6.4.

Fig. 6.4. An example of an optical telecommunications mining cable type ZW-(QG)GNOTKSdD 6J adapted to particularly difficult working conditions

In mines, it can be used to connect the end elements of the underground fiber optic network (e.g. cameras, machine or device controllers) with distribution frames or local stations. This applies in particular to, for example, the connection of a longwall apparatus train with permanent fiber optic infrastructure. Attempts were also made to connect the longwall shearer with the operator station and the visualization system installed in the bottom gate. This cable can be pulled by the shearer and guided in the gates of the face scraper conveyor.

The ZW-(QG) GNOTKSdD 6J cable contains an optical module equipped with six gradient (G50 or G62.5) or single-mode J optical fibers. The fibers are placed in a tight buffered tube (S), in which the inner layer is an acrylic material and the outer layer is polyamide. The optical module is reinforced with aramid dielectric yarn (d) and then with armor made of FRP dielectric rods (white in Fig. 6.4). The cable core is protected by several layers of coatings and reinforcements. The inner coating is made of black thermoplastic rubber, which is then again reinforced with yellow (Fig. 6.4) aramid dielectric yarn. The outer sheath is two-layer (QG); the inner layer is made of thermoplastic rubber (3 mm), and the outer layer, 1.5 mm thick, is made of non-flammable polyurethane.

The disadvantage of fiber optic cables is the inability to remotely power subscriber devices. An example of the need for remote power supply may be the installation of cameras with fiber optic image transmission. This inconvenience can be eliminated by hybrid cables containing both copper conductors and optical fibers. In some cases, such cables are produced (usually in small quantities) for companies that produce and install systems that require such cables. Fig. 6.5 shows the structure (cross-section) of the Z- XOTKts 2 – 96 + 4x2.5 mm^2 hybrid cable, which contains two multi-wire cores with a cross-section of 2.5 mm^2 and 2÷96 optical fibers.

A major inconvenience of using this type of hybrid cable is the method of termination in the subscriber's device or distribution set, as well as the repair of the damaged section of the cable in the excavation. Most often, this involves replacing the entire section of the damaged cable, and the installation of endings and repairs take place at the equipment manufacturer's or in surface workshops.

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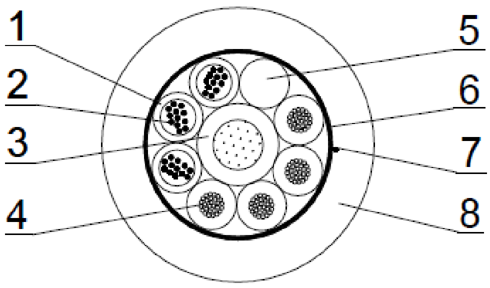


1 – loose tube
2 – optical fibers
3 – central strength element
4 – copper wire
5 – filling insert
6 – swelling tape
7 – rip cord
8 – outer sheath

Fig. 6.5. Construction example of a hybrid cable type Z-XOTKts 2 – 96 +4x2,5 mm^2

6.5. The use of optical fiber

The link between two points in a mine fiber optic network can have the following configurations:

– One optical fiber; the transmission runs in one direction from the Tx transmitter to the Rx receiver (Fig. 6.6 a).
– Two optical fibers, each used for a separate transmission direction (Fig. 6.6 b).
– One optical fiber in which the transmission is bidirectional using WDM wavelength division multiplexing (WDM – Fig. 6.6 c). In this configuration, the second transmission window (1300 nm) is used in one direction and the third transmission window (1550 nm) is used in second direction. The light streams are separated by diplexers. This type of fiber optic use is abbreviated as **WFM BiDi** *(Bidirectional)*.

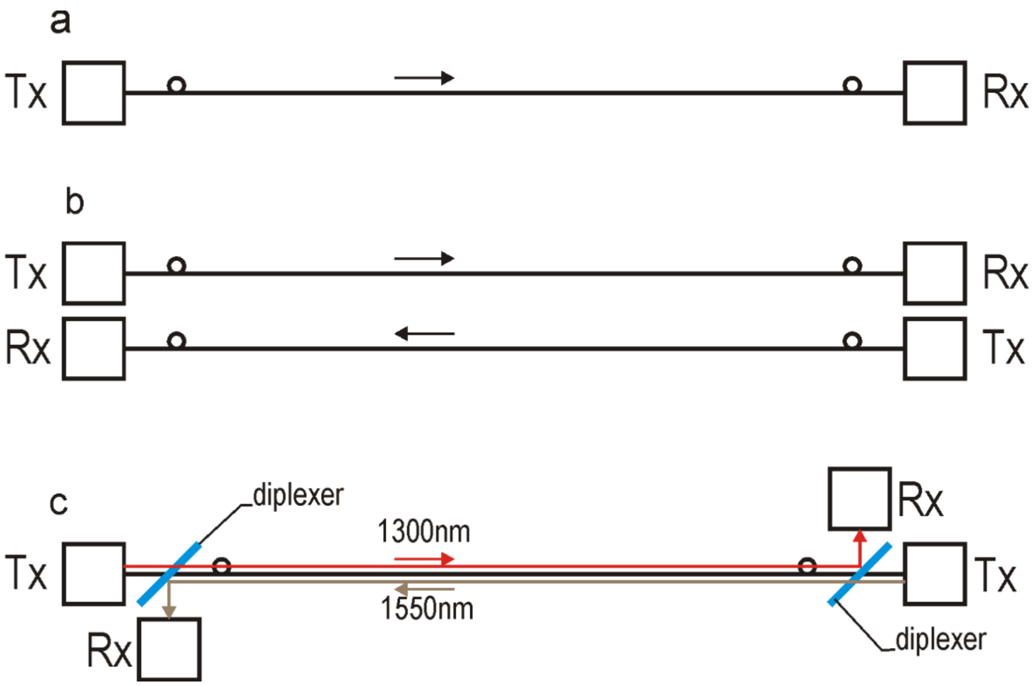


Fig. 6.6. Fiber optic link configurations

Configuration a) (Fig. 6.6) is used for transmitting images from cameras with analog output. The composite video signal from the camera is converted into a light signal in the transmitter (e.g. VT 4030 by IFS) and converted back to the composite video signal in the receiver (e.g. VR 4030). Configuration b is most commonly used in mining fiber optic networks. In configuration c, different types of fiber ports should be used on both sides of the link. The types are called as type “a” (1310 nm transmitting and 1550 nm receiving) and type “b” (1550 nm transmitting and 1310 nm receiving). WDM BiDi transmission allows for increasing the use of optical fibers in existing cables.

6.6. Construction of fiber optic network devices in methane mines

For methane mines, devices using fiber optic technology are designed and built for specific applications of elements (devices) available on the market to meet functional requirements and possible explosion-proof requirements. From the point of view of the explosion-proof structure of fiber optic devices, the following can be distinguished:

- Devices installed in rooms with no risk of methane and/or coal dust explosion (on the surface or in underground workings with explosion hazard level "a"). This type of devices should have a guaranteed power supply (UPS and power generator). Fiber optic ports of such devices should be inherently safe and marked op is.
- Category M2 devices, installed in potentially explosive atmospheres. In such cases, fiber optic devices are powered directly from the power grid (the power supply is located inside the device) or from an external power supply with an intrinsically safe output (with marking ib). However, this type of explosion-proof power supplies must be turned off by the automatic methane measurement system when the methane concentration exceeds the permissible value. Fiber optic ports of such devices should be marked op is, and external electrical ports (e.g. RS or FE from Fig. 6.7) should be marked ia. External electrical ports for local connections (e.g. connection for an external keyboard) may be marked ib. Components of the device with marked ia can be equipped with battery backup.
- Category M1 devices, installed in potentially explosive atmospheres. All internal components of the device must be intrinsically safe with ia protection level, and fiber optic ports must be inherently safe. The devices are powered from external power supplies with battery backup and intrinsically safe output circuit with marking (protection level) ia. They can operate at any methane concentration. The battery backup time depends on the battery capacity and power consumption of the device. There are also mobile devices of the M1 category (e.g. radiotelephones) with an internal battery that can operate at any methane concentration.

In terms of functionality, mine fiber optic networks can be distinguished (e.g. Fig. 6.7, Fig. 6.9, Fig. 6.11):

- Active devices containing typical computer network elements, such as:
  - SW switches allowing you to create computer network nodes,
  - MC media converters (Fo /FE) allowing you to connect a fiber optic network (Fo port) to switches with electrical connections (FE),
  - serial port servers allowing you to connect serial ports (RS485, RS422, RS232) to the Ethernet network,

- IoLogik measurement modules enabling connection of binary inputs and outputs to the Ethernet network.

Depending on the location and method of implementing the explosion-proof structure, the components may be of ordinary or intrinsically safe construction, while the fiber optic connections must be marked as op is, and external electrical connections (RS, FE, binary) must be marked as ia. Active devices are configured for a specific application.

- Passive devices, mainly connectors (joints) and fiber optic distribution boxes used to connect fiber optic cables.
- Both active and fiber optic distribution boxes.

6.6.1. M1 category devices

M1 category device must contain intrinsically safe elements with Ex ia I Ma marking and fiber optic ports with marking Ex op is I Ma. All elements must be mounted in an enclosure with a protection level of at least IP 54. The device should be powered by a battery-backed power supply with an intrinsically safe output circuit with protection level ia. Fig. 6.7 shows a simplified block diagram of the RSS-1 local station by ELEKTROMETAL [ELEKTROMETAL].

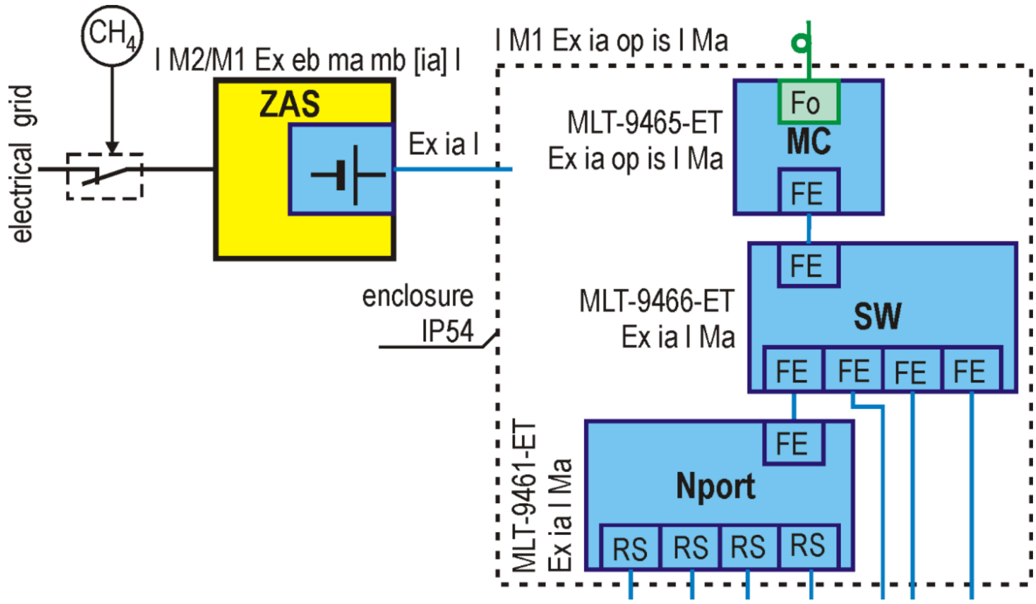


Fig. 6.7. Simplified block diagram of the RSS-1 local station

In Fig. 6.7 intrinsically safe devices and connections are marked in blue, inherently safe fiber optic ports are marked in green, and explosion protection for M2 category devices is marked in yellow (mb – encapsulaltion, eb – increased safety).

In the example shown, RSS-1 contains the following elements:

- five-port intrinsically safe switch SW type MLT-9466-ET,
- Nport serial port server, type MLT-9461 (RS485/RS422, RS232), which enables to connect some serial ports in networks with TCP/IP protocols,

– intrinsically safe MC media converter type MLT-9465-ET with an inherently safe fiber optic port.

The station is powered by an intrinsically safe external power supply (with battery backup) with protection level ia. It has the I M1 Ex ia marking op is I Ma and can operate at any methane concentration.

Fig. 6.8 shows views of selected components of the RSS 1 local station. The blue color of the front panels of these elements usually means an intrinsically safe (or optically safe) device.

a) b) c)

Fig. 6.8. Views of MTL intrinsically safe components: a) MTL-9466 ET managed switch, b) MTL-9465-ET media converter, c) MTL-9461-ET serial port server

6.6.2. M2 category devices

An example of an M2 category device is **the flameproof optoelectric visualization station** OOSW developed by Timler [OOSW]. The manufacturer provides various versions of this device depending on its purpose. Fig. 6.9 shows a simplified block diagram of the OOSW version B device, including:

– SEP separators with intrinsically safe output (ia) for RS485 ports,
– SEP separator with intrinsically safe output (ib) for the keyboard,
– Nport serial port server,
– SW network switch,
– MC media converter with inherently safe optical port Fo (Ex op is I),
– computer (komp in Fig. 6.9) and monitor (MON in Fig. 6.9),
– external intrinsically safe keyboard with ib protection level.

The elements are placed in a certified standard flameproof enclosure manufactured by BOHAMET. This enclosure is equipped with a window under which a 19" LCD monitor is placed (Fig. 6.10). The device is powered by the power grid. If the methane (CH_4) concentration exceeds the alarm threshold (2% or less), the automatic methane measurement system turns off the power to the OOSW device. A keyboard is connected to the computer (klaw in Fig. 6.9) via a SEP separator. The keyboard and the computer connection are intrinsically safe with protection level ib. The OOSW device is marked I M2 (M1) Ex d [ia / ib op is] I Mb.

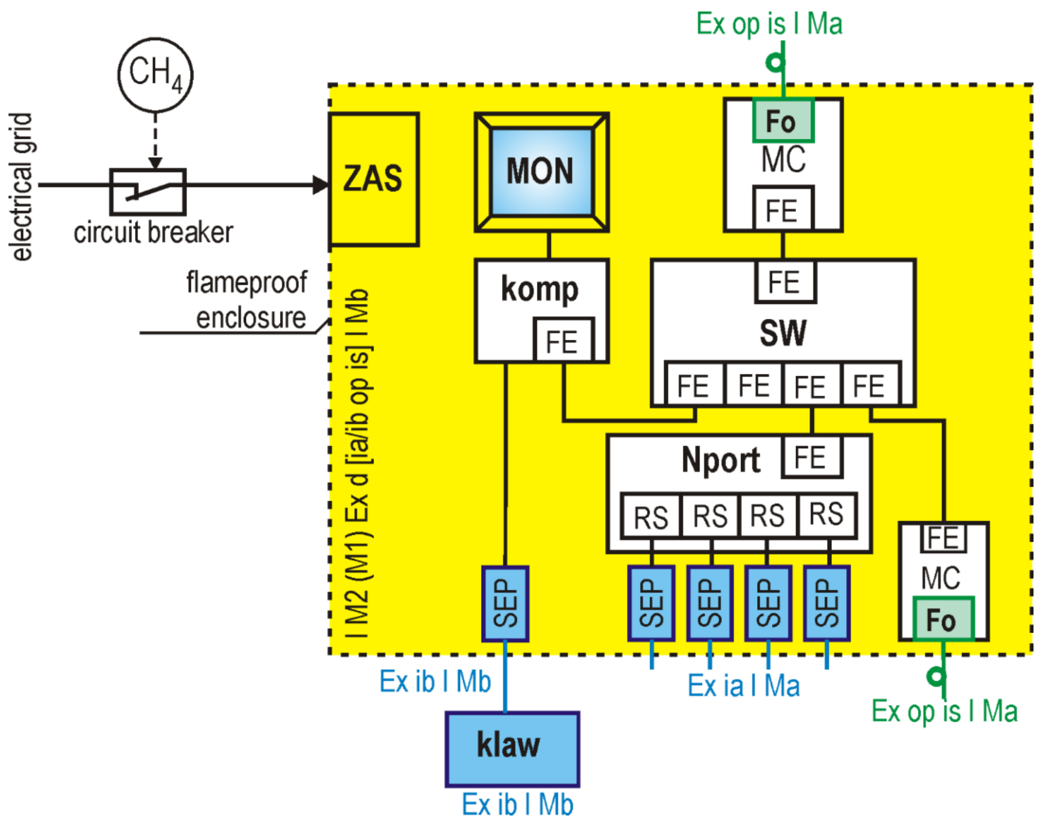


Fig. 6.9. Simplified block diagram of the flameproof optoelectric OOSW visualization station, version B

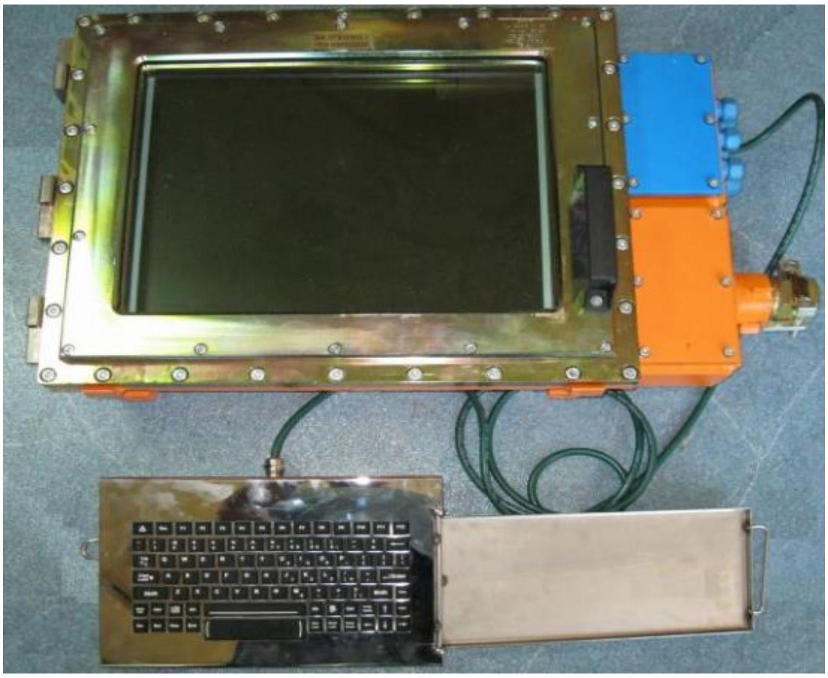


Fig. 6.10. View of the flameproof optoelectric visualization station of the OOSW

Manufacturers of universal explosion-proof enclosure for mining equipment mark the flameproo connection (device) with orange, and the chamber for connecting intrinsically safe or inherently safe devices (cable lines) with blue (e.g. Fig. 6.10).

6.6.3. Teletransmission devices installed in a safe zone

Some teletransmission devices may be installed in a safe zone:

– on the surface (e.g. in the back of the control room),
– underground in workings with explosion hazard level "a"; these are often rooms of the main 6 kV switchboards in the area of the intake shafts.

In the case of such a location, these may be devices of ordinary construction with the exception of fiber optical ports (for cables installed in explosion-hazardous workings), which must be inherently safe (Ex op is I Ma) and electrical ports (for cables installed in explosion-hazardous workings) which must be intrinsically safe with the ia protection level (Ex ia I Ma). The enclosure of devices installed on the main surface depends on the installation location (often in an appropriate rack), while the enclosure of devices installed in underground workings with explosion hazard level "a" must have a protection class of at least IP54.

An example of a teletransmission device intended for installation in underground working with an explosion hazard level of "a" is the RMX-1 (RMX-2) fiber optic concentrator by RNT SA [RMX]. Fig. 6.11 shows a simplified block diagram of an RMX concentrator.

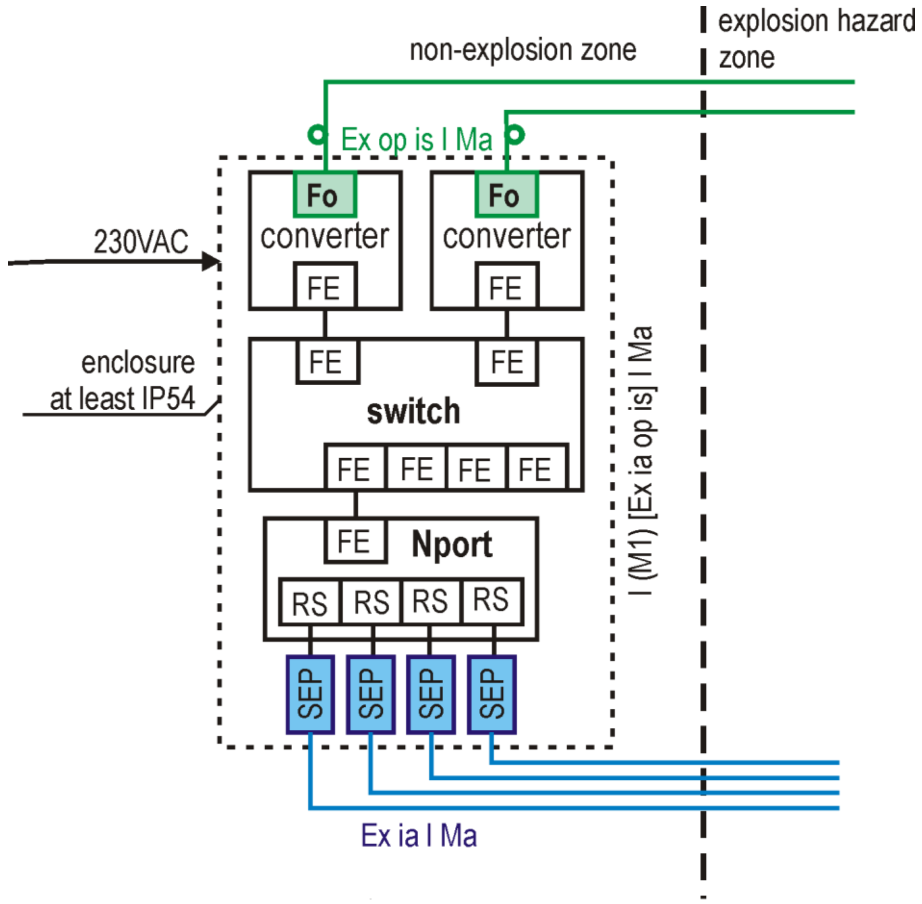


Fig. 6.11. Block diagram of RNT's RMX concentrator

The RMX-1 concentrator contains standard devices inside, except for external ports. RS485 port are equipped with SEP intrinsically safe separators, due to which RS circuits can be routed to potentially explosive atmospheres. Fiber optic port (Fo) is equipped with intrinsically safe converters (Ex op is I) due to which fiber optic lines can be run in potentially explosive atmospheres. The RMX-1 concentrator is marked I (M1) [Ex ia op is Ma] I.

6.7. Examples of teletransmission devices for methane mines

6.7.1. Elements of teletransmission devices

The chapter presents examples of modules of optical fiber teletransmission elements used in JSW SA mines and intended for installation in devices:

– electric so-called "high current" e.g. transformer stations, circuit breakers, switchgears, etc.,
– teletransmission systems with appropriate enclosures, e.g.:
  - flameproof enclosures for M2 category devices,
  - enclosures conventionally called "intrinsically safe" for M1 category devices,
  - metal enclosures with a protection level of at least IP54 for devices installed in safe zones.

Fig. 6.12 shows devices from the EFI-**-13 series by ELEKTROMETAL [ELEKTROMETAL]. The electronic components of these devices are built in modular housings type ME 45 UT/FE, 45 mm wide, manufactured by Phoenix Contact (the base of the housing is made of plastic). The base of this housing also has a latch that allows it to be mounted on a 35 mm TS rail.

a) b) c) d) e)

Fig. 6.12. Views of modules (intended for installation in electrical and teletransmission devices) by ELEKTROMETAL: a) EFI-BAR-13, b) EFI-BRI-13, c) EFI-CON-13, d) EFI-CON-13/B, e) EFI-BRI-13/B

The EFI-BAR-13 module (Fig. 6.12 a) is a media converter (FE/Fo) between the non-intrinsically safe 100Base-TX Ethernet port (RJ45 connector) and the inherently safe fiber optic port (SC connector). It is marked I (M1) [Ex op is Ma] I.

The EFI-BRI -13 module (Fig. 6.12 b) is a switch containing 3 FE ports (100Base-TX) and 2 inherently safe Fo fiber ports (100Base-FX). The EFI-BRI -13/B module (Fig. 6.12 e) is a switch equipped with battery backup.

The EFI-CON-13 module (Fig. 6.12 c) is a serial port server. It has 3 RS485 ports, 1 four-wire RS485/RS422 port, 1 RS232 port as well as an FE port (100Base-TX) and an inherently safe Fo fiber port (100Base-FX). The FE and Fo ports enable the implementation of a ring topology in the Ethernet network.

The EFI-CON-13/B module (Fig. 6.12 d) performs similar functions to the EFI-CON-13 module and additionally has an internal battery that ensures autonomous battery operation time of approximately 8 hours. The fiber optic ports of the EFI-CON-13, EFI-BRI-13, EFI-BAR-13 modules enable the connection of two single-mode fibers, or one single-mode fiber for bidirectional transmission (WDM BiDi).

When powered from a power supply with an intrinsically safe output with protection level ia, the EFI-BRI-13 and EFI-CON-13 modules are intrinsically safe devices with the marking I M1 Ex ia [op is Ma] I Ma, and in the case of power supply from another power supply, they are devices with an inherently safe fiber optic port and are marked I (M1) [Ex op is Ma] I.

Other manufacturers of fiber optic devices for mining have similar technical solutions for server modules or switches. Fig. 6.13 shows, for example, the IPS-2 serial port server by ATUT (used in the Pniówek mine) with the marking I M1 Ex ia op is I Ma, containing 4 RS485/422 ports, a 100Base-FX optical port and a Wi-Fi port. Fig. 6.14 shows the intrinsically safe ISE-1 switch by ATUT with the marking I M1 Ex ia I Ma, containing 5 10/100Base-TX ports.

Fig. 6.13. ISPS-2 serial port server by ATUT

Fig. 6.14. Intrinsically safe ISE-1 switch by ATUT

Fig. 6.15 shows the SOMAR SFX-100M fiber optic switch. It is a device of ordinary construction. Depending on the version, it can be a managed or unmanaged switch equipped with 4÷14 FE ports (10/100Base-TX) and one or two inherently safe fiber optic ports (100Base-FX).

Fig. 6.15. SFX-100M fiber optic switch

Fig. 6.16. Intrinsically safe SM-SPS1 serial port server

https://doi.org/10.32056/KOMAG/Monograph2024.2

Fig. 6.16 shows the intrinsically safe SM-SPS1 serial port server by SOMAR. It is equipped with 2 or 4 RS485 interfaces and an inherently safe fiber optic port (100Base-FX). It is marked I M1/M2 Ex ia/ib op is I Ma/Mb.

Fig. 6.17 shows the MKE-S/1 media converter by Carboautomatyka, and Fig. 6.18 shows the CFC-* media converter by HASO. Both converters are standard devices with an inherently safe fiber optic connection and are marked I (M1) [Ex op is]. The CFC-* converter, when equipped with a CFC-SFP/M type SFP module, can be a 10/100Base-TX to 100Base-FX media converter, and when equipped with a CFC-SFP/G type SFP module, it can be a 10/100/1000Base media converter -TX to.

Fig. 6.17. Media converter MKE-S/1

Fig. 6.18. CFC-* Media Converter

Switch ports can be equipped with sockets of a standardized design for placing an SFP *(Small form-factor module pluggable)* containing a transmitter and a receiver (Fig. 6.19). SFP, a small SFP transceiver, often called an SFP module by manufacturers (industrial standard for small pluggable gigabit transmitter and receiver module), is a hot-swappable metal element that, when connected to another device via a cable (copper or fiber optic), allows data transmission; The SFP transceiver is inserted into the SFP socket (port) (also often called an SFP module) on the network device. In fiber optic networks of methane mines, SFP modules must be inherently safe (marking (M1) [Ex op is Ma] I). SFP modules can have a fiber optic connection for two single-mode fibers, a single fiber using bidirectional transmission (WDM BiDi) at a bit rate of 100 b/s or 1000 b/s.

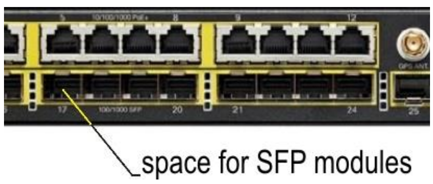
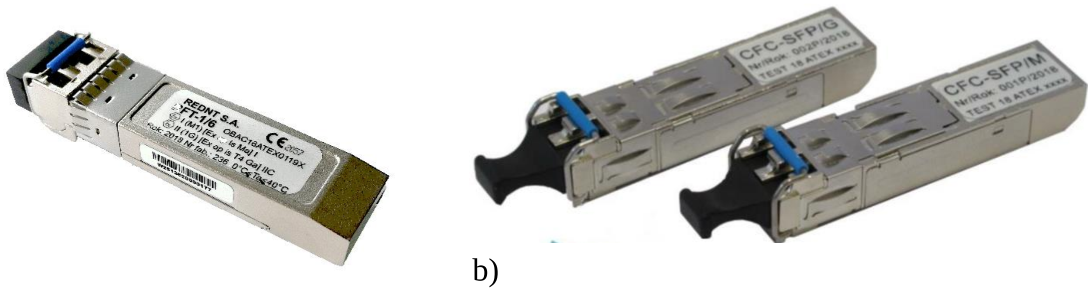


Fig. 6.19. Slots for SFP modules in the switch

Fig. 6.20 shows examples of inherently safe RFT 1/* SFP modules (1Gb/s throughput) by REDNT (a) and CFC-SFP/G and CFC-SFP/M (100 Mb /s) by HASO (b).



a) b)

Fig. 6.20. Modules a) SFP type RFT-1/6, b) CFC-SFP/G and CFC-SFP/M

To transmit an analog video signal (composite video) in a fiber optic network, it is necessary to use a video signal transmitter with an optical output and a video signal receiver with an optical input. Examples of such devices are the SM-VTi1 fiber-optic video transmitter (Fig. 6.21) and the SM-VR4 fiber-optic video receiver (Fig. 6.22) by SOMAR. The SM-VTi1 transmitter installed in potentially explosive atmospheres is intrinsically safe with an inherently safe fiber optic port. The SM-VR4 receiver is installed on the surface and is a standard device, it does not have any explosion-proof marking because it does not have an optical transmitter.

Fig. 6.21. Intrinsically safe SM-VTi1 fiber-optic video transmitter by SOMAR

Fig. 6.22. SM-VR4 multimode fiber optic video receiver by SOMAR

6.7.2. Intrinsically safe M1 category teletransmission devices

The chapter presents examples of M1 category teletransmission devices that can be used in workings of methane and/or coal dust explosion hazard and can operate at any methane concentration.

Fig. 6.23 shows a view of the SPSG-16 serial port server by ELEKTROMETAL. The server is placed in the SM300 housing. EFI-CON-13 modules (EFI-CON-13/B with internal battery) and optionally EFI-BRI modules can be installed in the SPSG-16 serial port server. The serial transmission port terminals, the 100Base-TX port terminals and the power supply terminals are placed on the terminal strip. The device is equipped with DP or DPT entries enabling the connection of an external intrinsically safe power supply, serial and Ethernet transmission paths, and optical fiber to the op is port.

Fig. 6.23. SPSG-16 serial port server by ELEKTROMETAL, marking I M1
Ex ia [op is Ma] I Ma [ELEKTROMETAL]

Fig. 6.24 shows the intrinsically safe media converter type IK1-R/F with a hybrid connection (for Fo and Cu on the side of the device) by HASO.

Fig. 6.24. View of the intrinsically safe media converter type IK1-R/F by HASO with a hybrid connection (for Fo and Cu on the side of the device), marking I M1 Ex ia op is I Ma [HASO]

The intrinsically safe IK1 - x/x type converter is a device used to convert digital signals in the following standards: serial RS232/422/485, Ethernet 100base-TX, optical 100base-FX, radio Wi-Fi IEEE 802.11b/g and Modbus / RTU RS- xxx and Modbus /TCP. It comes in the following versions:

– IK1-R/F - converter of the RS232/422/485 standard to 100 Mb/s optical fiber (Fig. 6.24),
– IK1-R/W - converter of the RS232/422/485 standard to the Wi-Fi standard,
– IK1-R/E - RS232/422/485 to Ethernet 100 Mb/s converter,
– IK1-E/F - converter of the Ethernet standard 100 Mb/s to optical fiber 100 Mb/s,
– IK1-E/W - converter of the Ethernet standard 100 Mb/s to the Wi-Fi standard,
– IK1-RM/F - converter of the Modbus /RTU RS-xxx standard to the Modbus /TCP standard via 100 Mb/s optical fiber,
– IK1-RM/E - converter of the Modbus /RTU RS-xxx standard to the Modbus /TCP standard via Ethernet 100 Mb/s.

The converter can be powered redundantly through the power connector, hybrid connector (power supplied with optical fiber) or through the connector of the second channel of serial transmission (cooperation with a power supply with an intrinsically safe output type ZIB-x). Fig. 6.25 shows an example of using the IK1-x/x converter.

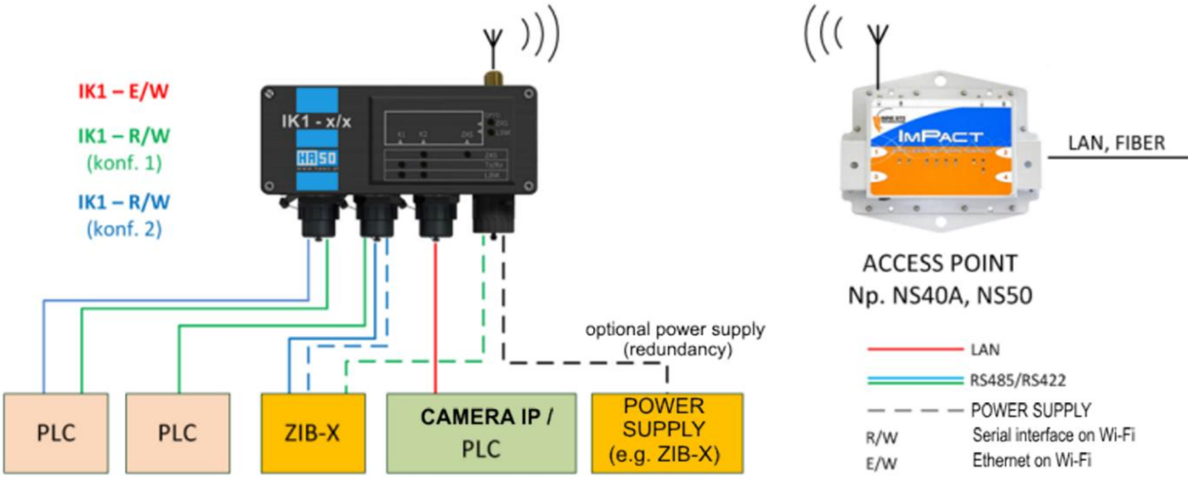


Fig. 6.25. Example of using the IK1-x/x media converter in a mine

Fig. 6.26 shows the intrinsically safe ISG-1 switches by HASO (Fig. 6.26 a) and BCOM Switch 8/* by BECKER MINING SYSTEM (Fig. 6.26 b). The switches are marked I M1 Ex ia op is I Ma. The ISG-1 switch has two to eight 10/100Base-TX or 100Base-FX ports depending on the configuration. The BCOM switch has eight inherently safe optical ports. Some ports may operate in a ring.

Other companies specializing in the production of teletransmission devices for mining also have similar solutions, e.g. the ISE-3FX switch by ATUT, which has three inherently safe fiber optic ports. Depending on the configuration, the port enables the connection of two fibers or one fiber in a bidirectional system (WDM BiDi).

a)

b)

Fig. 6.26 a) Intrinsically safe mining switch ISG-1 by HASO

Fig. 6.26 b) Intrinsically safe BCOM Switch 8/* by Becker

Ethernet switch by ELEKTROMETAL can be equipped with e.g. EFI-BRI-13 or EFI-BRI-13/B modules (Fig. 6.12). The device usually has 2 100Base-FX ports (inherently safe) and 3 100Base-TX ports.

Fig. 6.27. DKPD underground measurement data concentrator by Carboautomatyka

Fig. 6.27 shows a view of the DKPD underground measurement data concentrator by Carboautomatyka. The DKPD concentrator is an M1 category device, contains a computer with a monitor and keyboard, and can be equipped with two fiber optic connections and 10 measurement connections using FSK transmission (for gasometric sensors) or RS485. Some of the connections can be used to cooperate with modules with four binary inputs and outputs. It can be used in gasometric systems as a raised underground telemetry center. It acquires and processes measurement data.

Fig. 6.28 shows an example of a block diagram of a gasometric system using the DKPD concentrator.

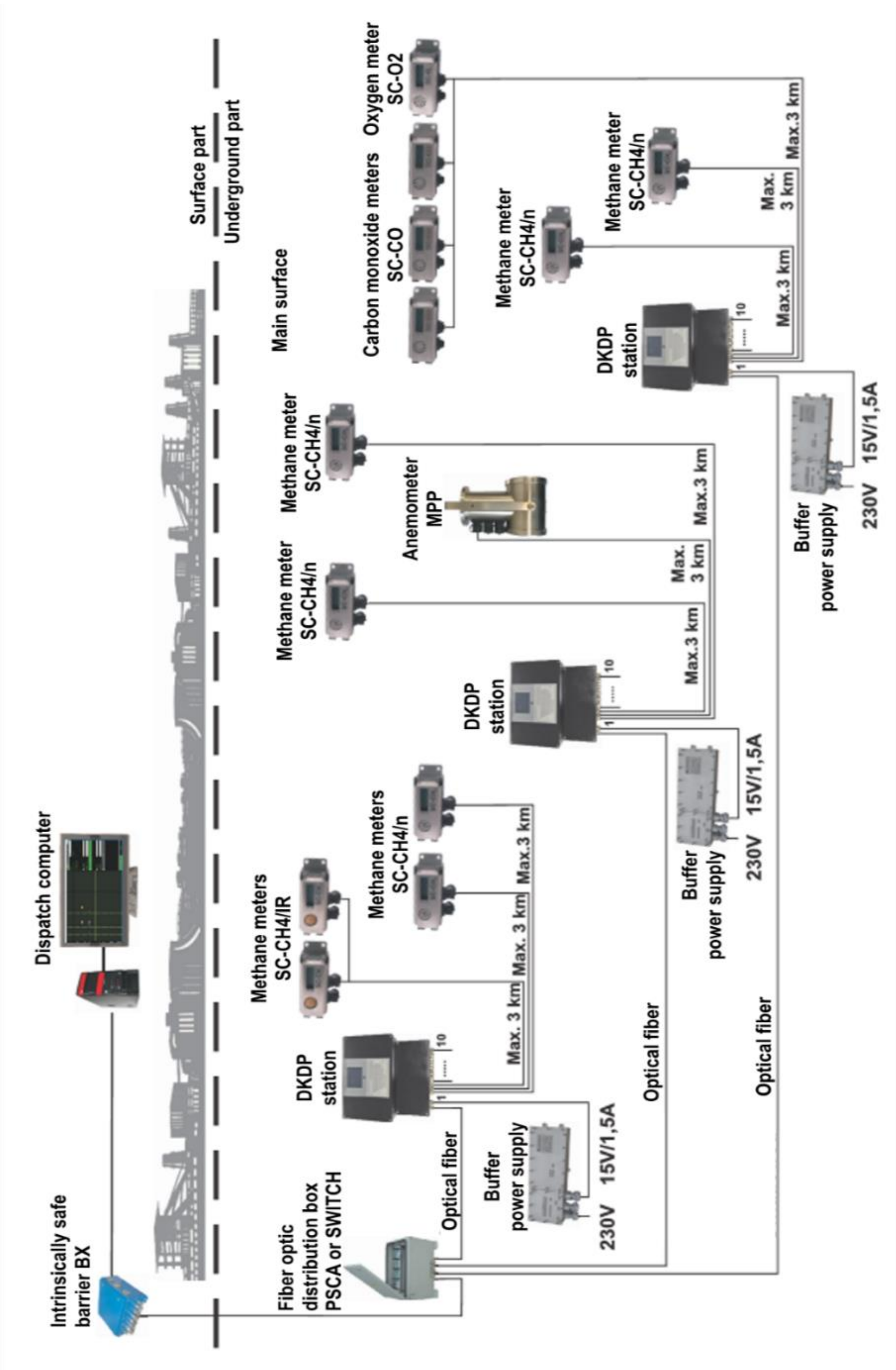


Fig. 6.28. Example of a block diagram of a gasometric system using the DKDP concentrator [CARBOAUTOMATYKA]

Timler has developed optoelectronic transducer stations ALFA-I, ALFA -II, ALFA-III and ALFA-IV [Timler, 2019]. These are devices marked I M1 Ex ia op is I Ma, which may be installed in potentially explosive atmospheres. The internal configuration of these devices (as in solutions of other companies) depends on the functions performed.

6.7.3. Devices in a flameproof enclosure

In some cases, it is not necessary to operate teletransmission devices when the methane concentration is above the alarm threshold. Then, a teletransmission device can be built from standard construction elements placed in a flameproof enclosure, while the external connections of such devices must be equipped with appropriate barriers or separators with an output marked as Ex ia I or Ex op is I (in the case of a fiber optic port). An example of this type of device is the flameproof PLC-BRI converter (Fig. 6.29) with the marking I M2(M1) Ex d [op is Ma] I Mb equipped with a pass-through connection enabling the connection of a PLC network (*Power Line Communications* - data transmission over the power grid) and a fiber optic Ethernet network connection (Ex op is) 100BaseFX. It enables bidirectional communication between the PLC network and the fiber-optic Ethernet network. Fig. 6.30 shows the OP485d optoconverter in a flameproof enclosure by Carboautomatyka. It is an RS-485 serial port server with an inherently safe optical port.

Fig. 6.29. PLC-BRI-16 feed-through converter by firmy ELEKTROMETAL

Fig. 6.30. OP485d optoconverter in a flameproof enclosure by Carboautomatyka

6.7.4. Devices for installation in safe rooms

JSW IT Systems has developed **a Backbone Teletransmission Node** SWTx intended for installation on the surface and in underground of mines in workings with no risk of methane explosion. Fig. 6.31 shows the basic structure of the SWTx Backbone Teletransmission Node, with particular emphasis on the method of guaranteed redundant power supply for its individual SW switches.

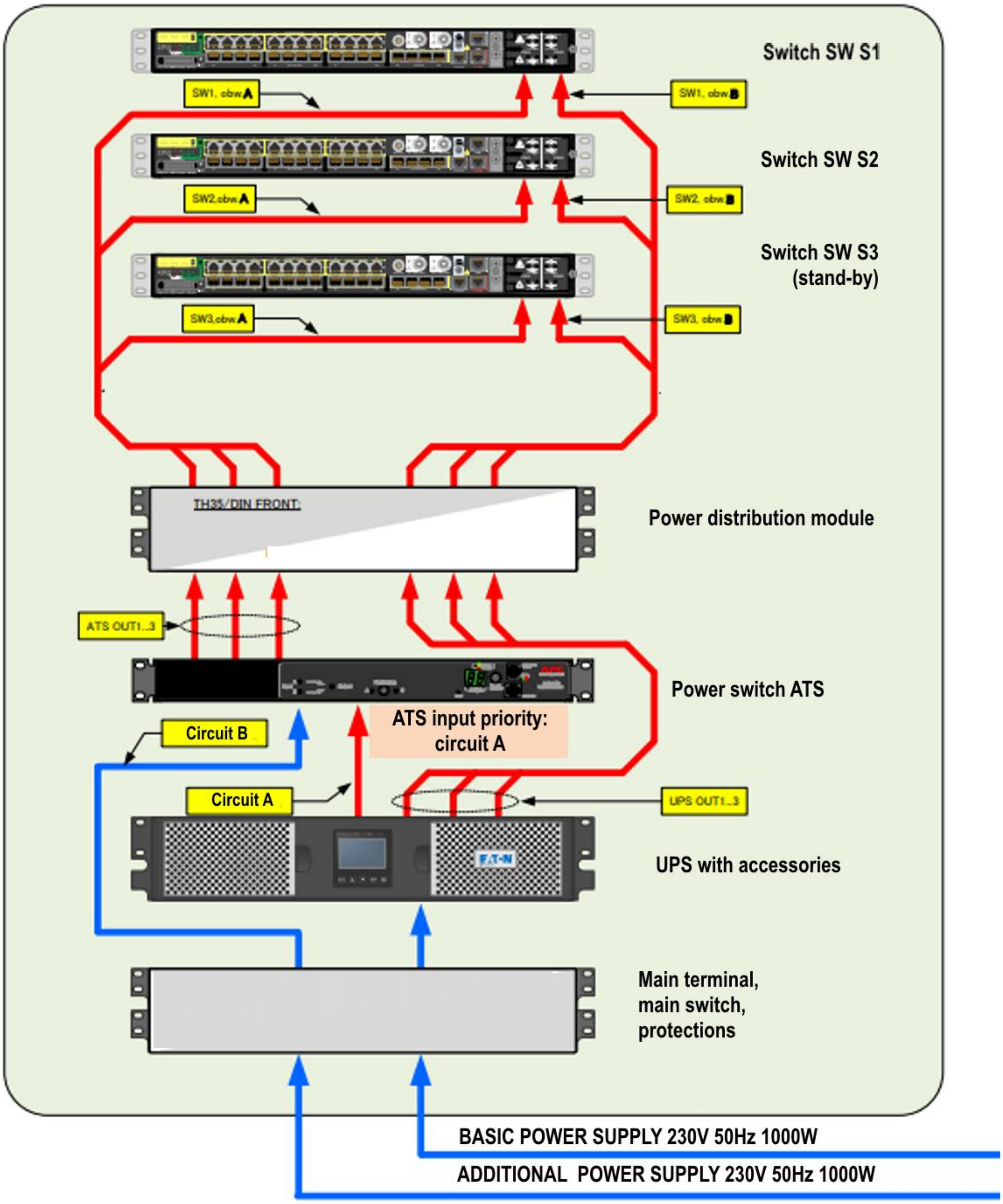


Fig. 6.31. Basic equipment and method of guaranteed (redundant) power supply for the SW switches of the SWTx device

Each SW switch has two power supplies. One of the power supplies is powered from the main power source (power grid) through a UPS power supply (with an external battery module) with battery operation time (9÷30 min). The second switch power supply is powered by the ATS transfer switch. The ATS power switch is supplied with voltage from an additional power source (power grid) and voltage from the UPS power supply. The ATS power switch selects the power source (mains/UPS) for the second SW switch power supply.

Due to the environmental conditions in the SWTx cabinet (including, above all, temperature and mounting restrictions), no more than three LAN switches with a height of 1U each can be placed in one SWTx device housing. Each SW switch consumes several hundred watts, and the large number of SW switch ports available to the user creates certain assembly and installation limitations.

The basic elements of a node are stacks of switches (SW) which are placed in CoB (Core of Backbone) and HoB (Hub of Backbone) assemblies. The CoB assembly acts as a backbone node (connected to other SWTx nodes) and contains a stack of switches with two power supplies. It can be equipped with a maximum of 120 optical ports (three SW switches). A view of the IE-5000 series SW switch with the arrangement of slots for SFP modules is shown in Fig. 6.32.

Fig. 6.32. View of the IE-5000 series switch with the arrangement of SFP modules marked

HoB unit serves as an access node (connected to other devices such as IP cameras, serial port servers) and also contains a stack of industrial switches (CISCO, MOXA, DCN) and one UPS power supply. It can be equipped with a maximum of 288 optical ports. Each optical port is equipped with an SFP module type RFT-1/* by REDNT.

Fig. 6.33. View of the SzK-3 converter cabinet by Carboautomatyka

Fig. 6.33 shows a view of the Szk-3 converter cabinet by Carboautomatyka. The cabinet contains standard construction elements and elements with an inherently safe fiber optic port, as well as intrinsically safe separators on RS485 ports. Depending on the configuration, the following are installed in the Szk-3 cabinet:

- MKE-S/1 media converters,
- CISCO switches,
- MOXA serial port servers,
- galvanic separators for the RS-485 link.

6.7.5. Mining fiber optic distribution boxes

Mining fiber optic distribution boxes are most often placed in a steel sheet housing with an IP54 protection level. Inside there are: a panel or modular distribution box and the necessary assembly accessories. An example is the T-1 distribution box by Timler. The capacity of the frame can be from 12 to 999 optic fibers. Fig. 6.34 shows the view of the T-1 distribution frame and the view of the open distribution frame installed in the mine.

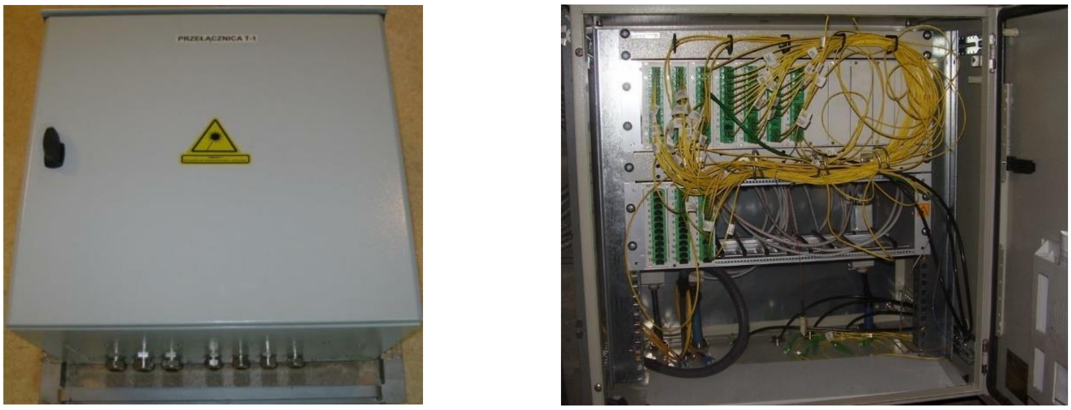


Fig. 6.34. T-1 fiber optic distribution frame by TIMLER: general view of the distribution frame and its interior in one of the mines

Fig. 6.35 shows a view of the AT-PSG fiber optic distribution box by ATUT. Depending on the version, the frame can have a capacity of up to 144 connectors.

Fig. 6.35. AT-PGS fiber optic distribution box by ATUT

T-1 and AT-PSG distribution boxes are marked I M1 Ex op is I Ma. Active elements of fiber optic networks can also be installed in fiber optic distribution boxes. An example of such a solution is the EMFOS-18 fiber optic distribution box by ELEKTROMETAL (Fig. 6.36). In the upper part of the frame there are modules with fiber optic connectors, and in the lower part there is a TS-35 rail for mounting active elements. The panel can be equipped with EFI-xxx modules (Fig. 6.12) or other M1 category modules. If M1 category modules are installed in the panel and the panel is powered from an intrinsically safe power supply with an ia protection level, the panel will be marked I M1 Ex ia op is I Ma, and can be installed in potentially explosive atmospheres.

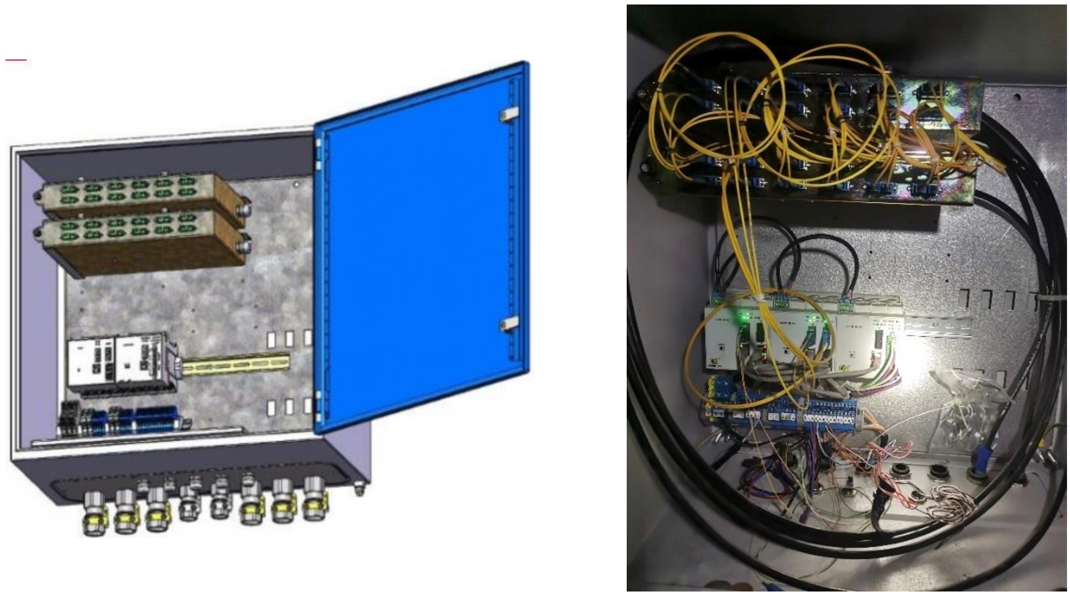


Fig. 6.36. EMFOS-18 fiber optic distribution frame by ELEKTROMETAL: general view of the distribution frame and a photo of the interior of the distribution frame in one of the mines

6.7.6. Cameras used in fiber optic networks of methane mines

The most important properties of cameras used in methane mines include:

- mechanical structure and explosion-proof marking:
  - increased safety device marking "e", (or "eb" when the EPL protection level is also given); a device in which explosion protection has been achieved by encapsulation, marking "m" (or "mb" with an alternative indication of the EPL protection level), e.g. I M2 Ex eb mb [ia op is] I Mb,
  - device in a flameproof enclosure, e.g. I M2(M1) Ex d [ia op is] I Mb,
  - an intrinsically safe device (marking "ia"), as well as inherently safe (marking "op is" I M1) e.g. I M1 Ex ia op is I Ma or I M1 Ex ia I Ma,
- form of the camera output signal:
  - analog composite video signal in cameras with analog output,
  - digital signal in accordance with appropriate compression protocols, e.g. H.264 in cameras with digital output - called IP cameras,
- image resolution: e.g. 1920x1080, 1280x720, 704x576, 640x480, 320x240 pixels,
- type of connection:
  - for digital signals: fiber optic or RJ45,
  - for analog signals: copper coaxial or symmetrical, possibly fiber optic,
- power supply method:
  - directly from the power grid or an external power supply for cameras with the I M2 marking,

- from a power supply with an intrinsically safe output with battery backup in the case of cameras marked I M1.

Views of cameras (several manufacturers and various types) used in underground workings of JSW SA mines are shown in Fig. 6.37 a) ÷ 6.37 j).

Fig. 6.37. a) Bb CAM-01 flameproof camera by BARTEC
(I M2(M1) Ex d [ia op is Ma) I Mb)

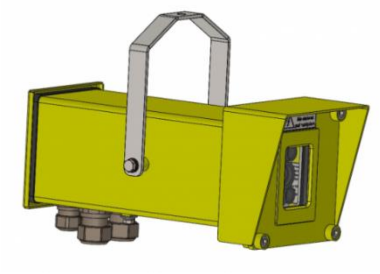


Fig. 6.37. b) OKA-1/C flameproof camera by ATUT with digital output
(I M2 Ex db eb [op is Ma] I Mb)

Fig. 6.37. c) Flameproof camera CAM-1 by FAMUR I M2 (Ex d e [op is] I Mb)

Fig. 6.37. d) KOR-4 flameproof camera by Carboautomatyka

Fig. 6.37. e) HASO KG-3 camera with digital output
(I M2(M1) Ex eb mb [ia op ps] I Mb)

Fig. 6.37. f) HASO KG-2 camera with digital output
(I M1 Ex ia op is I Ma)

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Fig. 6.37. g) IKA-1/D intrinsically safe camera by ATUT with digital output (I M1 Ex ia op is I Ma)

Fig. 6.37. h) KTi-2sj intrinsically safe camera by SOMAR with analog output (I M1 Ex ia op is I Ma)

Fig. 6.37. i) FAMUR CAM-1 intrinsically safe camera with analog output (I M1 Ex ia I Ma)

Fig. 6.37. j) KTI-3 intrinsically safe camera by SOMAR with analog output

6.7.7. Computers and monitors in potentially explosive atmospheres

Computers (monitors) are increasingly used in potentially explosive atmospheres as:

- local monitors for cameras installed in very dangerous zones (e.g. at risk of rock bursts, integrated threats),
- as elements of local systems for monitoring, supervision and control of technological processes.

Fig. 6.38 shows examples of computers (or only monitors) in flameproof enclosure (M2 category), intrinsically safe computers (M2 and M1 categories) and ordinary computers with ports of ia protection level and/or op is protection level. Certified flameproof enclosures by the Polish company BOHAMET SA are used to build computers and monitors. Computers with monitors in flameproof enclosure have a large mass, e.g. BbCM by BARTEC - 150 kg (Fig. 6.38 a), EMPC-15 by ELEKTROMETAL with a 19" monitor, 130 kg (Fig. 6.38 b), EMPC-08 by ELEKTROMETAL, with a 17” monitor and without keyboard, has a mass of 60 kg (Fig. 6.38 d). The weight of monitors depends in particular on the diagonal of the monitor screen, the size of the flameproof connection box of the power supply system and the ITC connection box. Intrinsically safe devices with ib protection level have a relatively low mass, e.g. the ET-09Ex analog monitor by FAMUR, weighing 21 kg (Fig. 6.38 g), and M1 category devices, e.g. the MG-1 monitor by HASO, weighing 8 kg (Fig. 6.38 h) and intrinsically safe industrial computers, e.g. HPC-1 (I (M1) [Ex ia op is Ma] I) in a metal housing IP54 (Fig. 6.38 i). Various converters and barriers can be installed in the housing. The computer can be operated using a keyboard with a pad placed on a bracket attached to the housing (weight up to 40 kg).

Fig. 6.38. a) BbCM computer by BARTEC
I M2 (M1) Ex db eb [ia ib] I

Fig. 6.38. b) EMPC-15 computer by
ELEKTROMETAL
I M2 (M1) Ex db [ib] [ia op is Ma] I Mb

Fig. 6.38. c) Computer EH-O/06/06.xx
by Elgór Hansen

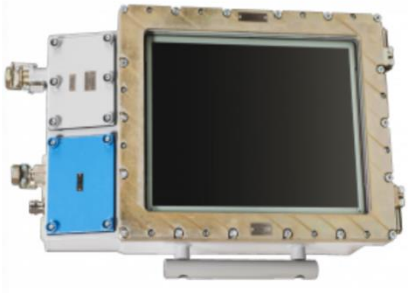

Fig. 6.38. d) Flameproof computer EMPC 08 by
ELEKTROMETAL, 17” monitor

Fig. 6.38. e) MTO-3 monitor by
Carboautomatyka

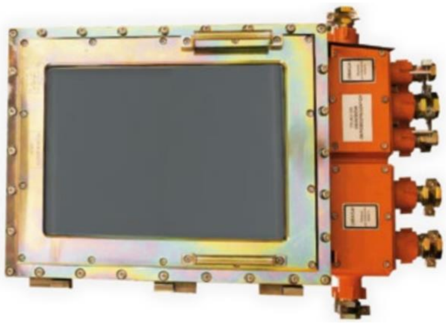

Fig. 6.38. f) Monitor EH-0/06/04 by
Elgór Hansen

Fig. 6.38. g) ET-09Ex analog monitor
by FAMUR, I M2 Ex ib I Mb

Fig. 6.38. h) Intrinsically safe mining monitor
MG-1 by HASO, I M1 Ex is op is I Ma

Fig. 6.38. i) Industrial computer by HASO intended
for coal mines I (M1) [Ex ia op is Ma] I

Quite new are intrinsically safe tablets intended for coal mines, which are already used at JSW SA. Fig. 6.39 a) and 6.39 b) show examples of intrinsically safe tablets:

- Agile X IS tablet in 17-ABF version by BARTEC with I M1 Ex ia op is I Ma marking,
- AEGEX-10 tablet by ELEKTROMETAL with I M2 Ex ib Mb marking.

Intrinsically safe tablets can be used by workers in underground part of mine to enter certain data into the computer system (particularly in areas with radio coverage of Wi-Fi access points).

Fig. 6.39. a) Intrinsically safe Agile X IS tablet
by BARTEC

Fig. 6.39. b) AEGEX-10 intrinsically safe tablet
by ELEKTROMETAL

6.8. Video monitoring systems at JSW SA

Table 6.2 shows the number of cameras operating in individual JSW SA mines. In total, 281 cameras were installed in JSW SA mines in 2019. This number is variable (and constantly growing) because cameras are installed both on the surface and in workings, depending on the current needs of various services of the mining plant (plant security, coal sales, needs of dispatchers, management and traffic supervision, places of particular risk).

Number of cameras in JSW SA mines [Timler, 2019]

Table 6.2.

Mines/Sections in JSW SA	Number of cameras (as of April 9, 2019)
Coal Mine Budryk – server No. 1	47
Coal Mine Budryk – server No. 2	75
Coal Mine Pniówek	60
Coal Mine Borynia-Zofiówka-Jastrzębie, Section Borynia	18
Coal Mine Borynia-Zofiówka-Jastrzębie, Section Zofiówka	41
Coal Mine Borynia-Zofiówka-Jastrzębie, Section Jastrzębie	16
Coal Mine Knurów-Szczygłowice, Section Knurów	12
Coal Mine Knurów-Szczygłowice Section Szczygłowice	12
Total	**281**

Signals from the cameras are fed to:

- local computers (acting as monitors),
- station part (e.g. STTS) equipped with video servers recording the image,
- visualization stations, among others in control rooms of mining plants and in Energy and Mechanical Supervision Centers of mines.

Category M2 cameras must be turned off when methane concentrations exceed the permissible value. In such a situation, the lighting is also turned off and the operation of cameras monitoring technological devices is not needed. M1 category cameras can operate at any methane concentration, but the lack of illumination of the workings significantly reduces the image brightness despite the infrared illumination. MILESTONE software is most often used to record video signals from cameras. Recorded video signals are stored in video servers for a minimum period of seven days.

Cameras are installed, among others, in the following places:

- shaft bottoms,
- shaft tops,
- passenger stations,
- material stations,
- distribution centers,
- conveyor belt transfers.

Fig. 6.40 a) ÷ 6.40 d) show examples of views from cameras installed in various places in the workings and on the shaft tops.

Fig. 6.40. a) Example of a view of a passenger station

Fig. 6.40. b) Example of a view of the mine shaft [Warchoł, 2019]

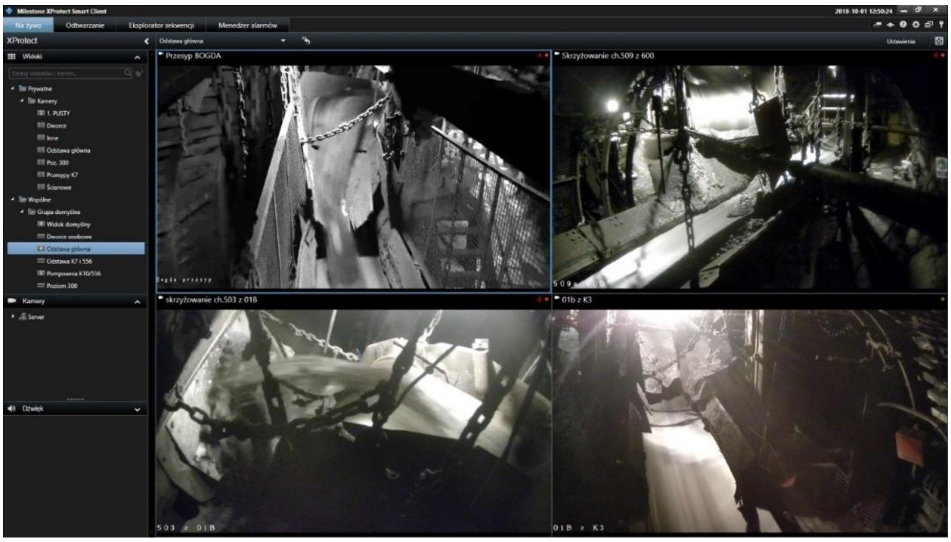

Fig. 6.40. c) Images from several cameras on one screen

Fig. 6.40. d) Plant control room with a large-format screen showing various images from cameras

6.9. Logical structure of fiber optic networks in methane mines

The simplest logical structure of a fiber optic transmission network includes separate links between underground equipment and a rack of substation equipment. Fig. 6.41 shows this type of structure containing cameras with analog output (KA) and IP cameras with digital output (KIP).

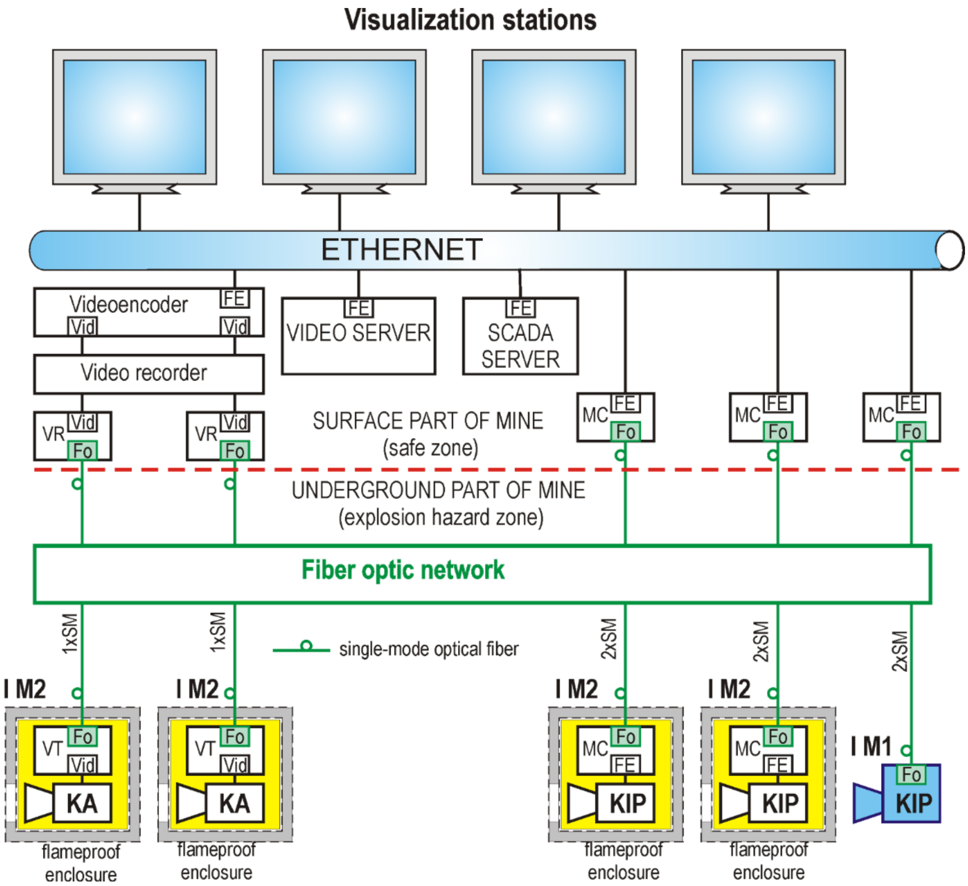

Fig. 6.41. Example of a video surveillance block diagram with direct fiber optic links Vid analog video connection

Cameras with analog output (KA) placed in a flameproof enclosure contain VT fiber optic transmitters with op is marking. The signal from the camera is transmitted via a single fiber to the station equipment rack, where it is fed to VR receivers and then as a composite video signal to the recorder and video encoder, where it is converted into a digital signal with an appropriate compression algorithm. The digital signal is directed to the appropriate visualization stations via the video server. The output signal from IP cameras (KIP) is send through a media converter or directly from the IP camera to media converters in the racks of station equipment and then to the video server and then to the visualization stations.

In the fiber optic cable network connecting end devices with station devices, there are a large number of fiber optic distribution frames. A more extensive structure of the fiber optic telecommunications network includes concentrators (Fig. 6.42). The following devices can be used as concentrators:

- converter station by Timler in version for safe zone (stations ALFA I, ALFA II) and for explosion hazard zone (stations ALFA III, ALFA IV category M I),
- intrinsically safe local RSS station,
- RMX fiber optic concentrator,
- computers with a monitor in a flameproof enclosure (e.g. OOSW flameproof optoelectric visualization station),
- switches (e.g. ISE-17, BCOM Switch 8/*, ISE-3FX, ISG-1),
- SWTx Backbone Teletransmission Node.

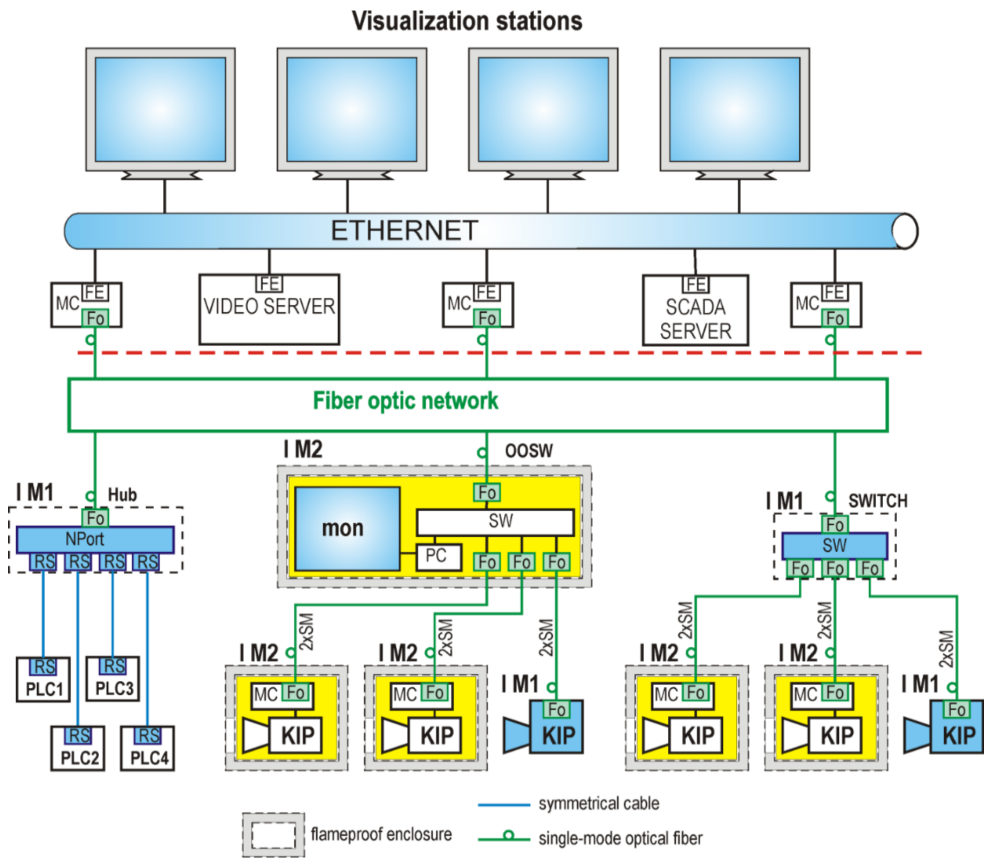

Fig. 6.42. Example of a block diagram of a fiber optic network with concentrators: NPort - serial port server, RS - RS485 connection, MC - media converter, PLC - controller

In all visualization systems using fiber optic network, underground devices (concentrators, cameras, controllers, etc.) require appropriate mains power supply (intrinsically safe), buffered in most cases by batteries (only in the case of M1 category devices or parts thereof).

Hybrid cables can also be used in visualization systems. An example of the simplest connection structure of intrinsically safe mining devices used in the visualization system (camera, ISG fiber optic switch, media converter) along with the power supply system using hybrid cables and HASO devices is shown in Fig. 6.43.

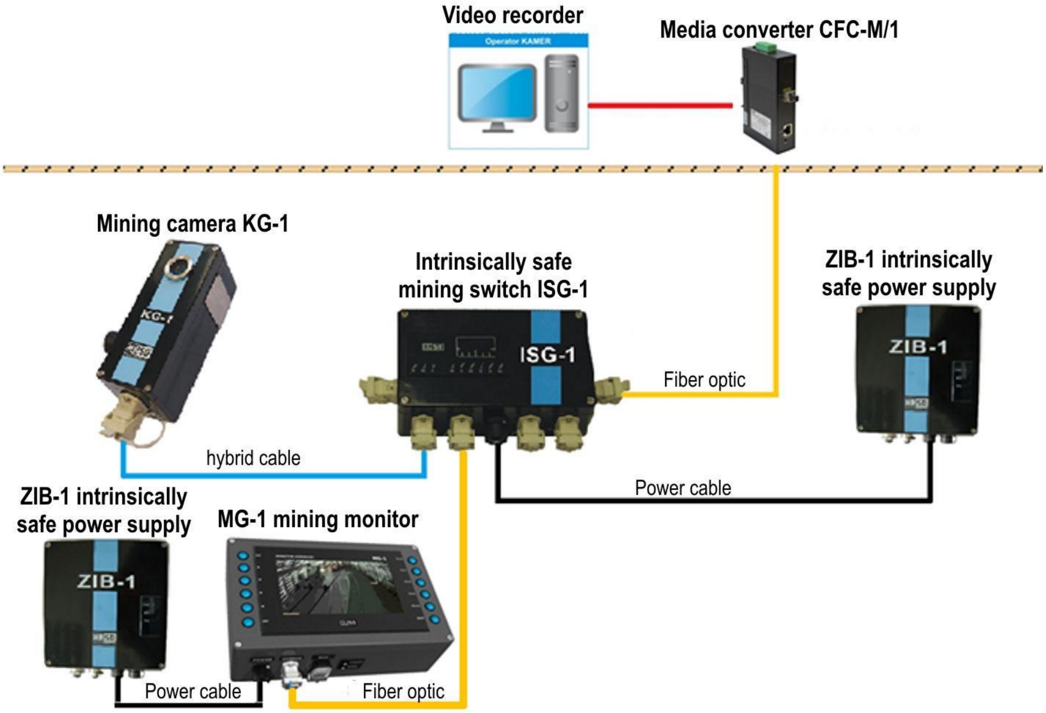

Fig. 6.43. An example of a simple connection structure of intrinsically safe devices used in the visualization system (camera, ISG fiber optic switch, media converter) with a power supply system using HASO devices

6.10. Cable structure of the fiber optic network in underground mines

The mine's fiber optic network includes:

– a main telecommunications network characterized by a relatively long period of existence; is built up: from the control room and cable rooms located on the surface in direction of shafts, shafts and main workings at individual levels,

– departmental telecommunications networks built for the duration of operation of individual regions, longwalls and faces; some of the end devices of this network, e.g. built in apparatus train, in longwall headings, in the areas where the longwall meets the heading, they are moved along with the advance of the longwall or working face,

– surface network servicing basic facilities and technological lines on the surface, such as: processing plants, coal sales points, entrance gates, and also mine control rooms, permanent supervision points, management and mine supervision rooms.

The fiber optic network consists of active elements such as:

https://doi.org/10.32056/KOMAG/Monograph2024.2

- stands of station equipment (e.g. STTS – Fiber Optic Technological Transmission Stand),
- cameras with local surface or underground visualization stations in industrial version,
- concentrators usually containing serial port servers, possibly switches,
- underground explosion-proof visualization stations, e.g. (OOSW - flameproof optoelectric visualization station),

and passive elements (mainly fiber optic distribution boxes and cable rooms) connected with fiber optic cables.

Taking into account current and future needs, JSW SA has developed general recommendations regarding the capacity of fiber-optic cables built and used (Table 6.3).

Recommendation regarding the use of optocommunications cables in JSW SA [Polityka, 2020]

Table 6.3.

Designation	**Number of fibers**	**Place of application**
Z-XOTKtsd	min. 72J	surface network
YOTKGtsDFoyn	min. 72J	installations in shafts
YOTKGtsFtlyn	72J, 36J, 16J	main network
YOTKGtsFtlyn	12J, 8J, 4J	department network
CDAD	12J, 8J, 4J	department network

Fig. 6.44 shows an example of a block diagram of a fiber optic network in one of the mines of JSW SA. The majority of the mine uses elements of the fiber optic network by TIMLER.

Currently, in all JSW SA mines, fiber optic cables are routed through at least two shafts. The structure of each network allows the transmission network to be switched to another shaft. Fiber optic cables are run at all levels where operation is carried out. Fiber optic lines are connected to all apparatus trains located in the longwall roadways of JSW SA's operational longwalls, which constitute an important element of their monitoring. In the second and third quarter of 2020, 24 longwalls were operated at JSW SA. Each of them was continuously monitored using a fiber optic network. On average, three longwalls were operated and monitored in each mine. In extreme cases, in the second quarter of 2020, individual mines operated from seven to one longwall.

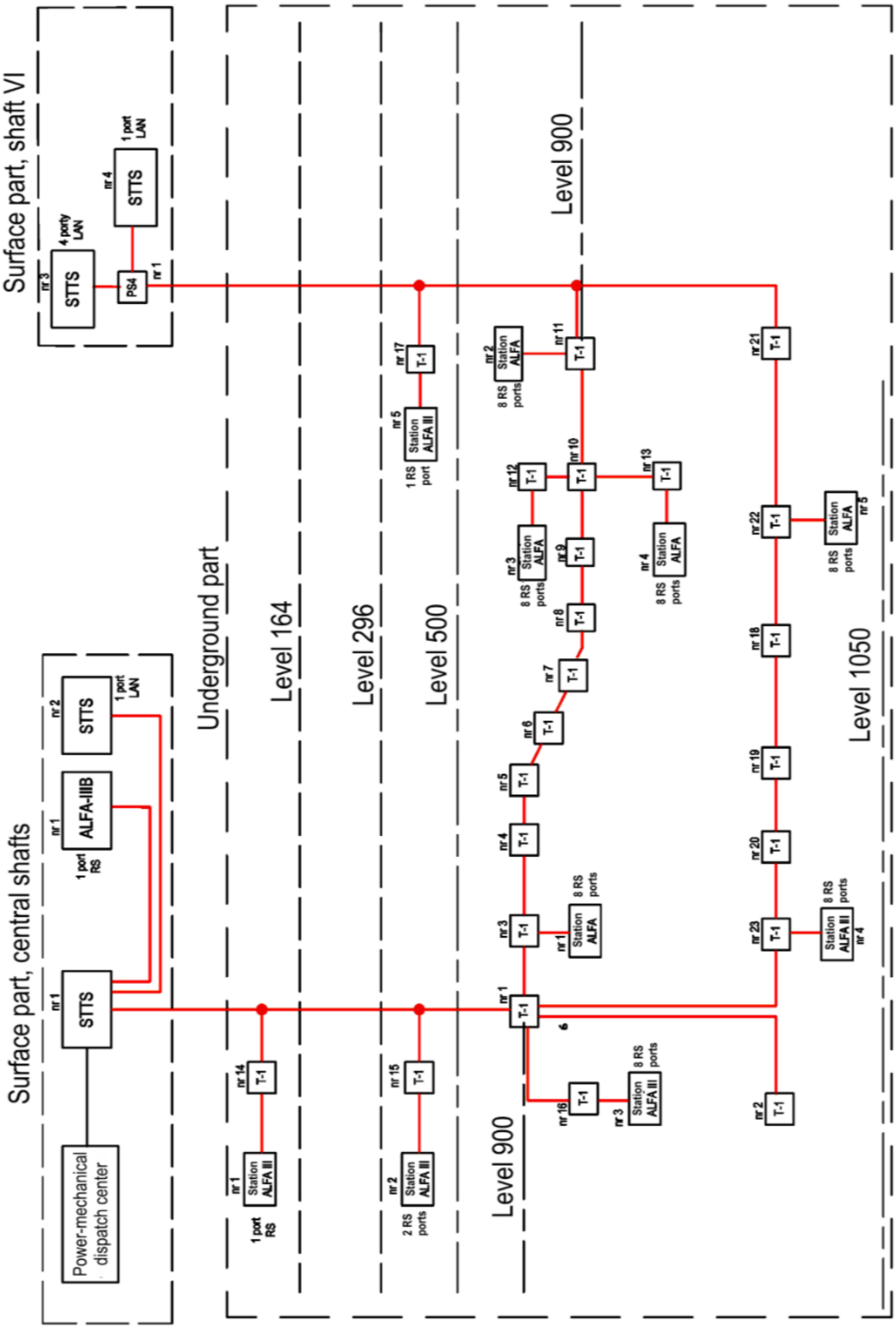

Fig. 6.44. Example of a block diagram of a fiber optic network: T-1 - Timler fiber optic distribution box, STTS - fiber optic technological transmission rack, ALFA Station - concentrator with a serial port server

Table 6.4 provides a summary of the total length of the bus fiber optic network. In all JSW SA mines, the total length of the main fiber optic network in 2019 was approximately 190 km.

Summary of the length of the main fiber optic network in JSW mines (December 2018) [Timler, 2019]

Table 6.4.

Mines/sections in JSW SA	Length of the main fiber optic network [km]
Coal Mine Budryk – server No. 1	40
Coal Mine Pniówek	30
Coal Mine Borynia-Zofiówka-Jastrzębie, Section Borynia	25 (+50**)
Coal Mine Borynia-Zofiówka-Jastrzębie, Section Zofiówka	25 (+16,5**)
Coal Mine Borynia-Zofiówka-Jastrzębie, Section Jastrzębie	25 (+14,5**)
Coal Mine Knurów-Szczygłowice, Section Knurów	20 (24,7*)
Coal Mine Knurów-Szczygłowice, Section Szczygłowice	22 (34,5*)
Total	**187**

* – length of the entire network [Tąpała, 2019]

** – network expansion in 2019 [Dziemdziora, 2019]

7. Systems for locating people and devices

Kazimierz Miśkiewicz, Antoni Wojaczek

7.1. Introduction

This chapter partially uses the material contained in the authors' monograph Miśkiewicz K., Wojaczek A.: *Radiocommunication in underground mines*, Wydawnictwo Politechniki Śląskiej, Gliwice 2020.

As already mentioned in the chapter, the three radiocommunication systems used in underground mines are used not only for audio communication or data transmission, but also for many other tasks that, from a formal point of view, should be performed by every Mining Plant Operations Manager (KRZG). Regarding systems for locating and registering persons in the Geological and Mining Law and its supplementary acts [PGG, 2023; RRM, 2004; RM, 2017] the general principles and conditions of operation of such systems are defined. The most important of them are:

– The entrepreneur should keep records of persons staying at the mining plant.
– Persons staying in workings are provided with personal lamps equipped with locating transmitters adapted to emit a signal continuously or periodically upon request from a locating device for not less than 7 days. The mining plant uses tracking systems consisting of location transmitters and receiving devices enabling the location of the transmitter from a distance of not less than 20 m in all directions.
– Systems for locating and recording employees in underground mining plants should be designed to enable efficient management of employee movement in both normal and hazardous situations. They should record employees' passage through system checkpoints and inform the dispatcher in alarm mode that there is a person in the danger zone or that the permissible time of a person's stay in the danger zone has been exceeded. Alarm information transmitted to the dispatcher should be simultaneously transmitted (as feedback) to the person affected by the event.

The regulations also specify general minimum requirements for radiocommunication devices used in mining plants, which include in particular:

– Explosion-proof telecommunications systems should be used in methane mines. In particular, wired and radio communication systems together with transmission systems should be intrinsically safe (in the case of optical fibres, inherently safe) and adapted to work at any methane concentration.
– Electrical and telecommunications equipment should be resistant to external factors at the place of intended use. The equipment casing should be made of non-flammable or flame-retardant materials. The materials used for this type of housing should be resistant to chemical, mechanical and electrical factors. During normal operation, the equipment casing should provide a protection level not lower than IP54.

The current capabilities of radio communication systems make it possible to implement electronic systems for identification, location, access control and crew records in underground mines using the RFID or its extension called RTSL. These types of systems are formally

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classified as so-called safety systems and more detailed functional requirements are formulated, among others, in point 3.4.6. Annex No. 3 in the Regulation on Admission [RRM, 2004] specifying that security systems used, for example, for locating and recording employees in underground mine workings should be designed in such a way as to enable efficient management of the movement of employees both in states of normal operation and in states of threats, record the employee's passage through system checkpoints and also inform the dispatcher in alarm mode that:

– there is a person in the danger zone,
– the permissible time of stay of the endangered person in the danger zone has been exceeded.

To clarify certain formulations, it is necessary to define selected basic terms appearing in this chapter.

Identification, called RFID, is a technique of remote reading (in the range of cm to several meters) of data contained in electronic identifi ers.

Location – is a way of determining the current location of a miner or machine or transport container (in time and space). It often also allows determining the direction of movement of a miner or machine. Location systems are one example of the use **of identification.** There are two ways to implement localization:

– **Zone location** defining in which zone the miner, machine or transport container is located; Gates reading data from identifiers are installed at the zone border.
– **Precise location,** called RTLS, determining (with an accuracy of several meters) the position of a miner, machine or transport container in the working.

Access control - checking the authorization to pass through the gate based on the gate's reading of data from the identifier. **The access control system** may enable passage through the gate (opening the turnstile or tilt gate, opening the door) or may optically and/or acoustically signal a prohibition to pass through the gate. This applies, for example, to gates in mine workings in areas with special hazards or rooms with limited access (electricity switchboards, explosives chambers, etc.).

Location – not every location system allows identification (personalization) of the located miner or facility. An example is the GLON system **locating transmitter** (short for mining personal locating transmitter). Using the GLOP **Locator Receiver**, you can locate an object but cannot personalize it. This type of localization in mining is called **location**. To search for miners during cave-in operations, the intensity of the magnetic field generated by locating transmitters placed in miners' personal lamps is used. The measured value of the magnetic field strength allows only the determination of the distance to the location transmitter.

7.2. RFID identification systems

In RFID systems (radio frequency identification) there are always two devices (Fig. 7.1): an identifier and a reader. The system is complemented by a computer (server) to which data from the reader is sent (online) and which makes it available to users. Sometimes the reader is equipped with memory and the data is transferred offline to the server.

Often **the identifier** is called **a transponder**, **a tag**, **a label, a chip**, and sometimes (as in the case of e.g. electronic banking) **a proximity card**. The information read by the reader is sent to the computer system, where it is used in the identification system.

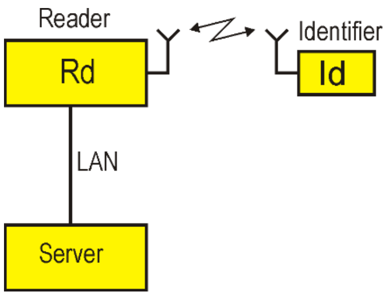


Fig. 7.1. Main elements of the RFID system

From the point of view of the direction of transmission of useful signals, one can distinguish one-way and two-way identifiers, in which the reader, in addition to receiving the characteristic identifier code, sends other useful signals (e.g. alarm, information, paging) generated in the system.

If there is an identifier near the reader, the reader uses the reader-ID radio link and uses a previously defined protocol to "read" the data stored in the identifier's memory. These may be:

– data saved in the identifier memory by the manufacturer,
– data saved in the identifier memory by the user (installer) of the RFID system,
– data collected by the identifier (e.g. from sensors) in the time between subsequent readings.

A characteristic feature of RFID systems is wireless data transmission between the reader and the identifier. The distance, depending on the application and the adopted electronics solutions, may range from millimeters to hundreds of meters.

RFID systems can be classified according to:

– way of powering the identifier,
– method of transmitting information (protocol) between the reader and the identifier,
– frequencies used in the radio channel,
– ID functionality,
– ID memory size,
– application.

Due to the method of communication between the identifier and the reader, three basic RFID systems can be distinguished [Miśkiewicz, 2020]:

– Passive, in which the identifier does not have its own autonomous power source (Fig. 7.2). The RFID reader emits a radio signal (treated as a query) at appropriate time intervals. The identifier receives the signal from the reader through its antenna and, by rectifying and multiplying it, creates a supply voltage for its electronics. After obtaining the appropriate supply voltage, the identifier sends its identification number by acting on the signal from the reader (e.g. through amplitude modulation). The reader receives the modified signal by reading the ID number of the identifier. In this case it is a transponder.

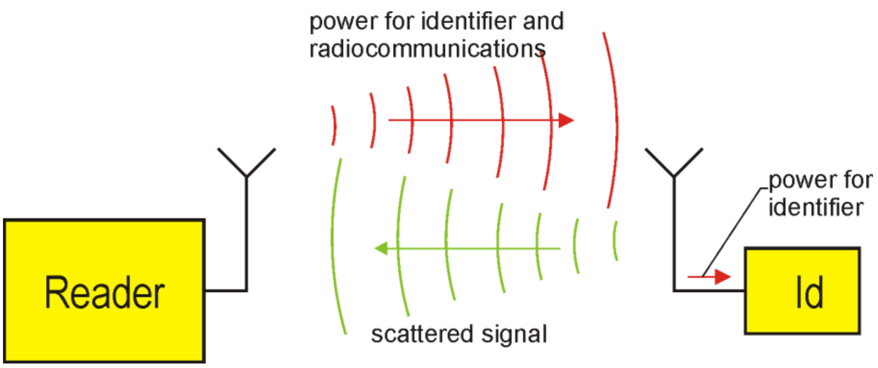


Fig. 7.2. Block diagram of an RFID system with a passive radio identifier (ID)

– Semi- passive, in which the identifier has its own power source for its electronics (Fig. 7.3). Communication between the reader and the identifier is similar to passive systems. The transponder is activated signal from the reader.

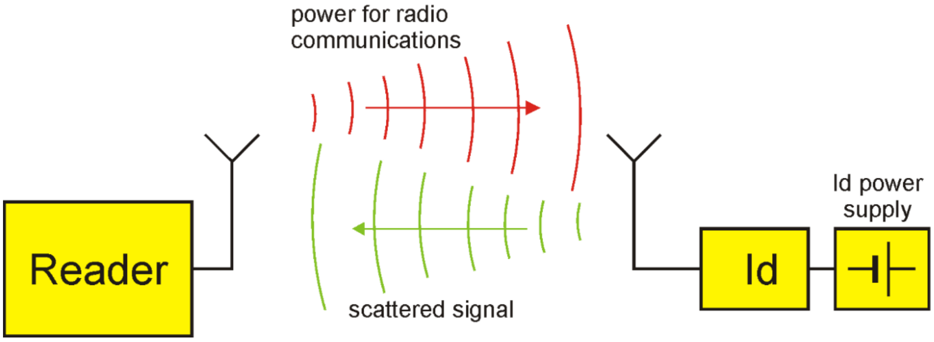


Fig. 7.3. Block diagram of an RFID system with a semi-passive ID identifier

– Active, in which the identifier has its own power source and its own radio signal transmitter (Fig. 7.4). Most often, the identifier in active systems sends its identification number continuously, at very short, pseudo-random intervals.

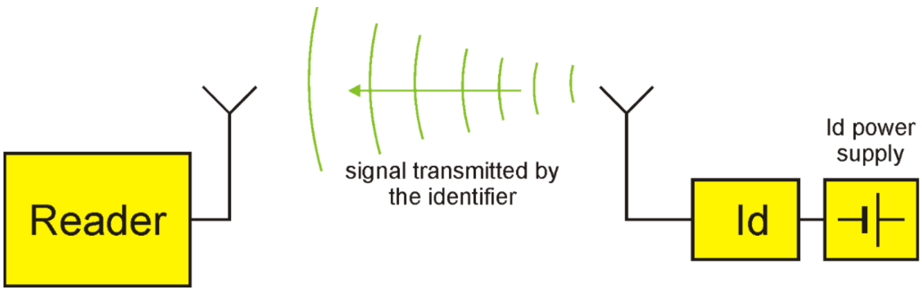


Fig. 7.4. Block diagram of an RFID system with an active ID identifier

The range of frequencies used in RFID systems results from certain legal regulations in the field of radio communications, mainly the relevant regulation of the minister "responsible for communications" regarding the use of radio transmitting devices without a permit [RMC, 2022]. This regulation specifies, among other things:

– what frequencies can be used in RFID systems,
– maximum allowable parameters of transmitting devices, such as radiated power EIRP, or magnetic field intensity at a specific distance from the transmitter (e.g. 10 m),

– shape of the transmitter antenna radiation beam,
– transmitter activity.

The most frequently used are RFID systems operating in the frequency bands 125/135 kHz, 13.56 MHz, 868/915 MHz, 2.45 GHz. There are also other frequency bands, e.g. 433 MHz.

Due to functionality, the following systems can be distinguished:

– 1-bit identifiers (EAS); these are most often anti-theft systems in stores, where the reader only detects the presence of an ID and generates an alarm when an attempt is made to take goods out of the store without payment; operating the cash register with a very strong magnetic field irreversibly destroys the identifier;
– read-only identifiers;
– identifiers for writing and reading;
– identifiers with anti-collision mechanisms, where it is possible to read many identifiers within the reader's range;
– identifiers with authentication and encryption;
– smart identifiers (cards) containing a cryptographic processor.

Fig. 7.5 shows an example of a passive TRID (125 kHz) transponder from ELSTA [ELSTA], used to identify elements of the mining section of a powered support (a), the internal structure of a passive identifier (card) (b) and an active identifier with an alarm button (Mobile Communicator from Venture) used, among others, in American mines (c).

a) b) c)

Fig. 7.5. Examples of passive (a, b), active identifiers with an emergency button (Mobile Communicator) Venture (c)

The reader's operating (reading) zone should be understood as the area around the reader in which the identifier located there will be correctly read. The size and shape of the operating zone depend, among other things, on the current location of the identifier (due to the directionality of the identifier's antenna) as well as on the location of moving machines and devices and sometimes the shielding effect of the human body and its personal equipment.

The size of the operating zone of passive and semi- passive transponders is small, ranging from centimeters (e.g. for payment cards with a contactless function) to several dozen cm (e.g. for EAS identifiers).

In the case of passive or semi-passive systems, the coupling between the reader and the identifier may be [Finkenzeller, 2003]:

– induction,
– capacitive,
– with backscatter (electromagnetic backscatering coupling),
– induction close (on the order of mm).

Active transponders are equipped with a power source and their own transmitter. The operating range of active ID readers can be from several to several hundred meters. Since there may be many identifiers in the reading zone, it is important to use a communication protocol that will ensure that all identifiers are read by the reader in a short time.

A simple method of reading multiple identifiers is to use the ALOHA protocol [Finkenzeller, 2003]. It involves the identifiers emitting frames with the identification number at random intervals, regardless of the occupancy of the radio channel. Sometimes a collision will occur, i.e. frames or their fragments will be transmitted simultaneously, which prevents their correct reception and reading of the identification number (Fig. 7.6).

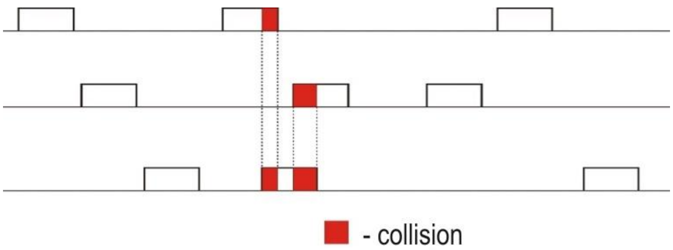


Fig. 7.6. Illustration of a collision in the case of three identifiers in the reader's reading zone

For example, the TTAG-868FSK/L type identifiers of the ARGUS type radio identification system for personnel and equipment installed in the lamps of all miners working in the Pniówek mine send their unique identification package twice per second for 5 ms.

By using an appropriately long reading time for identifiers (sending at random, irregular time intervals), the probability of reading all identifiers close to one can be achieved. In many solutions, the size of the reader's reading zone can be adjusted programmatically by setting the reader's sensitivity.

7.3. Possibilities of using RFID systems in mining

7.3.1. Registration of working time and underground workday

RFID identification can be used to **register working time (RCP)** in the surface part of mine (“surface workday”) and in the underground part of mine (“underground workday”). Access control gates are installed at the entrance to the mine, allowing people to pass after reading and verifying the miner's personal ID. The gate includes, among other things, a reader and possibly mechanical elements blocking the passage (e.g. a turnstile or a bolt). The reader is connected to the RCP system. Fig. 7.7 shows examples of access control gates (readers) installed in JSW SA mines and performing various functions in the mine.

At the main entrance gates, multi-station one-way gates are used, separate for entry and exit from the workplace (Fig. 7.7 a÷c). Reading the ID allows one person to enter, and the read data is sent to the T&A system to document the employee's stay at the workplace.

Similar one-way gates can be installed on the pithead to **register workers' descent** into underground workings (Fig. 7.7 e). On peripheral shafts and when there is a small number of miners working in a given area, integrated gates are used that perform both RCP functions and “underground workday” registering functions. Before applying the ID to the reader, the miner consciously selects (using buttons A, B, C, D, Fig. 7.7 f) the reason for his presence in this area. On some communication routes terminal readers are installed, most often only the readers (Fig. 7.7 d) and a separate large display.

The RCP working time registration system and the “underground workday” registration system can also be treated as a broadly understood **zone location system**, which has information about who (name and surname) is in the mine (the location zone is the mine) and who went down (the location zone is the pithead, the shaft and all underground workings). The systems mentioned above perform the functions **of zone location.**

Fig. 7.7. ZAM A.70 readers: a) in a housing screwed to the ground, b) in a line arrangement on the main entrance gate of the mine, c) view of the front panel, d) terminal version reader,

e) reader on the pithead f) in a housing screwed to the wall near the peripheral shaft, which serves both the RCP function and records the “underground workdays”

RCP systems from the Czech company ZAM are used in JSW SA mines. RCP system readers are installed, configured and serviced by JSW IT Systems (ITS). Selected technical data of these readers:

– display dimensions 70x40 mm,
– operating range of proximity cards (8 cm MIFARE, 12 cm UNIQUE),
– large number of remembered registrations – 100,000 or 200 000,
– multi-color illuminated optical element (pictogram) signaling events in blue, red or pink,
– event signaling (sounds, optical element),
– cooperation with proximity cards adapted to work in rooms at risk of explosion.

The electronics is based on a 32-bit ARM processor and two ATMEGA processors. The gateway can be powered by 230 V mains voltage or direct current (12 V to 48 V). It is equipped with an emergency operation backup (12 V battery, minimum backup time 4.5 h). It has standard interfaces: RS232, RS485 (with opto-isolation), Ethernet 10/100 Mb /s. It enables cooperation with many different external devices such as lock, gate, turnstile, relay. The internal clock time is maintained by an additional battery (independent of the battery).

Depending on the reading head used, the reader allows cooperation with UNIQUE or MIFARE programmable proximity cards. Signaling reader events (e.g. registration) is presented using sound and a two-color pictogram. The reader also allows you to save certain information on programmable MIFARE proximity cards. It has the option (in OFFLINE mode) of additional verification of the person using the card by forcing an individual code containing up to 8 characters to be entered from the keyboard. The reader's reaction time to presenting the card is less than 1 second (searching 10,000 authorized cards). When an employee is registered, the display may not only show his name and surname, but also, for example, the balance of hours, the validity of periodic tests, the number of days of leave to be used or any other message. When used in conjunction with a turnstile, the gate has, for example, the ability to:

– allow the employee to enter only on specific days and at specific times,
– block multiple registrations of the same card between registration readings,
– display the number of unread registrations on the screen,
– use an identification card as a pass (possibility to set the expiry date of the card).

Radio RCP systems based on individual employee identifiers are used in all JSW SA mines. Persons from external technical services and other guests receive a one-time or periodic identifier at the mine's pass office. The input reader requires the ID badge to be brought closer to the reader (a few cm). The employee ID does not have its own power source, it is a passive element. To register the entry (send the appropriate code to the crew records system), it uses energy collected from the reader via an electromagnetic field.

Fig. 7.8 (a, b) shows an example (view and internal structure) of the MIFARE identification card used in the mining plants of JSW SA. It is also used on pithead when registering access to underground workings of authorized persons. MIFARE proximity cards

(Classic, or Plus) are used in the version with a 7-byte unique serial number (UID), in accordance with the ISO 14443 type A standard.

a) b)

Fig. 7.8. Examples: a) an identifier authorizing you to enter the premises of JSW SA, b) the inside of the MIFARE proximity card of a personal identifier

The card is delivered in white (PVC material), adapted for printing on dye-sublimation printers. Selected card technical data:

- dimensions: 85.6 x 54 x 0.76 mm,
- contactless chip (RFID): NXP MF1 IC S50 or NXP MF1SPLUS60x,
- operating frequency: 13.56 MHz, compatible with ISO 14443A,
- total EEPROM memory: 1024 bytes 2048 bytes,
- has a unique 7-byte serial number (and/or) a non-unique 4-byte serial number,
- encryption: CRYPTO1 48-bit and AES 128-bit (for Plus cards).

MIFARE cards use NFC protocol to communicate with the reader. This protocol ensures data exchange over distances of several cm, using the 13.56 MHz frequency.

In JSW SA mines that do not use RFID systems in underground workings, the registration of underground workplaces of employee groups, as required by law, is carried out in the mine's control room by receiving (from the shift foreman) a general telephone report on the number of miners working in a given area and the nature of the work they perform. Based on these telephone reports, the dispatcher prepares a general shift report. This report often differs from the current picture of miners' movements during a given work shift.

7.3.2. Zonal location

The use of, for example, revolving (or tilting) access control gates or gates requiring insertion of an identifier into a reader in underground workings is unjustified due to the need to ensure safe and quick movement of the crew in the event of a threat, restrictions on the movement of people, transport of materials and other equipment. In underground workings, by equipping employees with active identifiers, **zone location** can be achieved.

At the borders of individual zones, sets of at least two readers called **RFID gates** will be installed (Fig. 7.9 a). The reading zones of the readers must partially overlap. In each gate, based on the sequence of identifier readings by individual readers, the direction of identifier movement (whether it moves into the zone or leaves the zone) can be determined. By installing two RFID gates in the excavation, zone localization can be achieved, as shown in Fig. 7.9 b).

If there is a limit on the number of people staying there at the same time because it is **a zone of particular risk of rock bursts**, then banners are placed near the gates on the border of the zone, which display the words "NO ENTRY" when the maximum permissible number of people is in the zone. The location system displays appropriate inscriptions on banners based on the number of registered people in the zone.

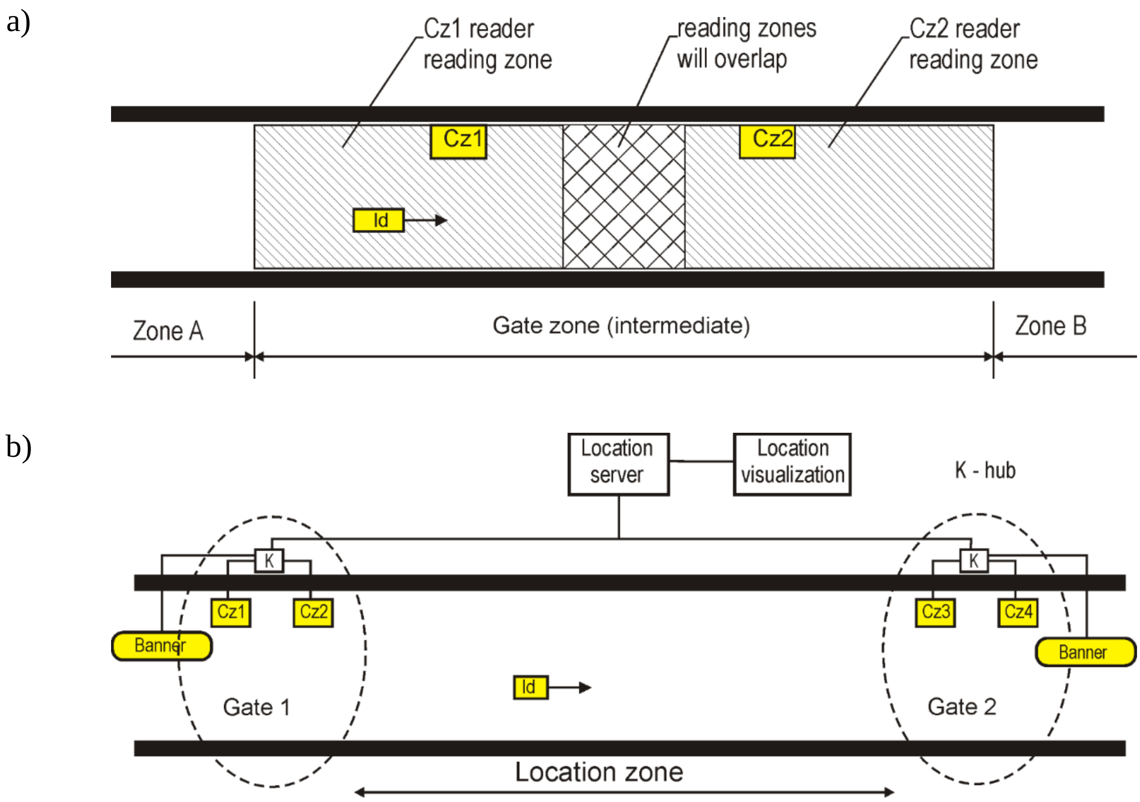


Fig. 7.9. Illustration of the operation of an RFID gate in an underground mine (a), example of implementing zone location in a working (b)

7.3.3. Exact location - RTLS systems

As already mentioned, RFID techniques used in zone location systems operate on the principle that readers read a unique identifier code (when passing near the reader) and transmit it to the system server. The exact location of the identifier at a given moment is not important. It is only important to confirm the presence of the identifier inside the zone.

RTLS location systems are a development of RFID techniques. In such systems, the reader not only reads the radio signal sent by the tag, but also measures certain parameters of the received radio signal (e.g. level or time of arrival of the signal from the tag) so that the system can calculate the location of the tag with a certain accuracy in the working at the time of transmission the signal. RTLS systems are therefore often called **precise location systems**, which means that such a system calculates the location of the identifier with a specific accuracy.

There are the following methods of locating identifiers on a two-dimensional plane in RTLS systems:

- AOA *(Angle of Arrival)* - a method of measuring the angle of arrival of the signal from the identifier,
- TOA *(Time of Arrival)* - a method of measuring the time of arrival of the signal from the identifier,
- TDOA *(Time Difference of Arrival)* – a method of measuring the difference in arrival times of signals from the identifier,
- RSS *(Received Signal Strength),* sometimes abbreviated RSSI (*Received Signal Strength Indicator)* – a method of measuring the level of the radio signal emitted by the identifier.

There are also hybrid solutions using two of the above-mentioned methods, e.g. AOA and TDOA (UBISENSE solution).

In the case of locating the Id identifier using the AOA method, two readers are used at a distance d (Fig. 7.10 a). Each reader is equipped with an antenna that allows determining the angles a and b arrival of the signal from the identifier. Knowing the distance d and angles a and b allows you to determine the location of the identifier using geometric relationships regarding the triangle.

In the case of the TOA method, three readers should be used (Fig. 7.10 b). The readers indirectly measure the distance d_1, d_2, d_3 to the tag by measuring the time needed for the electromagnetic wave to travel the distance from the tag to the reader. Time can be measured in two ways:

- bidirectional (reader – Id – reader) taking into account the response time,
- unidirectionally, where the identifier sends signals at defined times. Because i.d. clocks cannot be synchronized readers, the time measurement result is influenced by the unknown time shift of the ID and reader clocks. The time shift of clocks can be determined using an additional reader (e.g. three readers for location on a plane or four readers for location in space), using the concept of pseudorange (similarly to GPS systems [Narkiewicz, 2003]). Knowing the distances d_1, d_2, d_3, and the position of the readers allows you to determine the location of the identifier using typical geometric relationships.

a) b)

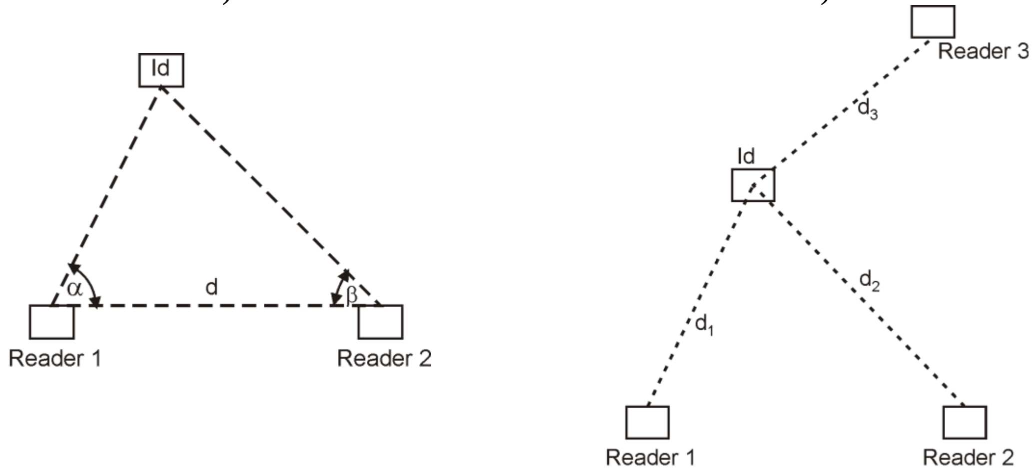


Fig. 7.10. Illustration of ID location methods: a) AOA, b) TOA, TDOA, RSS

In the case of the TDOA method, readers with synchronized clocks are used and the difference in arrival times of the signal from the identifier to two readers is measured. When three readers are used, time differences allow determining distance differences $D_{12} = d_1 - d_2$, $D_{23} = d_2 - d_3$. Knowing the distance differences allows you to determine the location of the identifier using typical geometric relationships.

In the case of the RSS method, readers measure the level of the signal received from the identifier. If the electromagnetic wave propagation model is known (the relationship between the signal level and the distance), the value of the signal level received by individual readers will allow determining the distance d_1, d_2, d_3 and the location of the identifier.

It should be noted that due to the shape of the underground corridor workings, location in two-dimensional space is not possible, which affects the accuracy of the identifier location in the workings.

Zonal location, and in some workings precise location, is important in the event of mining disasters (e.g. rock bursts). Then, information about the location of people at the time of the disaster allows for better management of rescue operations. On May 5, 2018, there was a tremor in Zofiówka Section, which injured seven miners. The body of the last miner was found after 12 days of operation. One of the significant problems in conducting the rescue operation in Zofiówka Section was the location of the miners' bodies. The course of the rescue operation prompted the Management Board of JSW SA to test several available RTLS systems for the precise location of miners. Due to the shape of the corridor excavations, it is only possible to locate the identifiers in the axis of the excavation without locating them in its cross-section. This is **a one-dimensional location** (there is only one coordinate), i.e. the location of the identifier is defined as the distance from the reference point (e.g. from the conventional beginning of the excavation). For tests in JSW mines, the required location accuracy was assumed to be approximately 2 m. Two RTLS location methods may be practical in underground mines:

- time difference measurement method (TDOA),
- radio signal level (RSS) measurement method.

7.3.4. TDOA exact location - time difference measurement

The localization method by measuring the difference in arrival times of TDOA signals consists in the tag sending a radio signal that is received by at least two readers (Fig. 7.11). The difference in time when this signal is received by these readers is measured. The signal propagation time from the transponder to reader 1 is equal to t_1, and the signal propagation time from the transponder to reader 2 is equal to t_2.

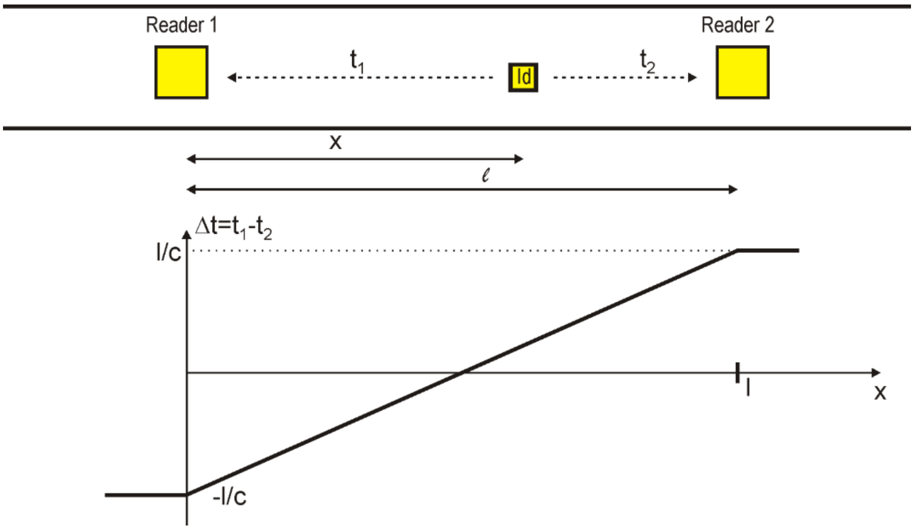


Fig. 7.11. Illustration of linear localization using the TDOA method

If in the excavation the identifier is located between two readers 1 and 2, at a distance x from reader 1, and the distance between the readers is equal to *l* (Fig. 7.11), the measured time difference Δt will allow the determination of the distance x according to the relationship:

$$x = \frac{c \cdot \Delta t + l}{2} \tag{7.1}$$

If the identifier is located outside the space between the readers in the excavation, determining the location using the TSOA method is not possible. This can be remedied by installing readers in such a way that the identifier is within the reach of more than two readers.

The condition for using the TDOA method is the ability to measure time with nanosecond accuracy. Such high accuracy of time measurement can be achieved by using broadband CSS modulation (chirp spread spectrum).

7.3.5. Precise location RSS - measurement of the radio signal level

The location method by measuring the RSS radio signal level is that the identifier sends a radio signal that is received by two readers (reader 1, reader 2), and the difference in the transponder signal level (ΔRSS) received by reader 1 and reader 2 is measured in the system Fig. 7.12 shows the location of the transponder in relation to two readers.

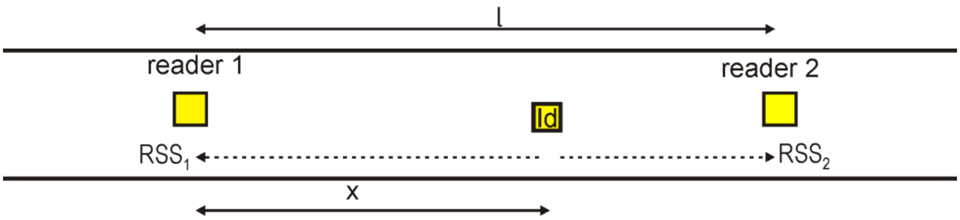


Fig. 7.12. Illustration of the location using the RSS radio signal level measurement method

The difference in the level of signals received by the readers is approximately equal to:

$$\Delta RSS = 10 \cdot n \cdot lg\frac{l-x}{x} \tag{7.2}$$

where *n* is a coefficient depending on the conditions of radio signal propagation in the excavation (within the range of 1.2 to 1,6).

From equation (7.2), the distance x between the identifier and reader 1 can be calculated. The tests carried out at JSW SA show that for the RSS location system we obtain an accuracy of approximately 10% of the distance x between two readers, and the largest absolute location error (for the assumptions made to estimated calculations) is equal to ±1.5 m and occurs in the middle between the readers.

7.4. Implementation of zone localization in mines

7.4.1. Typical installation locations for gates

The location systems installed so far in mines are zone location systems. With the exception of the Pniówek coal mine, they control only selected areas or workings. These are most often areas where there are integrated environmental threats and areas with strong rock bursts. When deciding on the construction of a location system in a given mine, two trends are noticed:

- Striving to achieve relatively high accuracy (only in a specific small area, e.g. a hazardous area). This goal is achieved primarily through skillfully selected places and the number of gate locations.
- Covering large areas with the identification system (e.g. entire mining levels), thus reducing the accuracy of the location of miners' identification.

7.4.2. Lamp room, pithead and pit bottom

The development of a zonal location system in a mine must always take into account several basic areas of the mining plant, such as lamp rooms, pitheads, pit bottoms and basic mining areas. The construction of such a system in a mine requires the miner to check the correct operation of the transmitter after taking a personal lamp. Checking its operation involves receiving information from the identification system used in the mine (e.g. optically on a banner located om pithead) that a given miner has the correct lamp. Outsiders coming down in the lamp room should be entered into a computer database. Therefore, it is necessary to install a gate on the access route from the lamp room to the pithead, so that each employee, after collecting the lamp, can check the correct operation of his transmitter.

Gates installed at the pit bottom inform the dispatcher about the number of miners working on a shift at a given level. The basic points in the pits where gates should be installed are usually short sections of the passage between the shaft gates and the first fork of the workings at the level. Placing the gates in these places will enable quick monitoring of the condition of all crew at each mining level of the mine.

7.4.3. Roadway faces

Due to the high hazards in specific workplaces, zone identification in each mine should include miners working in face workings ventilated with ventilation pipes. There are usually no more than 20 people in this type of excavations, and their maximum length does not exceed several kilometers. To increase the accuracy of identification, in the case of long runs of these workings, it may be necessary to install (in addition to the fixed gate) a second so-called a “moving gate” that will be rebuilt as the face advances.

7.5. ARGUS zone location system

An example of an intrinsically safe zone location system is ARGUS, developed by TRANZ-TEL and installed at the Pniówek Coal Mine (Fig. 7.13).

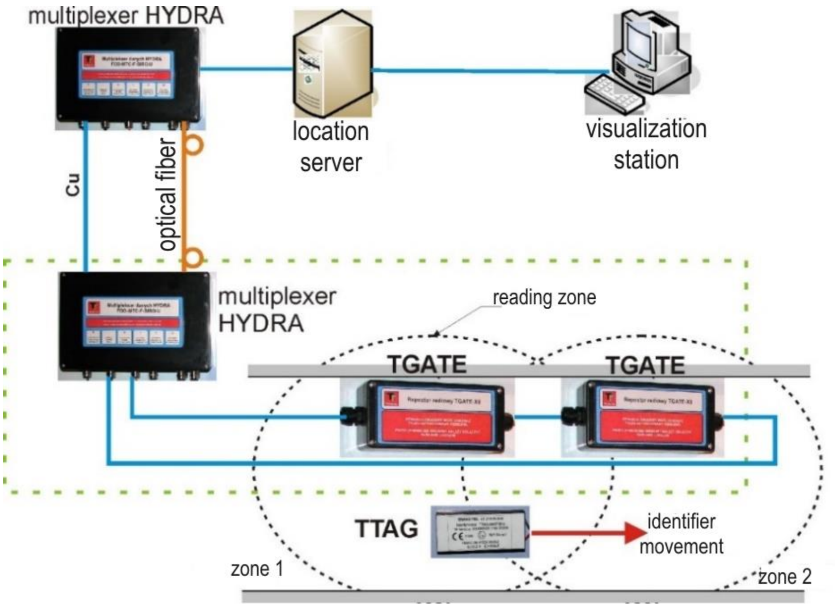


Fig. 7.13. General block diagram of the ARGUS identification system

The construction of the system in the mine began in 2011. TTAG identifiers were installed in 6,980 personal lamps (which were in the lamp room at that time) (Fig. 7.14 a), 268 lamps (Fig. 7.14 h) had the ability to receive text messages. 1,000 TTAG-B battery identifiers were also prepared for transport units. Selected technical data of the TTAG identifier are presented in Table 7.1.

Selected technical data of the TTAG identifier mounted in a personal lamp

Table 7.1.

No.	Symbol	Parameter	Size	Unit
		Power supply		
1	P_n	Average power consumed	1	mW
2	U_n	Working voltage	3 – 5	V
3	I_n	Average current consumption	200	μA
4	I_{min}/I_{max}	Standby/Transmitting	10/12	μA/mA
		Broadcast		
5	F_{av}	Carrier frequency	868	MHz
6	F_{dev}	Deviation/Modulation	90/FSK	kHz
7	P_{tx}	Transmitter power	6	dBm
8	T_{tx}/F_{tx}	Transmission time/frequency	5/2	Ms/Hz
		Dimensions		
9	L/W/H	Length/Width/Height	60/27/8	mm

https://doi.org/10.32056/KOMAG/Monograph2024.2

Identifiers TTAG-B are equipped with a non-removable or replaceable battery (Fig. 7.14 b) with a minimum battery life of 3 years. In the material logistics system, they are permanently attached to transport containers.

In the first period of operation of the ARGUS system, only wired TGATE transponders were used as identification gates, which were connected to HYDRA multiplexers using the RS485 protocol. Due to difficulties in transmitting such large amounts of data to the dispatch center, a decision was made to build a fiber optic network in the mine.

Currently, TGATE2 wired radio transponders (Fig. 7.14 g) are used only in fixed points of the zone identification system (e.g. lamp room, pithead and pit bottom). They are constantly listening on the 868 MHz frequency. They require a DC 8-20 V power supply (current consumption approximately 20 mA). They can also be used as RS485 signal repeaters. They have optical (TGATE2-8Lx) and/or acoustic (TGATE2-8LG) signaling systems.

The ARGUS system has been approved by the President of WUG. The system's teletransmission devices enable data transmission via fiber-optic or copper cables and using radio waves. Due to the use of the TRM-VHF radio modem, it was also possible to transmit data via the radiating cable of the MCA-1000 system. All devices have a standard interface, which makes it possible to cooperate with the universal multiplexer of the ST-HYDRA teletransmission system. The visualization was carried out by the Monsteer -D computer dispatcher supervision system.

ST-HYDRA is a data multiplexer with a wide variety of input ports and applications. It is an essential element of the ARGUS personnel and equipment identification system. It can perform, among others, the following functions:

– serial transmission converter with galvanic separation of various media (RS485, V.32 modem, multi-mode and single-mode optical fiber, radio modem),
– repeater / separator RS485 bus,
– input data acquisition: binary inputs, analog 0.4÷2 V, 4÷20 mA,
– control devices via relay outputs.

Currently, ARGUS system gateways include:

– Multigate control panel (also called Multigate controller or Multigate gateway); the control panel has eight ports for Multigate probes, is powered by 8÷16 V DC (power consumption approximately 1.7 W),
– readers (called Multigate probes or active antennas by the manufacturer) that can be connected to the Multigate control panel with a cable up to 100 m long.

Fig. 7.14 shows the basic elements of the ARGUS system, such as: TTAG and TTAG-B identifiers with a battery adapted to be attached to transport containers, the Multigate control panel and the Multigate probe (reader) (marked Cz in Fig. 7.15) with a cable connecting it to the Multigate control panel, HYDRA multiplexer and banner.

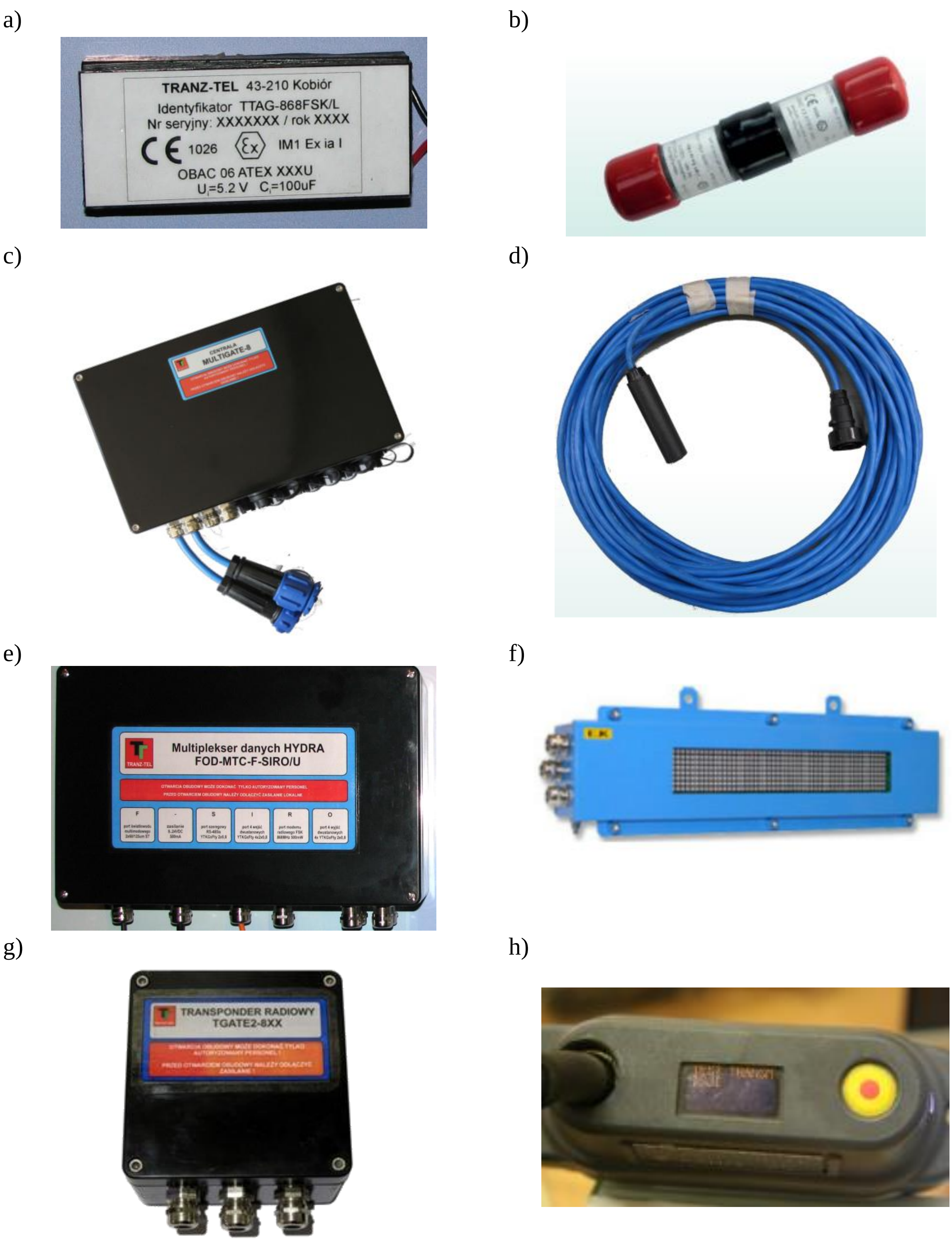


Fig. 7.14. ARGUS system elements: a) TTAG identifier for installation in the battery cover of the helmet lamp, b) TTAG-B identifier with a replaceable battery adapted to be attached to transport containers, c) Multigate control unit, d) Multigate probe with power cables, e) HYDRA multiplexer, f) banner, g) TGATE2 radio transponder, h) personal lamp with the ability to receive text messages and an alarm button

Multigate probes connected to the control panel depends on the gateway configuration (Fig. 7.15):

– three readers are planned for the type I gate (dividing the excavation into two zones),

– four readers are planned for the T-type gate (one-way intersection),
– five readers are planned for the X-type gate (intersection with two workings).

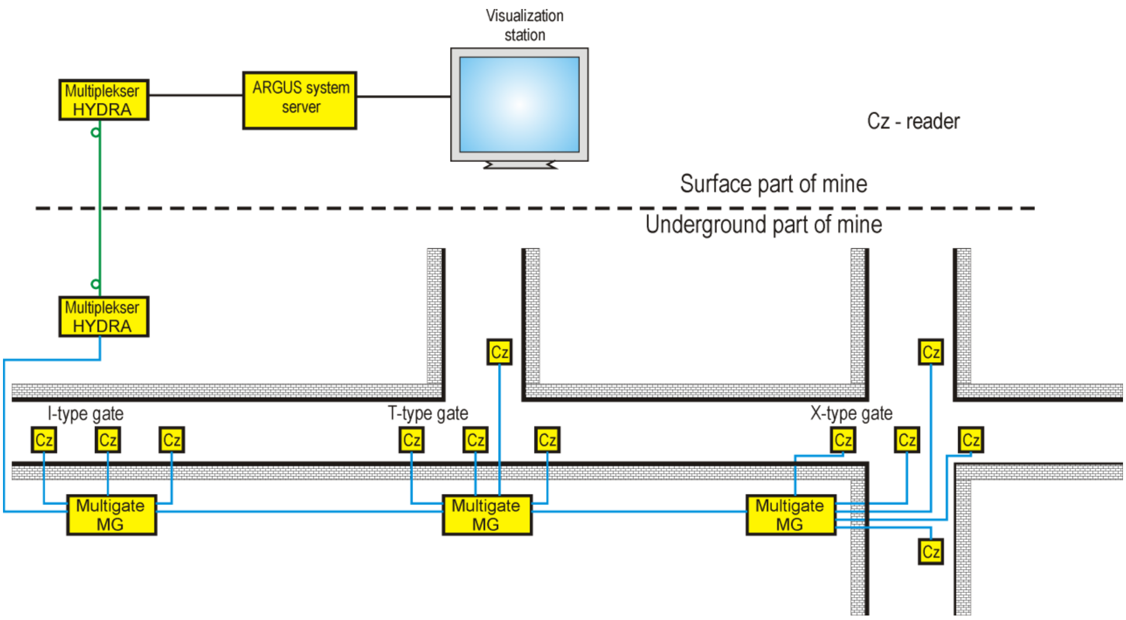


Fig. 7.15. Block diagram of the ARGUS system and configuration of basic types of gates

Multigate probes are connected via RS485 links to the Multigate control panel. Individual Multigate controllers are connected via a bus line (RS485) to the HYDRA downstream multiplexer. The HYDRA underground multiplexer is connected to the HYDRA surface multiplexer via a fiber optic link, RS485 link or modem link. The gate may be equipped with banners (Fig. 7.14 f) signaling, for example, "NO ENTRY" when the permissible number of people is in a particularly dangerous zone.

An example structure of the ARGUS system in a mine is shown in Fig. 7.16. In this drawing, three Multigate control panels are connected in series and are powered by one ZBI-1 intrinsically safe power supply through a junction box. The fourth Multigate control panel and the wired TGATE radio transponder are powered by separate power and transmission cables (intrinsically safe RS485i + power supply). Radio probes are connected to all Multigate control units, creating a specific type of gate (Fig. 7.15) in controlled areas of the mine. Then, through the HYDRA underground data multiplexer, via a fiber-optic cable, signals from the gates are brought to the surface to the central unit of the MONSTEER-D dispatcher supervision system, and further to the dispatcher and the ARGUS system operator station. Using the mirror server, information from the ARGUS system is transferred to authorized positions in the mine's computer network.

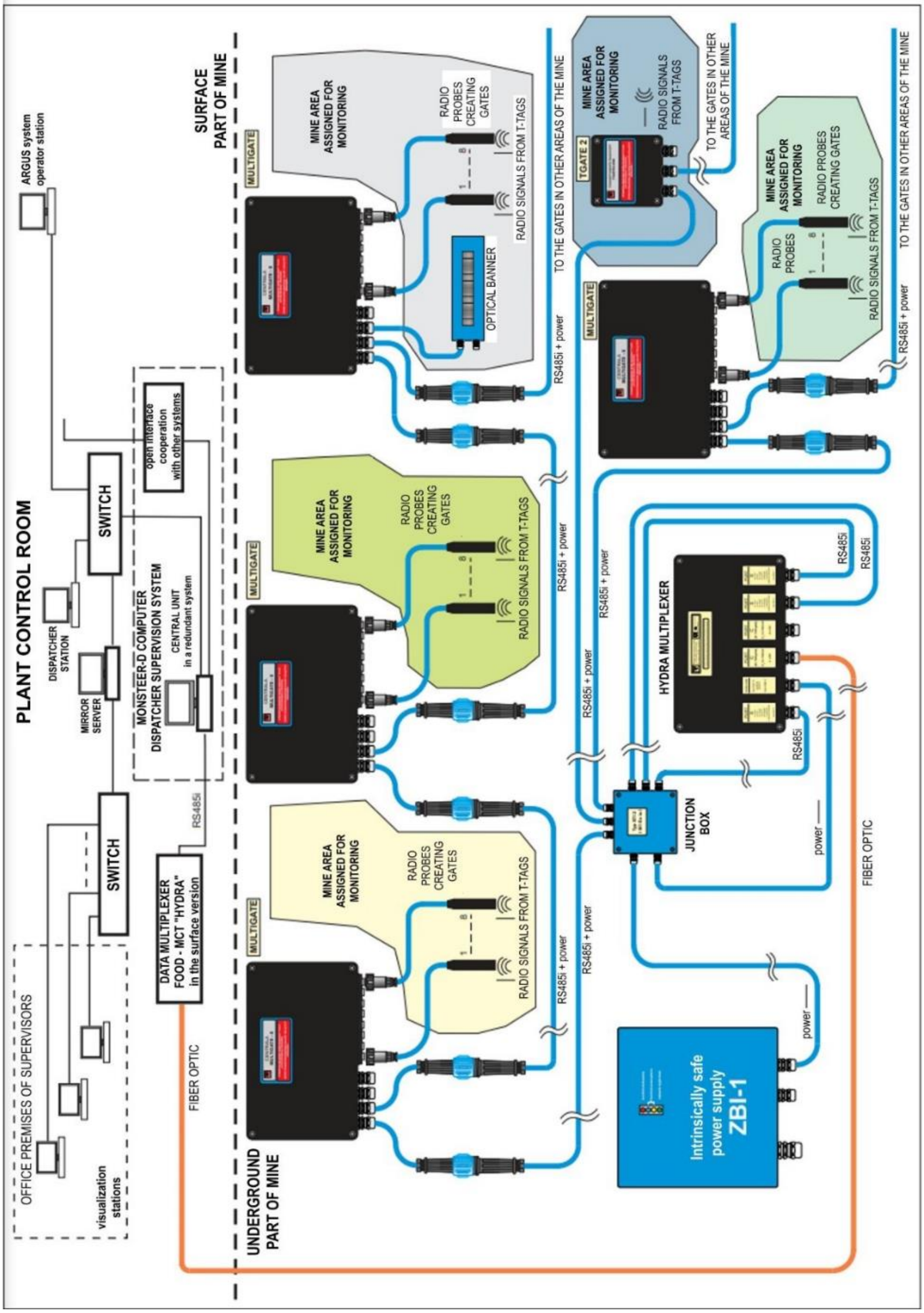


Fig. 7.16. An example of the general structure of the ARGUS system in a mine

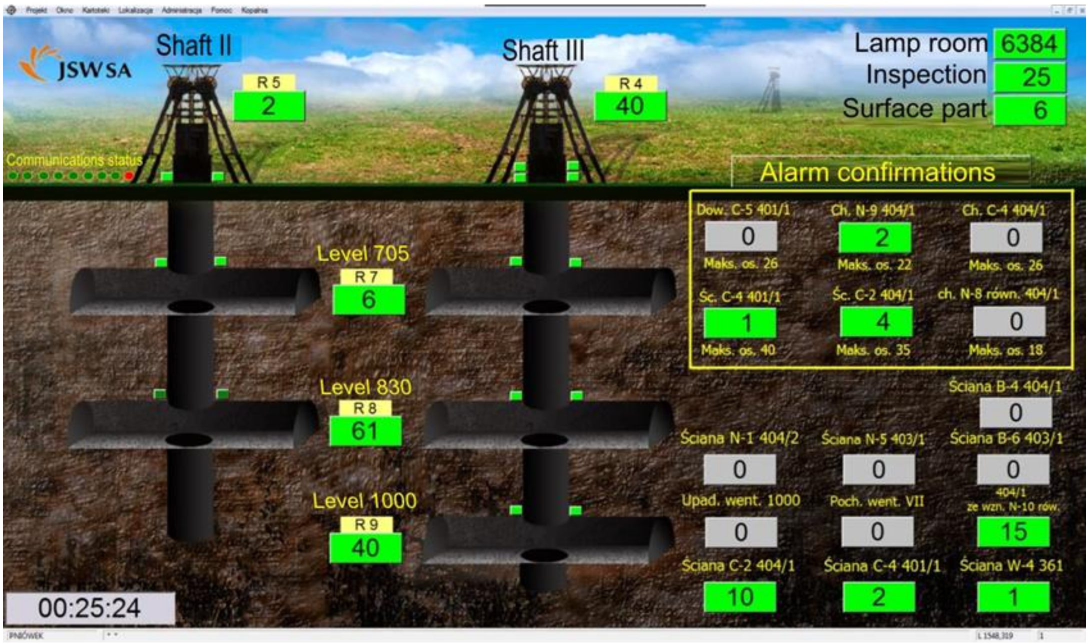


Fig. 7.17. View of the main ARGUS program window

Fig. 7.17 shows the main window of the ARGUS program. The dispatcher has an overview of the number of people in particular areas of the mine where the system gates are installed, highlighting areas where there are particular threats (in a yellow frame). When the number of people in a particularly dangerous zone approaches the maximum permissible number, it is signaled by changing the background color of the icon corresponding to this area from green to yellow, and exceeding this number triggers an acoustic signal and causes the background of the icon to turn red. Gray color – no people in the zone.

Fig. 7.18 shows an example of the visualization screen of the ARGUS type personnel and equipment identification system for a selected mine area. Multigates are marked with the B symbol, and banners are marked with the T symbol. The B and T symbols on a green background indicate communication of these devices with the server. B and T symbols on a red background mean no communication with the server. R symbols indicate zone numbers along with the number of people present in the zone. Four-digit red numbers (e.g. 6717) are the telephone numbers near the gate. The small green squares near Gate B are the number of readers connected to that gate.

Currently, there are approximately 100 gates intended for zone locations on two operational levels (850 and 1030). There are approximately 5,000 identifiers installed in the lamps. The system records the number of people staying in particular zones.

The existing infrastructure of the ARGUS system in the Pniówek mine was also used to launch the material logistics system (with the company name KAJTO). The KAJTO system currently uses approximately 2,500 battery tags mounted on trucks and transport containers. The KAJTO system enables, among others:

– keeping records and locating transport units,
– location of the material taking into account its type,
– indication of the target unloading station,
– indication of the owner of the transported material,

– transport history analysis.

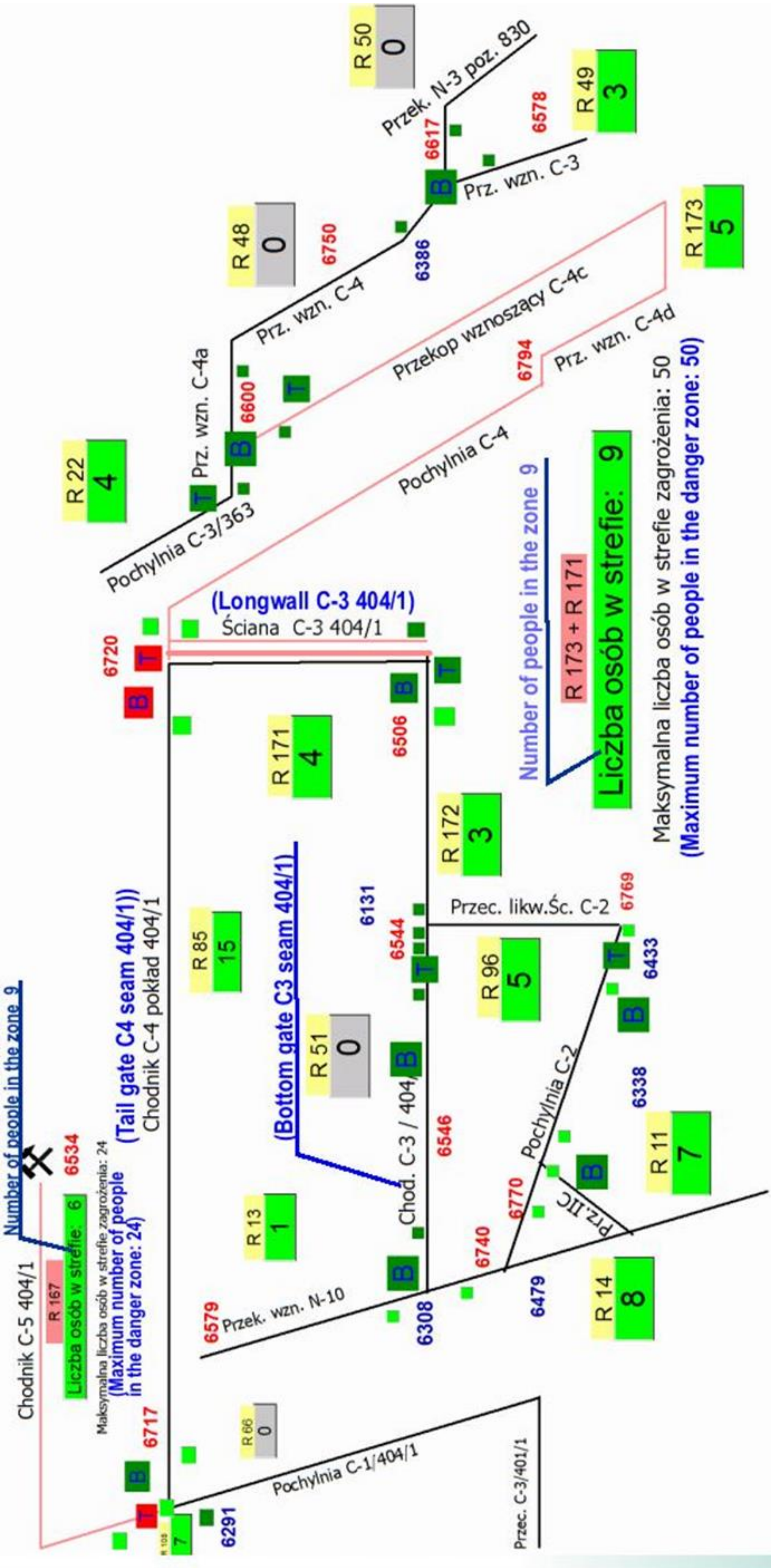


Fig. 7.18. Example of arrangement of ARGUS system elements in the longwall area

7.6. Examples of RTLS systems for mining

As already mentioned, in 2018, a rock burst occurred in Zofiówka Section, which resulted in the death of five miners, and rescue teams had great difficulty in finding the injured. This fact prompted the Management Board of JSW SA to take action to launch RTLS systems in particularly endangered mine areas. It was taken into consideration that in the event of a disaster underground, every telecommunications system operating in the area would be damaged. However, the RTLS location system will provide information on the location of people seconds before the disaster itself, which will make it easier to reach and find the injured faster. Therefore, four location systems were tested in JSW SA mines. Each system implemented:

- **zonal location** in the lamp room, pithead, pit bottom and at the passenger station,
- **exact location (RTLS)** in the area of the longwall, including the bottom gate, the longwall and the tail gate.

The tests concerned the following systems:

- EMLOK-16 by ELEKTROMETAL,
- PORTAS by EMAG/SEVITEL,
- ISI by ZAM Servis,
- ATUT-Location by ATUT.

Each of these systems was installed in a different JSW SA mine at permanent positions (lamp room, pithead, pit bottom) and in selected areas of the walls of these mines with similar parameters. The underground elements of these systems are intrinsically safe with the marking I M1 Ex ia I Ma, and the fiber optic ports are marked op is and can be used in methane mines.

Readers were installed in the longwall area at distances (specified by the companies participating in the tests) resulting from the properties of these systems. RTLS systems calculate the location of the identifiers in relation to the readers. However, for the user it is important to determine (as accurately as possible) the position of the identifier in the excavation in relation to the adopted reference point, e.g.:

- in the longwall, distance from the bottom gate x_s,
- in the bottom gate, the distance from the intersection with the inclined drift x_{ps},
- in the tail gate, the distance from the intersection with the inclined drift x_{ns}.

Fig. 7.19 shows an example of a coordinate system for locating in the longwall region.

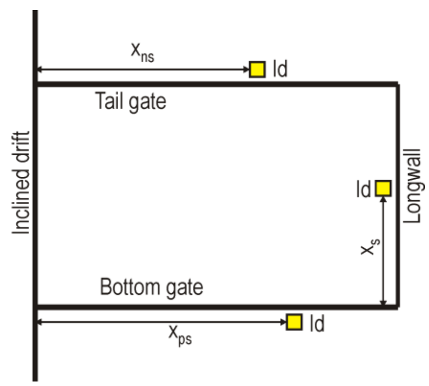


Fig. 7.19. Coordinates for locating identifiers in the longwall area

To correctly calculate the identifier coordinates, it is necessary to enter the coordinates of all readers into the location system database. As the longwall advancees, the RTLS locating system configuration should be modified. When operating from borders, longwall roadways are shortened, which necessitates the removal of the furthest readers and their removal from the RTLS location system database. In the software to visualize the location of the identifiers, it is necessary to convert the location coordinates into the coordinates of the map of workings in the longwall area.

7.6.1. ATUT location system

ATUT Location system from ATUT performs accurate localization using the TDOA method in the 2.4 GHz frequency range. This system consists of the following parts:

- underground part containing: AT-NODE/(L2 - L9) nodes connected by a fiber optic network, AT-LTAG-1 identifiers in a version with and/or without a display, teletransmission antennas (ANTi-2G4), intrinsically safe readers and power supplies,
- surface area containing, among others, the ATVisio2 server and visualization system stations in the control room.

A simplified block diagram of the ATUT- Location RTLS system using AT-NODE/L2 nodes is shown in Fig. 7.20. The AT-NODE may include, among others, the following modules:

- KMi-1 – electro-optical converter,
- AT-LBS-1 – a module that serves as two readers for RTLS locations in the 2.4 GHz band,
- ISE-1 – intrinsically safe switch,
- ATX566 – intrinsically safe battery.

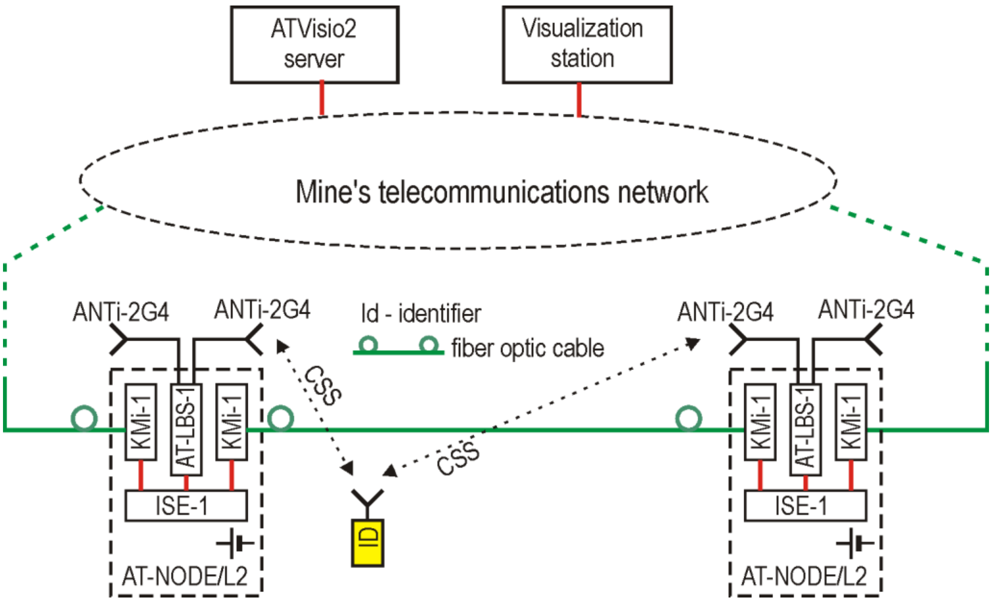


Fig. 7.20. Block diagram of the RTLS location system using AT-NODE/L2 nodes

The block diagram of the ATUT- Location RTLS location system for the longwall area, implemented for testing purposes in one of the JSW SA mines, is shown in Fig. 7.21.

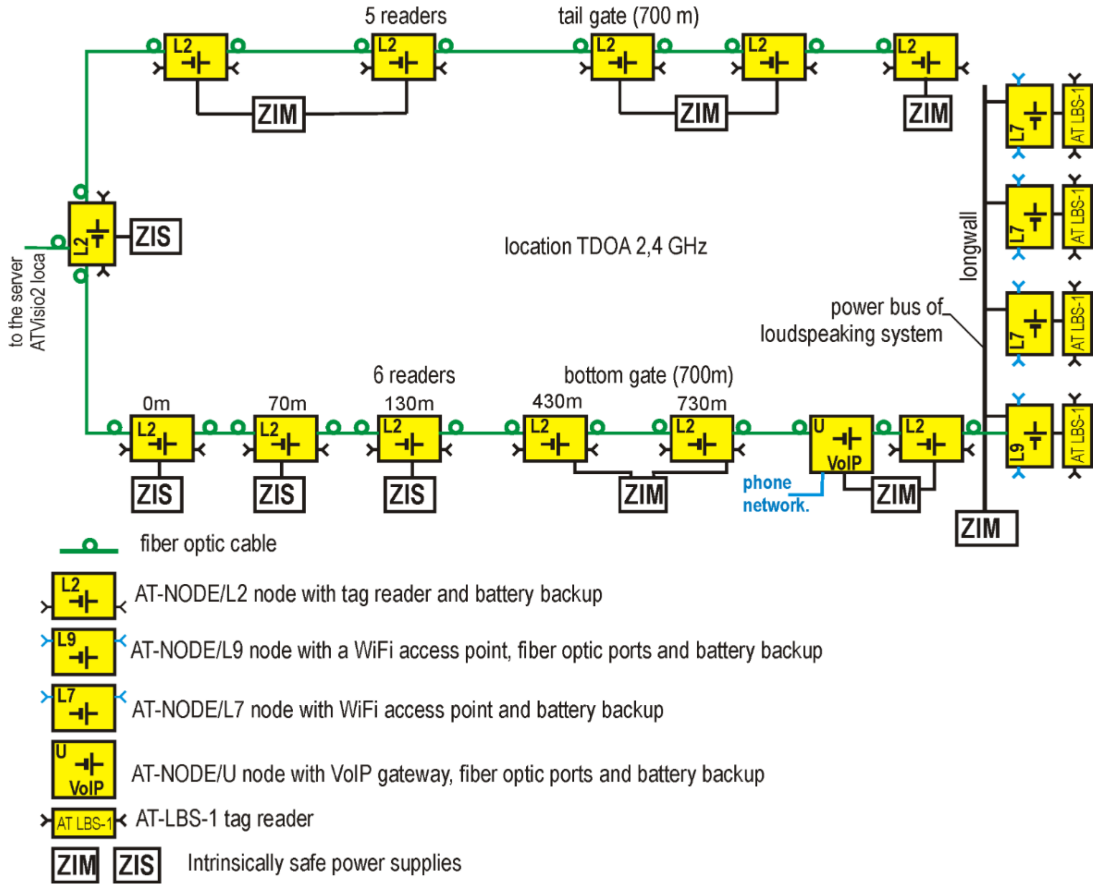


Fig. 7.21. Block diagram of the ATUT-Location accurate location system in the longwall area

Fiber optic cables were used in the bottom gate and tail gate to connect AT-NODE nodes, and 802.11 access points used for VoIP telephone communication in the longwall were used to transmit data from readers. Near the outlet of the longwall to the bottom gate, an AT-NODE/U node containing a VoIP gateway was used to connect VoIP mobile terminals with the mine's telephone communication network. The installation of a fiber-optic cable in the longwall was omitted and additional AT-NODE/L9 nodes with separate ANTi-2G4 antennas operating as 802.11 access points in the 2.4 GHz band were used to transmit data between AT-LBS-1 modules.

AT-NODE/L* nodes (Fig. 7.19, Fig. 7.20) are powered by intrinsically safe power supplies and contain an internal battery. In the mine installation, distances between AT-NODE/L* nodes of up to 300 m were used.

ANTi -2G4 type panel antennas with dimensions of 12x12 cm and gain of 8 dBi are connected to the AT-LBS-1 module. Communication between readers and identifiers takes place using CSS modulation. AT-LTAG-1/LCD display identifiers have additional functionality:

– displaying text messages sent by the dispatcher,
– sending an alarm (to the dispatcher) using a button,
– motionless detection using an accelerometer.

Fig. 7.22 shows selected elements of the ATUT- Location system.

a) b) c) d)

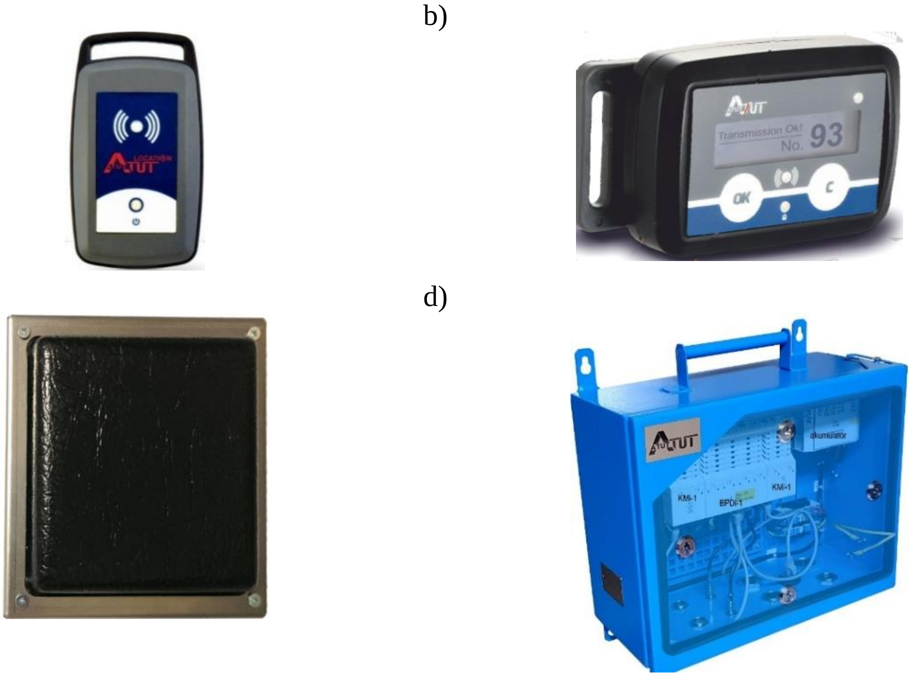


Fig. 7.22. Elements of the ATUT-Location system: a) AT-LTAG-1 identifier, b) AT-LTAG-1/LCD identifier, c) ANTi-2G4 antenna, d) AT-NODE/L7 node

7.6.2. PORTAS system

The PORTAS location system performs zone localization (of people and materials) and RTLS precise localization by measuring the level of the RSS radio signal in the 868 MHz frequency band [PORTAS 2019]. It uses the following identifiers (Fig. 7.23):

– UltraTAG-L designed for installation in the battery housing of a helmet lamp,
– PersonalTAG with its own power source and a holder for attaching a tag,
– UltraTAG-B with its own power source adapted for mounting on a transport container or vehicle.

a) b) c)

Fig. 7.23. Views of PORTAS system identifiers: a) UltraTAG -L adapted for installation in the battery housing of a helmet lamp, b) UltraTAG -B adapted for mounting on a transport container or vehicle, c) PersonalTAG with its own power source and a holder for attaching a pendant

Fig. 7.24 shows a general block diagram for implementing zone localization in the PORTAS system.

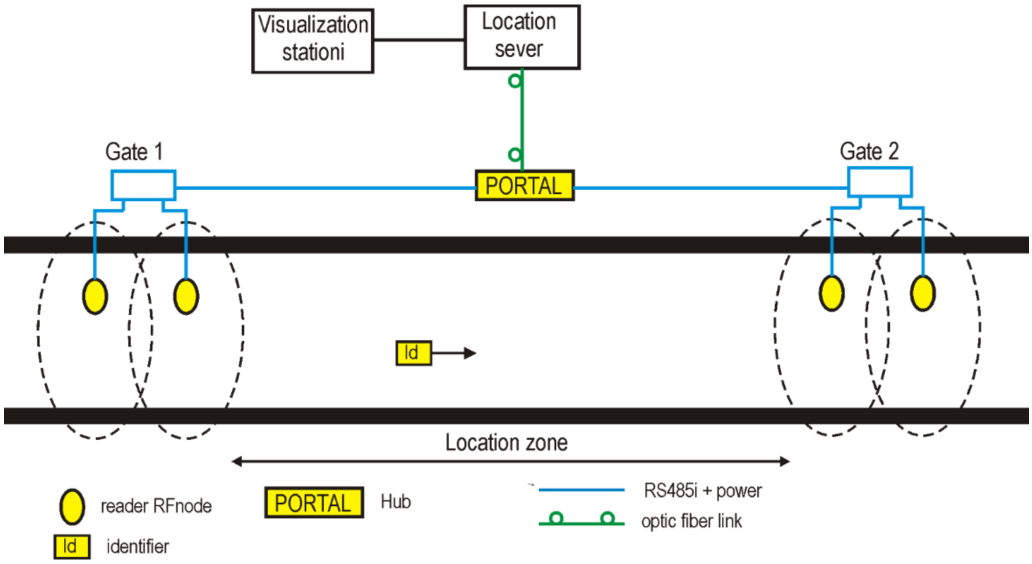


Fig. 7.24. Block diagram of zone location in the PORTAS system

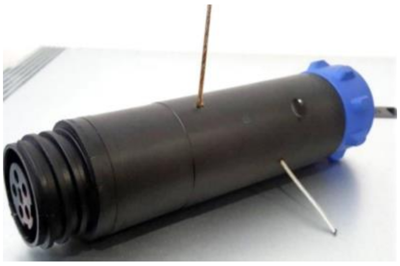
RFnode readers are used (Fig. 7.25) wired to the PORTAL hub (Fig. 7.26). The PORTAL hub has five RS485 ports with power terminals and a fiber optic port. RFnode readers are connected to the PORTAL hub with a dedicated cable containing two 2.5 mm^2 wires for power supply and 2x0.8 mm for data transmission.

Fig. 7.25. RFnode reader view

Fig. 7.26. View of the PORTAL hub

The PORTAL concentrator is powered by an intrinsically safe power supply. Data from the PORTAL concentrator is transmitted to the database in the location server via a fiber optic network. For RTLS localization in the PORTAS system, WireNode readers are used (Fig. 7.27) connected to each other by a cable in a chain system. WireNode readers connected to the main cable are placed in the working at distances of 20÷40 m. The coordinates of the readers' installation location must be entered into the RTLS system database.

a)



b)

Fig. 7.27. View of the WireNode reader: a) with end cover, b) in a pass-through arrangement

To carry out the tests, the zone location was activated in the lamp room, in the pithead, in the pit bottom and at several passenger stations SO1-SO3 and SO-30. In the longwall area (bottom gate, longwall, tail gate), RTLS localization was activated, but the entire longwall area was also treated as one zone. Zonal location visualization provides the user with, among others, the following functions:

– displaying the number of identifiers in the zone in real time (with a second delay),
– report on the movement of the identifier around the mine.

An example of a zone location report of a selected identifier during a test in a mine

Table 7.2.

Position	Entry	Time of visit
Lamp room	2019-01-28 07:30:25	00:08:27
outside the lamp room	2019-01-28 07:38:52	00:00:14
pithead	2019-01-28 07:39:06	00:03:35
outside the pithead	2019-01-28 07:42:41	00:01:34
pit bottom	2019-01-28 07:44:15	00:03:26
outside the pit bottom	2019-01-28 07:47:41	00:11:29
SO1-SO3 station	2019-01-28 07:59:10	00:07:24
outside SO1-SO3	2019-01-28 08:06:34	00:05:08
SO-30 station	2019-01-28 08:11:42	00:03:34
outside SO-30	2019-01-28 08:15:16	00:18:52
longwall D-1	2019-01-28 08:34:08	01:15:01
outside the longwall	2019-01-28 09:49:09	00:22:06
SO-30 station	2019-01-28 10:11:15	00:05:46
outside SO-30	2019-01-28 10:17:01	00:03:05
pit bottom	2019-01-28 10:20:06	00:06:03
outside the pit bottom	2019-01-28 10:26:09	00:01:38
pithead	2019-01-28 10:27:47	00:0210
outside the pithead	2019-01-28 10:29:57	00:03:26
Lamp room	2019-01-28 10:32:23	

In Table 7.2. an example of a report on the movement of one selected identifier during tests conducted on January 28, 2019 is shown. The report shows the time the identifier stays in individual zones and the time of entering and moving between zones. Fig. 7.28 shows an

https://doi.org/10.32056/KOMAG/Monograph2024.2

example of the installation diagram of the PORTAS system implementing RTLS location in the area of the longwall selected for testing.

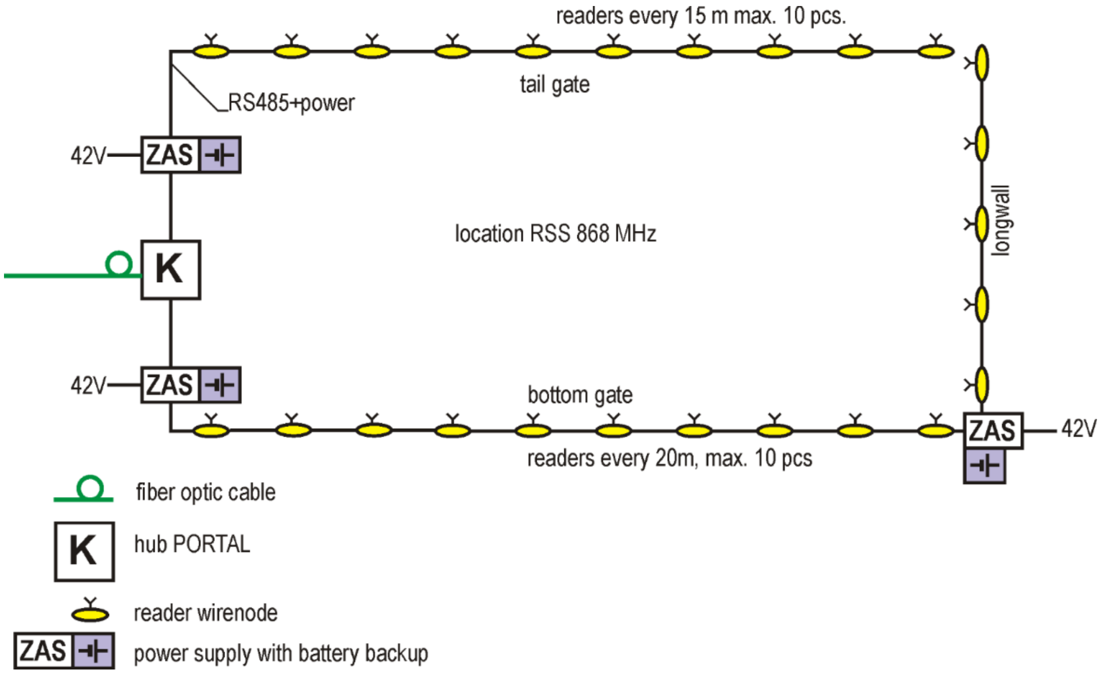


Fig. 7.28. Block diagram of the PORTAS system installation in the mining wall area

The PORTAS system allows the position of individual identifiers to be presented on the map of the region where RTLS location was implemented.

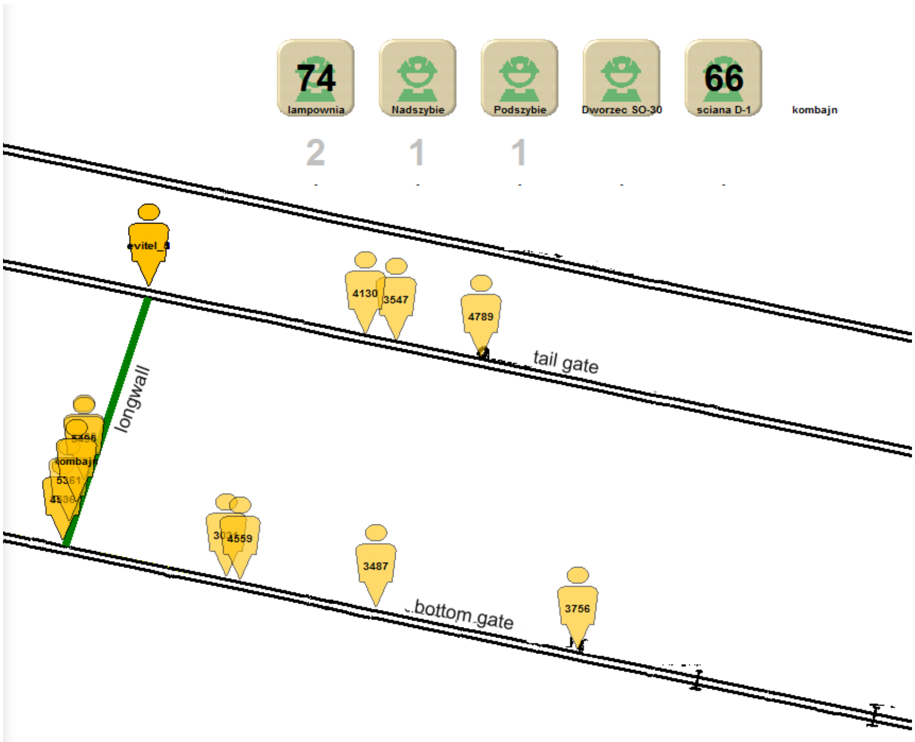


Fig. 7.29. An example of presenting the location of identifiers in the longwall area

Fig. 7.29 shows an example of a visualization system board presenting the positions of individual identifiers (miners) in the longwall area. The number of identifiers in individual zonal location zones is shown in the upper part of the screen.

The PORTAS system can also generate the history of movement of individual identifiers in a given time period. Fig. 7.30 shows the history of movement of the selected identifier during passage along the bottom gate, longwall and tail gate heading, showing the coordinates in the coordinate system as in Fig. 7.18.

Fig. 7.30 shows a disturbance in the movement in the wall from 9:22 to 9:25 (around the point t=82 min) caused by the temporary disconnection (for the test) of reader No. 26 located in the wall at a distance of approximately 87 m from the wall heading. The points of discontinuity on the time diagram result from the adopted reference systems for the longwall headings and the mining wall.

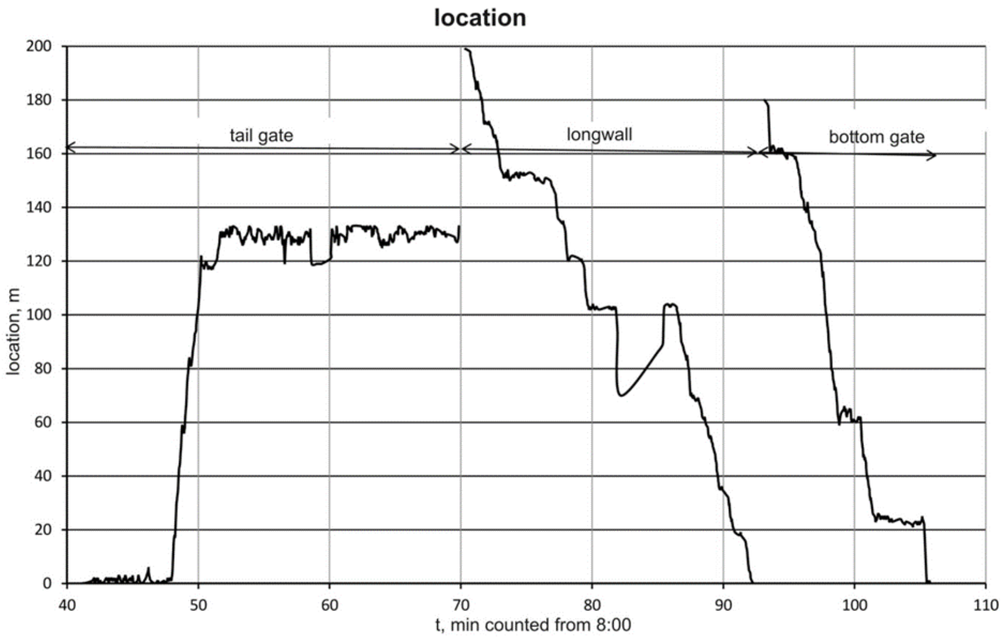


Fig. 7.30. Time graph of the movement of the selected identifier in the longwall area

7.6.3. EMLOK-16 system

The EMLOK-16 system from ELEKTROMETAL performs RTLS localization using the TDOA method in the 2.4 GHz frequency band. It consists of the following basic devices:

- EMTAG identifiers installed in lamps powered by the lamp's battery and identifiers with autonomous power supply,
- readers identifiers SID type,
- concentrators, TDS converters and SPSG serial port servers,
- power supplies with intrinsically safe output; e.g. ZIS-10.

SID-16 readers are made in two versions shown in Fig. 7.31. They are connected by wire via a system bus analogous to that used in the UGS-10 loudspeaking communication system. In occasional cases, modular intrinsically safe Wi-Fi radio access points (2.4 GHz or 5 GHz), e.g. MR-14/5G, can be used to connect SID-16 readers.

The SID-16 reader provides two-way radio communication with EMTAG mobile identifiers. Communication between the reader and identifiers is carried out using CSS modulation. Data from the readers are sent to the identification and visualization system server. On their basis, it is possible to determine the location of identifiers in real time.

a) b)

Fig. 7.31. EMLOK identification system readers: a) SID-16, b) SID-16S

At the same time, it is possible to send information from the SID-16 device to identifiers within its range, which enable the reception of dispatcher information. This may be, for example, short text information shown on a display installed on the cable connecting the battery with the light source of the miner's personal lamp (EMTAG 16W Fig. 7.32 b).

The rated supply voltage of the SID device is from 13 to 15 V. Current consumption does not exceed 90 mA. The devices can be equipped with a graphic display, an autonomous power source (operating time min. 8 h) type 3ZZI-5/2 and a socket for connecting an external radio antenna [ELEKTROMETAL].

Various identifiers may be used in the system. The EMTAG-16 identifier (Fig. 7.32 a) is intended to be placed in a miner's lamp. It uses its power supply and enables data exchange with the lamp processor via a bidirectional serial transmission port. It is also equipped with a motion sensor.

a) b) c)

Fig. 7.32. EMTAG type identifiers: a) EMTAG 16, b) EMTAG 16W, c) EMTAG-16B

The EMTAG-16W identifier (Fig. 7.32 b) is also powered by the miner's lamp. It is mounted on the cable connecting the lamp head with the battery. It enables sending text messages from the supervisory system to a selected user. The user is notified of receiving a message by the pulsing light emitted by the head and by additional signaling elements (sound and vibration signals). The built-in button allows you to confirm the received message, which is presented on the OLED display. The identifiers are powered by a voltage of 3.1 - 5.0 V.

The current consumption during transmitting/receiving does not exceed 130 mA / 80 mA. In the so-called "sleep state" the consumption is approximately 1 μA.

The EMTAG 16B identifier (Fig. 7.32 c) is powered by an autonomous power source. It is equipped with a button, LED, sound and vibration alarm, and also a motion sensor. It enables the reception (and transmission) of communication and alarm signals. The built-in yellow button enables confirmation of received signals, as well as the function of notifying the user about impending danger.

Teletransmission devices (hubs) are SPSG-16 serial port servers and TDS-16 converters (Fig. 7.33). The SPSG-16 device can be equipped with several modules enabling the conversion of RS485 or RS232 transmission (e.g. in the MODBUS RTU standard) into TCP transmission available through the 100Base-TX port (RJ45 connector) or 100Base-FX (SC connector). In the event of a power outage, the device can continue to operate due to the battery module. In the case of transmission of Ethernet signals to the control room via symmetrical copper lines using DSL or fiber optic modems, TDS-16 Ex converters should be used. They have an intrinsically safe and inherently safe (op is) structure. They require a DC power supply (12 V, 0.3 A). To ensure the flexibility of various types of connections, the converter cover is equipped with a set of flameproof entries.

a) b)

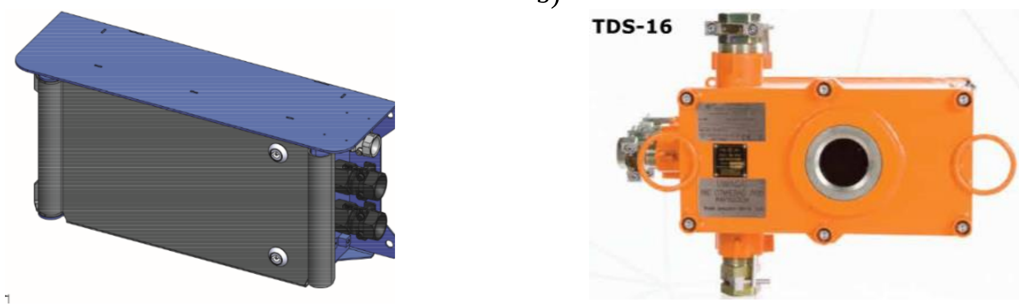


Fig. 7.33. Teletransmission devices: a) SPSG-16 serial port server, b) TDS-16 converter

Fig. 7.34 shows an example of a block diagram of the installation of the EMLOK system implementing RTLS location in the area of the longwall of one of the mines of JSW SA selected for testing. Signals from individual SID-16 readers are transmitted via the RS485 bus to the SPSG-16 serial port server and further via a DSL modem (TDS). -16) symmetrical mining telecommunications cables of the TKG type to the EMLOK system server in the control room.

Workstations of the EMLOK-16 system on the surface provide the user with data collected in the server in the form of on-screen presentations or in the form of prepared reports.

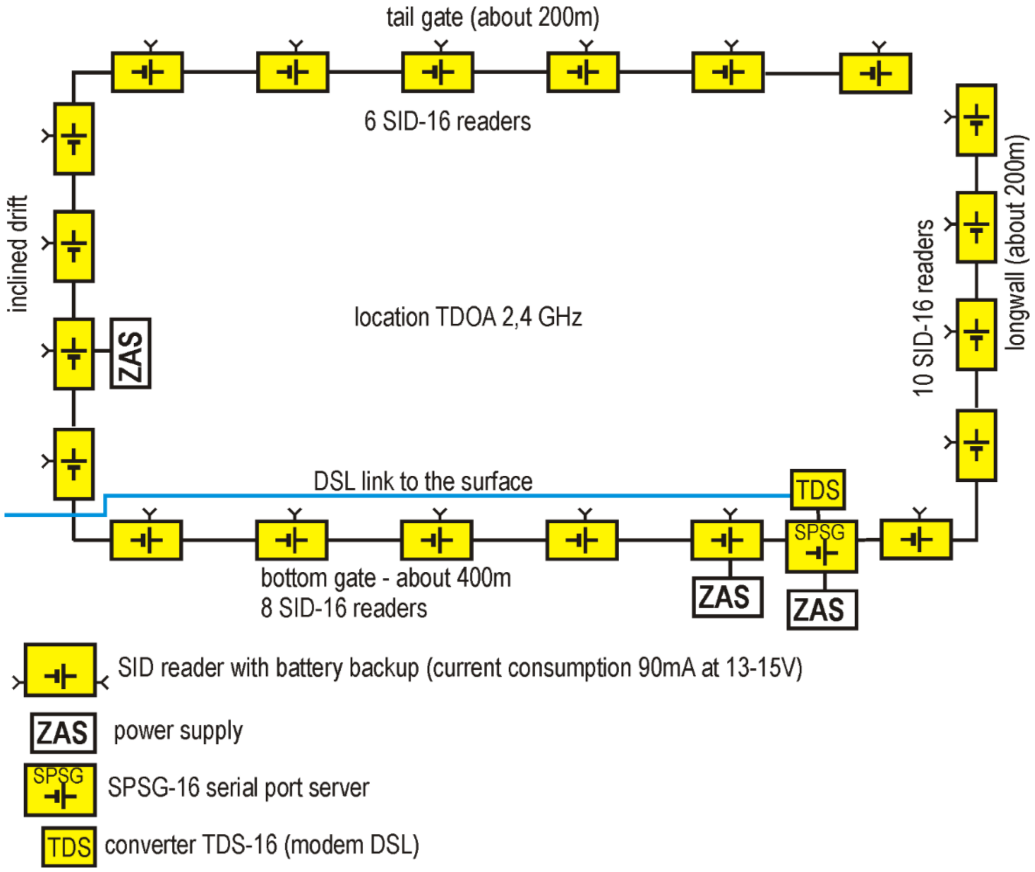


Fig. 7.34. Block diagram of the EMLOK-16 system installation in the area of the longwall

7.6.4. ISI system

ISI type RTLS location system from ZAM Servis s.r.o. performs RTLS localization using the RSS method in the 868 MHz frequency band. The ISI system uses identifiers of the following type:

- TAG-ZAM-01 (Fig. 7.35 a) built into the helmet lamp battery housing,
- TAG-ZAM-08 (Fig. 7.35 b) with its own power supply.

a) b)

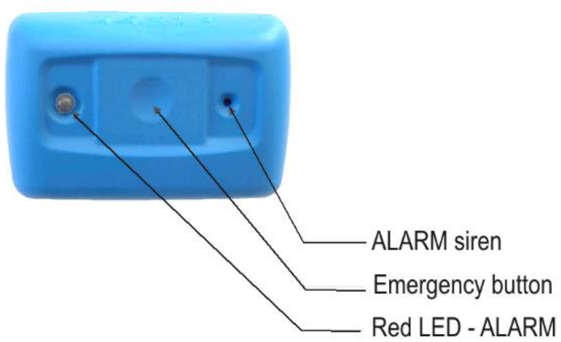


Fig. 7.35. Identifiers used in the ISI system; placed in the TAG-ZAM-01 type helmet lamp battery (a), with its own TAG-ZAM-08 battery power supply (b)

The basic element of the ISI system is a dedicated RFK-01 cable, 200 m long, with ID readers installed every 40 m.

a) b)

Fig. 7.36. Fabrication section of dedicated RFK-01 telecommunications cable (a), with ID readers (b)

Fig. 7.36 shows a view of the factory section of the RFK-01 cable with installed readers. The RFK-01 cable is connected to the DKD-11 data concentrator (Fig. 7.37). The DKD-11 concentrator is equipped with four RS485 ports and is powered by the SME-02 intrinsically safe power supply with battery backup. Three sections of the RFK-01 cable can be connected in a chain to one RS485 port. All readers are powered by the RFK-01 cable. It also ensures data transmission from readers to the concentrator via RS485 links with retransmission in each reader. The DKD-11 concentrator is connected to the location server via a fiber optic link. The location server, based on information received from DKD-11 concentrators, calculates the positions of individual identifiers and provides data for visualization stations.

Fig. 7.37. View of the DKD-11 concentrator

Fig. 7.38 shows an example of the installation of the ISI system by ZAM Servis in the area of the mining longwall for the purposes of testing the functioning of the RTLS location system in the mines of JSW SA.

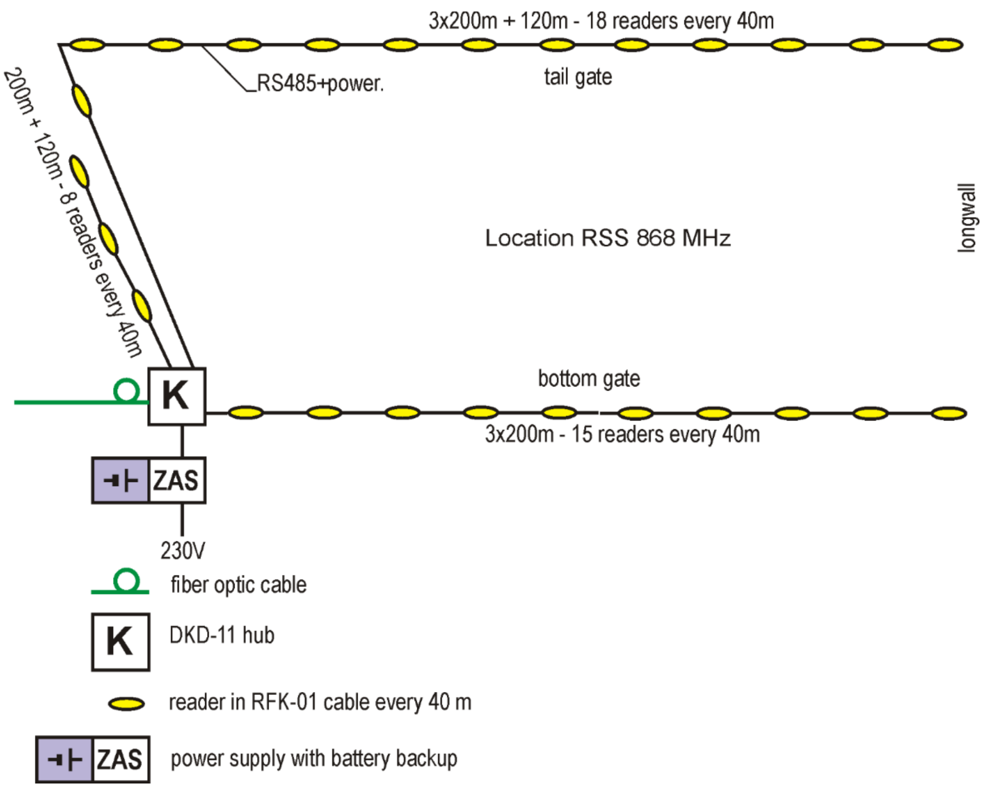


Fig. 7.38. Block diagram of the ISI type locating system in the wall area

7.6.5. Conclusions from research on RTLS systems in JSW SA mines

Two ways of functioning of RTLS systems were tested in JSW SA mines:

- measurement of the radio signal level (RSSI) in the 868 MHz band,
- measurement of the time difference of flight of a radio wave (TDOA) in the 2.4 GHz band.

RTLS localization on the surface should be implemented in two-dimensional space. It should be noted that due to the shape of the underground corridor workings, trilateration for the purpose of precisely determining the location of the identifier is only possible in one-dimensional space. It is therefore necessary to measure (strength or time of flight) of the radio signal from a given identifier from at least three readers located in one line in the corridor excavation. One-dimensional RTLS localization has a significant impact on the accuracy of the identifier location in the excavation, as well as on the arrangement and horizontal distance between subsequent readers in the heading.

Since electromagnetic waves in the 868 MHz range (ISM band) are characterized by better propagation in underground workings compared to the 2.4 GHz range, and devices using this wave range are characterized by much lower power consumption compared to devices using the 2.4 GHz range, then in the case of battery power for radio communication devices, frequent power outages in methane mine workings, this may have some significance.

When choosing an identification system, you should strive to determine the static location accuracy. In the case of RTLS systems, this is the accuracy specified in meters and can be defined as the RMS value of the deviation of the calculated tag location from the current tag position. In RTLS systems, each read (with a stationary ID) gives a slightly different position.

Attention should also be paid to the dynamic properties of the location system. The dynamic properties of the RTLS system should be understood as the delay between changing the position of the identifier and determining its new position. In the case of zone location, the delay between crossing the zone border and obtaining information about the appearance of the identifier in the new zone is important. This type of delay should be defined for a single ID.

In the case of systems with zone location, the accuracy of determining the boundary between zones is important. It seems that a reasonable accuracy of a zone location system should be 3÷5 m.

The reading time of many identifiers located in the operating zone of one reader is also important. You must specify how many identifiers and at what time the reader should read. This type of problem consortiums readers, especially readers placed in pit bottom or in cases of crew escape in a dangerous situation.

Worker location systems should use active transmitters that will be integrated with the miner's personal lamp and mounted in its head.

The teletransmission system from underground multiplexers or concentrators to the surface should be based on fiber optic technology.

7.7. Location of trapped miners

An important element of some rescue operations (e.g. in the case of collapses) is the location of trapped miners. Locating miners should be possible regardless of the miner's condition (the miner may be unconscious).

Due to the electrical properties of rocks in the cave (conductivity), electromagnetic waves of very low frequency (about 5 kHz) are used to locate miners. Each miner's personal lamp is equipped with a transmitter that can be treated as a source of a magnetic field. The following systems are used in mines:

- GLON - an abbreviation of the words: mining personal location transmitter (generator about 5 kHz),
- LOK used in copper ore mines operating at a frequency of approximately 250 kHz.

Miners are equipped with location transmitters (placed in the battery housing of a personal lamp). A locating receiver is used during a rescue operation. Using appropriate measurement procedures, it is possible to determine whether a miner is trapped near the receiver antenna and to approximately determine the distance to the location transmitter.

For several decades, in the Polish coal mining industry, the use of location transmitters has been required by appropriate regulations [PGG, 2023; RME, 2016]. The locator transmitter should emit a signal for at least seven days without recharging the battery. To meet this condition, the lamps are equipped with systems that turn off the lamp's light source so that the battery has a sufficient charge to ensure the operation of the location transmitter during this period.

It is worth recalling that on March 23, 1971, a wall collapse occurred in the Rokitnica mine. One of the trapped miners (Alojzy Piontek) was freed after seven days of rescue operations. Perhaps this case of saving the miner was the reason for introducing the requirement for the locating transmitter to operate for seven days. In February 2006, using the GLON/GLOP location systems (mining location measurement receiver), a miner trapped after a collapse in the Halemba Coal Mine was rescued after 111 hours.

Currently, GLON location transmitters are used operating in the frequency range 4100÷5840 Hz in eight frequency channels. Such a low frequency is due to the fact that the propagation of electromagnetic waves through the rock mass is only possible effectively at very low frequencies.

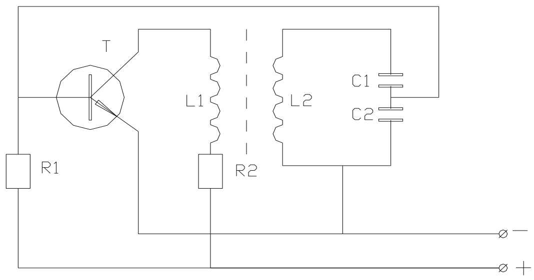


Fig. 7.39. View of the GLON system location transmitter (before encapsulation) and its schematic diagram

Everyone going down is obliged to take a personal lamp. Each lamp is equipped with a GLON generator (Fig. 7.39) powered by the miner's lamp battery. During a rescue operation, the rescue team is equipped with a GLOP type locating receiver, which allows measuring the distance to the GLON transmitter. Using the device's receiver, we can locate an object, but we cannot personalize it. Locating systems do not allow this because the number of frequency channels of miners' personal transmitters is only eight.

Miners were first equipped with location transmitters in 1968 in a Czech coal mine in Ostrava. These transmitters operated at frequencies in the range of 0.7÷0.9 MHz. Using an ordinary radio receiver for reception, a location range of approximately 5 m was achieved. Similar transmitters, operating only in the lower frequency range (0.3÷0.4 MHz), were introduced a few years later in Polish coal mines. It was a GON type device (mining personal transmitter). The reception range through rocks was up to several meters. In both frequency ranges, defects were revealed during locating, which initiated work on a new system in the 1970s. The essential feature of this new GLON system was a significant frequency reduction to a range of approximately 5 kHz. This reduction is justified because in this frequency range the attenuation of the electromagnetic wave in the rock mass is very small, so the components of the wave field at a given point will not depend on the type of rock, the degree of its moisture or cracks, and the field distortions caused by metal installations in the excavations will are smaller.

The rated magnetic moment of the GLON locating transmitter is 0.08 Am^2, and the maximum current consumption from the miner's personal lamp battery (approximately 3.6 V) does not exceed 20 mA. GLOP locating receivers are equipped with the District and Central Mine Rescue Stations (OSRG, CSRG Bytom). In the past, analog GLOP locating receivers (produced by ADVANCE Katowice) were used, and now most commonly used are intrinsically safe digital locating receivers MinSearch (Fig. 7.40) developed by ELEKTROMETAL.

MinSearch receiver consists of a desktop and an isotropic antenna receiving the magnetic component of the field. For precise searches at close range, a directional antenna (spotlight) is attached to the desktop. The receiver is a type of selective voltmeter in which selectivity is achieved by using a fast Fourier transform (FFT). To analyze the measurement result, the amplitude characteristics of the signal received by the antenna are used, which allows you to determine the levels separately for each frequency channel of the GLON transmitter. Elimination of noise from the environment is possible by performing several transforms and then averaging them (this extends the operation time because a separate measurement is performed for each transform).

Fig. 7.40. View of the MinSearch-15 locating receiver with antenna, searchlight and headphones

To increase measurement accuracy on a given channel, a set of key-controlled capacitors is placed in the antenna, setting the antenna's resonant frequency to the center of the channel's bandwidth. There is a programmable signal generator in the antenna that allows you to automatically scan possible key settings and determine for which capacitors the resonant frequencies correspond to the band centers (this process is called key tuning).

The occurrence of resonant frequencies means that the amplitude characteristics for each channel are not flat. Appropriate correction factors are used to correct the receiver's frequency response. They are determined using a signal generator built into the antenna, a process called FFT correction. The location range is up to 30 m and depends on the noise level of the magnetic component of the electromagnetic field.

In some mines, taking into account that each miner's lamp has a locating transmitter and using modified locating receivers (e.g. the WAJL switch from ELEKTROMETAL), we can detect, for example, illegal cases of miners using conveyor belts with mined material and perform an emergency stop on these devices. This is an example of additional use of personal transmitters in mines.

Locating systems are also used in the supervision of restricted access zones (e.g. conveyor zone in front of the crusher, conveyor zone behind the disembarkation platform), where it is important to determine the presence of e.g. a location transmitter and initiate the response of the security system, e.g. turning off the crusher, conveyor or starting alarm. Location transmitters are installed in each mining lamp regardless of RTLS identifiers.

In some mining lamps, the correct operation of the GLON transmitter is indicated by a pulsating white diode located on the battery container cover. It is controlled by a microcontroller installed in the lamp, which checks the correct operation of the location transmitter. The generation of vibrations by the transmitter antenna and the frequency of the generated signal are constantly monitored.

Ultrasonic Technology Plant in Gdańsk has developed a LOK type system for locating trapped people. In this system, all miners' transmitters operate at one frequency of 250 kHz, with each transmitter operating in pulses with double keying at a frequency of 1 kHz and il Hz. As a result, a very characteristic, easily distinguishable sound is heard in the receiver. You can easily distinguish whether the sound is coming from one transmitter or more than one. The LOK transmitter is mounted in the miner's personal lamp.

The receiver works with a loop antenna, and the distance from the transmitter is read using a light bar marked in meters (Fig. 7.41). A loudspeaker (or headphones) is helpful in determining direction.

Fig. 7.41. View of the image on the MinSearch receiver screen while performing location measurements

Information about the predicted distance to the LOK transmitter is provided in a central area. The horizontal bar below the displayed distance shows the current signal level. On its right side there is a small triangle indicating the increase or decrease of this level:

– directed to the right – the currently received signal is larger than the previous one (the transmitter is closer),
– directed to the left - the currently received signal is smaller than the previous one (the transmitter is located further away).

Zasięg The maximum range (up to 50 m) is achievable with a low level of ambient noise and in the presence of steel masses such as pipelines, rails, etc. The measurement accuracy (determined by performing many tests) is approximately: from 0.5 m (in range 1 m < L < 5 m), up to 2.0 m (in range 15 m < L < 50 m) [MinSearch, 2018].

7.8. Other ways of using identification and registration systems in mines

7.8.1. System for identifying and recording mining machinery components

In 2004, the KOMAG Institute of Mining Technology began working on a system for electronic identification and registration of elements of the longwall section of the powered roof support. The basic goal of a reliable assessment of the technical condition of the elements of the powered support section is to eliminate from operation those elements of this section in which the probability of damage caused by fatigue and corrosion processes is the highest. For this assessment, reliable information must be collected about their current work and operating conditions.

In the allocation process, the elements of a section are often subject to repeated disassembly and assembly of its individual elements, which often results in replacement of elements in the modernized individual sections. This state of affairs creates the need to identify all basic elements of the casing section in order to isolate those containing the oldest, most worn elements or those that worked in particularly difficult environmental conditions.

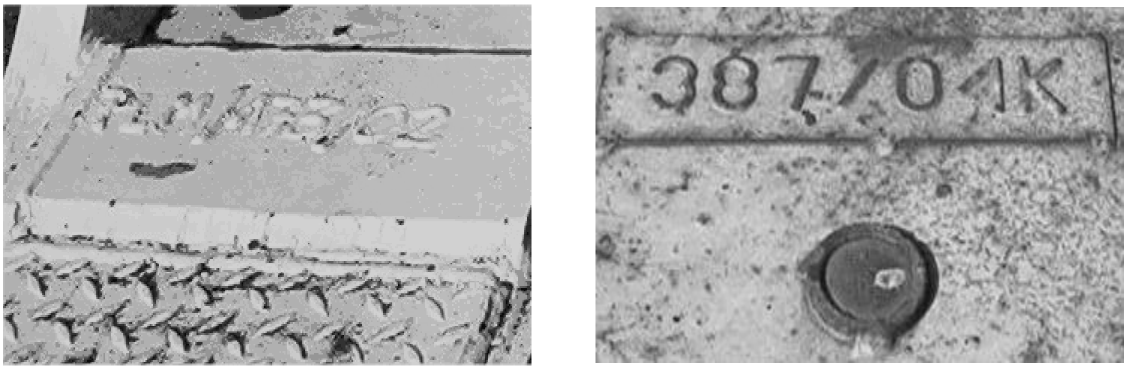


Fig. 7.42. Methods used for marking section elements [Fitowski, 2006]

The methods of identifying section elements previously used in mines in the form of nameplates, hardfacing identification codes or marking with paint often did not ensure durability and legibility in difficult operating conditions, which made it difficult to reliably assess the technical condition and conduct inspections, and additionally multiplied the possibility of errors when identifying machine elements (Fig. 7.42).

The emergence of the possibility of marking elements using RFID technology made it possible to develop a system for electronic identification of elements of the longwall section of a powered roof support, consisting of:

- passive TRID transponders permanently mounted on the elements of the housing section,
- TRH type RFID readers connected, e.g. by cable or using the Bluetooth protocol, to a TRMC-01 or ET type underground microcomputer,

– appropriate computer software enabling management of a database of information about sections and their elements.

In this system, the basic elements of the powered roof support section are marked with TRID type RFID transponders manufactured by ELSTA, which enabled, among other things, rational management of fixed assets in this area (Fig. 7.43). This system uses transponders adapted to work in potentially explosive atmospheres [Mikuła, 2012; Rogala-Rojek, 2012; Fitowski, 2006; Szczurkowski, 2006].

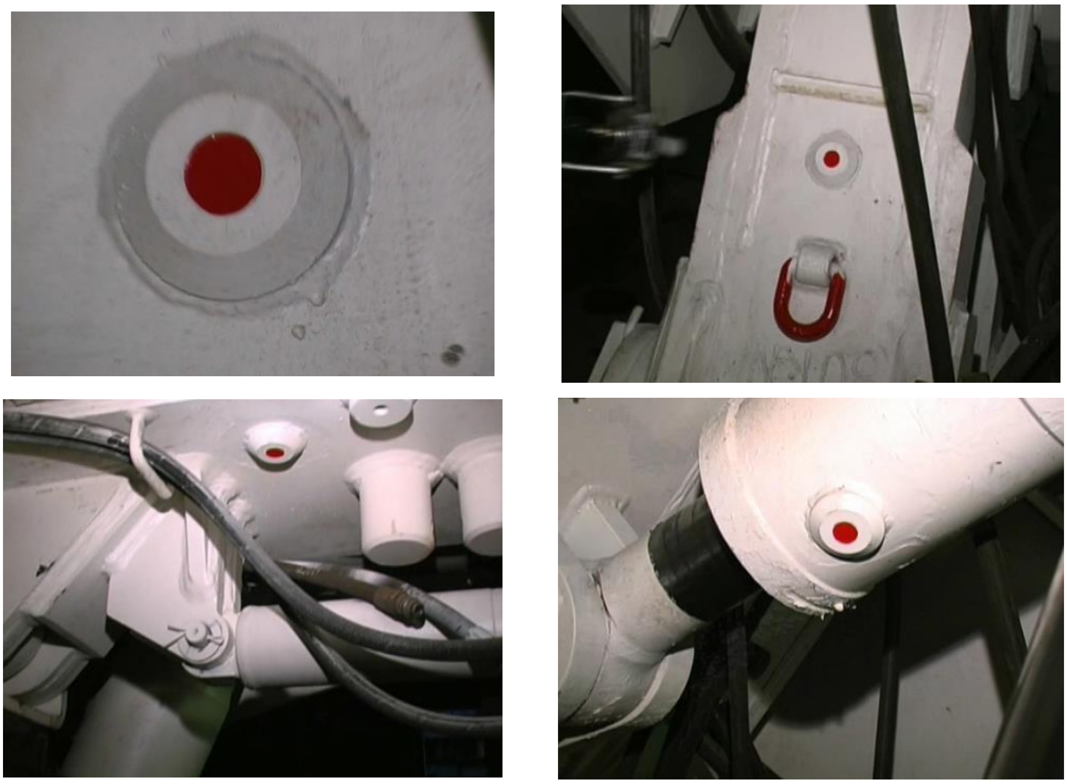


Fig. 7.43. Examples of methods of mounting RFID transponders on elements of the wall section of a powered roof support [Jaszczuk, 2009]

To read TRID identifiers in the wall, e.g. TRH-01 or TRH 04 there are used readers and mobile underground microcomputers: TRMC-01 or ET-02 (Fig. 7.44 a, b) [ELSTA, 2022]. The TRID transponder operates in the 125 kHz frequency range. Readings from the microcomputer's memory can be copied on the surface to a database used to record and evaluate individual elements of powered roof supports. All system elements are intrinsically safe and can be used in methane mines. The task of the RFID reader is to read transponder identification numbers, inventory the section elements and analyze them in the database used.

The TRH-04 RFID reader is an intrinsically safe device used to read RFID tags. It is equipped with a Bluetooth 2.0 interface, which enables wireless transmission of read data to an intrinsically safe terminal located nearby. The device is designed to work with all portable terminals or microcomputers equipped with a Bluetooth interface. It may be, for example, a mobile terminal type ET-02 manufactured by ELSTA Elektronika from Wieliczka. The TRH-04 reader is powered by an internal two-cell lithium-ion battery with a rated capacity of 1800 mAh.

a) b)

Fig. 7.44. Components of the system for identifying elements of the powered roof support section: a) TRH-01 and TRH-04 readers, b) TRMC-01 underground microcomputer and ET-02 intrinsically safe mobile terminal

The ET-02 type mobile terminal is an intrinsically safe portable computer running the Microsoft Windows Embedded Compact 7 operating system. The device has a color LCD display, which, combined with a touch panel and keyboard, allows the user to easily interact with the operating system and its applications. The ET-02 terminal is also equipped with a 1D and 2D barcode reader used in materials management in the mine. Wireless digital interfaces (Bluetooth and Wi-Fi) enable communication with the terminal when working in an explosion hazard zone, while outside the zone, when using the SDET-01 docking station, an additional universal USB interface is available. The ET-02 powered system uses Li-Ion cells to ensure long operation of the device. For safety reasons, ET-02 is charged outside the explosion hazard zone, using a dedicated charger [ELSTA, 2022].

An integral part of the system for identifying the elements of a powered longwall support section is database computer software, which serves as management software in the system, used to register and process identification data, record section elements and prepare the RFID transponder reading device for the appropriate operating mode (adding new elements, grouping elements into sections and changes in location) (Fig. 7.45) [Fitowski, 2006; Jaszczuk, 2009].

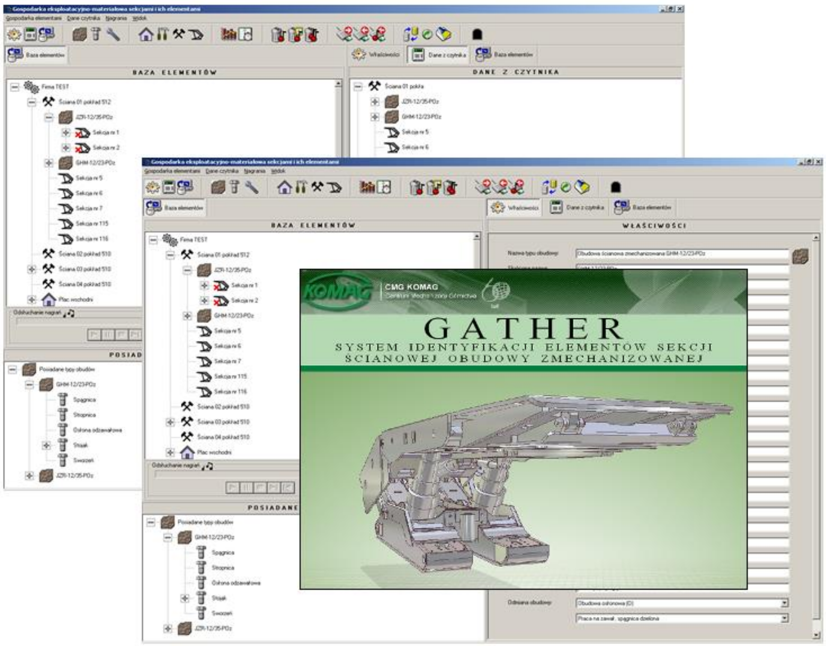


Fig. 7.45. GATHER software [Fitowski, 2006]

The software also allows you to electronically create reports containing data regarding the use of powered support sections and supporting elements, including: decision-making in the process of assessing the technical condition of a section (Fig. 7.46) [Fitowski, 2006].

LIST
of elements of the powered support section built in the newly launched longwall no. 1000

Section no	Section type	Name of the element	Number records	Year of production
1	MKK-12/28-POz	Roof-bar	0001/08	2008
		Gob shield	0002/08	2008
		Floor base	0003/08	2008
		Front connector	0004/08	2008
		Rear connector	0005/08	2008
		Canopy support	0006/08	2008
		Hydraulic leg	0007/08	2008
2	MKK-12/28-POz	Roof-bar	0008/08	2008
		Gob shield	0009/08	2008
		Floor base	0010/08	2008
		Front connector	0011/08	2008
		Rear connector	0012/08	2008
		Canopy support	0013/08	2008
		Hydraulic leg	0014/08	2008

REPORT
about the technical condition of the elements powered support sections built into the wall 1000

Section	Element			State technical
	Name	Number	Year	
Sekcja nr 1 MKK-12/28-POz	Roof-bar	0020/99	1999	weld crack 0,4 m
	Gob shield	0021/99	1999	side cover bending
	Floor base	0022/99	1999	no comments
	Front connector	0023/99	1999	no comments
	Rear connector	0024/99	1999	no comments
	Canopy support	0025/99	1999	damaged eye of the canopy support
	Hydraulic leg	0026/99	1999	damage to the core surface

Fig. 7.46. Examples of reports generated using the GATHER application

The system for identifying the elements of the longwall section of the powered roof support ensures clear identification of the load-bearing elements of the section, registration of the time of use of these elements and their operating conditions, and also allows the processing of the necessary data to assess the degree of wear of these elements. The use of RFID technology allowed us to improve logistics processes and minimize the risk of errors generated by previously used identification systems.

7.8.2. iRIS - System for identifying machines, devices, fixed assets and transport

The increased interest in modern management systems for machines, equipment, fixed assets and means of transport used in hard coal mines was the basis for work on a comprehensive system for their identification. In 2011, the first works were undertaken to develop the iRIS system, which would be a tool for maintaining electronic records of fixed assets in JSW mines. Currently, this system consists of five platforms (Fig. 7.47) [Rogala-Rojek, 2012; Warzecha, 2011]:

- PECM - intended for machines, devices and parts used in underground workings,
- PEUBP - intended for explosion-proof machines and devices,
- PEŚT - intended for means of transport,
- PEMP - intended for machines and devices used on the surface,
- PEŚTB - intended for office equipment.

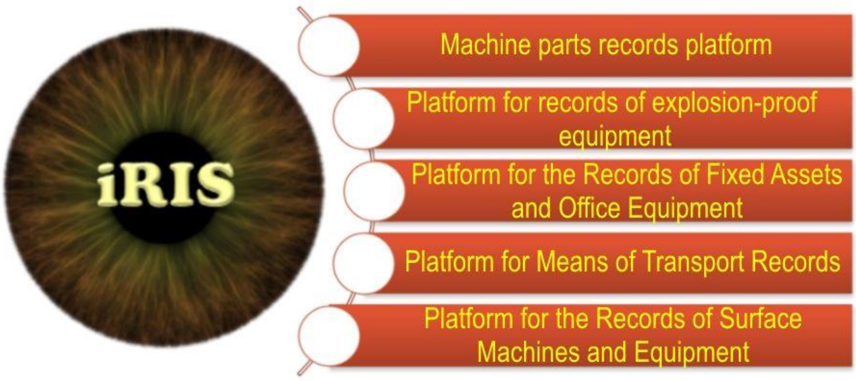


Fig. 7.47. iRIS system platforms [Rogala-Rojek, 2012; Warzecha, 2011]

The Machine Parts Registration Platform (PECM) was created as an integral part of the system for electronic identification of elements of the longwall section of a powered roof support, and is currently an independent database software [Mikuła, 2012; Rogala-Rojek, 2012].

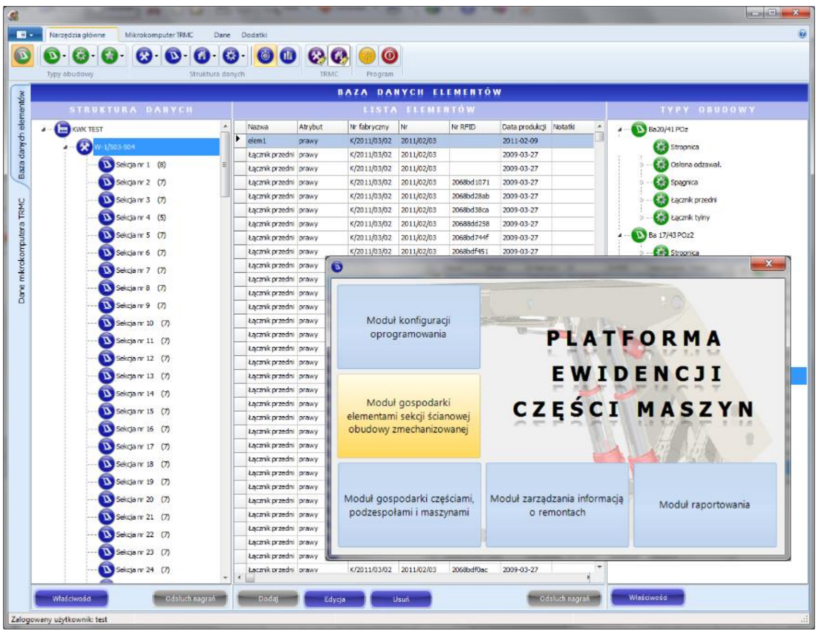


Fig. 7.48. Machine Parts Inventory Platform (PECM) [Mikuła 2012; Rogala-Rojek 2012]

https://doi.org/10.32056/KOMAG/Monograph2024.2

PECM software allows you to record the elements of the longwall section of a powered roof support and to process the necessary data to assess the degree of their wear, which is extremely important in terms of the safety of mining crews. An example view of one of the PECM software boards is shown in Fig. 7.48.

The Surface Machinery Records Platform (PEMP) also uses RFID readers. The means of transport records platform (PŚT) was designed to record and monitor the movement of transport units both on the surface and in underground mines. The IT system supporting the maintenance of records of explosion-proof devices (PEUBP) takes into account the provisions of applicable law regarding the operation of devices in potentially explosive atmospheres.

Presented above technical solutions adopted with software facilitate work and enable obtaining a source of reliable information about the technical condition of individual elements, machines and devices [Mikuła, 2012; Rogala-Rojek, 2012].

8. Monitoring of technological processes

Kazimierz Miśkiewicz, Antoni Wojaczek

8.1. Introduction

The Geological and Mining Law [PGG, 2023] obliges the enterprise to keep records of persons staying in the mining plant, **monitor** environmental threats and **monitor** the technological process. An important element for the safety of miners working in underground mines is not only current knowledge about their current location and the state of the atmosphere and technical environment of the underground mine, but also **monitoring** the operating condition of basic mining machines and equipment used in mines.

For mining machines and equipment, the term "**monitoring"** may refer to:

- **cyclical control** and analysis of selected parameters of a device, machine or vehicle along with their presentation on a local indicator board that is an element of this mining device (meters, displays or signaling elements in the driver's cabin) or remotely on monitors (hence the concept of monitoring) at technical supervision points, and technological process control,
- **ongoing monitoring**, i.e. observations using cameras and presenting these images on monitors at supervision and management points; e.g. in central or horizontal control rooms, power switchboards, observation posts, etc.

The common definition of monitoring systems in mines is associated with the second meaning of the word monitoring, because cameras are commonly used in mines.

Due to the development of microprocessor devices, PLC controllers and their use in modern mining equipment, the first definition of the word "monitoring" (as cyclical control) is becoming more and more important for the efficient, including economic, management of technological processes in mines.

The state of the technological process in underground mines is determined by measuring many technological parameters, such as: currents, powers, speeds, temperatures, pressures, states of switching devices on or off, filling states, closing and opening states of ventilation dams, as well as parameters determining work safety, such as: gas concentrations (CH_4, CO, CO_2 , O_2), air velocities in workings or output signals of geophones and seismometers enabling the assessment of the risk of rock bursts. Complex functions of measured parameters are also used to assess the state of the technological process and safety.

Monitoring technological processes as well as the safety status (mainly ventilation parameters) is one of the basic functions performed in **the control rooms of on-site mines**. The scope and method of monitoring depended on the available technical implementation possibilities.

Data obtained by monitoring systems can be used to diagnose machines and devices as well as to analyze the organization of technological processes.

The following stages can be conventionally distinguished in the development of technological process monitoring:

https://doi.org/10.32056/KOMAG/Monograph2024.2

- **Electric/electronic monitoring systems** (until the early 1980s). The control room was supplied with binary signals informing about the status (on, off) of the most important devices (fans, pumps, ventilation dams, conveyors, etc.). The status of the devices was signaled in the control room by lights (often in the form of **synoptic boards** - also referred to as static synoptic boards, as opposed to dynamic synoptic boards). Moreover, in methane mines there were methanometric control rooms in which the time charts of methane concentrations and air speeds in selected points of the mine ventilation network were recorded in the racks of station equipment (on paper recorders) [Cierpisz, 2007].
- **Minicomputer monitoring systems**. Signals informing about the status of operating equipment in the mine were transmitted to the minicomputer. The signals were archived in the minicomputer's memory and could be presented to the dispatcher on the monitor screen in text or semigraphic form. Archiving made it possible to print appropriate reports. The concept **of SCADA** is associated with computer monitoring systems as an abbreviation of the term **Supervisory Control And Data Acquisition**.

The use of **computers with graphic monitors** allowed for a graphical presentation of the state of the technological process on the monitor screen in the form of the so-called **dynamic synoptic tables,** archiving technological parameters and creating various types of reports.

A graphical presentation of the state of a technological process on a computer screen is called **visualization** (of a technological process). **A visualization system should be understood** as equipment (computers, monitors, large-format screens) and software for graphical presentation of the technological process status, generating alarms and preparing reports.

The availability of explosion-proof computers (usually in a flameproof enclosure) also made it possible to implement **local visualization** near the monitored technological process (sometimes with the possibility of local control).

The general structure of monitoring systems using computers is presented in Fig. 8.1 [Wojaczek, 2016].

Data sources for monitoring systems include sensors, PLC controllers in devices, protection devices in power equipment, and cameras. Signals from data sources are transmitted via the telecommunications network to station devices (mainly servers). Data from the servers are transferred to visualization and control dispatcher stations and are presented on appropriate boards. In some situations, it is possible to control underground equipment (e.g. switching on and off switches in the power grid). Data from the servers are also transmitted to visualization stations in the mine's external (office) network using appropriate protection measures against cyberattacks.

Network monitoring systems. There was a need to present the state of the technological process and information about parameters coming from various transmission systems or individual SCADA systems. This requires agreement on methods of exchanging information and details of transmission protocols between software authors of different systems. One way to build network monitoring systems is to use open architecture and standardize information exchange protocols.

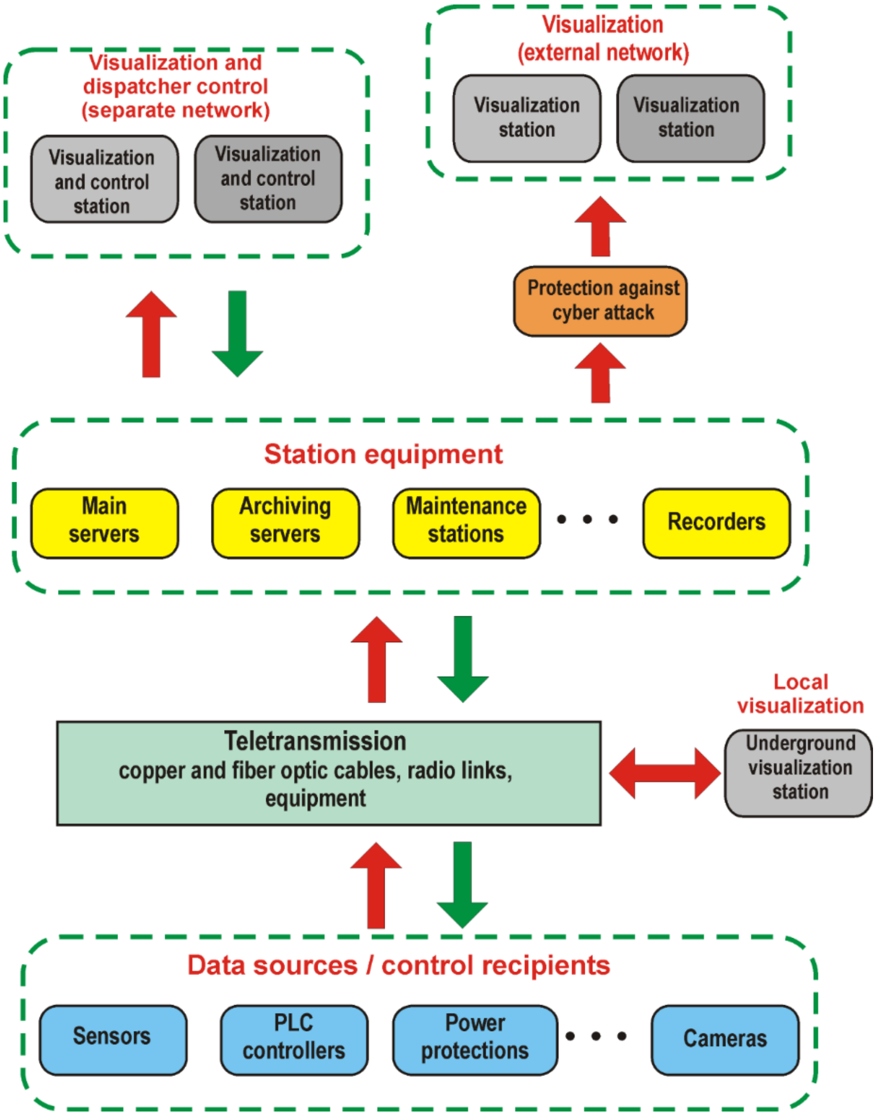


Fig. 8.1. General block diagram of dispatcher monitoring systems

In the structure presented on Fig. 8.1, we can distinguish **transmission** (from the information source to servers) and **visualization.** Manufacturers of various solutions began to offer their own (company) transmission systems, as well as their own software for visualizing the technological process and for visualizing ventilation parameters. This made it difficult to integrate monitoring systems. Creators of visualization systems had to agree on data exchange protocols with transmission system manufacturers.

Monitoring systems belong to the area of OT (Operational Technology). OT should be understood as hardware and software designed to track and detect or cause changes in physical processes by monitoring and/or controlling physical quantities using executive devices in the technological process [Polityka, 2020].

Monitoring systems can be integrated with the IT (Information Technology) area, which is important for the operational management and business management of a mining company. IT should be understood as all issues related to methods, means and activities related to information processing [Polityka, 2020].

Integrated OT/IT systems enable:

- Data transfer of selected technological data to the IT layer (including **the Center for Advanced Data Analytics CZAD**).
- Creation of specialized "power-mechanical control rooms" with visualization of detailed parameters of electrical machines (currents consumed by motors, temperatures, pressures), which are not important for the main dispatcher. In such control rooms, machines can be diagnosed and necessary service activities can be planned in advance.
- Implementation of remote access and transfer of selected technological data to machine manufacturers (owners renting equipment to mines) while maintaining cybersecurity principles [KSC, 2018].

Currently, a large number of electrical devices operate in the mine, which are the source of many technological parameters. It is estimated that in a typical mine there is on average [Kuśmirak-Brudnicki, 2019]:

- 120 medium voltage distribution panels,
- 200 flameproof transformer stations,
- 1,200 flameproof contactor switches,
- 380 flameproof transformer units.

8.2. Electric/electronic monitoring systems

The first mention of a dispatch system in a mine appeared in 1952, when the Ministry of Mining (Order of March 9, 1952) ordered the introduction of dispatch systems to mines. In 1955, the "Wujek" mine launched the first very simple dispatching devices in Poland (built with its own resources). In the following years (1956÷1967), several DKZ-60 type dispatch devices produced there in series were purchased in Czechoslovakia [Żymełka, 2000].

In 1959, the first Polish industrial mining dispatching device, type PUD/G-59, was created with visualization elements made of cube elements. It was also during this period **that the concept of a synoptic table** appeared in monitoring systems for the first time. The separation of visualization segments related to the control of the technological process and the control of the mine's safety status on a synoptic board was carried out in another Polish construction of a dispatching device (WSP-63 type).

The most perfect solution for the group of classic (non-computer) plant control rooms was a central dispatch device of the CDK-66 type with an AUD device as an alarm part and a multiple (24-channel) binary signal transmission system, initially of the UWP-3 type and then of the CTT-32 type. The above-mentioned devices were complemented by UDK-type dispatch and conference devices with a capacity of 110 NN, cooperating with the CKK-70 telephone exchange, and in methane mines, CTT-63/40U methanometric systems from the French company Oldham or its equivalents, e.g. CMM20 [Miśkiewicz, 2011].

Information about the state of technological processes (usually in the form of binary signals) was presented on static synoptic boards.

Various solutions for creating graphics and presenting device status were used in **static synoptic tables.** During this period, the most popular systems were those using:

– Drawing on glass - a colored drawing (technological or ventilation diagram) on a glass plate, with elements illuminated by telecommunication bulbs (DKZ-60) placed behind the plate; optical fibers glued to the glass were also used for the first time to illuminate drawings on glass (ZDT-G Elektrometal type board in the "Siersza" coal mine) [Żymełka, 2000].
– Cube elements - 1080x920 trusses filled with cubes (40x40); symbols allowing the creation of technological diagrams were marked on the front surface of the cube (PUD/G-59).
– Perforated plates; the dense perforation of the plates allowed for placing colorful strips on them intended to create mnemonic diagrams, square light symbols for technological devices and round light symbols to represent security parameters.
– Mosaic elements - structures of static synoptic boards of the FTM type were intended primarily for the needs of the power industry. The boards were built based on a welded metal supporting structure with an aluminum grid screwed on spacers allowing for the attachment of plastic caps (25x25 mm) which constituted the outer surface of the board. Appropriate mosaics were created, mapping e.g. selected technological processes or structural diagrams. The light signaling on the boards were made using TS 12 (24) V bulbs.

Fig. 8.2. Examples of elements of static (mosaic) synoptic tables

Since 1990, instead of FTM boards, ZPAS has been producing new types of STM boards (25x25 mm) and DTM boards (24x24 mm) with a self-supporting facade and signaling based on LEDs of various sizes and shapes (Fig. 8.2) [ZPAS, 1999]. Updating and changing the image on the board's facade is easy and quick due to the use of caps attached to the bodies. Almost all mines currently operate more or less extensive synoptic boards of this type in control rooms.

In mines, lighting elements can be controlled directly from the binary signal transmission system (e.g. FOD-900 system). Optical signaling devices of the USO-2 type are also often used, which additionally use pulsating light or an acoustic signal to inform the dispatcher about fundamental changes on the light board, which the dispatcher should pay attention to.

Current computer controllers for synoptic boards designed to light the diodes on synoptic boards consist of cassettes connected via RS-232 serial transmission links, containing PKW-001 type packages. Each package can control two matrices of 128 LEDs. One cassette allows you to control over 2560 LEDs. In addition to the PKW-001 packages, the controller cassette contains transmission protocol translators and controllers for lighting types and modes.

Fig. 8.3 shows an example of a mosaic synoptic board in one of the mine control rooms.

Fig. 8.3 Example of a mosaic synoptic board in a mine control room

8.3. Minicomputer systems for monitoring technological processes

In 1970, the ZKMPW companies (Zakłady Strukcyjno-Mechanizacyjne Przemysłu Węglowego in Gliwice, currently the Institute of Mining Technology KOMAG) and GIG (Główny Instytut Górnictwa in Katowice) launched the following in the "Automated Mine Jan" [Żymełka, 2000]:

- a comprehensive automation system of the "S" type from Polish production, with a minicomputer of the MKJ-25 type and then classic peripherals: a card reader and a tape perforator; the output device of the minicomputer was a teletypewriter, and the image of the printout on the teletypewriter was transmitted by a camera to an analog monitor in the dispatcher's room,
- mine mining and transport process control system of the "CES" type - with processing on an ODRA 1204 computer,

which initiated the era of computer dispatching systems, i.e. computer support systems supplementing static synoptic boards. At that time, attempts were also made to use a microcomputer from the French company Telemecanique, type T2000/20, specially designed for industrial applications.

In the 1980s, the use of one computer with high computing power, capable of controlling many technological processes, was abandoned in favor of decomposing the technological process and building separate dispatch modules controlling selected technological processes. In Poland, in the 1980s, a very successful design of an industrial microcomputer of the PRS-4 type (SMC-3 type computer adapted to mining conditions) was developed. The PRS-4 minicomputer was the basic equipment of the so-called modular dispatch systems type MSD-80.

The basic modules of the MSD-80 system (with the PRS-4 controller) were the following modules implemented in 1980 in the Moszczenica Coal Mine, the Wesoła Coal Mine and the Szombierki Coal Mine [Miśkiewicz, 2011]:

- HADES – designed to control the technological process and selected safety parameters (operation of fans, pumps, ventilation dams, fire protection installations, water level in sumps). This system was subsequently replaced by the mikroHADES (μHADES) system. It enabled cooperation with max. 352 two-state sensors and constituted an intermediate link for the visualization system of these processes.
- CMC 1/2 intended for the construction of a methanometric system for max. 128 sensors. After integration with the SWWP early fire detection system, it was the basis for the construction of modern gasometric systems produced by EMAG, type SMP (with CMC-3 or CMC-4 control stations).
- SAK (with a maximum capacity of up to 82 underground devices) designed to assess rock burst hazards based on passive seismoacoustics methods. It is currently being replaced by the ARES system.
- SYLOK (with a capacity of up to 16 underground devices) designed to automatically locate the place where a tremor occurs and determine its energy. Its modern version is the ARAMIS system.
- SWWP designed for early fire detection. The modernized version of this system, i.e. the SAP-1 fire alarm system, was integrated with the methane system and the SMP methane and fire system was created, which is currently used in many mines [Cierpisz, 2007].

A large number of text messages generated in the systems and appearing serially on the text monitors of computers used in the control room in the MSD-80 modular dispatch system at that time constituted a fundamental difficulty in the use of these systems by the dispatcher.

8.4. Monitoring technological processes using PCs

The development of computer technology enabled the construction of the so-called dynamic synoptic table DTS-1, in which information about the status of the technological process was displayed on graphic monitor screens. The basic goal of the modernization of the MSD-80 modular dispatch system carried out in the 1990s was to replace semi-graphics with graphics and specialized microcomputers with classic IBM PC computers. The mines started using modular dispatch systems of the MSD-90 type, the basic visualization element of which was a dynamic synoptic board of the ZEFIR type, initially (since 1991) using the IBM PC/DOS hardware and software platform. Since 1997, the ZEFIR visualization system has been transferred to computers with the Windows NT operating system.

8.4.1. ZEFIR monitoring system

Since network solutions (Novell networks) were already available in IBM PC computers, the ZEFIR system also enabled the visualization and dissemination (to computer stations of higher supervision of a given mining plant) of current information on the technological process and the safety status. Previously available only in control rooms, current information on the production status (and, e.g., current readings of gasometric systems instruments) could be analyzed on an ongoing basis in the mine supervision offices.

In Fig. 8.4. a block diagram of the ZEFIR visualization system in the network version is shown. Its basic parts are:

- central measuring module CYKLOP NT, collecting data from many systems listed in Fig. 8.4 via serial ports (COM),
- MAGIK system operator enabling the creation and modification of boards,
- computers with the ZEFIR NT application presenting visualization boards on monitors,
- HERMES NT mirror server separating a separate computer network in the control room from the mine's office computer network.

In the network version of the ZEFIR system, the first attempt was made to protect the mine's dispatch network against cyber attacks. A HERMES mirror server was used to which measurement data was transferred. ZEFR NT visualization stations located in the mine's office network downloaded data from the HERMES server, which eliminated the transmission of frames from the mine's office network to the dispatch network.

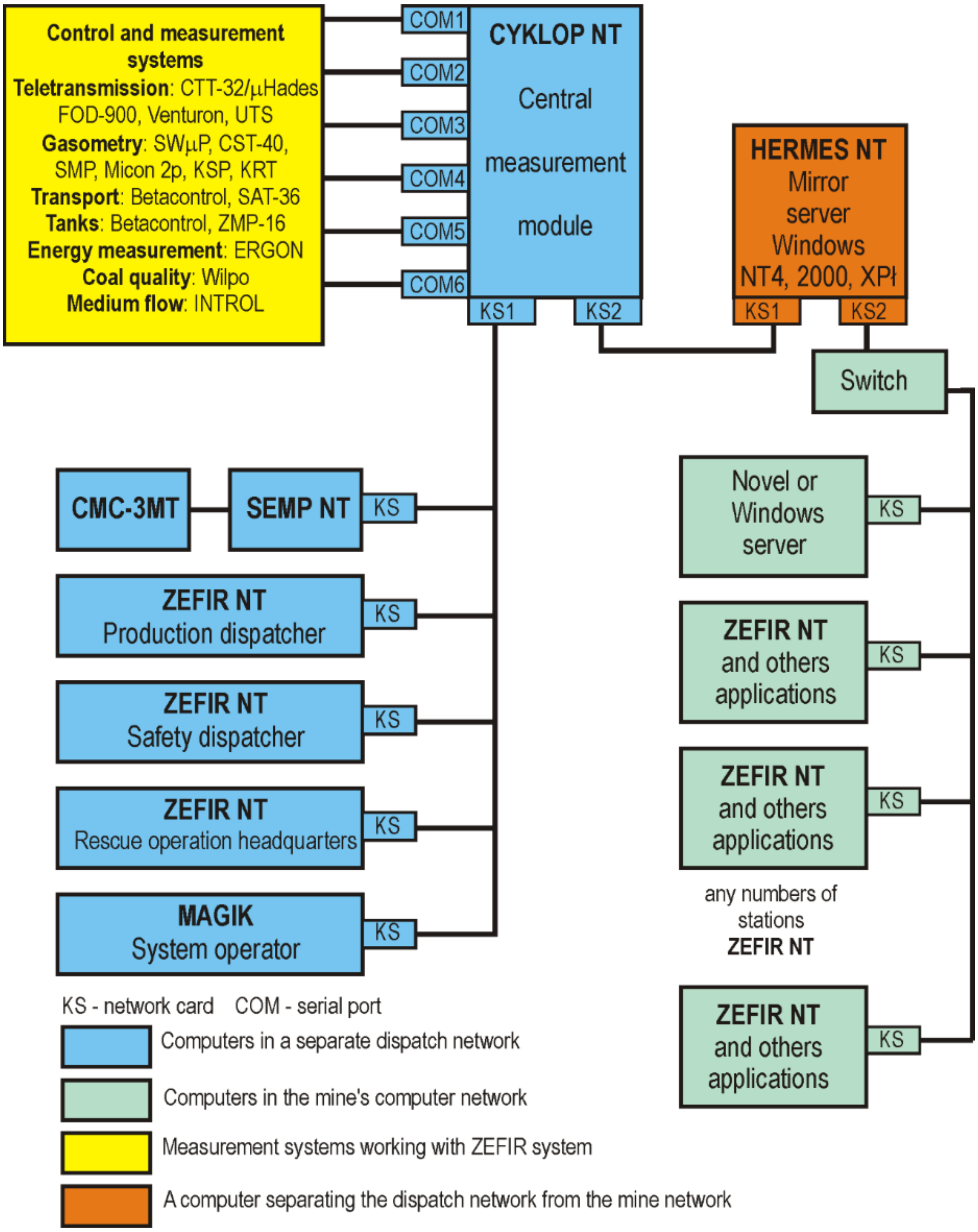


Fig. 8.4. Block diagram of the ZEFIR NT visualization system

8.4.2. SWμP and SP3 systems from HASO

A certain problem was the digital archiving and visualization of measurements from the systems of cyclic methanometry (e.g. CTT63/40U and CMM-20 types) not adapted to cooperate with computer systems. The solution was the launch (and operation in most Polish mines to this day) of a digital support system of the dispatcher for the methanometry, of SWμP type, by HASO. In Fig. 8.5 [HASO] shows the block diagram of the SWμP system (marked in blue) and its cooperation with various gasometric systems and individual methane meters (e.g. MIS). This system contains two basic computers:

– CMP Central Measurement Module.
– MRA Reporting and Archiving Module.

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The SWμP system receives data from the CST, SMP, KSP gasometric control centers, as well as from the CTT-63/40U analog control centers via the AMP analog measurement module.

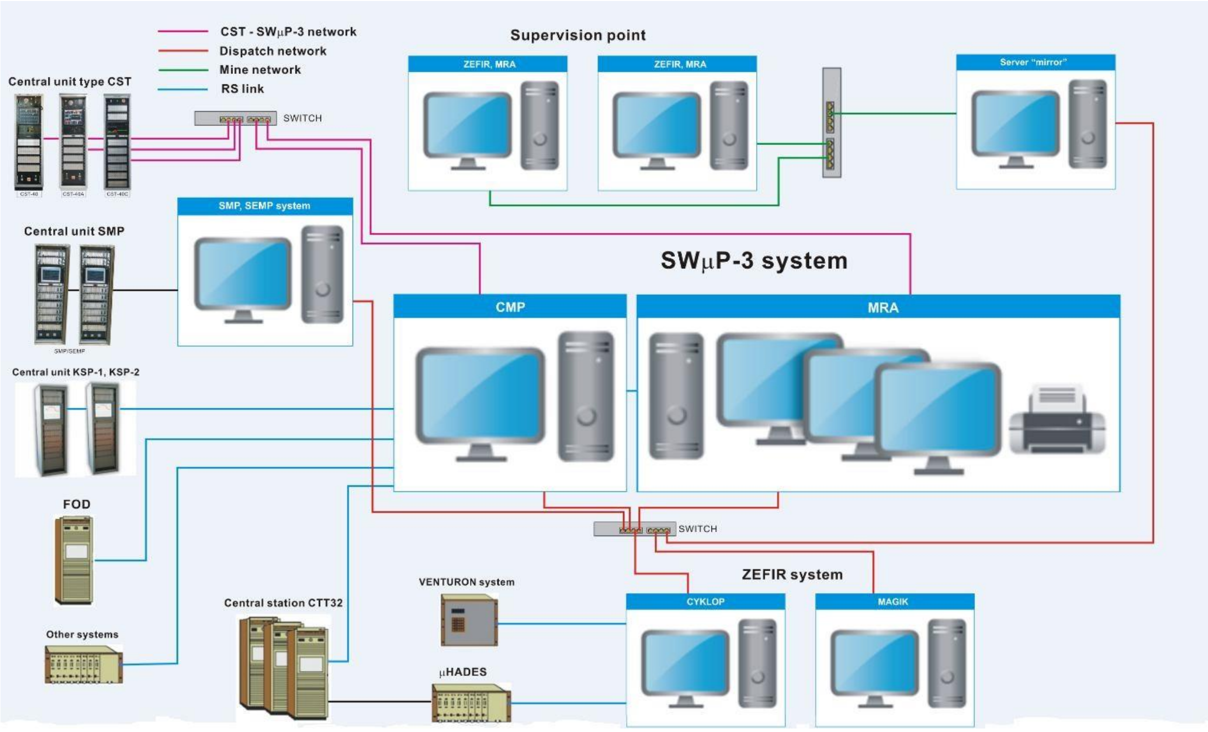

Fig. 8.5. An example of integration of gasometric systems and visualization using the SWμP system

SWμP provides other visualization systems in the control room (e.g. ZEFIR) with its autonomous database and enables control of the gasometric system. It also receives information from other technological systems (e.g. CTT32, FOD-900) about the operating status of mining machines and devices important from the point of view of safety systems (e.g. dams, fans).

HASO has developed the SP3 visualization system (Industrial Processes Presentation System), which allows you to visualize measurements from any type of sensors from various systems. It provides the user with the ability to graphically present measurements in a way tailored to their needs, as well as report and archive them. It consists of the following modules connected by a computer network:

- SP3-Constructor, a computer with software that allows you to create any type of fully scalable boards, maps, diagrams on which objects animating readings from user-defined sensors available in the system are placed.
- SP3-Servers (main server, mirror data server, external data server), which are used to collect, archive and share data for the entire system.
- SP3-Navigator, a computer with software that allows you to run previously created boards in separate windows and ensures continuous observation of current measurements (also in the form of graphic charts).

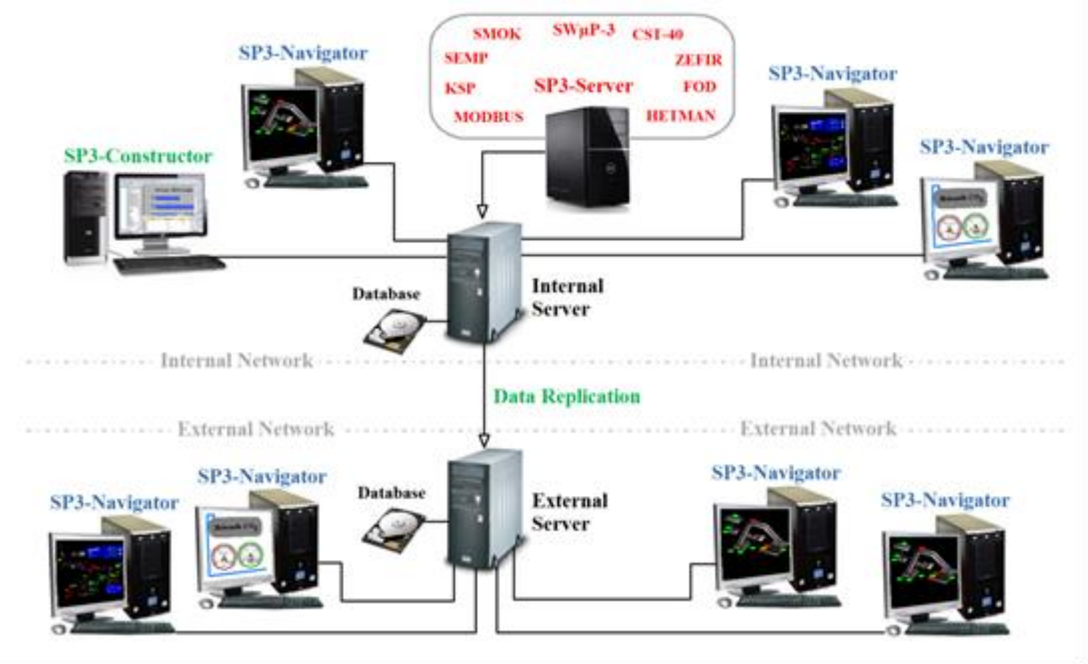

Fig. 8.6. Block diagram of the SP3 visualization system

Fig. 8.6 shows the block diagram of the SP3 system. SP3 servers can collect data from many systems used in mines, such as FOD, CST-40, SWmP-3, ZEFIR, SEMP, KSP, SMOK.

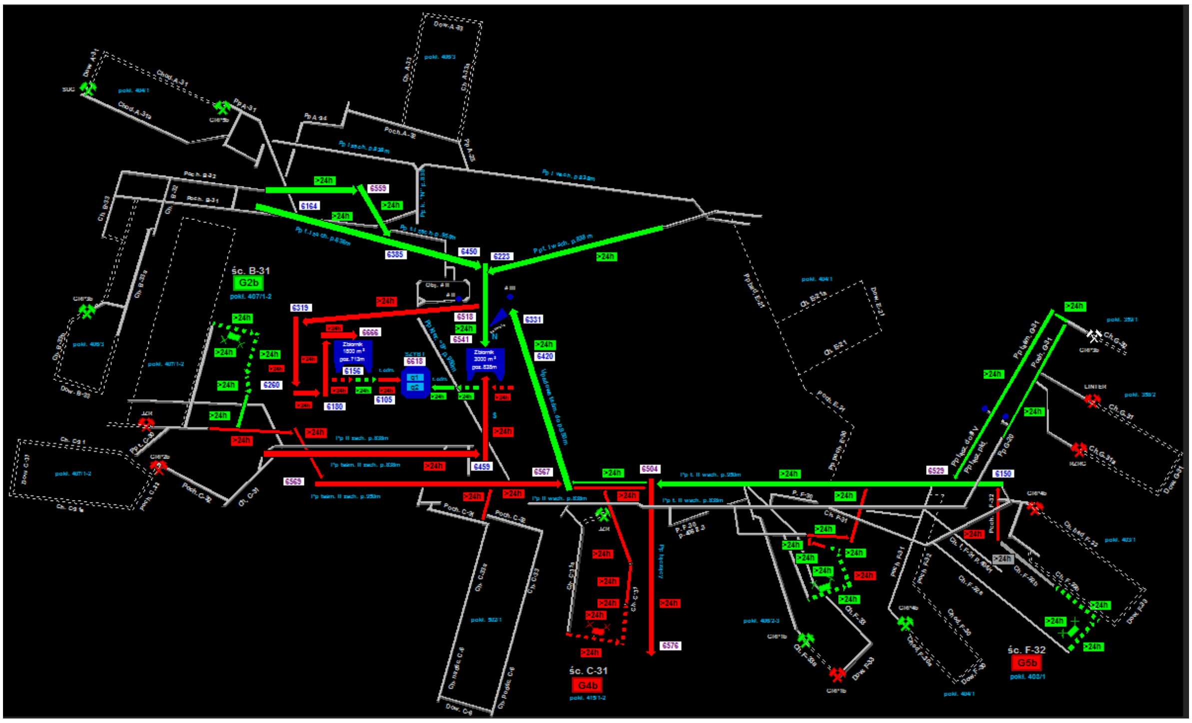

Fig. 8.7. An example of a board showing a conveyor haul system; working conveyors (on) are marked in green, and conveyors are turned off in red

In Fig. 8.7 an example of the SP3 system board showing the visualization of conveyor transport is shown.

8.4.3. SOMAR monitoring systems

SOMAR has developed one of the first systems for transmitting technological data from longwall and heading shearers called SMoK (also written as SMOK) to its own DEMkop visualization system. Data transmission from the shearer to the contactor switch takes place on the auxiliary conductors of the tire cable supplying the shearer using two TF4 transformer couplers and modems: the shearer and the switch modem, e.g. SM-PM6 (Fig. 8.8) [SOMAR].

Fig. 8.8. SM-PM6 shearer’s modem and TF4 transformer coupler

In the initial version, data transmission from the shearer's contactor switches, as well as longwall and beam stage loader, to the surface was carried out in copper telecommunications cables using narrowband modems. Currently, data transmission to the surface is carried out via a fiber-optic network.

Fig. 8.9 and 8.10 show the block diagrams of the SMoK-2 system for monitoring a roadheader and a set of several machines of the longwall system (a longwall shearer, a longwall conveyor, a beam stage loader, and a crusher), and Fig. 8.11 shows a board showing selected technological parameters of the shearer.

Archiving technological data enables their presentation in the form of graphs as a function of time. Fig. 8.12 shows an example of a screenshot with time-dependent graphs of cutting head motor currents, tractor motor currents, and the position and feed speed of the shearer during one cut. Fig. 8.13 shows the same graphs drawn using the memorized numerical data.

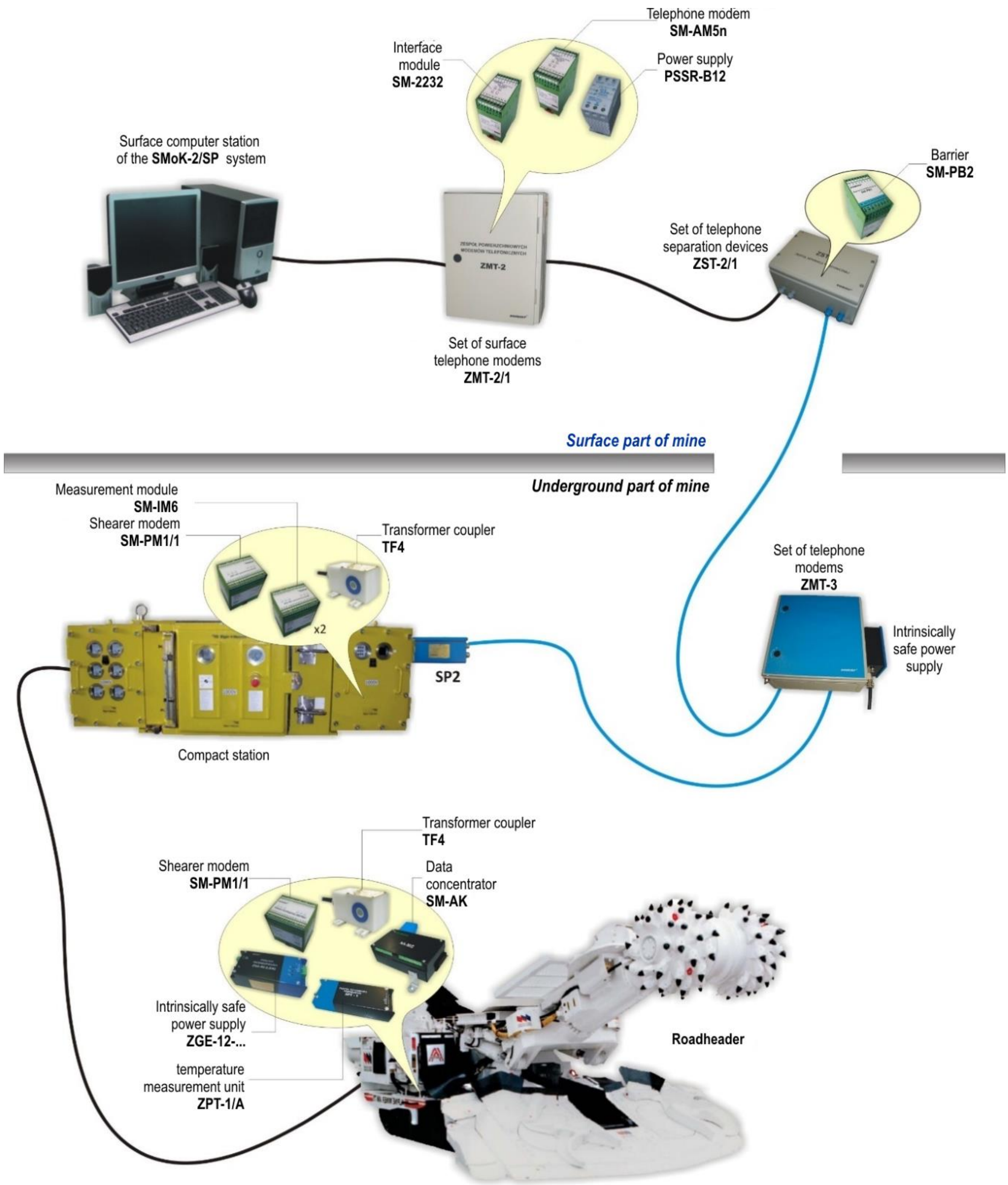

Fig. 8.9. Block diagram of the SMoK-2 system for monitoring a roadheader

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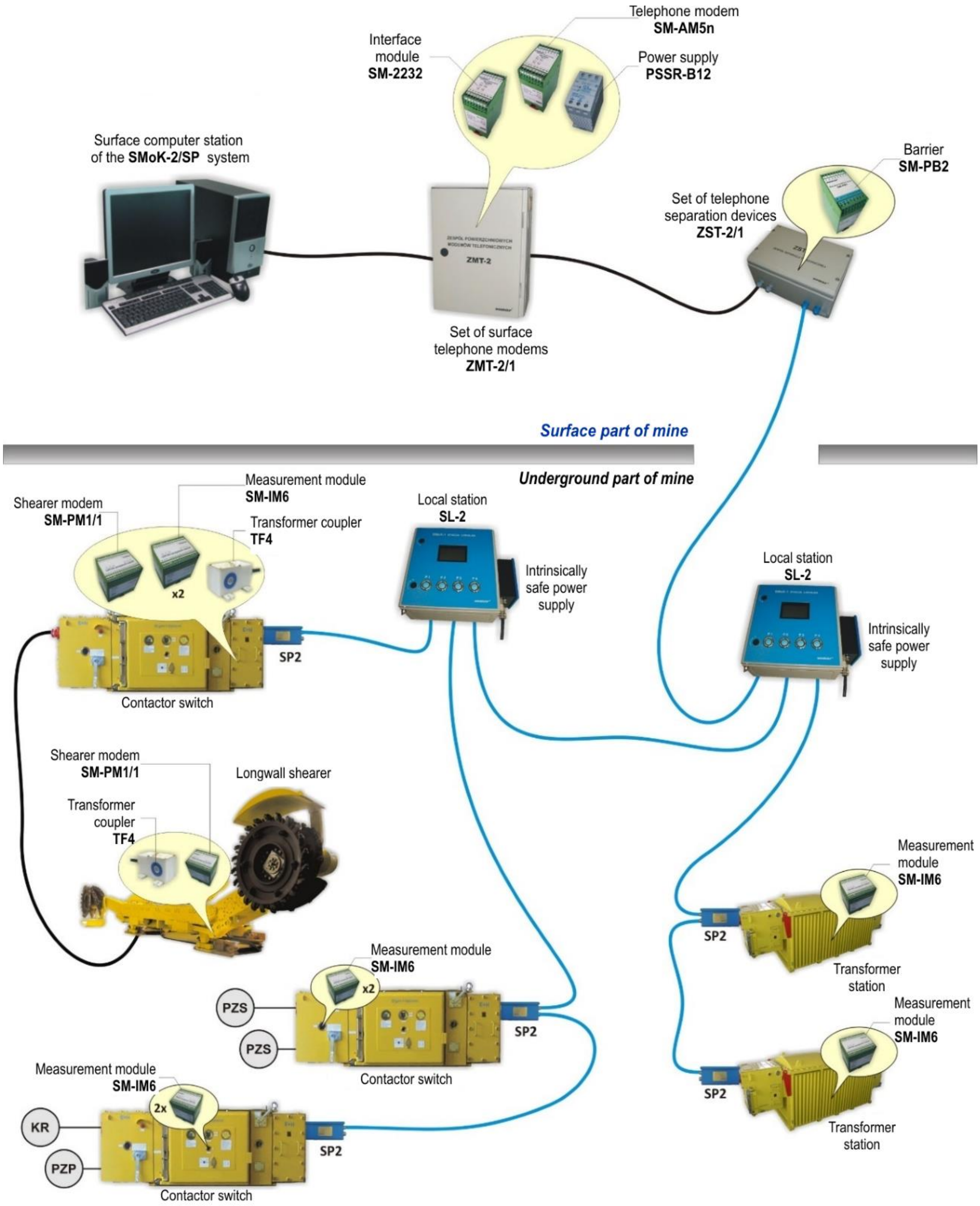


Fig. 8.10. Block diagram of the SMoK-2 system for monitoring longwall machines

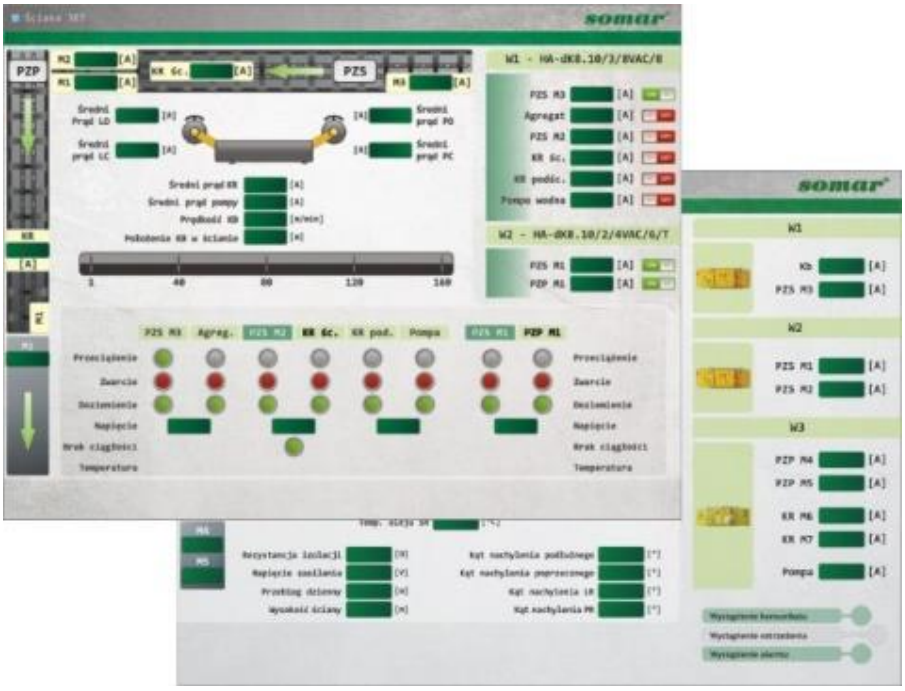


Fig. 8.11. An example of a DEMkop system board for visualizing a longwall shearer

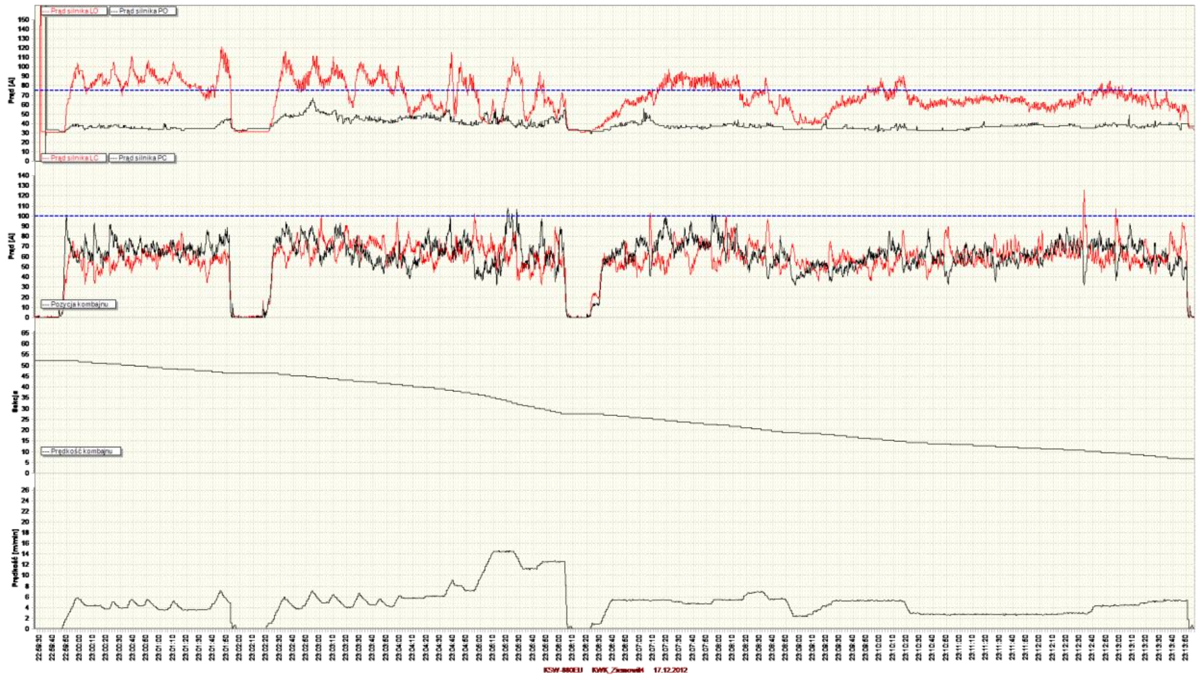


Fig. 8.12. Example of a screenshot with graphs of longwall shearer parameters. From the top: currents of cutting heads motors, currents of tractor motors, position of the shearer, feed speed of the shearer

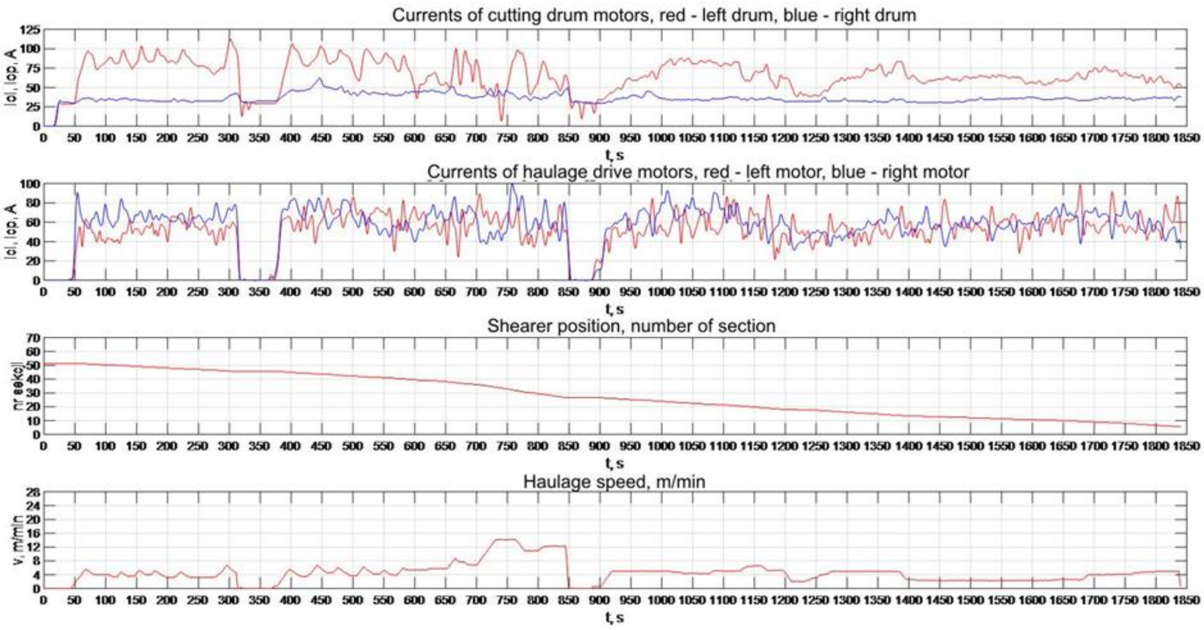


Fig. 8.13. Example of time charts of longwall shearer parameters according to data from Fig. 8.12

SMoK system can be used to monitor the condition of fire protection pipelines. The pipelines are equipped with pressure transducers, flow meters and electric valves. Signals from measuring transducers are transmitted via a copper telecommunications network using modems or a fiber-optic network (Fig. 8.14) [SOMAR]. An example of a screenshot from the visualization of fire protection pipelines in the Budryk coal mine is shown in Fig. 8.15 [Warchoł, 2019]. The pipeline monitoring system at the Budryk Mine is based on the SMoK system.

SMoK system can also be used for many other tasks related to monitoring technological processes in the mine. An example of a block diagram of a coal level monitoring system in a horizontal storage tank is shown in Fig. 8.16.

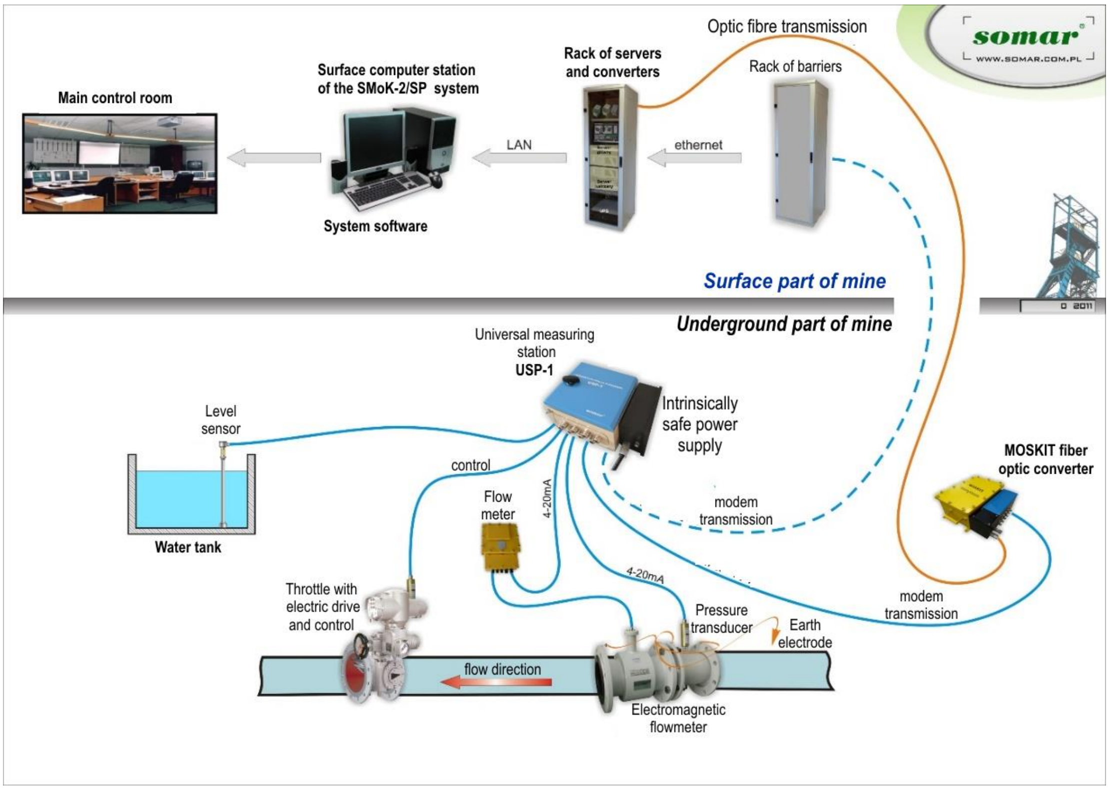


Fig. 8.14. Block diagram of the SMoK-2 system for monitoring fire pipelines

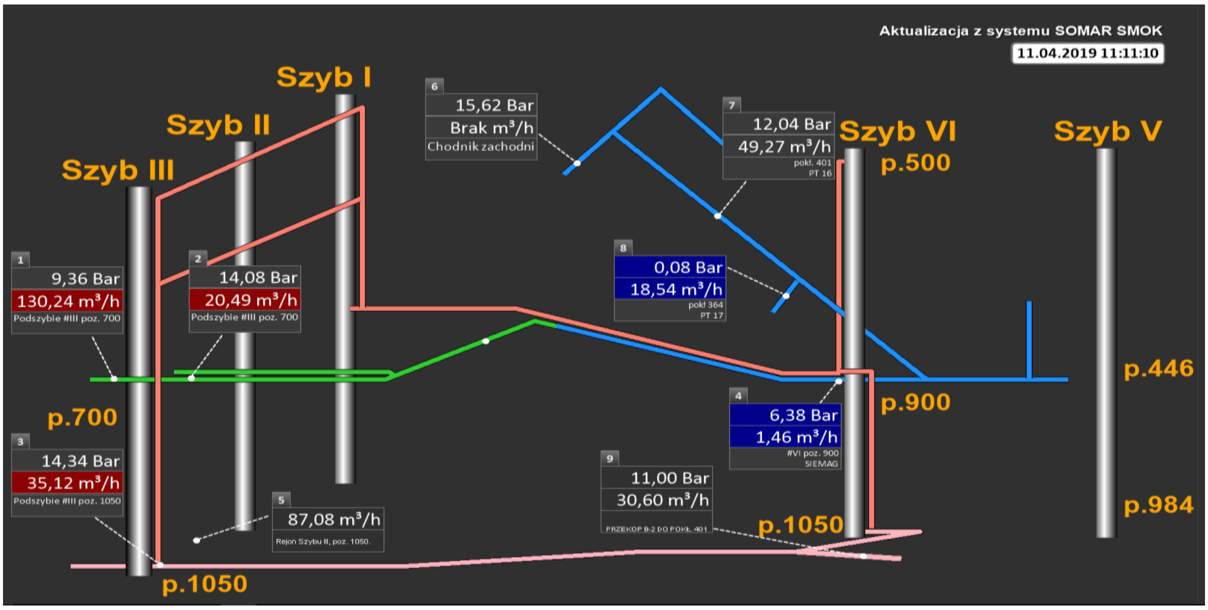


Fig. 8.15. An example of visualization from monitoring of fire protection pipelines in the Budryk coal mine using the SMoK system

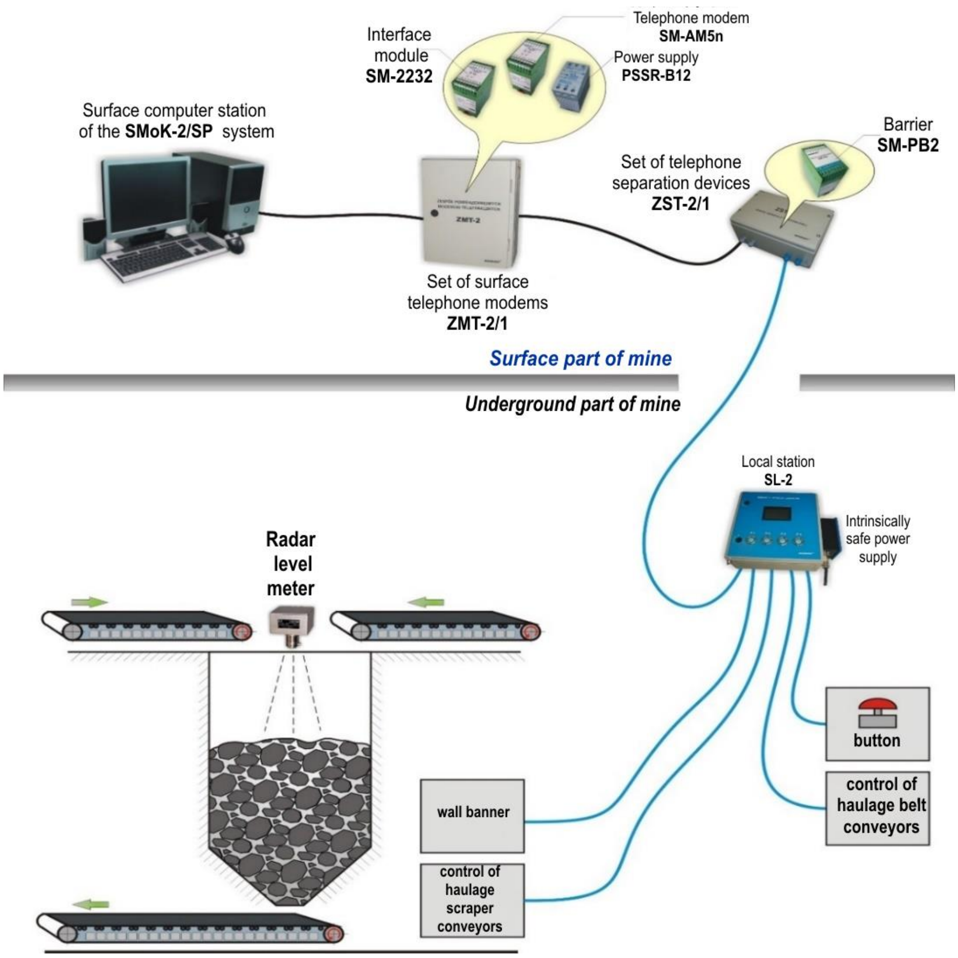


Fig. 8.16. Diagram of the SMoK-2 type monitoring system for the coal level in the retention tank

8.4.4. THOR visualization system

The THOR visualization system consists of the following parts:

- **database server** that collects, archives and processes all available data,
- **data delivery module**, which is responsible for communication with external systems and downloading and processing data,
- **layers of client applications** named: SKADI, LOKI, ODYN.

The centralized **database server** of the THOR system enables data archiving, guarantees its consistency and provides simultaneous access to data via client applications.

The structural diagram of the THOR system is shown in Fig. 8.17 [Wojaczek, 2015].

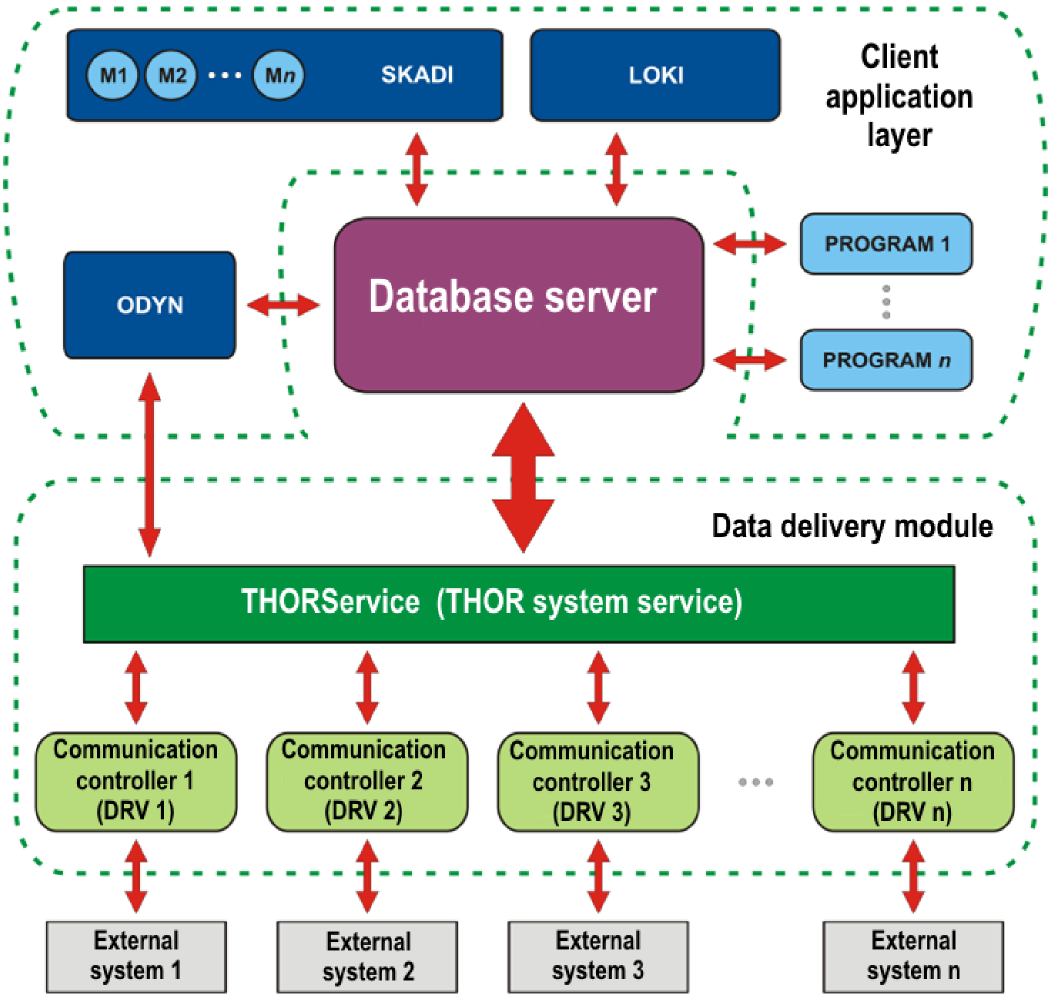


Fig. 8.17. Structural diagram of the THOR system

The data delivery module consists of **communication drivers** and the **THORService system service** that manages the drivers and loads data into the database. The task of communication controllers (DRV) is to ensure constant communication, via a fixed transmission channel and a specific protocol, with the source systems providing data, as well as their cyclical downloading.

The application part is a set of tools that enable the user to configure the system to meet their own requirements. The basic system applications include the following programs:

– SKADI – the main user program providing visualization, reporting and supervision of elements whose data is collected in the THOR system.
– LOKI – a tool for system administrators enabling the preparation of graphic boards.
– ODYN – a program for system administrators that allows configuration of drivers, alarm messages, and management of users and permissions.

Fig. 8.18 shows the structure of the THOR system with the main and mirror servers, communication controllers (DRV) and devices (measuring sensors) of systems supervised by the THOR system (U), and Fig. 8.19 shows an example of a visualization board [Wojaczek, 2015]. The THOR system acts as an "overlay" on autonomous telecommunications systems operating in mines, integrating them into one functional module. This ensures uniform operation, visualization, reporting and access to data from each "independent" system operated in the mine. It enables monitoring (with one visualization system) of many smaller, separate visualization systems.

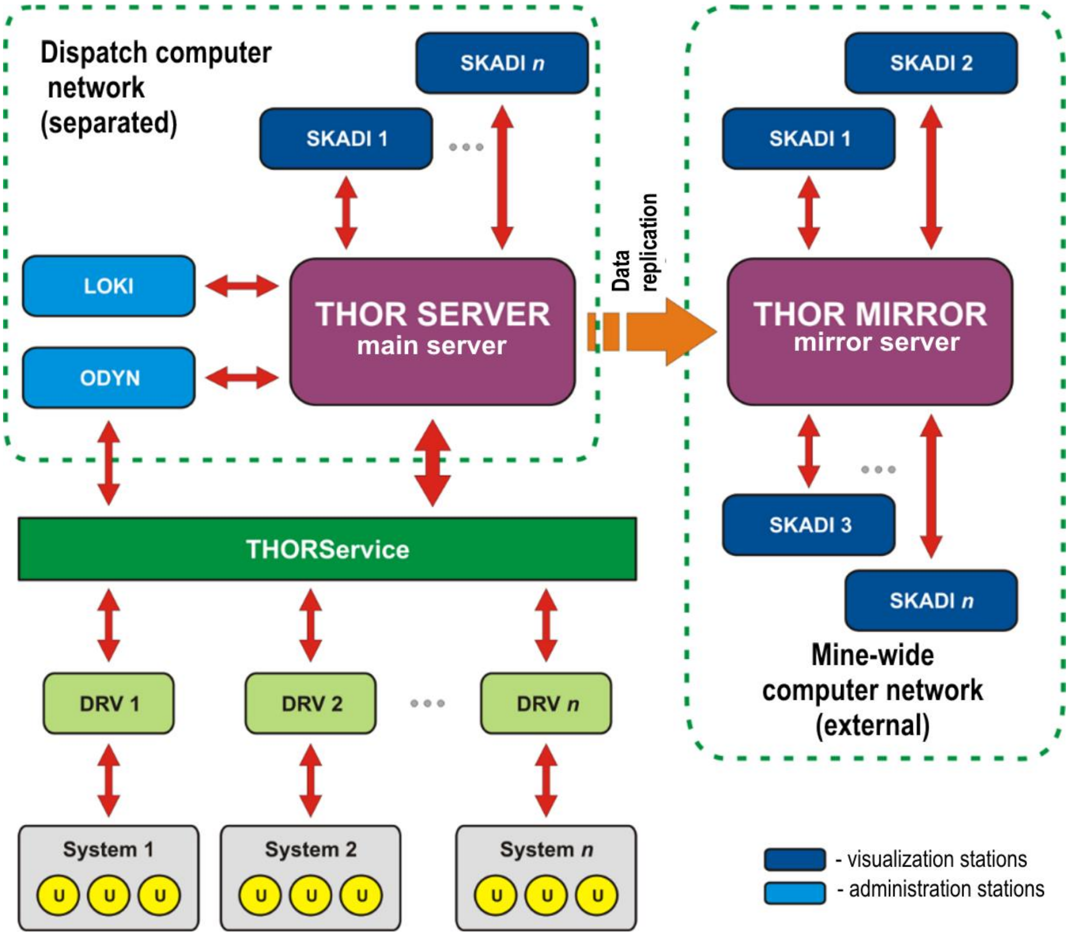


Fig. 8.18. The configuration of the THOR system in the mine is based on a main and mirror server

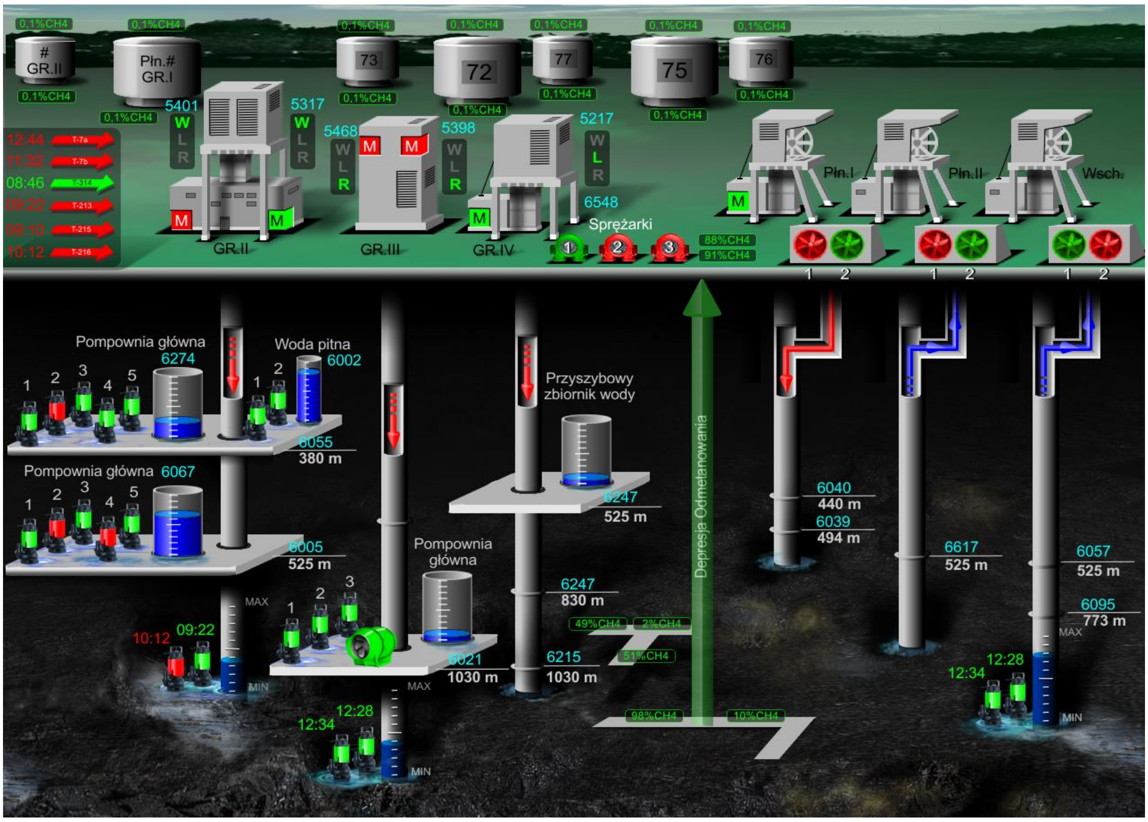


Fig. 8.19. An example visualization board in the SKADI program of the THOR system

8.4.5. SAURON visualization system

SAURON system is a dispatcher visualization system based on SCADA - ASIX software from ASKOM and additional programs from REDENT**.** Similarly to the previously described systems, the basic task of the SAURON system is to visualize the operating status of many machines and technological systems, as well as to control some devices of the monitored systems, e.g. switching on and off switches in mine power networks.

Fig. 8.20 shows the possibilities of using the SAURON system in mine control rooms to monitor many different machines, devices and technological lines (e.g. visualization tabs: haulage, aggregates, pipelines, pumping stations, faces, longwalls, air conditioning, mechanical coal processing plant, current state of mining extraction. etc.) [SAURON]. Fig. 8.21 shows an example of visualization of the status of all bays installed in the main 6 kV DRG-3 underground switching station at level 1000 in the Pniówek mine [Bieszczad, 2019], and in Fig. 8.22 an example of visualization of only one bay (No. 9) of the DRG switchgear along with a time diagram of phase currents and information about the last switching activities.

Fig. 8.20. Possibilities of using the SAURON system

Fig. 8.21. Example of visualization of the status of a 6 kV switchig station in the SAURON system

Fig. 8.22. Example of visualization of the bay status in a 6 kV switching station in the SAURON system

8.4.6. ATVISIO2 visualization system by ATUT

The ATVisio2 platform is an original solution of ATUT. It is a production process support system intended for mining plants. Using individual modules of the ATVisio2 platform, you can [ATUT]:

- supervise the current operation of machines and devices from any workstation in the plant network via a web browser,
- analyze the operation of machines, including in terms of their level of use and failure rate, as well as send control commands to selected devices,
- view historical data and generate reports based on the collected data,
- monitor the location of the crew, machines and transported material,
- receive up-to-date information, e.g. on current production efficiency, warning and alarm states occurring in the observed processes,
- view images from cameras located in the plant,
- manage documents (including technical documentation, operating manuals, service protocols) in electronic form.

The ATVisio2 system allows you to visualize and link collected measurement data with information entered by employees and contained in external ERP systems (financial, accounting and warehouse systems).

Fig. 8.23 shows an example of a longwall shearer monitoring board, and Fig. 8.24 shows a visualization of the communication and safety system of the SSG-2 type longwall system and the CUKS-5CX Digital Control Device. The board shows the operating status of the conveyors and communication system elements. By clicking on the menu items, the user displays device details [Warchoł, 2019].

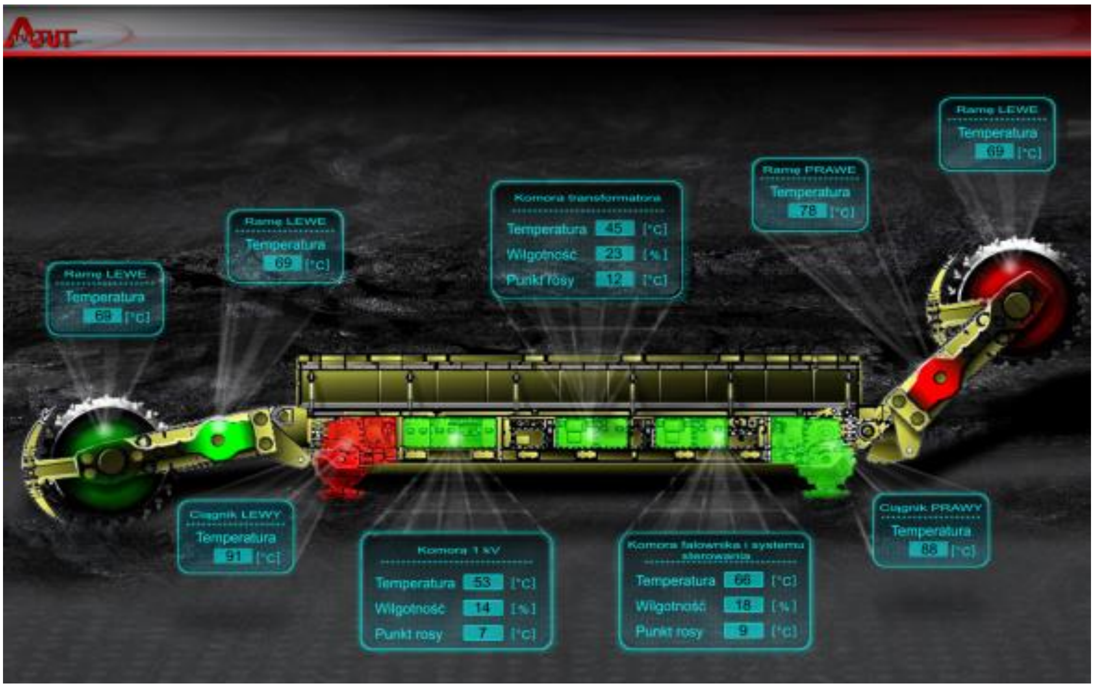
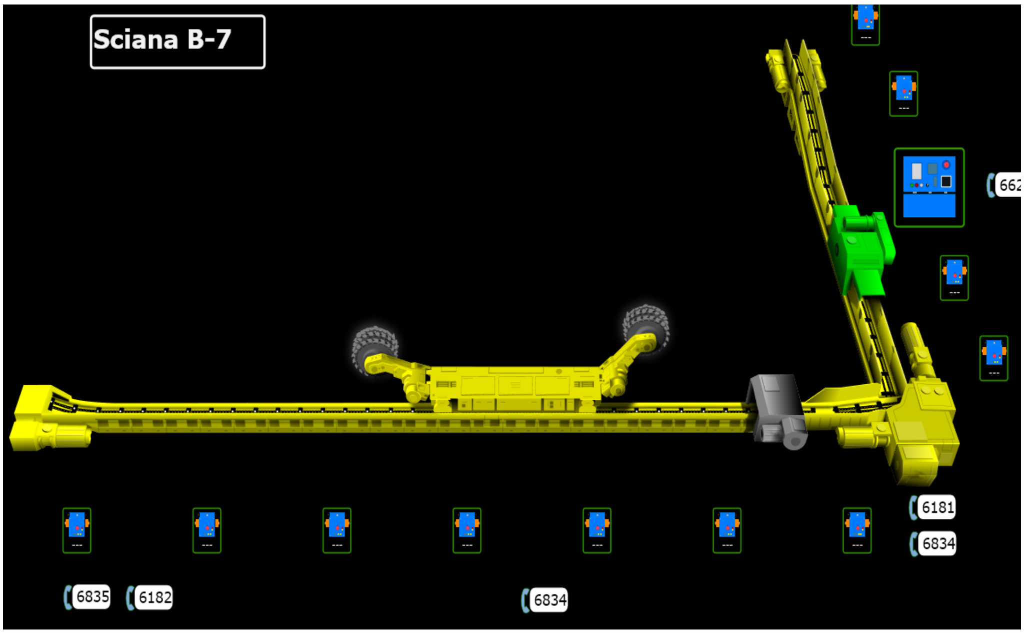


Fig. 8.23. An example of an ATvisio2 system board for visualizing the operation of a shearer

a)



b)

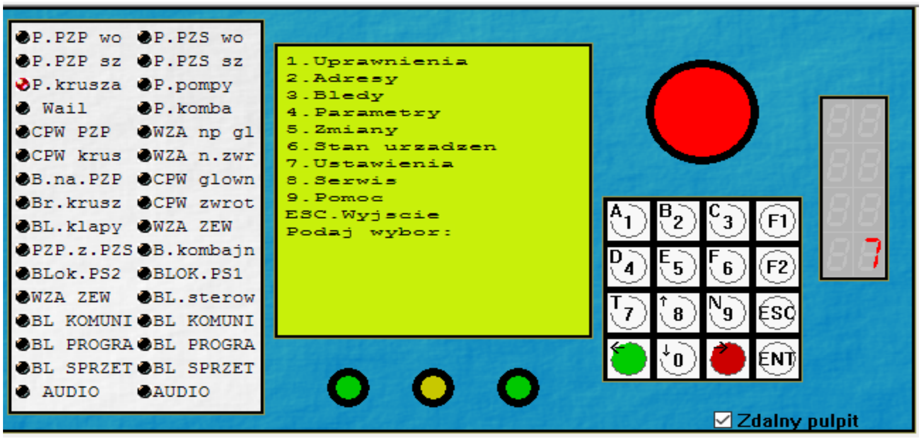


Fig. 8.24. Visualization board: a) SSG-2 system, b) CUKS-5CX controller

8.4.7. Elgór+Hansen visualization systems

Elgór + Hansen has developed an integrated EH-ATON monitoring and visualization system that can cooperate with many visualization and technological process control systems, such as [E+H; Lubryka, 2015]:

- EH-MineView - mine visualization system,
- EH-WallView - visualization system for mining systems,
- EH-WallControll - longwall system control system,
- EH-SmartWall - automatic control system for the longwall system,
- EH-PressCater Blue - pressure monitoring system of fire protection pipeline networks,
- EH-Wibro - vibration monitoring and diagnostics system,
- EH-HeadControl - control system for the roadheader system,
- EH-PressCater - system for monitoring the load-bearing capacity of longwall supports,
- EH-APD1 - microprocessor conveyor automation system.

Standard functions of individual systems with the general company name EH- View include, among others [Lubryka, 2015]:

- possibility of creating teletransmission systems of any size and complexity and with easy scalability (wide possibilities of system expansion),
- synoptic boards presenting in a transparent way the operating status of power and telecommunications devices related to the technological processes carried out there, along with the possibility of determining trends in these processes (visual presentation of process variables in the form of time charts),
- alarms – warnings and information allowing the identification of technical problems of a given technological process,
- user system - i.e. multi-level access to selected data or functionalities of the visualization system with the possibility of distributing the visualization on many computers in the rooms of various technical services of the plant,
- easy integration with other telecommunications systems using typical industrial data exchange protocols (including OPC).

Fig. 8.25 shows the general structure of the EH- MineView system. Each of the basic local technological processes (longwall systems, faces, etc.) has its own underground, local visualization station (computer in a flameproof cover) and data from the underground visualization stations are transferred to servers on the surface and then presented at surface visualization stations, e.g. in the control room.

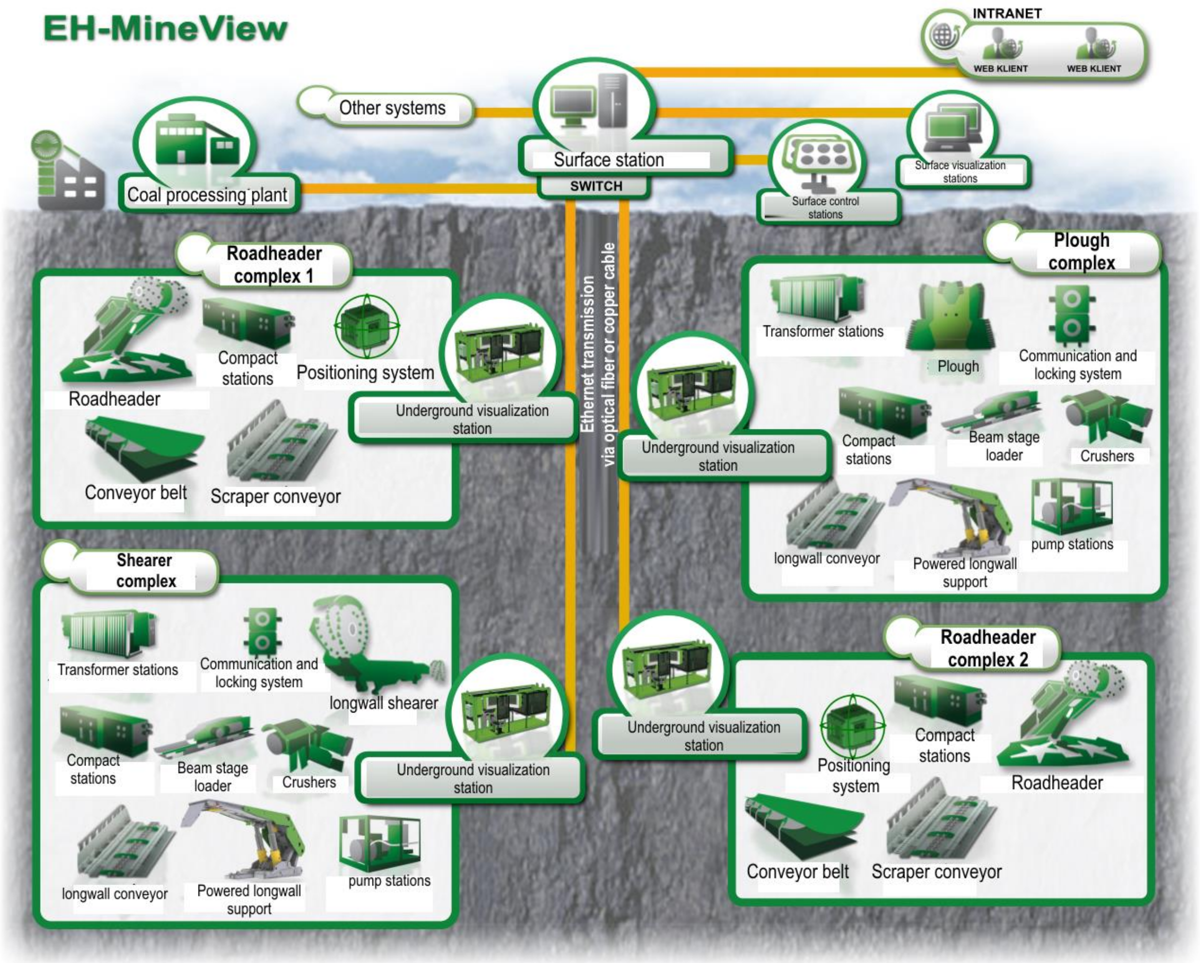


Fig. 8.25. An example of the structure of the EH-MineView system for a mining plant

Fig. 8.26 shows the structure of the EH-WallView system for monitoring a longwall system. Transformer stations, compact circuit breakers, a longwall shearer, longwall conveyor, beam stage loader, a crusher, pump stations, and communication and locking systems are connected to the underground visualization station. After activating the general icon of the device (e.g. longwall system), detailed data of the selected machine or device appears, as shown for example in Fig. 8.27 (longwall system of longwall C3) and in Fig. 8.28 (roadheader of the N-1 face in the Pniówek coal mine [Bieszczad, 2019].

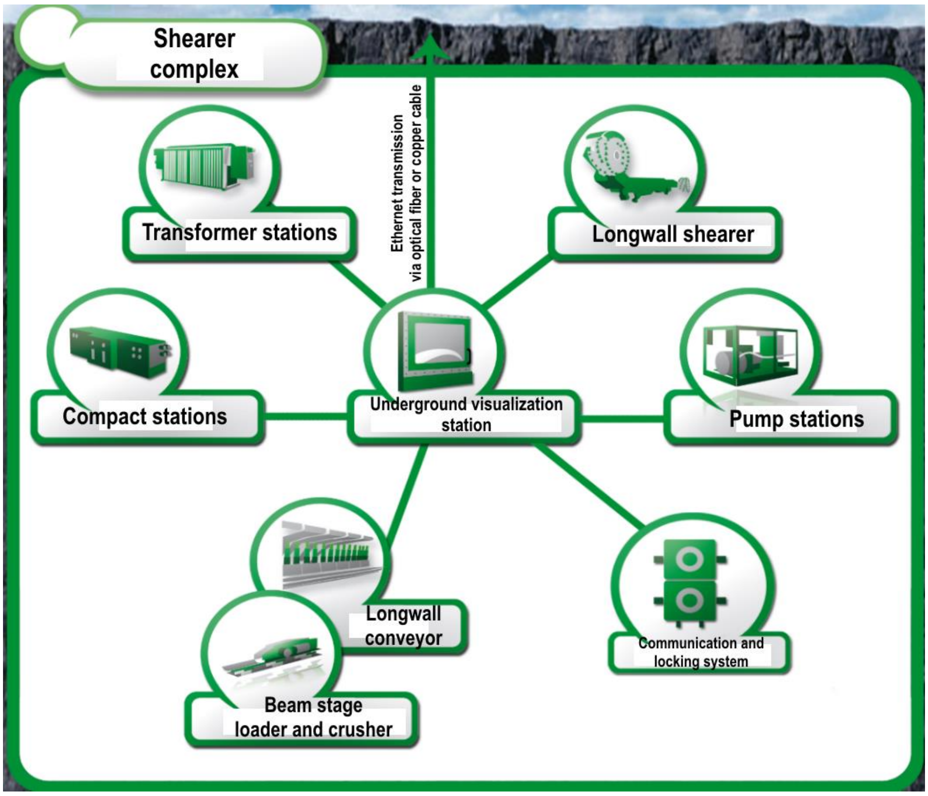


Fig. 8.26. Structure of the EH-WallView system for a longwall

Fig. 8.27. Example of EH-WAllView visualization board

Fig. 8.28. Example of the EH-HeadControl visualization board

8.4.8. FAMUR visualization systems

FAMUR has developed a monitoring and visualization system called e-mine. E-mine is a set of IT and hardware solutions that provide:

- aggregation, transmission, visualization and archiving of collected data,
- data analysis and generation of detailed reports,
- integration with systems from other manufacturers.

The e-mine system contains complementary elements, such as:

- teletransmission infrastructure,
- SCADA software with diagnostic systems: e.g. FAMAC RSPC wireless pressure measurement system, FAMAC VIBRO intrinsically safe vibrodiagnostic system,
- CCTV systems.

Fig. 8.29 shows a block diagram of the structure of the e-mine system [FAMUR]. Each local monitoring system: e-complex, e-transport, run-of-mine haulage, has an underground local visualization and control station (Local Station). Individual local stations transmit data to the underground GreenDiamont server and further to the surface to the server and visualization stations in the control room.

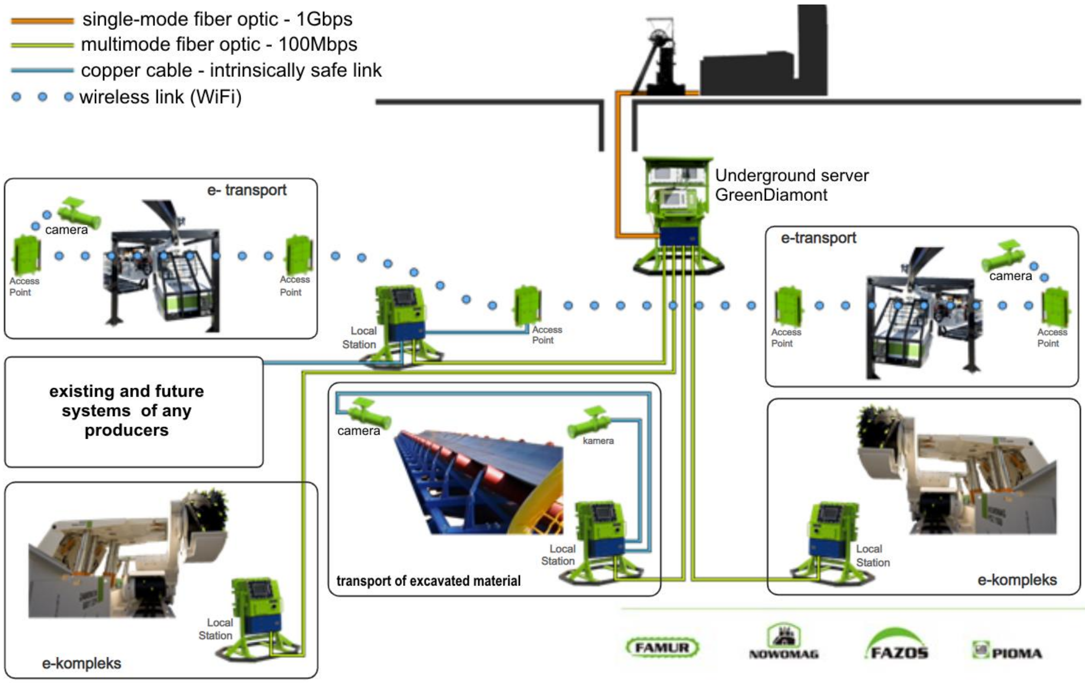


Fig. 8.29. Block diagram of the e-mine monitoring and visualization system

Other local systems may be connected to the underground server, such as the FAMAC VIBRO vibrodiagnostic system and the FAMAC GEO seismic phenomena monitoring system, as shown in Fig. 8.30 [FAMUR]. Fig. 8.31 shows the block diagram of the FAMAC VIBRO diagnostic system [Kępski, 2012]. In the FAMAC VIBRO system, machine diagnostics uses machine temperature measurement and machine vibration measurement, performed with an accelerometer.

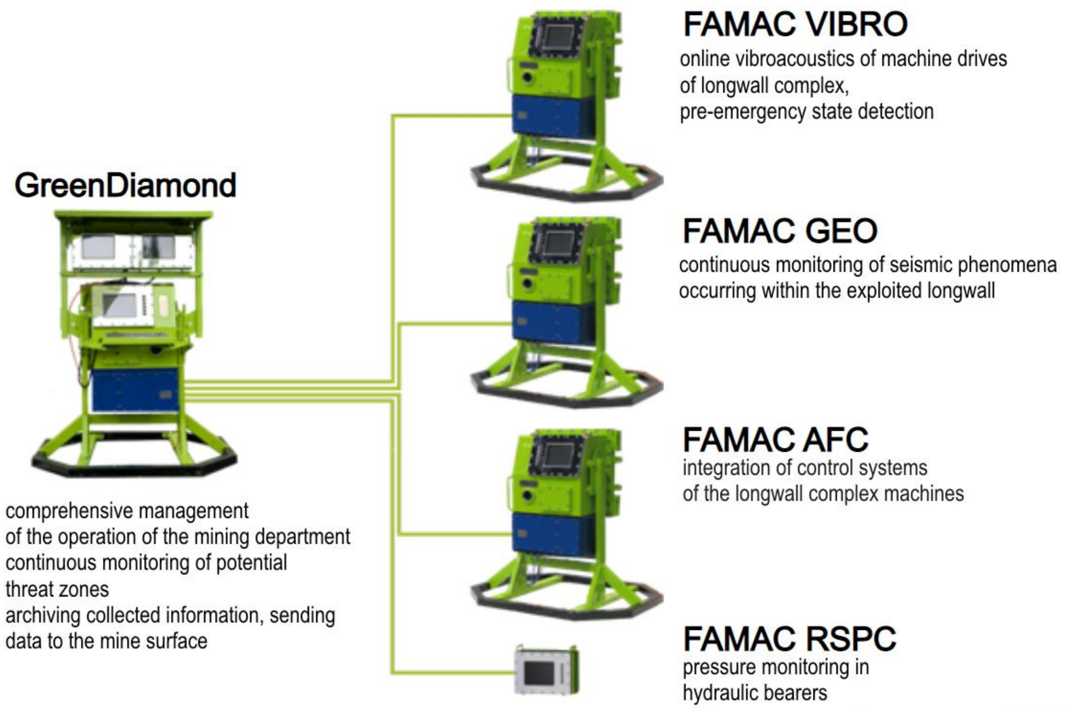


Fig. 8.30. Block diagram of diagnostic systems in the longwall system

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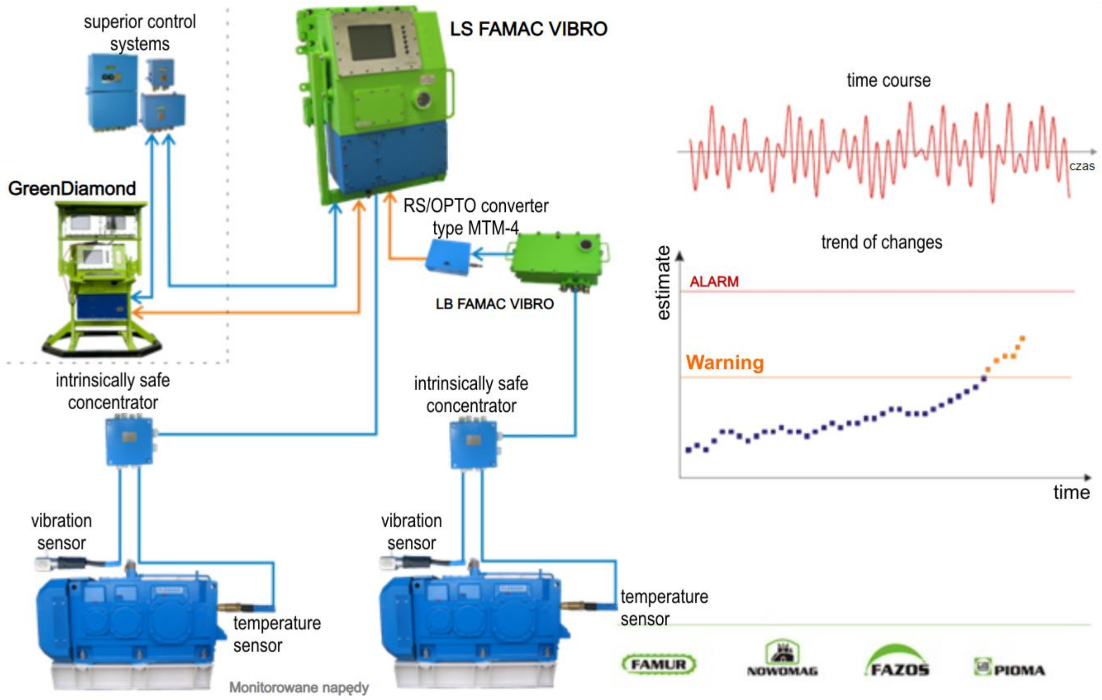

Fig. 8.31. Block diagram of the FAMAC VIBRO system

8.4.9. MonSteer-D visualization system

MonSteer-D visualization system was developed by TRANZ-TEL. The task of the system is to record and store digital and analog data (signals) describing the state of the object and to present them in a configurable graphical environment. The system is adapted to the requirements of mining plant dispatch services and in particular enables:

- displaying technological and ventilation diagrams with the measurement states of sensors,
- displaying the history of measurements of analog and binary sensors, as well as access to historical definitions of visualization boards,
- defining internal and alarm signals based on logical and arithmetic functions, along with the analysis and presentation of alarm situations (warning and emergency with the possibility of commenting on them),
- a complete information log (including time and responsible person) of all operations in the system and a flexible definition of all presentation elements (boards, symbols, signaling) and system logic (signal sources, signals, alarms, history aggregation).

MonSteer -D system is described in a database containing, among others:

- signal definitions - signal sources, signal structure, identification, principles of data interpretation and transformation (calculated signals) and storage of historical data and messages,
- board definitions – structure of visualization objects grouped in a project (or several projects), detailed attributes of objects defining their appearance and/or behavior,
- administrative data – user and authorization structure, installation configuration.

Fig. 8.32÷8.34 show examples of boards from the MonSteer-D system presenting:

a) visualization of the operating condition of the longwalls and the entire conveyor transport on one level in the Knurów Mine, (Fig. 8.32),

b) condition of mine dams at individual levels (Fig. 8.33),

c) readings of gasometric sensors in the longwall area (A – anemometer, M – methane meter, C – carbon monoxide meter, Tl – oxygen meter, CRC – differential pressure sensor) and the numbers of telephones and broadcasting telephones in this area (Fig. 8.34).

The MonSteer-D system is also used for the visualization of radio communication systems with a radiating cable MCA1000 (MCA1000 digi), as well as the ARGUS zone location system from TRANZ-TEL.

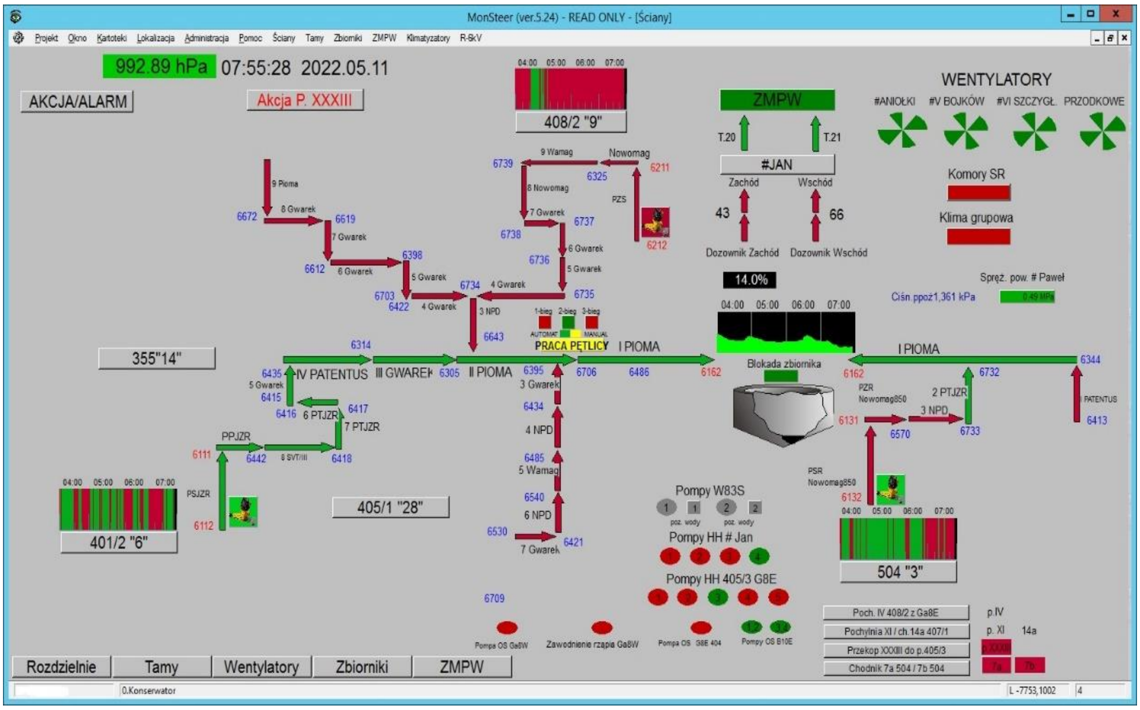

Fig. 8.32. An example of the MonSteer-D system board - visualization of conveyor transport

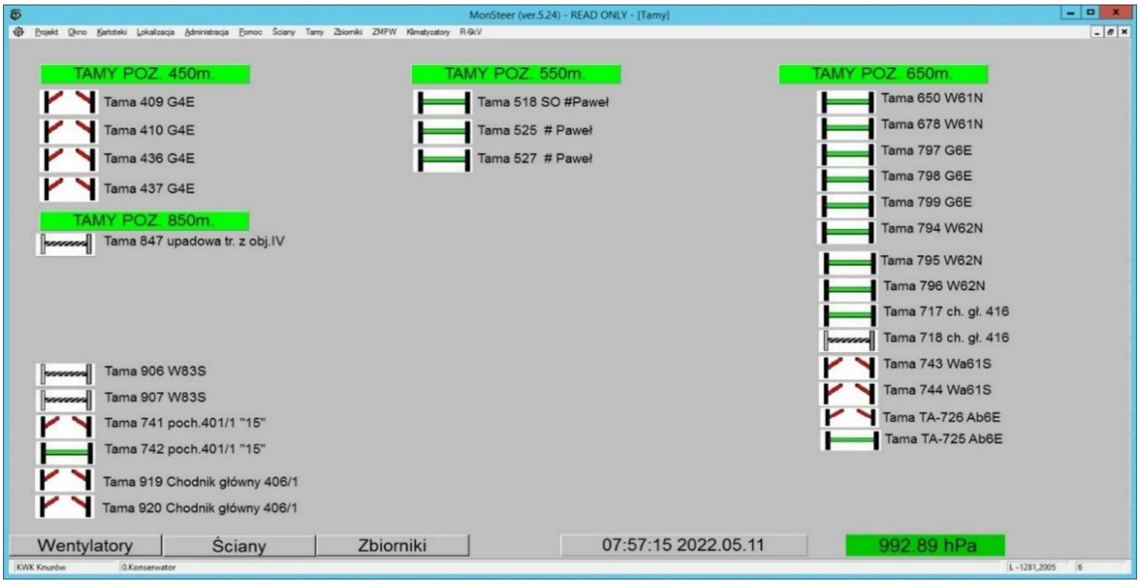

Fig. 8.33. MonSteer-D system board - visualization of mine dams on several levels

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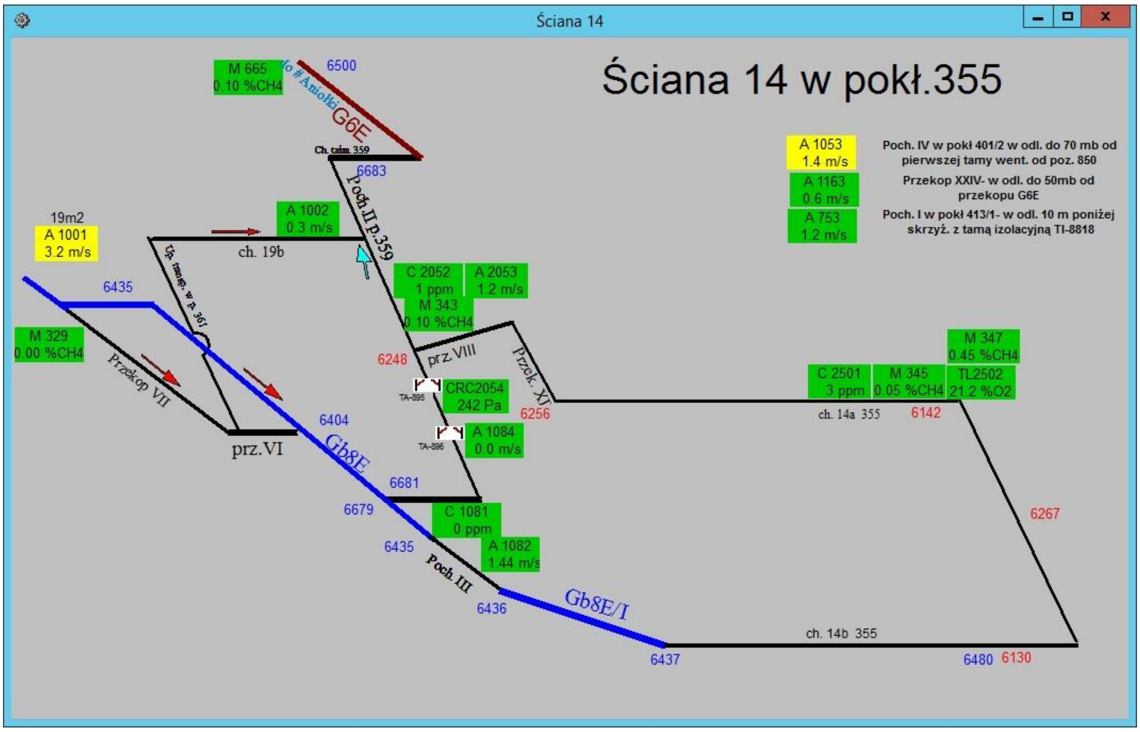

Fig. 8.34. MonSteer-D system board - visualization of sensor readings in the wall area

In JSW SA, this system is the basic visualization system in Coal Mine Knurów Szczygłowice, Section Knurów control room.

8.4.10. Hades visualization system

Hades is a SCADA system developed for the needs of JSW SA mining plants based on the Asix software platform Evo by Askom. The Hades system performs the following functions:

– acquisition of measurement data from devices and other systems,
– visualization of technological processes,
– technological process control,
– alerting about events,
– a data archiving, analysis of archival data and reporting analyses,
– sending data to MES, ERP and business analysis systems,
– sharing data to MS Office (Excel).

The Hades system includes:

– a virtual machine used as an application server with the installed Asix and Microsoft SQL Server software,
– Asix software installed with an RDS (Remote Desktop Services) license,
– user workstations (and administrators), i.e. computer stations connected to the network infrastructure that enable access to the Hades system via the Internet Explorer web browser or the RemoteApp service.

The architecture of the Hades system is shown in Fig. 8.35.

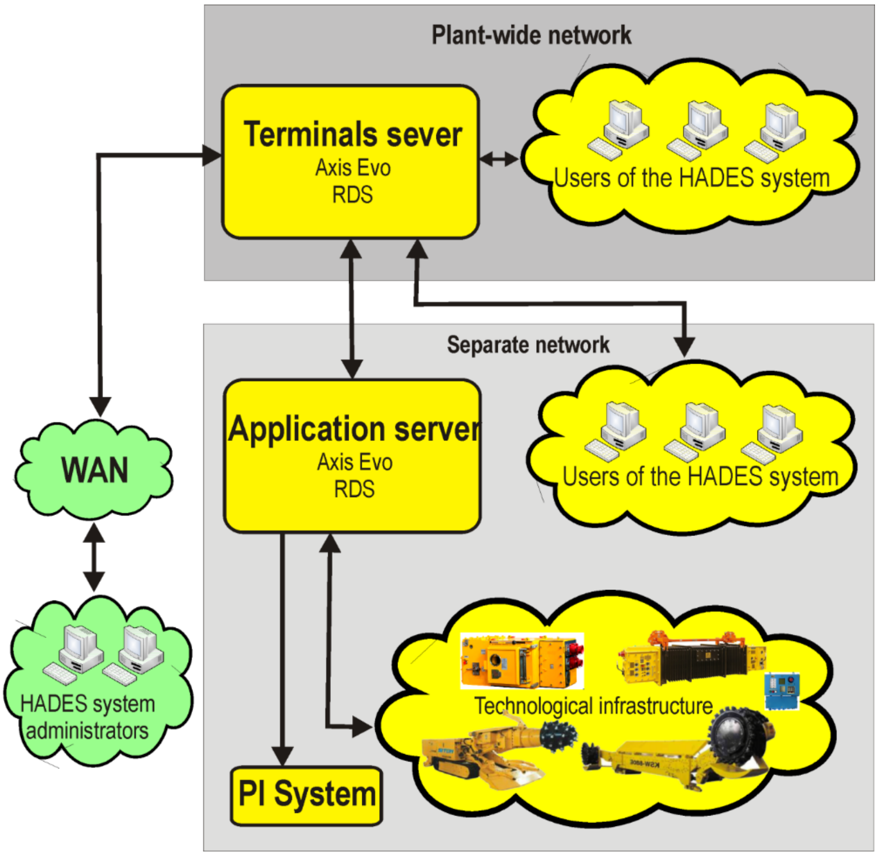

Fig. 8.35. HADES system architecture

Network communication is required to acquire data from devices that are sources of measurements, for further processing, archiving and making process data available for visualization and control. Control of automation actuators is possible via serial communication or via Ethernet networks using protocols implemented in the Hades system.

The acquisition of measurement data from technological devices is performed by software installed on the application server. Communication takes place over the LAN using industrial automation protocols such as OPC DA or UA, Modbus TCP/IP, S7 Communication or Profinet and other native protocols available in the Hades system. In the case of industrial automation protocols based on TCP/IP, the plant network or JSW WAN networks are used. In the case of serial communication, acquisition from end devices takes place via media converters or converters of appropriate protocols.

Data exchange between user stations and the application server is carried out indirectly by the RDS terminal server using the following protocols: HTTPS, Asix Network, RDP (RemoteApp) and ports 443, 6000, 47868 of the TCP/IP protocol. The flow of data between user stations in the company-wide network is filtered by a firewall. The Hades system has the ability to send data to the PI System in the Center for Advanced Data Analysis (CZAD) for further analysis of process data. Depending on the required exchange protocol, the application server configuration provides process data to PI System via the OPC UA or Modbus TCP/IP protocol.

Using the Hades system by a user requires authentication (confirmation of identity by entering a password associated with the account), and access to appropriate resources and the ability to perform certain operations requires authorization, i.e. checking the authorizations of the authenticated user. Authorization is related to assigning the appropriate role to the user. The following roles are defined in the system:

- observer – ability to preview application boards,
- operator - ability to preview application screens, alarms and locks, change descriptions,
- local administrator - ability to preview application screens, ability to control devices, clear alarms and locks, change descriptions, edit users and their permissions,
- administrator - ability to preview application boards, control devices, clear alarms and locks, change descriptions, edit users and their permissions, edit visualization boards and variable databases, add additional devices.

The Hades system performs daily, weekly and monthly backups of servers. Daily backups are made periodically at night and are stored for a period of two weeks. Weekly backups are made on the weekend and retained for a month. Monthly backups are made on the first weekend of the month and retained for a period of three months.

8.5. IT/OT infrastructure at JSW SA

The chapter was prepared on the basis of the document entitled "Policy of the Jastrzębska Spółka Węglowa SA in the field of architecture and technical infrastructure management of IT/OT systems" [Polityka, 2020]. By resolution of October 2020, this document was adopted and approved for use, among others, in all JSW mining plants.

Increasing the efficiency of the use of machines and equipment in mining processes and increasing the safety of underground mining crews resulted in the implementation of the following changes in the IT/OT infrastructure of JSW [Kwaśnica]:

- creation of CZAD within the structures of the Management Board Office,
- creation of Automation Departments (EDA) in the structures of all mines,
- development and implementation of the Central Technological Data Server (CSDT),
- expansion of systems for monitoring the operating parameters of machines and devices in the areas of network infrastructure and automation devices,
- standardization of solutions in IT/OT areas.

8.5.1. Architecture standards

The extensive integrated structure of the enterprise's IT system can be presented in the form of five levels [PN-EN 62264], as shown in Fig. 8.36.

Level 0 includes machines and devices implementing production processes. Level 1, called the object level, includes field equipment, actuators and measurement systems. Between levels 1 and 2 there is a communication network of object devices called SKOPO *(Communication Network of Devices of Object-Oriented Control or Measuring Systems)*.

Level 2A covers control systems using PLC programmable controllers *(Programmable Logic Controller)* and or distributed control system DCS (*Distributed Control System*). Systems should provide a communication interface using the following standards:

– Modbus RTU on RS485 links,

– Mobus TCP/IP or OPC on Ethernet links.

SKA *(Internal Automation Network)* between levels 2A and 2B.

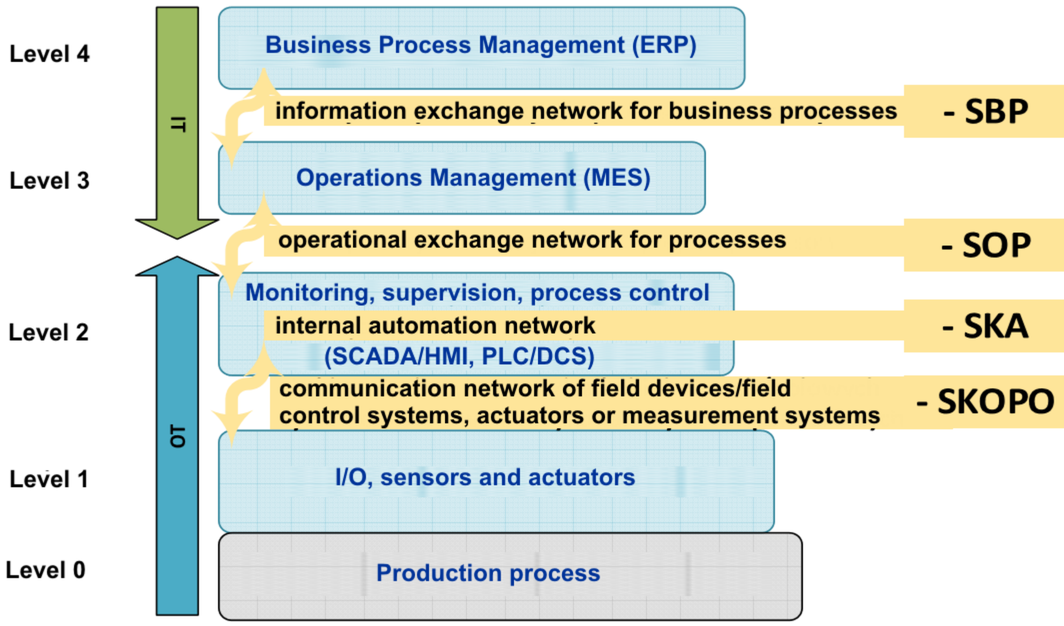

Fig. 8.36. Information exchange levels according to PN-EN 62264

Level 2B covers management and visualization of the technological process using SCADA systems. These systems support the following protocols:

– Modbus RTU and TCP,

– OPC (UA),

– TCP/IP.

Between levels 2 and 3, there is an information exchange network for SOP *(Standard Operating Procedure)* processes. Level 3, called the operational level (MES - *Manufacturing Execution System*), covers the management of production processes, monitoring of failures and downtime, maintaining machine operation, as well as organizing inspections and services. Between levels 3 and 4 there is an information exchange network for SBP *(Standard Business Process)*.

Level 4, called business level (ERP – *Enterprise Resource Planning)*, covers the business management of the enterprise. The data exchange model between individual layers for the JSW SA OT/IT system is shown in Fig. 8.37.

The OT layers (levels 0, 1, 2) contain machines and devices with controllers, data transmission systems and SCADA monitoring systems, as well as other data sources from the corporate network. Data from the OT layer is transferred to the operational management layer (level 3), the main element of which is the central technological data server CSDT. Data is transferred from local SCADA systems to the CSDT server using MODBUS or OPC (OPC UA) protocols. However, data transfer from other sources of the corporate network is carried out using the RDBMS system *(Relational DataBase Management System)* and UFL interfaces *(Universal File and Stream Loading)*.

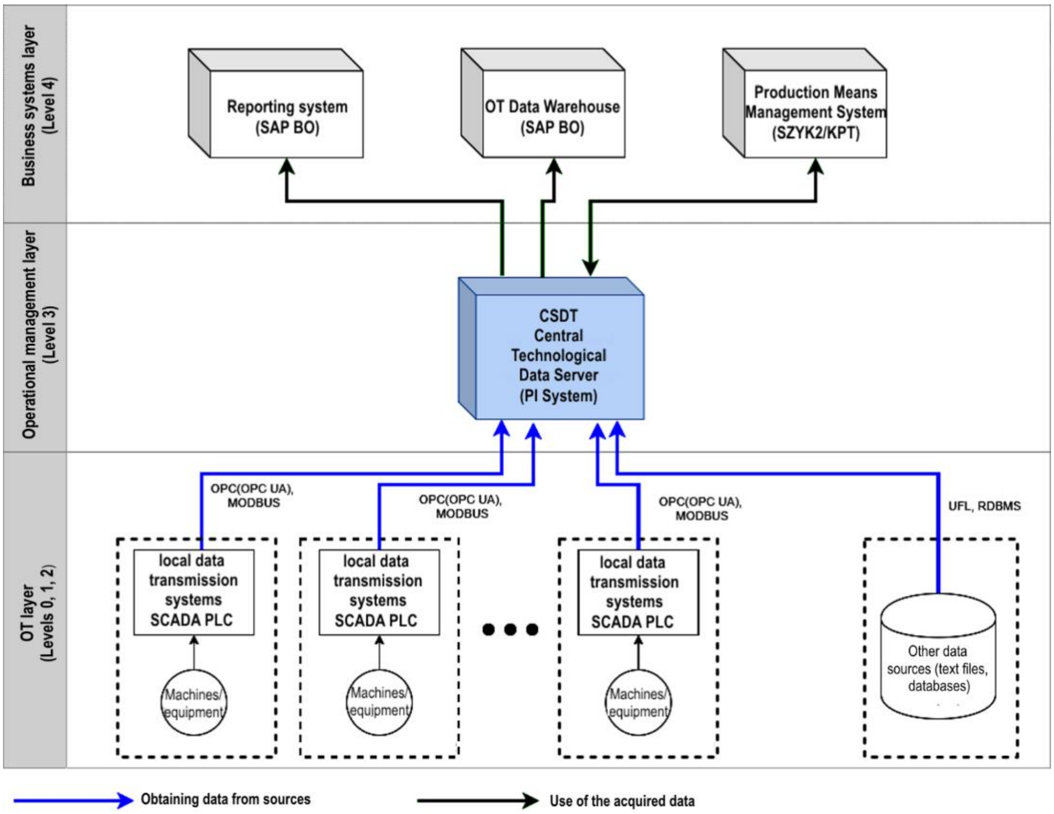

Fig. 8.37. Data exchange model in enterprise OT/IT systems

The business systems layer includes a reporting system (SAP BO), an OT data warehouse (SAP BO) and a production means management system (SZYK2/KTP).

PI System was chosen to implement CSDT, a product from OSIsoft that enables the processing of information from several hundred thousand recording devices in real time (PI DA). This is one of the historian – class systems that processes data in the form of time series that can be saved at any frequency set by the user and stored for any period of time, which distinguishes it from SCADA systems.

For the purpose of obtaining data from source systems, five types of interfaces were used, such as: OPC, OPC UA, MODBUS, RDBMS and UFL, which enable data buffering (PI Node Interface) in the event of connection loss. The basic elements of the CSDT architecture are shown in Fig. 8.38.

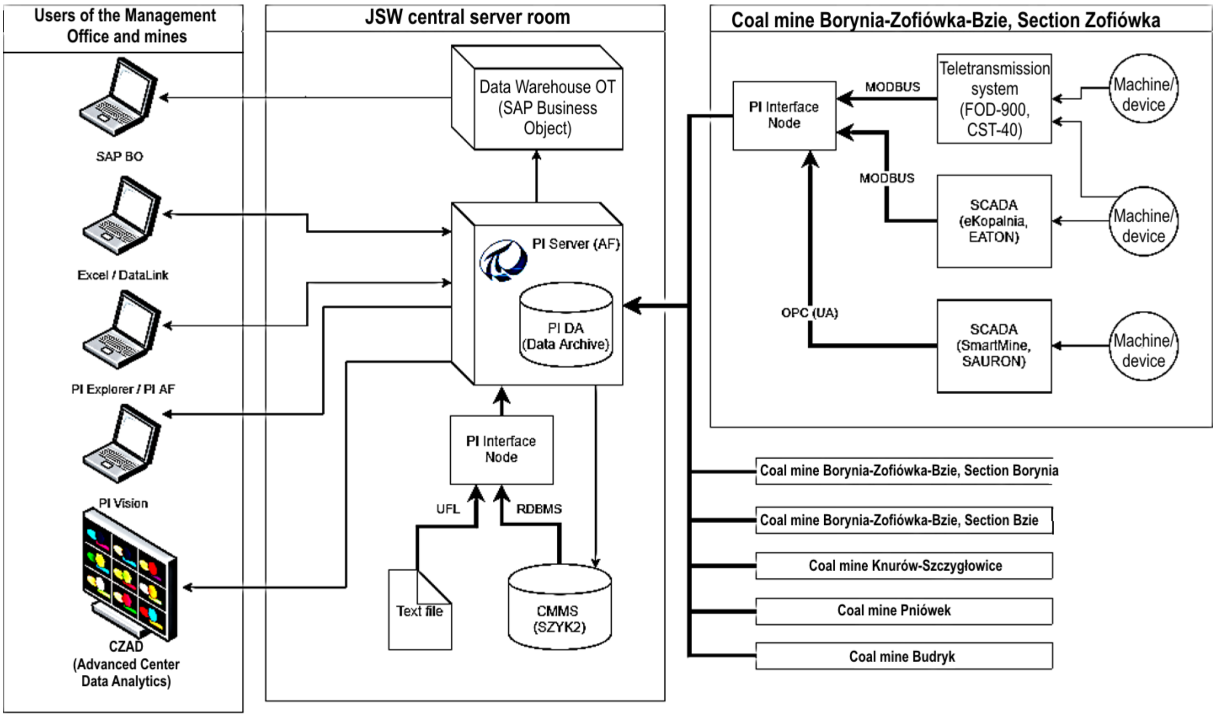

Fig. 8.38. Basic elements of CSDT architecture

8.5.2. OT infrastructure architecture – protocols

In the data transmission layer for end devices, mines use the following standards:

- Modbus RTU for RS-485 links,
- Modbus TCP within the TCP/IP packet network,
- OPC – wersja OPC UA.

When connecting the end device via an RS485 link, the Modbus RTU protocol with a bit rate of 9600 bps is used. The supplier of the end device always provides full specifications for the structure of the Modbus RTU protocol frame.

When connecting the end device via a TCP/IP network, the Modbus TCP protocol is used. Modbus TCP is independent of the physical layer and cooperates with the Ethernet TCP/IP protocol, using port 502 as standard. It also enables data transmission in Wi-Fi, GPRS or Bluetooth networks.

If the end device contains an OPC server, it can be directly connected to the Ethernet network, which enables data transport from the OPC server to SCADA or other systems (Fig. 8.39).

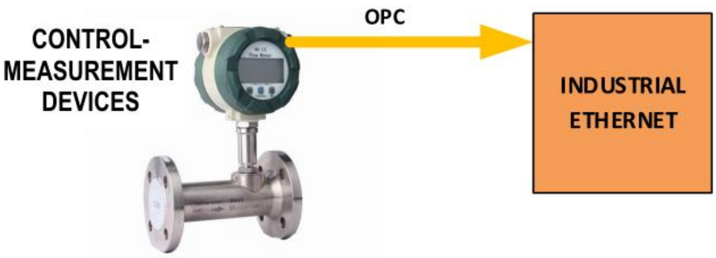

Fig. 8.39. Connecting the device with its own OPC server

If the end device does not contain an OPC server, there are two possible solutions:

– Variant A - use of the Modbus protocol frame, enabling data to be made available to the superior SCADA system with the OPC Server mechanism.
– Option B - use of a dedicated OPC server, constituting an interface between the end device and SCADA systems, in order to share data from the master software.

In variant A, the operating parameters of any machines and devices should be sent directly to the Ethernet network or through processing devices (data concentrator or serial port server). The Modbus protocol frame is then used, enabling data to be made available to the superior SCADA system with the OPC Server mechanism. An example solution is shown in Fig. 8.40.

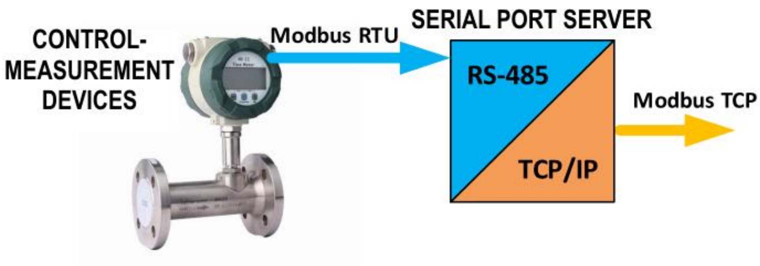

Fig. 8.40. Devices without their own OPC server - variant A

In variant B, the use of a dedicated OPC server was allowed, constituting an interface between the end device and SCADA systems in order to share data. This type of solution is recommended when:

– the superior software in the operational layer is dedicated to servicing a given object or process, and performs advanced computational, control or visualization functions (DCS, SoftPLC),
– devices constituting data sources in the process layer do not have the ability to share data in the OPC standard,
– devices constituting data sources are permanently integrated in hardware with the master system at the operational layer.

Software (delivered with the device), presenting data using encapsulation of own protocols by processing devices (data concentrator or serial port server), based on the existing network infrastructure, makes data available for other systems in the form of an OPC Server. An example solution is shown in Fig. 8.41.

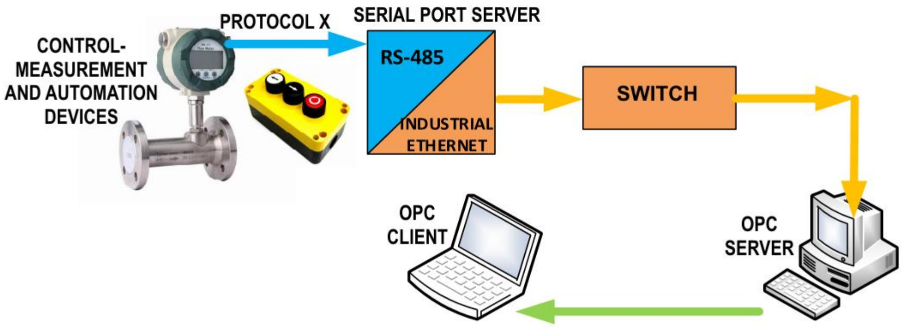

Fig. 8.41. Devices without their own OPC server - variant B

8.5.3. Formal requirements for IT/OT networks

The provisions of the Regulation of the Minister of Energy [RME, 2016] indicate the following systems requiring special protection (§ 750, point 1):

- plant-wide telephone and alarm communications,
- gasometry,
- location of employees,
- monitored rock burst threats.

Due to the fact that they are treated as critical to the operation of the mine, JSW SA has defined the following detailed requirements regarding security and access to data from these systems:

- operated in **the company's computer network** above-mentioned systems and other technological systems are placed in logically separated networks for reasons of security and compliance with applicable regulations,
- by using **a firewall,** outgoing and incoming traffic to the network of these systems is blocked, except for outgoing traffic to network elements located in the company network, which are intended to provide these systems with the ability to resolve DNS names and synchronize NTP time,
- by using **the firewall,** only traffic through a strictly defined protocol of the L4 layer of the ISO/OSI model, required to send data to the **access point** (e.g. Modbus TCP), is allowed,
- it is recommended that the servers of the secured systems (defined in paragraph 750 point 1) have a dedicated network interface (logical or physical) to which queries will be directed,
- access from **access points** to systems (defined in paragraph 750 point 1) is possible only after obtaining the consent of the Mining Plant Operations Manager, which precisely defines the system made available, the scope and purpose of making it available, as well as the **access point**, and:
  - access is provided only from designated **access points** and after logging in using a password (or a user and a password associated with it),
  - authorization, depending on the location of **the access point**, is carried out in **the firewall** for **access points** located within **the company's computer network.**

JSW SA as an entreprise mining hard coal is the so-called operator of a key service and therefore must meet the requirements of the Act on the National Cybersecurity System [KSC, 2018]. JSW IT Systems supervises OT systems to ensure compliance with this act.

Ensuring cybersecurity in JSW's IT/OT networks is very important due to the need for continuous operation of mine communication, alarm and gas measurement systems. The consequences of a successful cyber-attack are demonstrated by the incident in the Ostrava Karviná Mines (OKD). In December 2019, there was a hacker attack that paralyzed the underground telephone communication system, the methane and carbon monoxide concentration measurement system, drainage and ventilation monitoring, and consequently forced the evacuation of the crew and the cessation of mining [Danihelka, 2020].

8.6. Standardization of IT infrastructure

For the needs of better functioning of the IT network at JSW SA, principles of standardization of IT infrastructure have been developed. These include, among others, the following areas:

- server structure and availability of critical elements,
- physical interfaces,
- passive and active infrastructure,
- backbone network,
- separation and filtering of access to dedicated networks,
- access to time servers (NTP) and DNS servers,
- implementation of service access to separate computer networks from outside.

8.6.1. Standardization and availability of server infrastructure

Servers and virtual desktops are usually built as virtual resources. In special cases, it is allowed to implement solutions directly on physical machines. All equipment constituting the server infrastructure is dedicated exclusively to IT/OT purposes and is located in the local mine server room. Server resources are subject to regular backups.

The most important elements of IT/OT infrastructure should be built in high availability mode, which is achieved, among others, by:

- uninterruptible power supply using UPS power supplies and generators,
- use of double power supplies in devices, with the possibility of replacing a single power module while the device is operating (Hot-Swap),
- doubling of network elements,
- use of protocols supporting redundancy.

8.6.2. Standardization of infrastructure and physical interfaces

In the fiber optic infrastructure, single-mode fiber optic cables are used, mainly of the OS1 or OS2 category, containing at least 72 fibers in surface and shaft networks, 72, 36 or 16 fibers in trunk networks and 12, 8 or 4 fibers in branch networks. The backbone infrastructure at JSW SA is built in such a way that the most important transmission paths have alternative routes, enabling quick (<50 ms) switching of the transmission path from the damaged route to a backup route.

At JSW SA, the following standards are used in physical connection interfaces:

- interfaces in fiber optic distribution boxes - SC/APC connectors in single (simplex) and double (duplex) versions,
- interfaces in copper distribution frames: RJ-45 8P8C sockets, TIA/EIA-568-B connection standard, cabling category minimum cat.5e (for 100Mb/s bit rate),
- interfaces in active network devices: copper RJ45 8P8C (minimum 100Base-T), fiber optic LC/PC, sockets for installing optical modules: SFP, SFP+, QSFP, QSFP+,

– devices installed in potentially explosive atmospheres (including copper and/or optical connections) must have an explosion-proof structure (chapter 6).

8.6.3. Separation and filtering of access to dedicated networks

Each local infrastructure of the system operating in a dedicated network is separated using virtual VLANs and strictly defined IP subnets. Communication with separated networks is only possible through dedicated IT devices (router/firewall/L3 switch) using ACL rules specifying the method of traffic filtering. Therefore, computer devices operating in separate networks can configure the network card with classless IPv4 addressing along with defining static routing (network gateways - *default gateway*).

The JSW plant-wide networks include NTP servers that can directly synchronize time with reference servers operating in the public network, up to the STRATUM-2 or STRATUM-3 layer, as well as DNS servers. The dedicated network computers synchronize with the plant-wide NTP servers through the dedicated network firewall, as shown in Fig. 8.42.

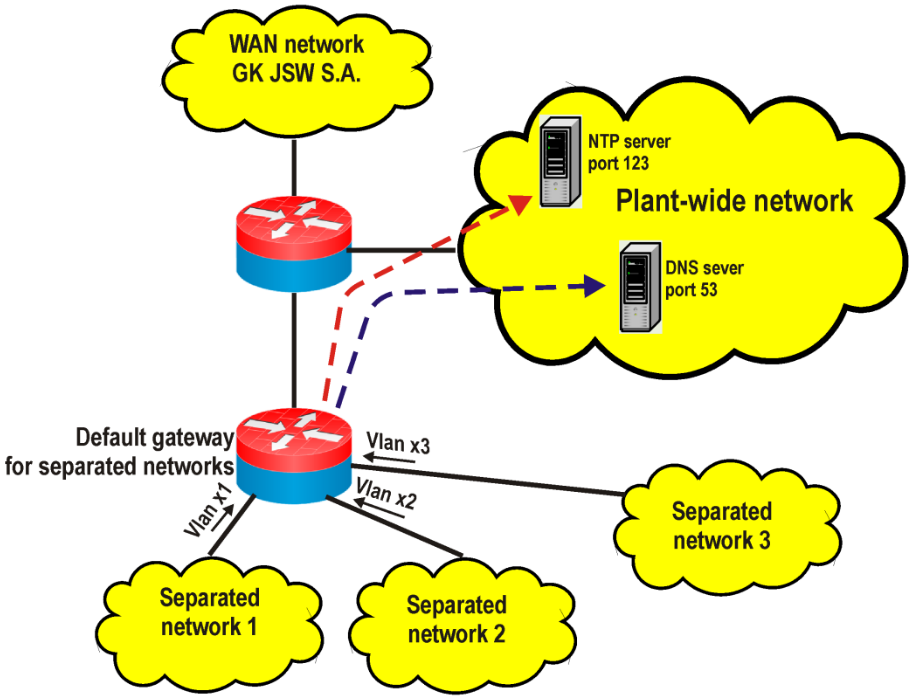

Fig. 8.42. Access to the time template server and DNS server from a separate network

8.6.4. Structure of JSW's IT/OT network

The structure of the surface part of the IT/OT network at JSW is shown in Fig. 8.43 [Jordan, 2019].

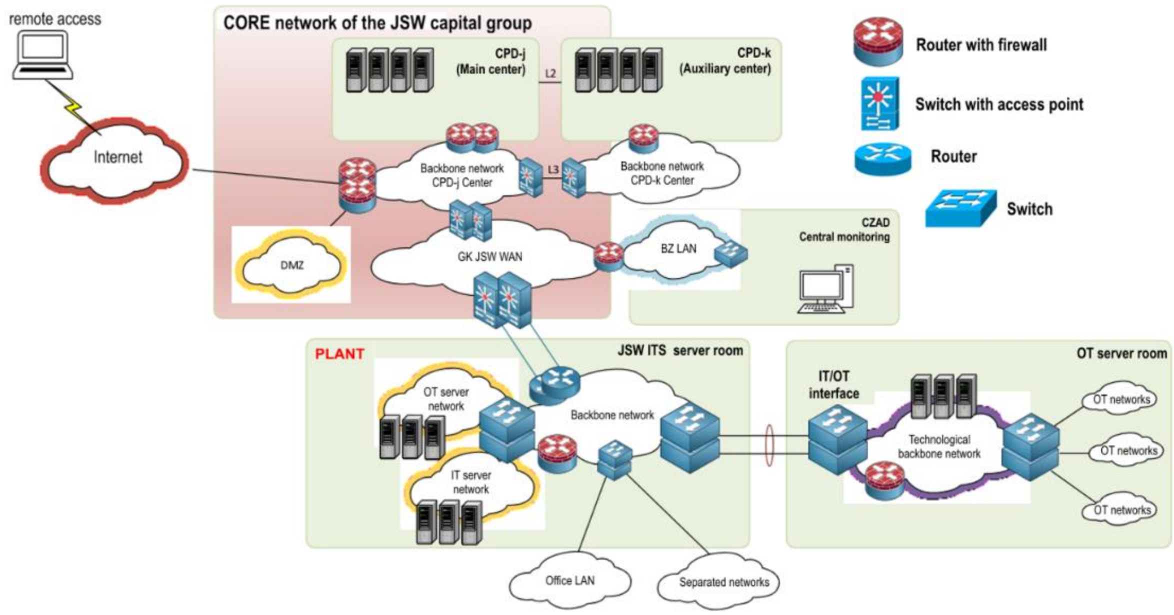

Fig. 8.43. Simplified structure of the IT network and the surface part of the JSW OT network

Each JSW SA plant has an OT server room and a JSW ITS server room with backbone networks and OT and IT servers. Office LANs and individual separate networks are connected to the JSW ITS server room backbone network. Backbone networks contain stacks of switches and routers with firewalls.

Individual JSW SA plants are connected to the JSW WAN network via switches with an access point. The backbone networks of two CPD data processing centers (main and auxiliary) and the LAN network of the Management Office are connected to the JSW WAN network. The **CZAD** network is connected to the LAN network of the Management Board Office, which serves, among other things, as an energy-mechanical control room at the level of JSW SA. The Internet network and the DMZ *(demilitarized zone)* are connected to the CPD backbone network through routers with firewalls. The structure of the surface and underground parts of the mine's OT network is shown in Fig. 8.44 [Jordan, 2019].

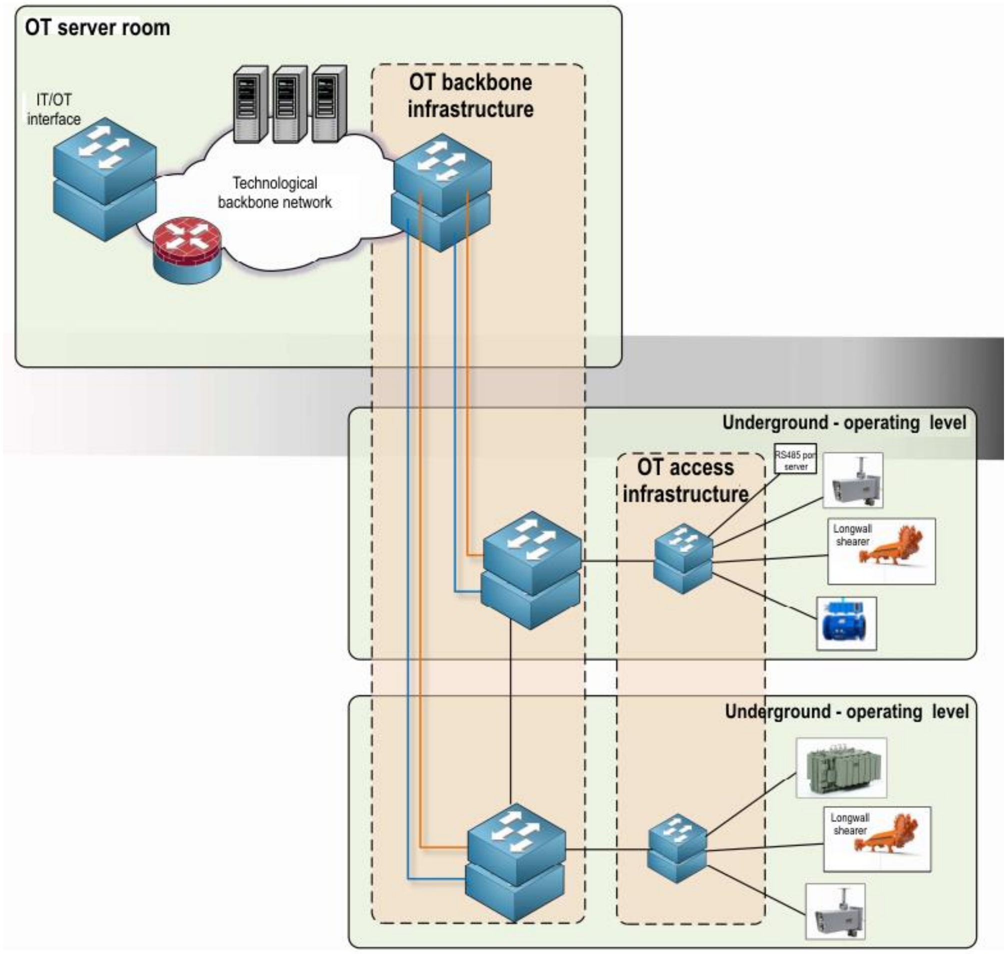

Fig. 8.44. Simplified diagram of the backbone part of the underground OT network in JSW mines

The surface part of this network includes the technological backbone network of the mine, the network installed in the shafts and nodes built in the pit bottom area. SWTx Backbone Transmission Nodes (chapter 6) developed at JSW SA are most often used in nodes. SWTx nodes include backbone and access switches connected in independent stacks. SWTx units do not have an explosion-proof structure and therefore can be installed in non-methane rooms or rooms with an explosion risk level of "a" (e.g. in main shaft switchboards).

An example of the downstream portion of an OT network is shown in Fig. 8.45. Data from the longwall shearer and the roadheader are transmitted via the auxiliary tire cable conductors to the compact station. Data from transformer stations, compact stations or contactor switches are transmitted to N-port serial port servers and further to SWTx nodes. Signals from IP cameras are also sent to SWTx nodes.

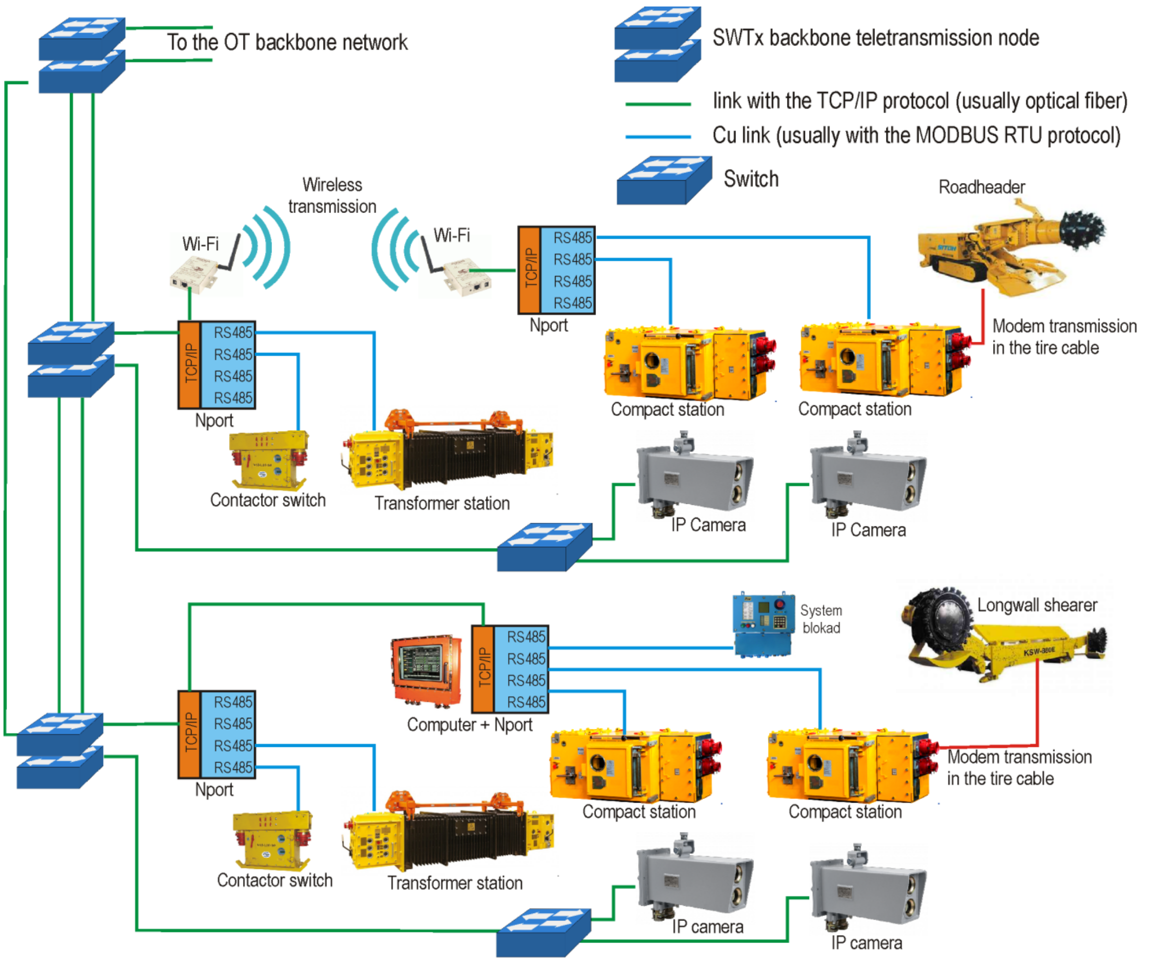

Fig. 8.45. Example of a block diagram of the underground part of the OT network in JSW SA mines

8.6.5. Defining parameters of machines and devices subject to monitoring

JSW SA has defined the minimum ranges of available parameters in the monitoring systems of machines, devices and transmission networks.

The minimum scope of available operating parameters of a longwall shearer (or plough) includes information available in the machine's local operator panel (HMI), in particular: operating states, including emergency states, media pressures and temperatures, load currents and power protection states, location of the shearer (plough) in the wall, speed and direction of travel (feed).

The minimum scope of the available operating parameters of the roadheader should also include information available in the local machine operator panel (HMI), such as: operating states, including emergency states, media pressures and temperatures, load currents and power protection states.

The equipment of the powered roof support control systems must have functionality enabling monitoring and signaling of operating states, in particular emergency states of the resistance system of the roof support section. In the powered casing, the following is monitored: pressure in individual section racks, in the supply and discharge mains at the beginning, middle and end of the wall. Monitoring of operating parameters of conveyors (scraper, belt) includes: operating states, acoustic and warning signals and technological interlocks.

Contactor switches supplying mining machines, as well as all underground distribution bays, send their operating states to the control room, including emergency states, load voltages and currents, and power protection states. Additionally, load currents for the secondary side and supply currents for the primary side are transmitted from the transformer stations.

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9. Monitoring the support and geometry of powered roof supports

Dariusz Jasiulek, Joanna Rogala-Rojek, Sławomir Bartoszek, Jerzy Jagoda, Jerzy Jura

9.1. Justification for monitoring resilience

One of the basic mining systems in hard coal mining is the longwall system. Mining in this system is carried out by a mechanized longwall system consisting of, among others, three main machines: a powered support (Fig. 9.1), a longwall shearer and a longwall conveyor.

Fig. 9.1. Powered support sections [BECKER]

The basic function of a powered longwall support is to protect other machines and crew working in the mining longwall [Rajwa, 2012, 2014; Szyguła, 2013]. Advance in the field of automation of mechanized longwall systems often did not include monitoring of the behavior of the roof and predicting uncontrolled phenomena resulting from the interaction of the rock mass with the mechanized support, such as rock falls in the face of the longwall or uncontrolled caving. The collapse of the roof within the mining wall and the uncontrolled behavior of the roof behind the line of the powered support constitute a real threat to human life and to the technical condition of machines.

Aspects related to the cooperation of the powered support with the rock mass, affecting the stability of the roof, have a significant impact on the efficiency and safety of operations in hard coal mines. The stability of the roof is influenced by, among others, the distance of the head path, hydraulic power supply and control, and the mining height. The chapter describes the experience of JSW SA and ITG KOMAG in the field of systems for monitoring the support and geometry of powered roof supports.

Falling of roof rocks in the case of longwalls generates danger for the crew and reduces the production efficiency of the longwall system. The roof movement in the longwall is a derivative of the stress of the rock mass created by its pressure and the support capacity of the lining. Appropriate roof management is crucial to ensure the stability of the longwall excavation and proper roof maintenance conditions, i.e. reducing the amount and volume of roof rockfall.

A number of factors influence the correct management of the ceiling, including:

- factors related to the mining and geological conditions of the region, such as the pressure of the rock mass increasing with increasing mining depth, longwall length, tectonic disturbances or mining edges of previously selected longwall plots in adjacent seams;
- selection of equipment for the longwall system (mechanized roof support, shearer or plow, longwall scraper conveyor), which allows for optimization of both the geometry and load-bearing capacity of the powered roof support sections and the span of the longwall workings;
- current organizational and technical factors such as: correct installation of the powered support by operators, maintaining the appropriate technical condition of power and control hydraulics for individual sections of the powered support, or ensuring adequate pressure in the supply main.

Optimal adaptation to geological conditions takes place at the stage of geological exploration of the deposit and production scheduling. In the mines belonging to JSW SA, mining and geological conditions are very diverse and considered difficult. The average mining depth is approximately 920 m, with the deepest longwalls at a depth of approximately 1,250 m. In order to optimally plan mining work schedules, MineScape and Deswik IT tools are used, which facilitate multi-variant analysis of work schedules based on a digital deposit model.

The selection of longwall equipment for a specific section of the longwall is based on the experience of the engineering staff and appropriate studies carried out by external research entities.

In the longwall, ongoing supervision over the technical condition of the powered roof support and the quality of the operators' work is carried out by the supervision services. However, due to the number of sections of powered supports and the constant impact of the rock mass on them, it is justified to implement systems that track their operating parameters. The systems used to monitor the operating resistance of powered roof supports sections measure the pressure in the under-piston part of the hydraulic rack. Due to their use, it is possible to obtain a continuous image of pressure changes on individual sections of the powered support.

It is known that inappropriate roof management or difficult geological conditions result in an increase in the number of accidents. In the Polish hard coal mining industry, according to data from the State Mining Office, in the period from 2017 to 2021, roof rockfall is responsible for approximately 20% of all accidents, including 33% of serious accidents and 16% of fatal accidents. These accidents result not only from the fall of roof rocks themselves, but also are caused by works related to securing the embankments.

9.2. Duty cycle of powered roof support

An important element in determining the correct operation of the powered roof support, its technical condition and correct operation is understanding its work cycle (from its expansion to its removal). The operator of the powered support section should expand it with an initial pressure that ensures proper cooperation between the support and the rock mass. In the case of JSW SA, the initial load-bearing capacity (Ps) for the vast majority of sections of powered supports built into the longwalls results from supplying them with a pressure of 25 MPa. The working support of the sections results from their construction, the internal diameters of the built-in stands and the settings on the relief valves protecting them against damage. In order to avoid damage resulting from too high pressures, the sections of the powered support are equipped with relief valves that start operating after reaching the working pressure (Pe). In the conditions of JSW SA, the working pressure always depends on the casing and the conditions in which it operates and ranges usually from 38 to 45 MPa.

The work cycle of the powered roof support is shown in Fig. 9.2 a). The section a-b corresponds to the expansion of the section by the operator, the section b-c corresponds to the increase in load due to the lifting and shifting of the adjacent section. Section c-d refers to the time of slow pressure increase in the powered support related to the impact of the rock mass. The accelerated pressure increase in section d-e results from the increased opening of the roof as a result of mining the coal bed by the shearer, e-f is a derivative of the stripping and shifting of the adjacent section, and section f-g is its stripping.

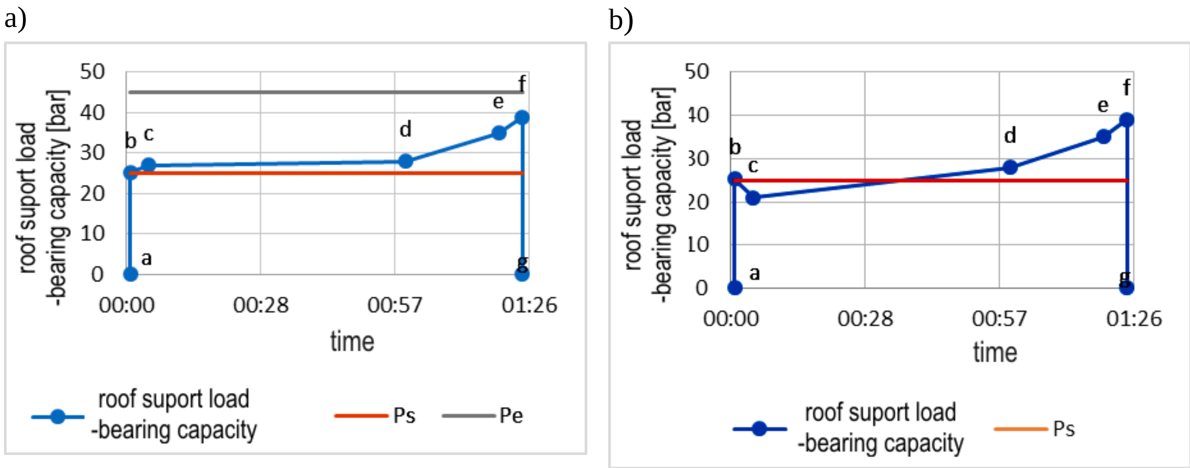

Fig. 9.2. The course of pressure changes during the work cycle: a) in the racks of the powered support, b) of the powered support in the conditions of JSW SA

In practice, in the conditions of JSW SA, one significant difference is visible in relation to the pressure course in the support stands presented in Fig. 9.2 a), which is shown in Fig. 9.2 b). In the operating conditions of the supports in the mines of JSW SA, a slightly different trend in the pressure course was observed in the operating cycle of the powered support. The section b-c, which corresponds to the reconstruction of the adjacent powered support in the conditions of JSW SA, is decreasing for most sections, which results from taking over part of the load by the adjacent section of the powered support. This entails some practical difficulties, because initially, the operators of sections equipped with systems for monitoring the support of the powered support, after expanding subsequent sections, had to go back to the previous support and reinstall it in order to obtain appropriate (correct) signaling. Currently, as a result of the accumulated experience and consultations with the Central Mining Institute - National Research Institute in Katowice (GIG), it has been decided that in the case of expansion of the support with appropriate initial support and then its drop to 5 MPa, too low pressure in the section stand is not signaled. This type of phenomenon is visible only in IT systems, as shown in Fig. 9.3. It presents the measurement results from two of the adjacent hydraulic racks of the powered support section. The time period on this chart is 3 minutes. The blue section was stripped first, rebuilt and expanded with a pressure of 25.5 MPa. After less than a minute, the adjacent (orange) section was also stripped, and rebuilt with initial pressure. During this period, the pressure in the blue rack decreased to approximately 22 MPa.

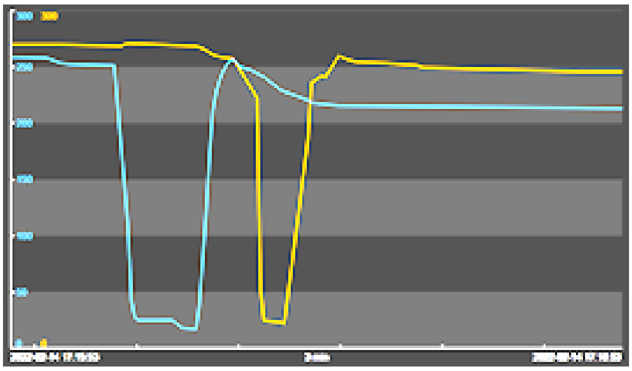

Fig. 9.3. Pressure behavior in adjacent powered supports during expansion

The last important issue related to the work cycle of powered roof supports is the operation of relief valves. As previously mentioned, it is intended to avoid possible damage to the hydraulic racks or housing structure. An example cycle of operation of a powered roof support, taking into account the operation of the release valve, is shown in Fig. 9.4.

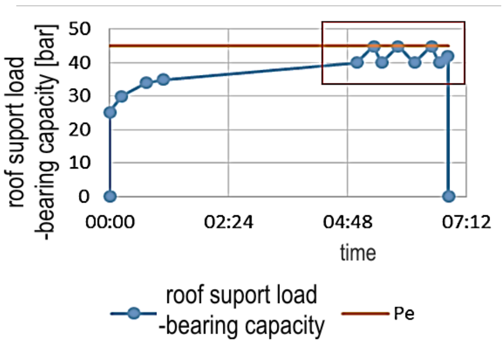

Fig. 9.4. Duty cycle of a powered roof support when the release valves are activated

The area marked with a red frame shows the course of the pressure in the roof suport when the relief valve is activated. In some cases, roof rocks do not undergo current collapse and hang behind sections of powered supports, causing increased operation of relief valves. This type of phenomenon is shown in Fig. 9.5.

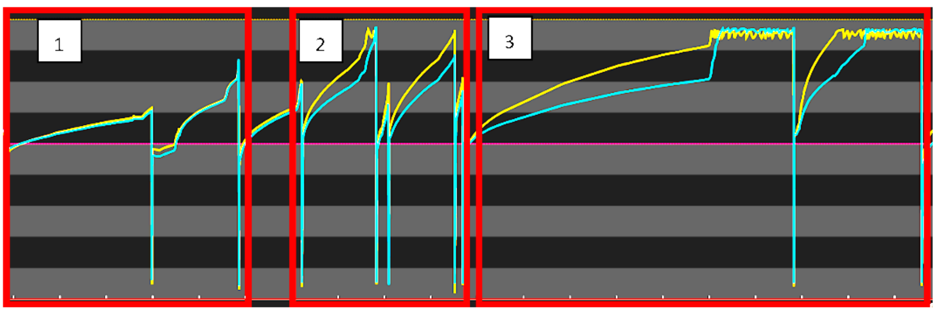

Fig. 9.5. Support cycles under rock mass pressure

In area 1 in this figure, a slow increase in pressure in the powered support is visible. In area 2, with subsequent loads, the rate of pressure increase in the powered support is higher than in area 1. In turn, in area 3, a rapid increase in pressure in the powered support to the working pressure and repeated activation of the relief valves is visible. Depending on the diameter of the stand, activation of the work valve results in its shortening by 1.5 mm to 5 mm. Repeated activation causes convergence of the longwall workings and may result in the fall of roof rocks. Therefore, in such situations, it is important to ensure regular longwall advance and/or use appropriate preventive measures to force a collapse behind the sections of powered supports (e.g. by hydrofracturing or torpedo firing).

The use of monitoring the work of roof support allows for [Krodkiewski, 2019]:

– detecting the lack of expansion of sections with the assumed initial support - indicating to the longwall staff the sections in which it is necessary to increase the pressure in the stands,
– control of hydraulic power parameters of the casing section, in particular too low pressure in the power supply line,
– identification of possibly leaking stands requiring intervention of plumbing services,
– identification of the operation efficiency of relief valves,
– monitoring the dynamics of the rock mass (warning against increased probability of tremors) based on:
  - current rate of pressure increase in the stands,
  - frequency of overflow valves release,
  - section operating time after reaching operational pressure.

9.3. Monitoring the load-bearing capacity of casing racks in longwall

Monitoring the load capacity of powered support racks requires the installation of pressure transducers in these racks. In existing solutions, pressure transmitters are battery-powered and transmit data at a frequency of up to 1 Hz.

In Fig. 9.6 a block diagram of the EH- PressCater casing support monitoring system is shown [Bazan, 2015]. This system includes the following types of devices:

– RPSI type pressure transmitters,
– IKT type transmission converter,
– underground computer type EH-O/06/06.xx with appropriate software.

RPSI type transducers measure pressures in the canopy stands and supports, as well as in the downstream and supply mains. The measurement results are transmitted via radio to the IKT transmission converter at a frequency of 1 Hz. RPSI transducers are powered by batteries with a capacity sufficient for 1 year of operation. Measurement results from the IKT converter are transmitted to the underground computer and then via DSL or fiber optic links to the server on the surface. The surface server is connected via an Ethernet switch to PC computer dispatching stations, which are equipped with EHPressCater Client data visualization software and ATLAS expert software. The stations work with a collective large-format LCD display.

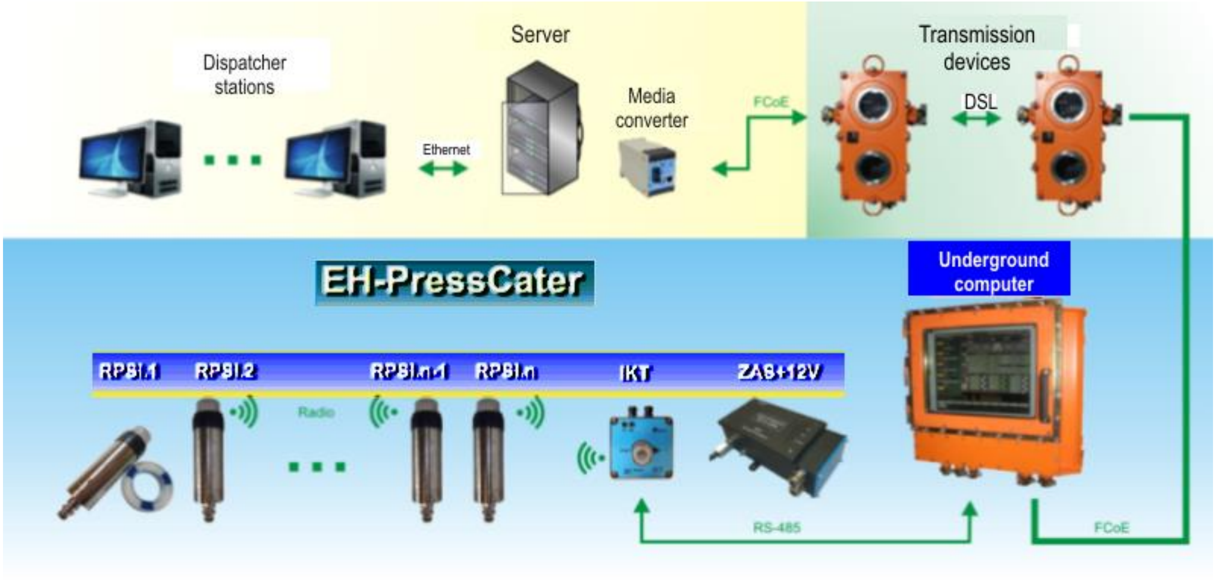

Fig. 9.6. Block diagram of the pressure monitoring system in the EH-PressCater housing racks

Fig. 9.7 shows a block diagram of the pressure monitoring system in the FAMAC RSPC casing racks [Tąpała, 2019]. The FAMAC RSPC system includes:

- ISP-2 pressure transducers,
- IPI-Tm transmission converter,
- MCP RSPC underground computer.

Data from the underground computer are transferred to the server and presented on visualization stations.

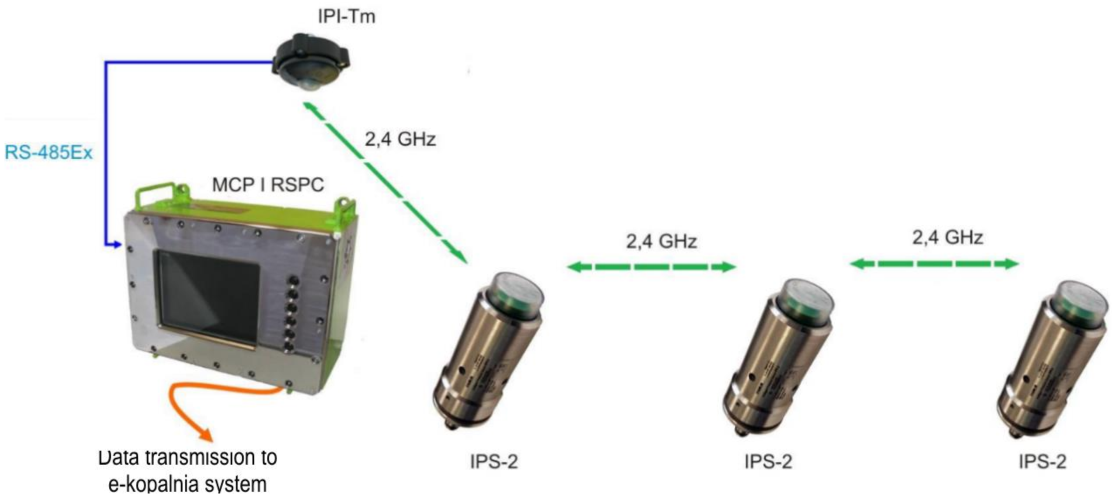

Fig. 9.7. Block diagram of the FAMAC RSPC casing rack pressure monitoring system

In Fig. 9.8 A block diagram of the pressure monitoring system in the DOH-DROPSY housing racks is shown. The DOH-DROPSY system includes [Szurgacz, 2020]:

- DROPSY-01 pressure transducers,
- DILER-01 transmission converter,

– underground computer.

Data from the underground computer is transferred to the server and presented on visualization stations.

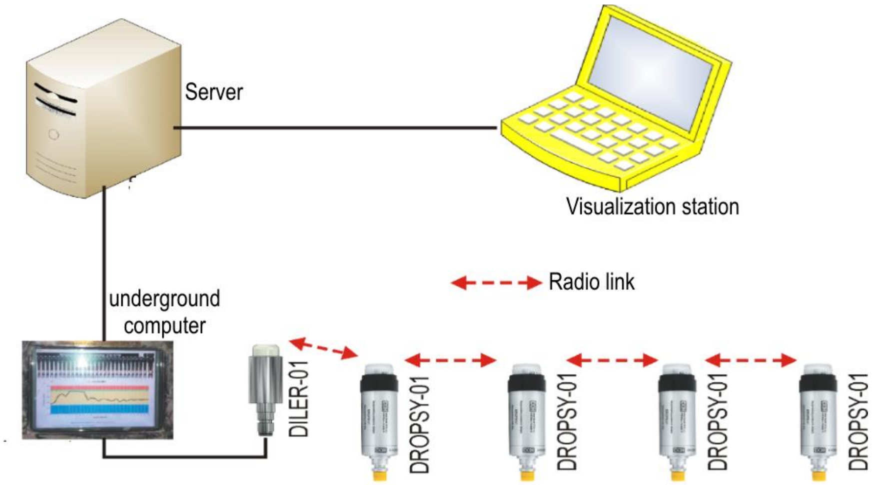

Fig. 9.8. Block diagram of the DOH-DROPSY casing load-bearing monitoring system

The current state of the support pressure can be presented on the underground computer screen (Fig. 9.9) [Szurgacz, 2020].

Fig. 9.9. View of the pressure visualization in the powered support racks on the DOH-DROPSY system underground computer

The current pressure distributions in the support racks can be presented at the visualization stations (Fig. 9.10, 9.11) [Cichy, 2019] along with the set limit values. A pressure map can be presented, i.e. the relationship between pressure (represented in an appropriate color) and the section number and time (Fig. 9.12). The pressure distribution as a function of time can also be presented in the form of a spatial diagram (rys. 9.13).

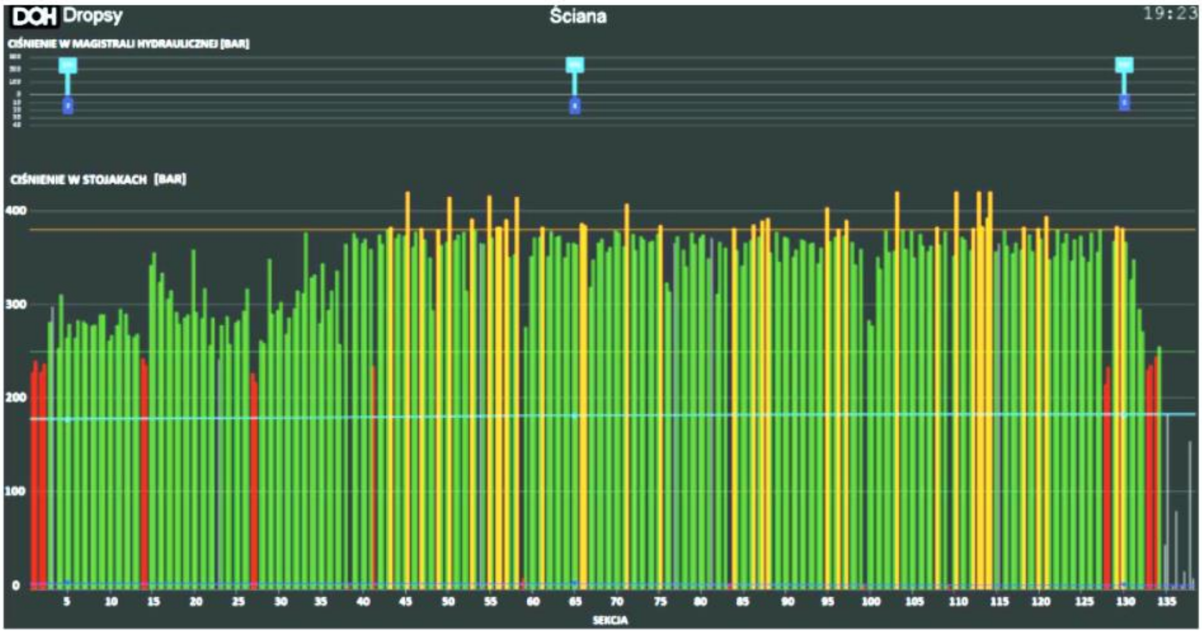

Fig. 9.10. Pressure distribution in the racks of the powered roof support - DOH-DROPSY system board

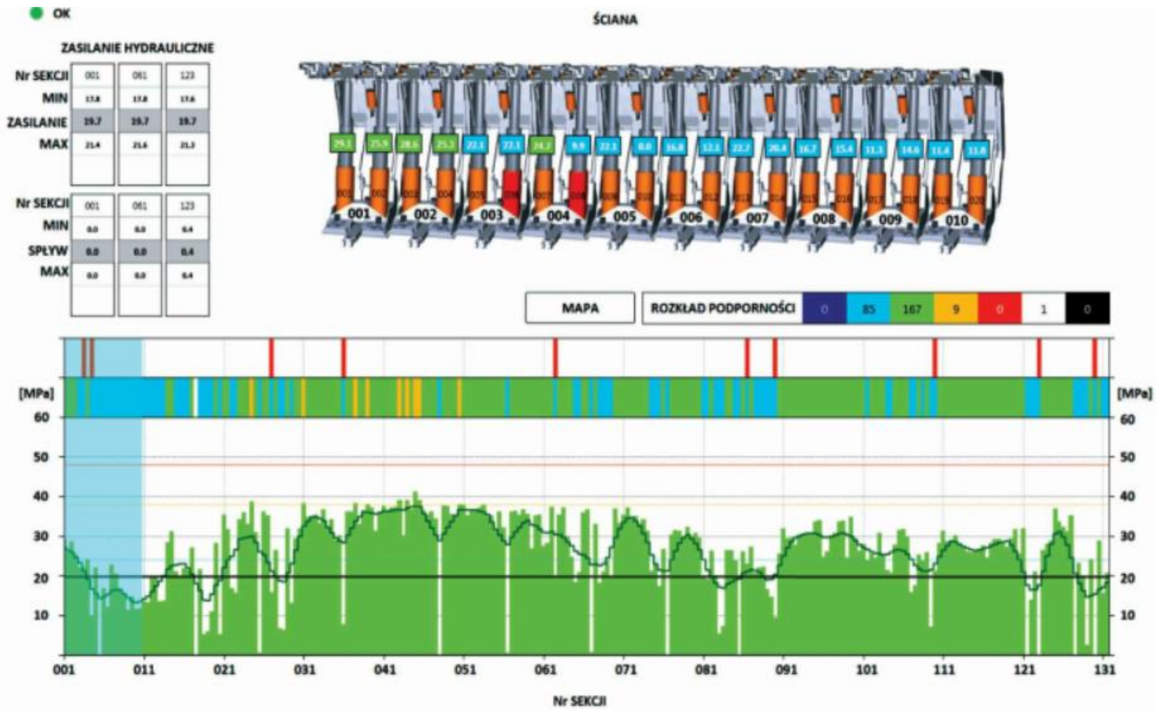

Fig. 9.11. Pressure distribution in the powered support racks - FAMAC RSPC system board

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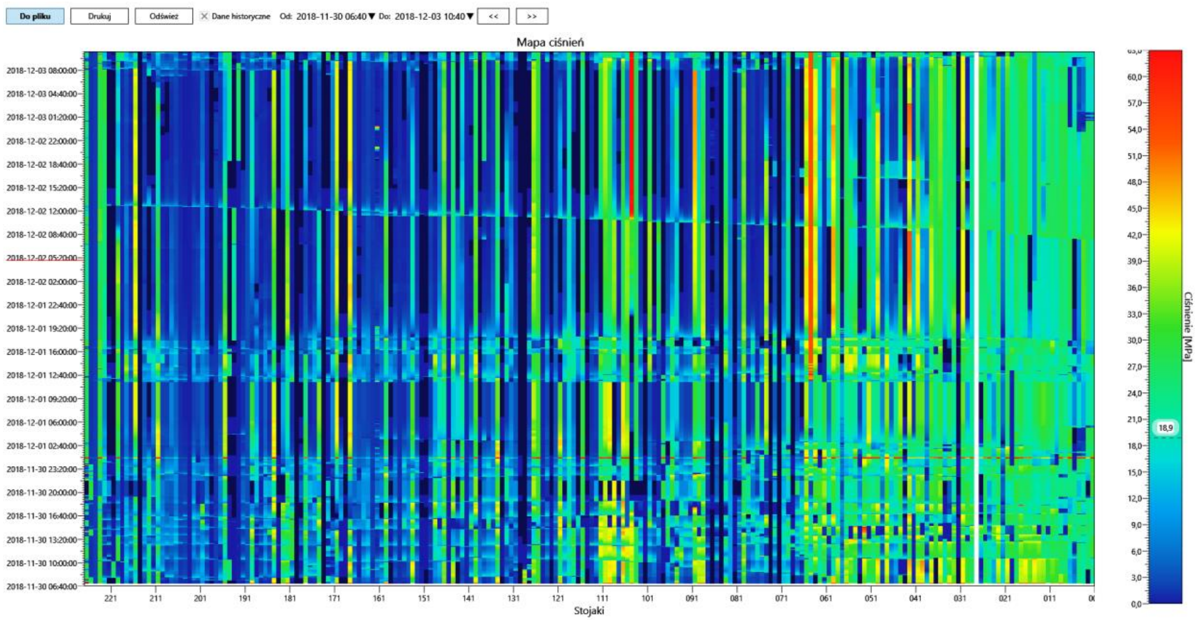

Fig. 9.12. Example of a pressure map – FAMAC RSPC system board [Krodkiewski 2019]

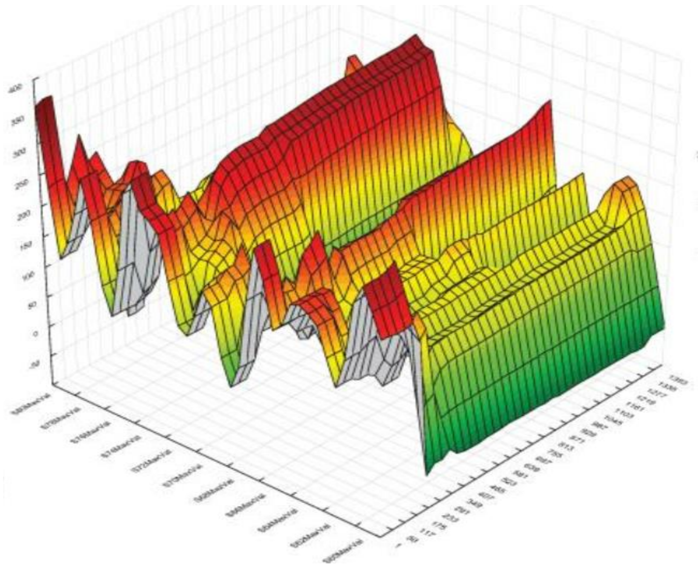

Fig. 9.13. Example of a spatial pressure graph in casing racks [Rajwa, 2014]

The use of casing support monitoring enables:

- detecting the lack of ceiling protection - indicating to the wall staff the sections where it is necessary to increase the pressure in the stands,
- control of hydraulic power parameters of the casing section,
- identification of racks of which failure has a particularly significant impact on the proper protection of the excavation roof,
- monitoring the dynamics of the rock mass (warning against increased probability of tremors) based on:
  - current rate of pressure increase in the stands,
  - operating frequency of overflow valves,

- section operating time after reaching working support.

In Fig. 9.14 [BECKER] presented pressure sensors included in the system for wireless monitoring of the load-bearing capacity of powered support sections, developed by Becker-Warkop as part of the PRASS III project.

Fig. 9.14. Wireless pressure sensors from Becker-Warkop

9.4. The process of implementing monitoring of the support capacity of powered roof supports at JSW SA

At JSW SA, the greatest experience in this area has been gained by the Knurów-Szczygłowice Mine Szczygłowice Section, which in 2013 (before being incorporated into the structures of JSW) operated longwall 7 in seam 408/1 equipped with this type of system.

In 2020, monitoring of the load-bearing capacity of the powered roof support was already launched in several longwalls at various JSW plants. Supervision employees reported the need to obtain additional functionalities from data from local monitoring systems. At the same time, during technical meetings and scientific conferences, GIG employees drew attention to the added value resulting from monitoring the powered roof support and in which longwalls this system should be installed first.

JSW SA has a PI System historian in which data generated by local systems for monitoring the load-bearing capacity of powered roof supports were well suited for aggregation and preparation of subsequent analyses. Therefore, specialized training in the basics of geomechanics, roof management and monitoring of the load-bearing capacity of the powered roof support was launched for the engineering and technical staff as well as employees working in mining longwalls. At the same time, the management board of JSW issued an order to equip new and modernized sections of the powered roof support with systems for monitoring the load-bearing capacity of the powered roof support.

Currently (early 2022), out of 22 active longwalls, 17 longwall systems are equipped with a support pressure monitoring system.

Due to the exchange of experience between users of powered roof support section monitoring systems and equipment suppliers, many faults in the first technical solutions were eliminated, and the current method of their installation makes the sensors clearly visible to the operator. In walls equipped with a monitoring system, depending on its dimensions, sensors are installed on the housing racks and, optionally, additional signaling devices are installed under the canopy. Sensors and indicators use light to indicate the current pressure status in the under-piston part of the stand:

– red light - below the initial support in the absence of expanding by the section technician to its level,
– green light – in the range from the initial load capacity to the nominal load capacity or up to 5 MPa below the initial load capacity, if the operator has expanded the section with initial load capacity.

Fig. 9.15 presents the preferred method of installing casing support sensors for walls up to 2.5 m thick, along with the method of securing the sensors.

Fig. 9 .15. The preferred method of installing sensors for walls up to 2.5 m thick

The installation method presented in the photo allows you to quickly identify the section in the event of any hydraulic problems. Pressure indication on subsequent sections is clearly visible. It allows you to quickly read the pressure value from the manometer, which is installed next to the sensor. Additionally, the clamp on the stand protects both the sensor and the pressure gauge against mechanical damage. This allows for good visibility of the wall expansion signal for operators and supervisors, as shown in Fig. 9.16.

Fig. 9.16. Visibility of support monitoring signals

Fig. 9.17. Installing sensors on a high wall

In the case of high walls, where it is possible for the excavated material to fall through the conveyor extensions, the sensors are mounted behind the racks (Fig. 9.17). In such a case, it is preferable to use signals under the canopy.

Additionally, local visualization systems present the current support status of individual sections in the longwall at computer workstations (e.g. as in Fig. 9.9), most often built on the apparatus train in the area of the longwall scraper conveyor. These systems are primarily used by supervisors for ongoing analysis of the support capacity of the support in mining longwalls.

9.5. An integrated method of reporting the load capacity of a powered roof support

JSW SA mines have systems for monitoring the load-bearing capacity of powered support sections from various manufacturers, and while from the point of view of one longwall it is not a problem to keep track of the local system on an ongoing basis, when a given mine has different monitoring systems, switching between them poses some difficulties. Data related to the load-bearing capacity of the powered roof support are not the only information that is interesting from the point of view of longwall guidance. Data from other systems, such as the location of the shearer in the wall or haulage operation, are also important for the overall picture of work quality and efficiency.

Data from all walls are sent to the Central Technological Data Server, which is the PI System. In terms of the support capacity of the powered support, algorithms have been developed to identify conditions that may indicate failures or signal potential problems related to the maintenance of roof rocks.

Automatically generated reports indicate where possible leaks may occur in the hydraulic system. Fig. 9.18 and 9.19 show the pressure profile in two sections in the stands, one of which is leaking.

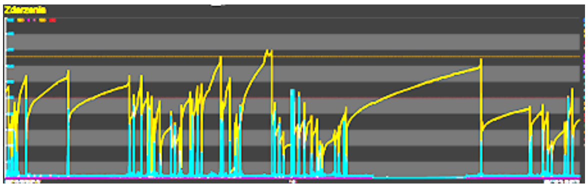

Fig. 9.18. Duty cycles of the powered roof support in the event of a leak in one of the racks

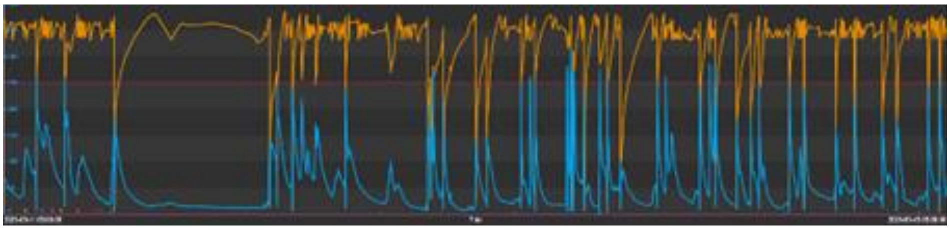

Fig. 9.19. Duty cycles of the powered roof support in the event of a leak in one of the racks while the release valves of the other one are operating at the same time

Fig. 9.18 shows the operating status of one rack that is operating in a typical manner (orange rack) and the other (blue rack) which is characterized by significant leakage. After expansion with initial support, the pressure drops rapidly to 1÷2 MPa.

However, in Fig. 9.19, in the blue rack, the pressure in the powered support drops slowly. At the same time, the second stand operates at the working pressure level and the operation of the relief valves is visible in virtually every work cycle. Despite the faster pressure drop in the blue stand of the first casing (Fig. 9.18), the absolute pressure difference between the pairs of stands is higher in the case of the casing from Fig. 9.19 and technical services should first verify its tightness. Another element that is identified in the reports is the number of operation of the relief valves. As already mentioned, their repeated activation may result in the fall of roof rocks - there are also cases shown in Fig. 9.19, where in the case of a leaky hydraulic stand, the second stand operates at the correct working pressure.

In addition, sections of the powered roof support are identified that are not expanded with proper initial support. There may be several reasons for this type of phenomenon. The first is the operators' inattention or negligence, in which case training and appropriate supervision over the quality of their work are necessary. The second is the lack of adequate pressure in the supply main. In this case, it is most often due to leaks in the pipelines supplying the emulsion to the wall or inappropriate selection of pumps. The third reason for not expanding the sections with the given initial support is their incorrect geometry in the mining longwall. In the event of a section inclination or the presence of voids in the roof of the working after the fall of roof rocks, first of all, efforts should be made to ensure (maintain) the appropriate geometry of the powered support section. The last element identified in daily reports is probable sensor damage.

Due to the important role of maintaining the appropriate pressure in the supply main, a histogram is created along with the pressure distribution function in the supply main. In the case of a large number of failures to provide proper expansion with initial pressure, it can be identified whether the problem is too low pressure in the supply main (Fig. 9.20).

Fig. 9.20. Histogram of the pressure in the supply main along with the distributor

The green line shows the initial load capacity for a given wall. The point of intersection of the green line with the distribution function shows what percentage of the time during the last 24 hours the pressure in the supply main was at a level that prevented the operators of the section from expanding with the given initial support.

An important element of integrated reporting of the support capacity of powered roof supports is the so-called "heatmap" (Fig. 9.21).

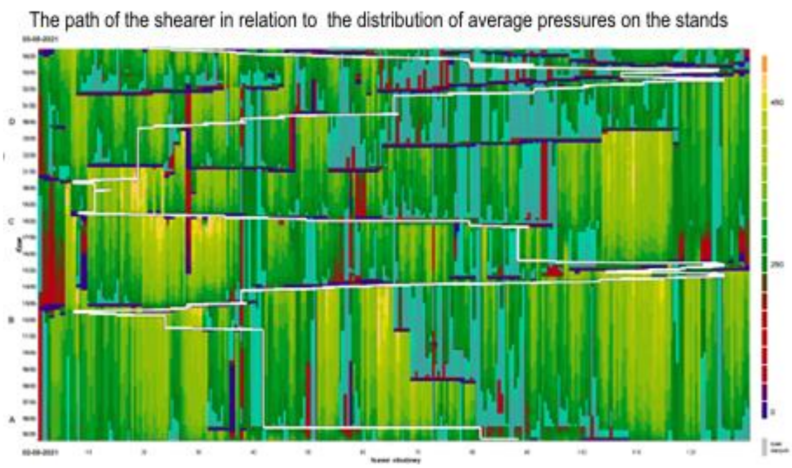

Fig. 9.21. " Heatmap " of pressure in the wall in 1 business day

It shows how pressure develops in individual sections (abscissa axis) as a function of time and work changes (ordinate axis). The dark blue color corresponds to the moment of reconstruction of the powered support section. The powered supports in which the pressure is too low are marked in red, the supports in which the pressure has dropped after their expansion to the set initial load-bearing capacity are marked in light blue. The casings in which the pressure is in the range from the initial load to the working load are marked in green, while the operation around the working pressure is marked in yellow. The white line marks the path of the combine in the wall.

Additionally, for each longwall, a chart is generated based on the Total Equipment Effectiveness (OEE) methodology, indicating the time of the most important statuses (Fig. 9.22), i.e. operation of the entire longwall system, operation of the shearer, operation of parts of the longwall system's machines, shutdowns up to and above 30 minutes, missing data and main train stops.

https://doi.org/10.32056/KOMAG/Monograph2024.2

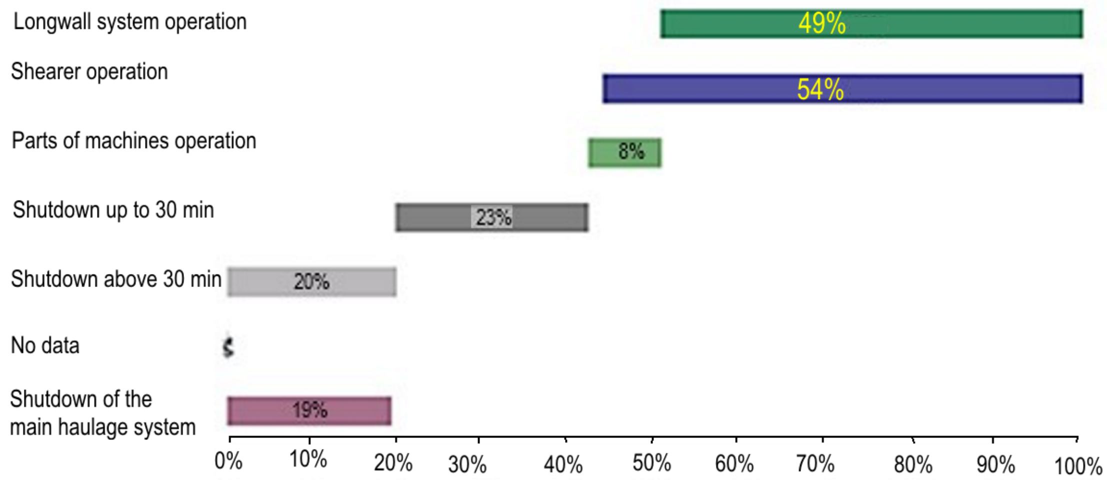

Fig. 9.22. Graph of the daily efficiency of the longwall system

An important element is the feedback from the mines regarding the repaired hydraulic faults, along with up-to-date commentary on issues related to the roof management on individual longwalls and potential hydraulic failures obtained from the analysis of pressure changes in individual sections. Once every two weeks, this information is forwarded by representatives of the rock burst and roof management departments to the management office of JSW SA and the mines' management. This information additionally identifies problems with different setting thresholds of the relief valves on the hydraulic racks of the powered roof support section (Fig. 9.23).

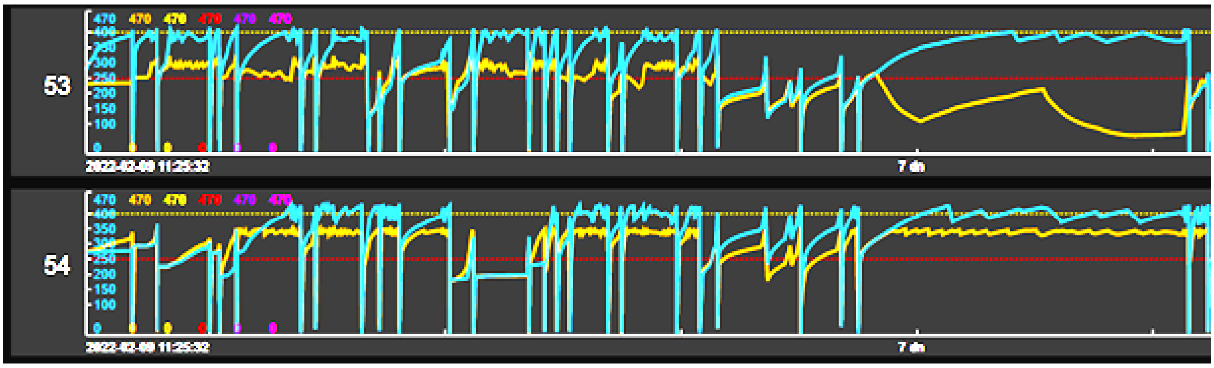

Fig. 9.23. Example of unequal settings when the relief valves are activated

In some longwalls, there are thick layers of high-strength sandstone in the roof, which causes large pressure increases. This phenomenon results in problems with the fall of roof rocks and high-energy tremors. Therefore, preventive works are being carried out to protect the wall against hanging roof rocks by torpedo shooting or hydrofracturing. Data from the powered support pressure monitoring system can be used to optimize this type of work in terms of the place and time of carrying out preventive activities.

JSW SA plans to further develop integrated reporting based on the following elements:

– time analysis: between the harvester pass and the reconstruction of the section,
– separation of identification of too low initial resistance due to low pressure in the supply

main and other reasons,

- automatic identification of uneven operation of relief valves,
- expansion of reporting with current data from the shearer, indicating problematic areas of the wall.

9.6. Effects of using powered roof support monitoring systems at JSW SA

As already mentioned, powered support pressure monitoring systems have been used at JSW SA for several years. However, a holistic approach to this topic including training, integrated reporting, exchange of experiences and feedback began at the end of 2020.

First of all, this system is used to identify potential hydraulic faults. Throughout 2021, a total of over 3,000 of them were fixed at walls equipped with monitoring systems. This allows for better cooperation between mining and hydraulic departments in mines. An important benefit obtained through the use of powered support pressure monitoring is the verification of the quality of supplies of power and control hydraulic elements to the reinforced walls at JSW SA. Using the powered support pressure monitoring system, technical services can quickly identify not fully functional stands and other hydraulic elements, which makes it easier and accelerates appropriate repairs, both warranty and post-warranty.

Previous experience in using the powered support pressure monitoring system shows that it is possible to identify potential stops related to roof rockfall. During the implementation, the load-bearing capacity of the walls where roof rockfall occurred was analyzed. In the area where roof rockfall occurred in the period preceding this phenomenon, the sections were not braced with the required initial support. Currently, employees of the rock burst departments constantly monitor the situation related to the load-bearing capacity of individual walls and are able to react appropriately if any disturbing indications occur.

An important factor in favor of the importance of the powered support pressure monitoring system in improving production efficiency is the share of longwall equipped with these systems in the total reported times of occurrence of technical problems related to the roof in the operated longwalls at JSW SA. In the period from January 2021 to January 2022, the share in the extraction of monitored walls was 56%, the share in occupancy was 48%, and the share in downtime related to roof problems was 30%. In other words, the longwalls that generate half of the occupancy at JSW SA generate 56% of the output and only 30% of the roof-related stoppages (Fig. 9.24). It should be noted that the monitored longwalls included the N-4 longwall in seam 505/1, which in the first quarter of 2021 ended its operation in extremely difficult roof conditions, and the C-5 longwall in seam 404/2, which in July and August passed through a network of faults parallel to the face of the wall. According to the mine services, it was one of the fastest passages through this type of disturbance.

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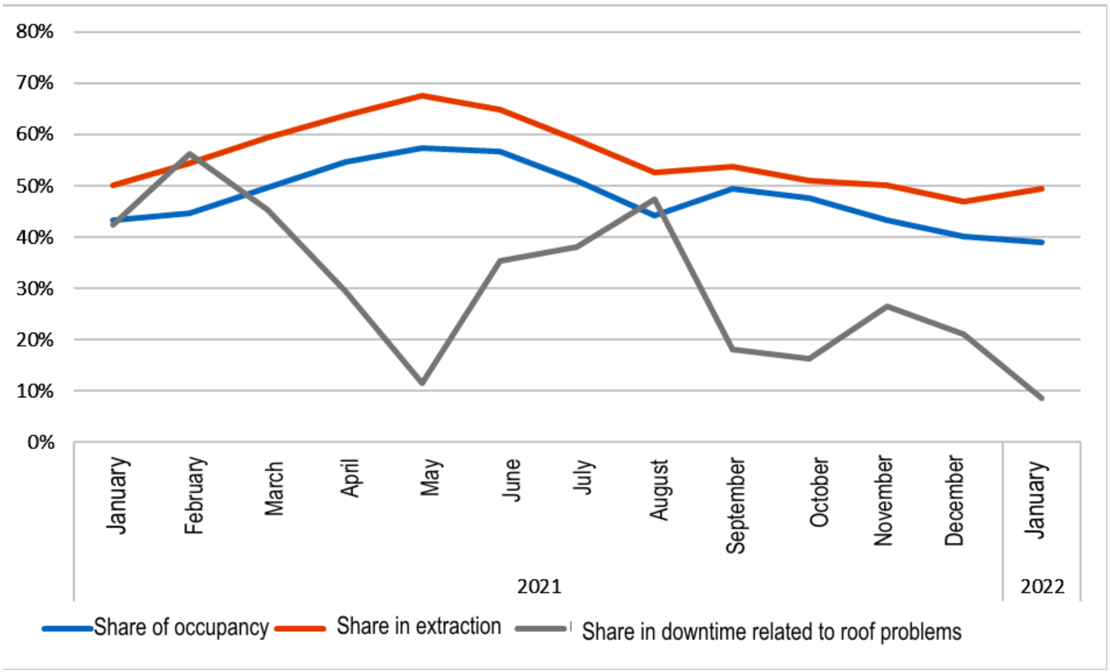

Fig. 9.24. The share of walls equipped with systems for monitoring the load-bearing capacity of powered roof supports in occupation, mining and stoppages related to the fall of roof rocks

The average downtime due to roof problems per shift was 18 minutes, while for the remaining shifts it was 38 minutes. This means that, on average, the stoppage is 20 minutes longer on unmonitored walls.

9.7. Monitoring the geometry of powered roof supports

As part of the PRASS III project, ITG KOMAG developed a system for monitoring the geometry of the SSMS type powered roof support section (*Shield Support Monitoring System*). The system includes section geometry measurement, frontal path measurement and a wireless transmission system. The SSMS system (Fig. 9.25) consists of the SSMS C central unit, the SSMS-I inclinometer and the SSMS-S frontal path kettle (*tip to face*).

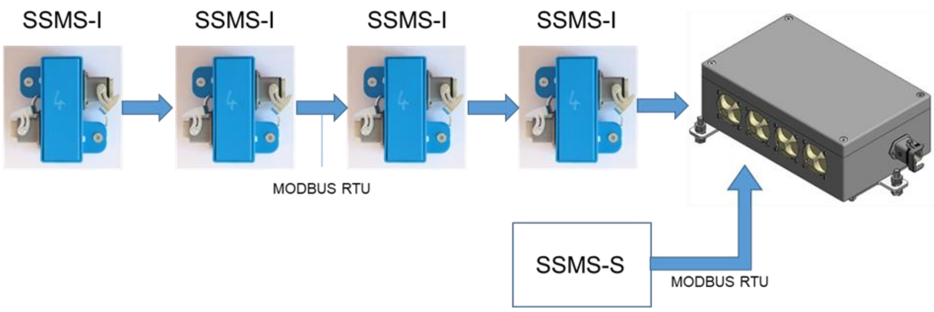

Fig. 9.25. Shield Support Monitoring System SSMS [KOMAG]

The main element of the SSMS system is the SSMS-C central unit (Fig. 9.26). Basic technical data of SSMS-C [KOMAG]:

- intrinsically safe design: I M1 Ex ia I M1 housing protection level IP 65,
- Wi-Fi radio technology: 17 dBm (50 mW),
- battery power: 4x3,6 V, 17Ah.

Fig. 9.26. SSMS-C central unit

The measuring element in the SSMS system is the SSMS-I two-axis inclinometer (Fig. 9.27). The inclinometer was designed based on assumptions made in earlier stages of the project. A prototype was made, certification tests were carried out and a certificate of compliance with the ATEX directive was obtained. The final result of the SSMS-I task is a prototype ready for installation on the powered support section in the mine.

Fig. 9.27. SSMS-I inclinometer

Front path measurement sensor (Fig. 9.28) is used to measure the distance between the canopy and the face of the wall. Its most important parts are a microcontroller managing the work, a communication interface, an internal power source and a measuring element.

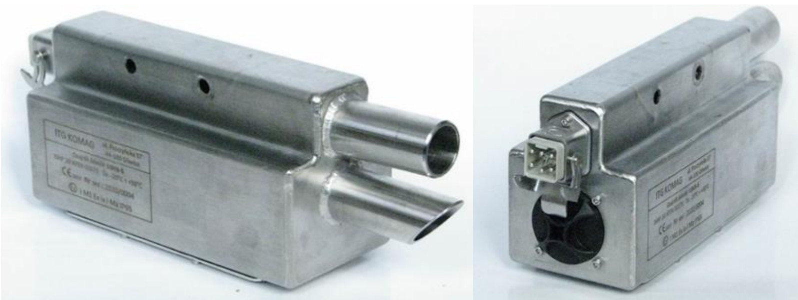

Fig. 9.28. SSMS-S frontal path measurement sensor

Selected basic parameters of the intrinsically safe SSMS-S sensor:

- MODBUS RTU serial communication;
- battery powered 2 x 3,6 V (17 Ah);
- ultrasonic transducers (transmitter + receiver) 32,5 kHz;

– operating range: 5 m.

9.8. Tests and operational tests of the SSMS system

As part of functional tests, one section of the powered housing in the fatigue testing station at the KOMAG research laboratory was equipped with inclinometers. The test stand enables tests with simulated deck inclination. Inclinometers were installed on a JZR 13/28 POZ motorized housing (Fig. 9.29).

Fig. 9.29. JZR 13/28 POZ housing

Inclinometers were installed using magnetic holders (Fig. 9.30).

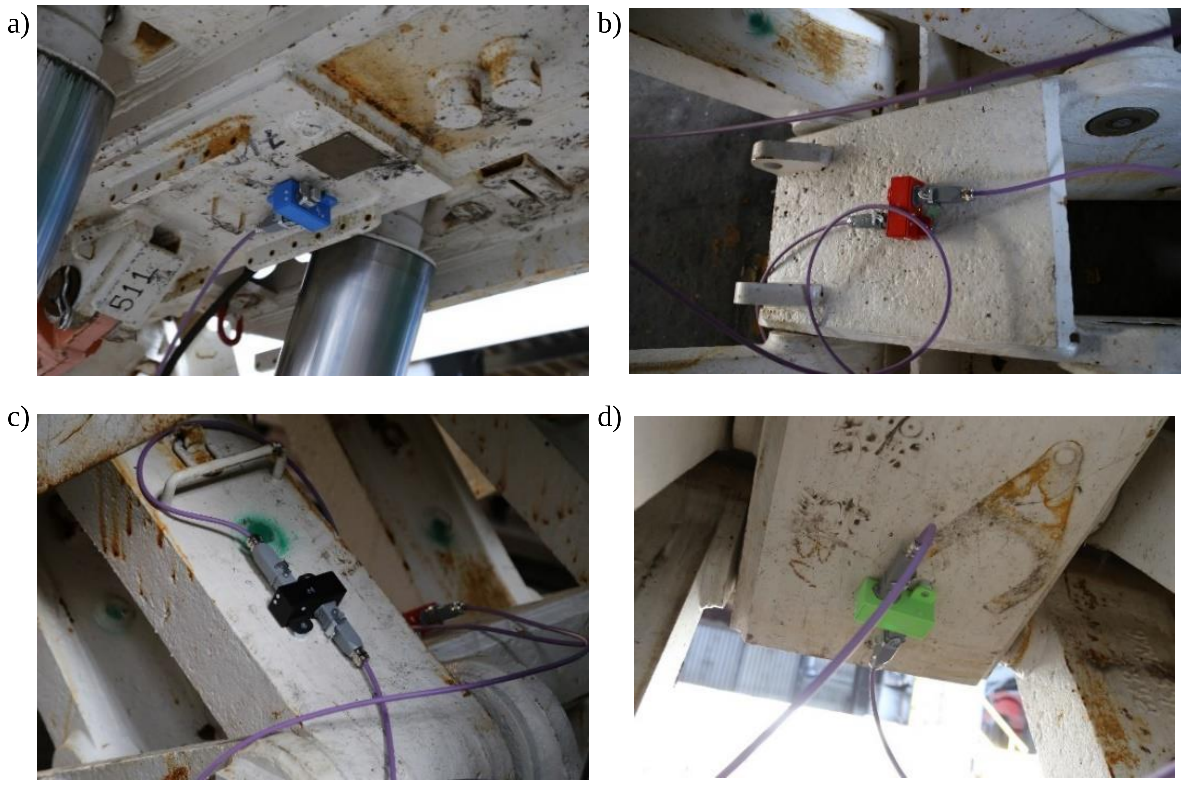

Fig. 9.30. Inclinometer installation locations: a) canopy, b) floor, c) lemiscate connector, d) cave-in protection

Fig. 9.31. Powered roof support section in a rotary station - SSMS system tests

The section equipped with inclinometers was tested in the hall and in the test stand (Fig. 9.31). During the tests, the correct operation of the developed system components was confirmed. Tests performed at various inclinations (Fig. 9.32) allowed for simulating the operation of the housing in real conditions. The result of laboratory functional tests, confirming the proper functioning of the system, allowed the SSMS system to be prepared for tests in the underground of the mining plant.

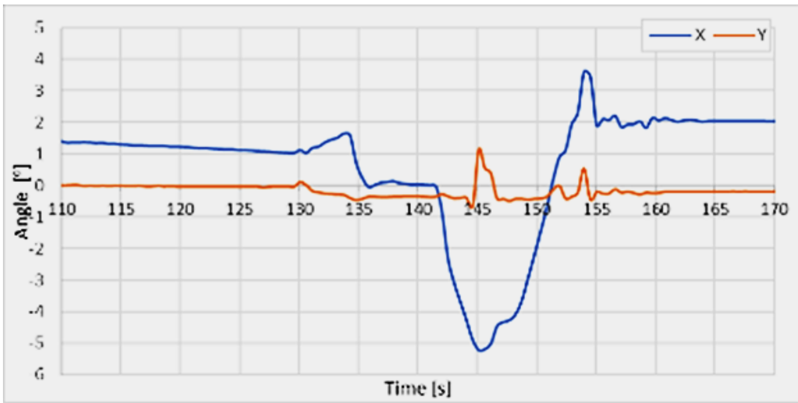

Fig. 9.32. Measurements of the canopy inclination angle during tests at the KOMAG ITG station

In the N7 wall of the Pniówek coal mine, elements of the SSMS system were installed in 10 sections. Measurements were conducted from July to November 2020. Before installing the system, it was adapted to the FAZOS 18/29 housing. Fig. 9.33 and 9.34 show the installed components of the SSMS system on the powered support section.

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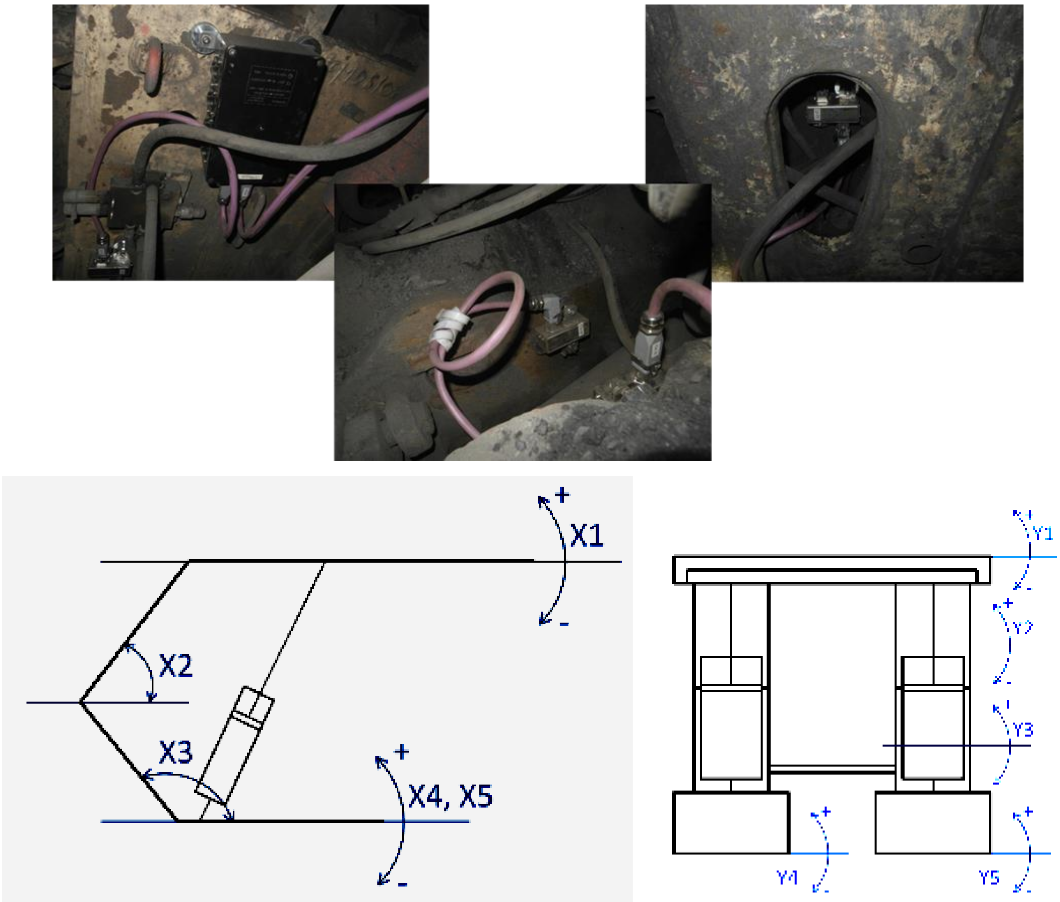

Fig. 9.33. Installation of the SSMS system in the Pniówek coal mine – SSMS-C and SSMS-I and the importance of angles

Fig. 9.34. Installation of the SSMS system in the Pniówek coal mine – SSMS-S

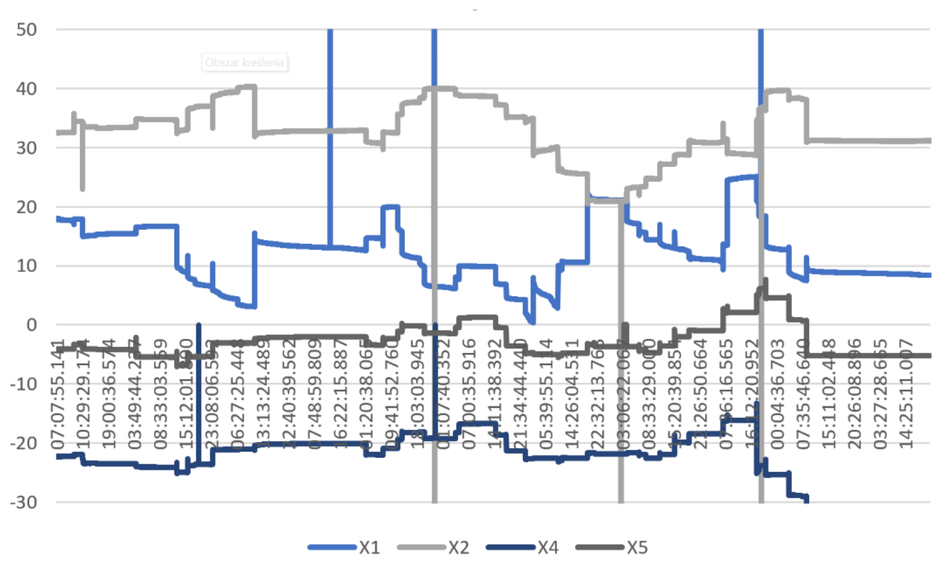

Fig. 9.35. Time course of angles on section No. 1 in the period from 30/07/2020 to 09/08/2020

Fig. 9.35 presents sample data flow - angles of inclination of individual section elements - recorded by SSMS-I sensors. The time course of the frontal path recorded by the SSMS-S sensor is shown in Fig. 9.36. This chart shows the distance of the end of the canopy from the face of the wall, expressed in cm.

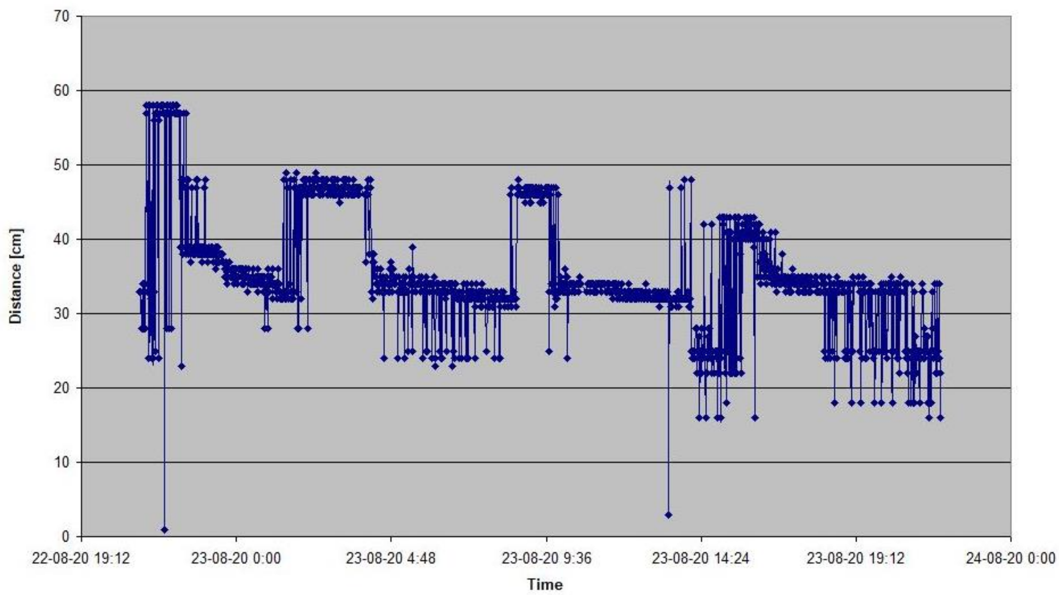

Fig. 9.36. Measurement of the frontal path of the N7 wall of the Pniówek Coal Mine

The SSMS system was also tested in the CZ-2 longwall at the Budryk Coal Mine. The housing is equipped with special mounting brackets. Inclinometers are mounted with screw connections. The housing manufacturer - Becker Warkop - adapted 10 sections for mounting the geometry measurement system. It was assumed that the SSMS system would operate in a wireless network with pressure sensors also developed by Becker-Warkop. Ultimately, the data will be transmitted to the mine surface via the fiber optic infrastructure of the Budryk Mine. Fig. 9.37 shows the system components installed in the CZ-2 wall of the Budryk Mine.

Fig. 9.37. SSMS components installed in the wall of CZ-2 Budryk Mine

During the tests, information obtained from sensors measuring the distance of the frontal path was combined with information about the support of the housing (Fig. 9.38).

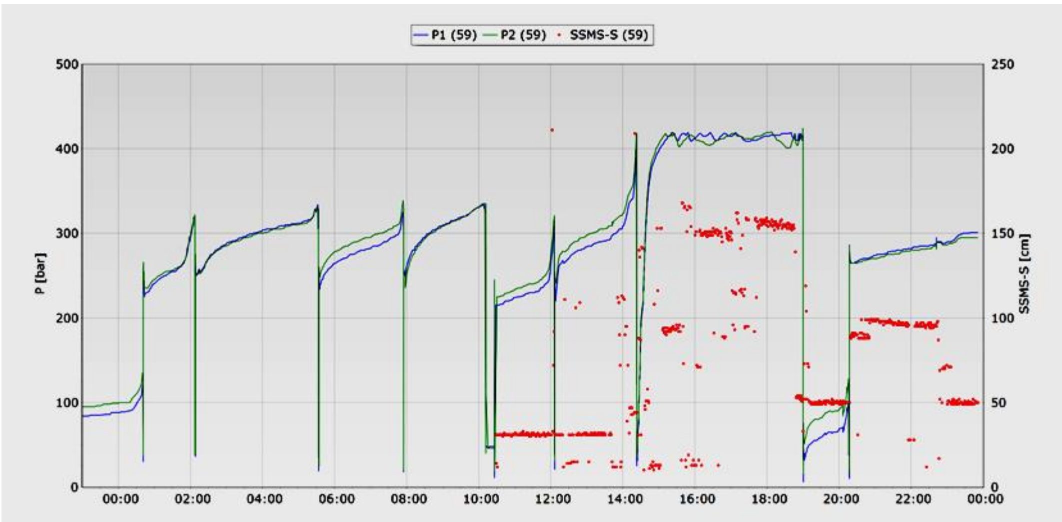

Fig. 9.38. Example test results in the CZ-2 Budryk Mine longwall: pressure and SSMS-S path

9.9. Summary

The effects achieved so far in the process of improving the roof management in the JSW longwalls are satisfactory. It should be kept in mind that simply having monitoring systems without actively using them, analyzing and drawing conclusions from the data obtained from them is pointless. Further development of the system operating at JSW related to the management of stoppages in longwall faces is planned. Additionally, measuring the section geometry on selected walls in order to more quickly identify threats on particularly problematic walls is considered. The last element, which has already been mentioned, is the further development of an integrated system for reporting the efficiency of longwall work.

10. Gasometric systems

Artur Dylong, Kazimierz Miśkiewicz

10.1. Introduction

At the beginning of the 1960s, the first mines were opened in the then Rybnik Coal District (1960 Coal Mine 1 Maja, 1962 Coal Mine Jastrzębie, 1965 Coal Mine Moszczenica) exploiting seams with high methane content, which resulted in a sudden increase in the risk of explosion in these mines. In the initial period, due to the huge increase in the methane threat level, the use of electricity was limited. Various pneumatically powered machines and devices were used (e.g. locomotives, drilling rigs, mine lighting, methane meters, central shooting, etc.). The desire to increase the mechanization of the mining process was associated with the need to introduce electric drives, the use of which depended, among other things, on the use of methanometric systems (called **automatic methanometry**), which automatically turns off the power supply to endangered areas in the event of methane concentrations above the permissible level (2% or less in some situations).

The first solutions of the automatic methanometry were introduced to Polish mines in the mid-1960s by the regulation of the Minister of Mining and Energy of March 14, 1967, which allowed the introduction of electrical devices on a large scale to methane mines, provided that automatic local methanometric protections are used in workings ventilated with circulating air, based on switch-off and recording methane meters. Then, Polish-made methane meters with a very innovative design, the BARBARA-ROW type with a WSA-3 switch-off device, were used. This methane meter was powered by a local generator driven by a turbine powered by compressed air. This air simultaneously ventilated the methane meter housing. It was the first analog automatic methanometry system [Klakus, 1985; Cierpisz, 2007].

In the 1970s (1975), the French CTT-63/40U system was introduced into the Polish mining industry, which enabled measurement of methane concentration and air velocity (with cyclical measurement every 4 minutes), as well as automatic power shutdown. It is a system with a telemetry central located in the control room. In the 1980s, systems allowing carbon monoxide measurement (ASCO, SATW meters) and smoke detection were introduced. The construction of the so-called early fire detection systems SWWP – 1981.

At the same time, construction work was also started on the possibility of integrating all systems for measuring mine atmosphere parameters. The first solution of this type was the SMP system (Methane and Fire System) by EMAG (1989). This type of integration also occurs in the Venturon system, introduced to the Polish mining industry in 1992. The introduction of intrinsically safe PLC controllers to underground gasometric systems (initiated in the Venturon system) introduced additional functional possibilities of gasometric systems, such as the transmission of binary signals or the possibility of building extensive interlock and shutdown systems. Initially (1970s), a four-minute measurement cycle of gasometric systems seemed to be sufficient. However, the detection of such threats as methane outbursts resulted in the need to shorten the measurement cycle of methane meters. The so-called "fast methanometry" with a measurement cycle every 60 s and (at the beginning of the 21st century) the so-called “continuous methanometry”.

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Detailed description of all gasometric systems in Polish mines, along with tabular summaries of:

- gasometric systems used in Polish mines,
- cyclic and continuous methane meters,
- meters for measuring ventilation parameters (continuous and cyclical),
- transducers for gasometric sensors, underground stations and switching devices in gasometric systems,

is presented in the literature [Cierpisz, 2007].

Intensive exploitation of seams in areas with a high level of methane hazard (category II, II, IV) and the demand for modern methane measurement systems resulted not only in the development of the CTT-63/40U system, but above all in the development of national digital solutions for gasometric systems. Compared to the first designs of methane measurement systems, the following modifications have been introduced in the new national solutions:

- reduced the energy consumption of methane meters,
- reduced the repetition time (in some cases to 1 s),
- used digital protocols for transmitting signals from sensors,
- developed a digital meter and other ventilation parameters (concentration of O_2, CO, CO_2, poisonous gases, pressure, temperature, humidity, pressure difference), which resulted in the expansion functionality of the gasometric system to also monitor fire hazard,
- added transferring data from gasometric systems to visualization systems,
- digital underground stations were built, enabling the implementation of extensive power supply shutdown systems for electrical devices in hazardous areas.

Gasometric systems currently used in Polish mines are supplied by four domestic producers [Cierpisz, 2007]:

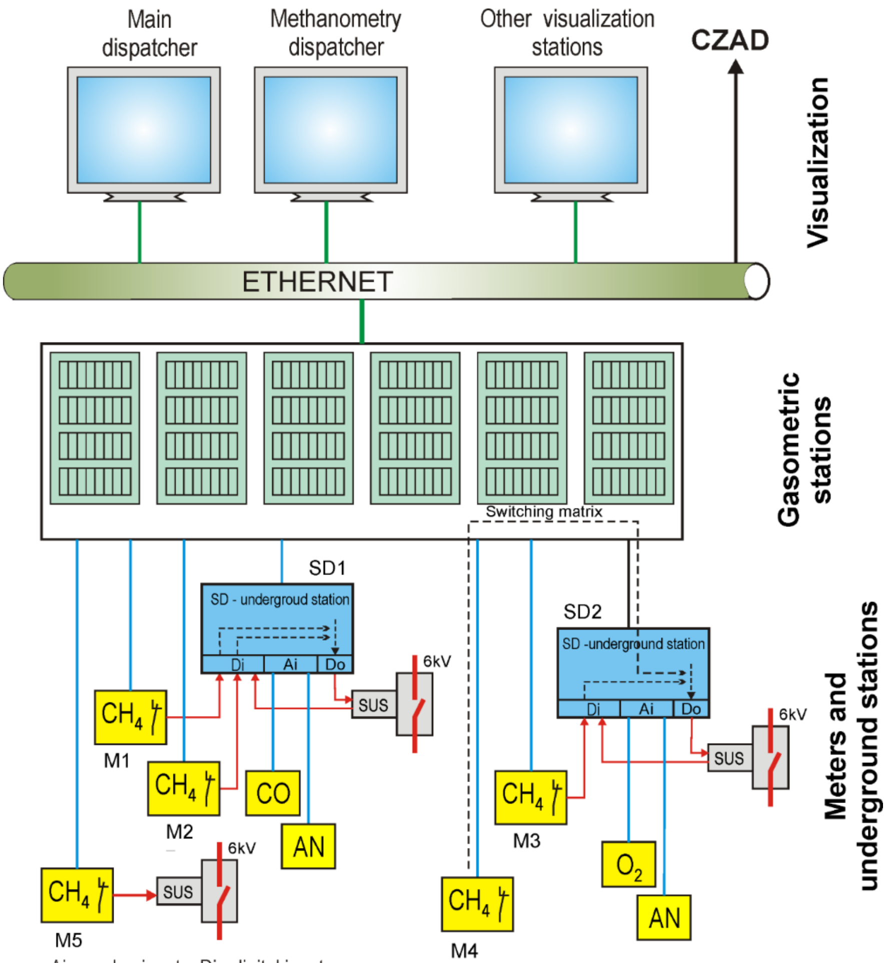
- EMAG/SEVITEL from Katowice - SMP-NT/A systems,
- HASO SC Tychy - telemetry systems type CST-40/x [Paszek, 2019] and methanometry dispatcher support system SWμP,
- CARBOAUTOMATYKA SA Tychy. Automation Systems Completion and Assembly Company - KSP-x computer measurement system,
- MICON Sp. z o.o. Research, Production and Service and Trade Company - VENTURON and MICON-x gasometric systems [Firganek, 1999].

In the 1980s, the SMP system was developed in the Research and Development Unit of the EMAG Mining Electrification and Automation Center in Katowice, the manufacturer of station equipment and system sensors was initially the Mining Electronics Plant ZEG Tychy, later EMAG SERWIS. Currently, the installation and ongoing service of the SMP system in mines has been taken over by SEVITEL from Katowice. In parallel, the company also started producing some sensors for this system. In this chapter, for simplicity, the name EMAG/SEVITEL will be used conventionally as the manufacturer of SMP system components.

10.2. Construction of a gasometric system

The gasometric system (Fig. 10.1) includes:

- the underground part containing measuring devices (gas content meters, anemometers, etc.) and underground stations,
- station (surface) part containing telemetry station with operator stations and necessary communication devices,
- visualization part containing visualization stations in the main control room, methanometric control room and in the rooms of functionaries; visualization boards contain data from the gasometric system and from other systems depending on your needs.



Ai - analog inputs, Di - digital inputs
Do - digital outputs, AN - anemometer, CH_4 - methane meter, O_2 - oxygen meter,
CO - carbon monoxide meter, SD - underground station

Fig. 10.1. General structure of the gasometric system

The stationary part of each gasometric system operated in a mine, due to the autonomous 12-hour operating time required by regulations [RME, 2016], must be powered by uninterruptible voltage from a power plant buffered by battery packs and a combustion generator.

Underground stations enable the implementation of a system of interlocks and shutdowns directly or through shutdown matrixes. The local shutdown matrix is programmed in the underground station (SD1 in Fig. 10.1), creating, for example, the logical product of exceeding the alarm thresholds in methane meters (M1, M2) or reducing the air speed below the alarm threshold (AN) or opening the ventilation airlock (simultaneous opening of two ventilation gates). The central shutdown matrix is programmed in the surface gasometrical control unit, including one or several surface telemetry control units, causing the shutdown signal to be sent to the appropriate methane meter or underground control unit (e.g. SD2) and further to the switch (via SUS) in the power grid. Fig. 10.1 shows an example of implementation:

– local shutdown matrix covering methane meters M1 and M2,
– global shutdown matrix including M3 and M4 methane meters,
– direct switching off 6kV switch by the M5 methane meter.

10.3. Underground measuring devices

Gasometric systems measure the content of certain gases in air, important from the point of view of safety in mines, such as:

– methane in the range 0÷100%,
– oxygen in the range 0÷21%,
– carbon monoxide in the range of 0÷2000 ppm,
– carbon dioxide in the range 0÷2%.

Additionally, gasometric systems measure air speed, humidity, temperature, absolute pressure, differential pressure, and monitor the condition of ventilation dams (also with differential pressure sensors) and duct fans.

The most important part of underground measuring devices (meters) is a sensor that converts the measured physical quantity into an electrical signal. The principles of operation of sensors are based on the use of specific physical properties of the measured gases.

The rest of the meter's electronics perform functions such as:

– converting the analog sensor signal into digital form,
– support for communication with the telemetry (gasometric) center or underground station,
– calibration support,
– handling warning and alarm levels,
– battery power backup,
– displaying measurement results,
– control of output relays.

The most important metrological parameters of gasometric sensors include [Cierpisz, 2007; Wasilewski, 2014]:

– measurement range,
– measurement accuracy,
– sensitivity defined as the ratio of the output signal to the content of the measured gas,

- static processing characteristics as a dependence of the output signal on the content of the measured gas (the characteristics can be linear or non-linear),
- cross sensitivity defined as the ratio of the output signal to the gas content not measured by the sensor (or another parameter such as temperature, humidity or pressure),
- transmission protocol between the meter and the telemetry center or underground station,
- repetition frequency,
- dynamic parameters, the most important of which is the T90 time, i.e. the time after which the sensor output reaches 90% of the value determined by a step change in the concentration of the tested gas at its input.

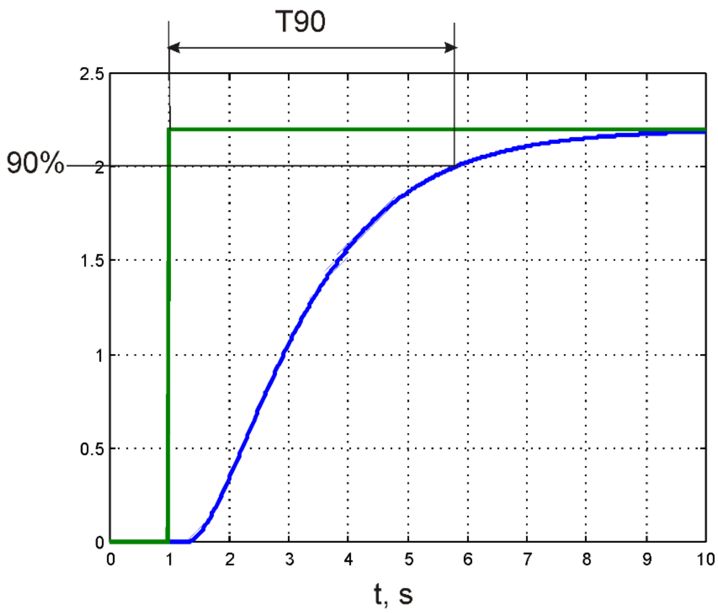


Fig. 10.2. Illustration of the T90 parameter definition

Fig. 10.2 shows the course of the output signal of the meter (methane meter) for a step change in methane concentration (from 0 to 2.2%) at the input with no digital filtering of the signal. In some solutions, digital filtering of the sensor output signal is used to reduce the T90 time.

10.4. Methods of measuring gas concentration

The following methods of measuring gas content are used in mining:

- catalytic combustion (measurement of methane concentration up to the lower explosion limit),
- thermoconductometric (measurement of methane concentration above the lower explosion limit),
- absorption of infrared radiation (measurement of methane and carbon dioxide concentration),
- electrochemical (measurement of oxygen and carbon monoxide concentrations).

https://doi.org/10.32056/KOMAG/Monograph2024.2

10.4.1. Catalytic combustion method

The most common method for measuring the concentration of flammable gases (methane) below the lower explosion limit is the catalytic combustion method; mainly methane. The measuring elements in this method are pellistors.

The pellistor (Fig. 10.3) contains a heat-resistant platinum heating coil embedded in a layer of aluminum oxide. The catalytic combustion method requires the use of two pellistors:

– active Pa covered with a catalyst,
– compensatory Pk.

The catalyst, characterized by high activity, allows methane combustion to occur at a temperature of approximately 720 K, which is lower than the ignition temperature of methane in the mine air. Exothermic combustion of methane on an electrically heated active pellistor causes an increase in its temperature and thus an increase in resistance.

Changes in pellistor resistance caused by methane combustion are measured in a Wheatstone bridge system. One of the arms of the bridge is the active pellistor Pa, on the surface of which methane is burned, the other is the compensation pellistor Pk without a catalyst (due to the lack of methane combustion, its resistance does not depend on the methane concentration). Both pellistors are located in the measuring chamber. The remaining two branches of the bridge form two resistors. The output voltage of the bridge is converted into a digital signal in the ADC converter and converted to the methane concentration value. In Fig. 10.3. an illustration of the principle of operation of the pellistor transducer is presented.

This method is suitable for measuring methane concentrations below the lower explosion limit (5%).

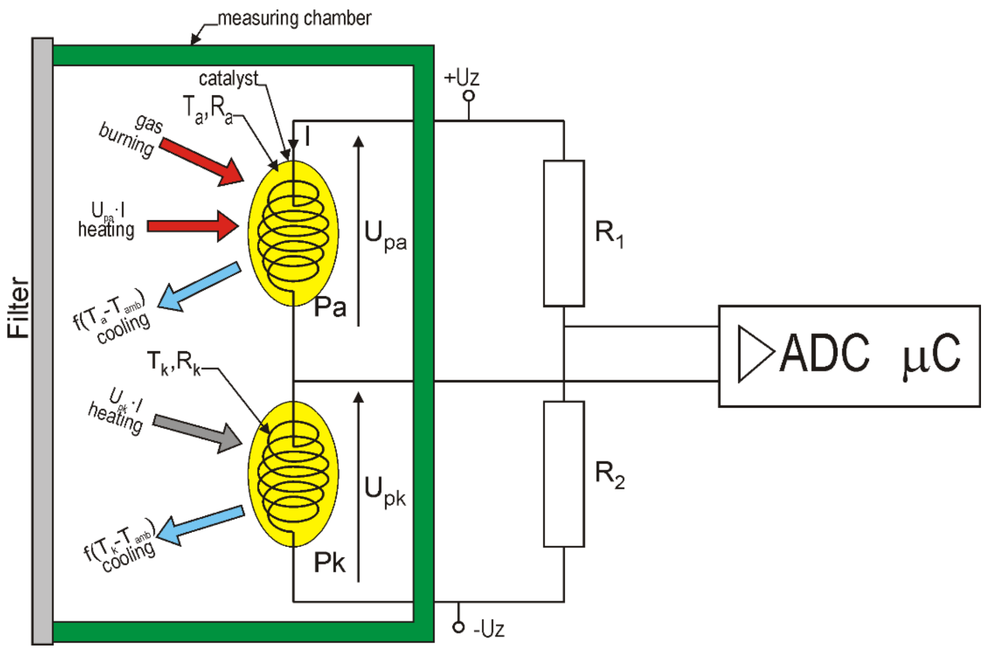


Fig. 10.3 Illustration of the operation of the pellistor bridge [Miśkiewicz, 2012]

In the catalytic combustion method, there is ambiguity of the bridge output signal for large and small methane concentrations. This is due to the fact that for high methane concentrations (above 9%), the amount of oxygen contained in the air is insufficient to burn methane, the intensity of methane combustion on the pellistor decreases, causing a reduction in the bridge output signal. For this reason, pellistor sensors are suitable for measuring the concentration of explosive gases (e.g. methane) below the lower explosion limit.

The disadvantage of the catalytic combustion method is the sensitivity of the pellistor to poisoning by certain chemical substances (e.g. silicones in adhesives or foams used in mines), which causes a temporary or irreversible loss of the measurement capabilities of the pellistor bridge. To limit this phenomenon, the measuring chamber is protected with an appropriate filter.

Sensitivity of pellistor bridges is in the range of several dozen mV/1%CH_4 [E2V].

10.4.2. Thermoconductometric method

Thermoconductometric method uses differences in the thermal conductivity of the measured gas and air. In mines, the thermoconductometric method is used to measure methane concentrations above 60% of the lower explosive limit. In Fig. 10.4. the dependencies of the thermal conductivity of air and methane on temperature are shown. At temperatures above 400°C, the conductivity of methane is twice as high as that of air.

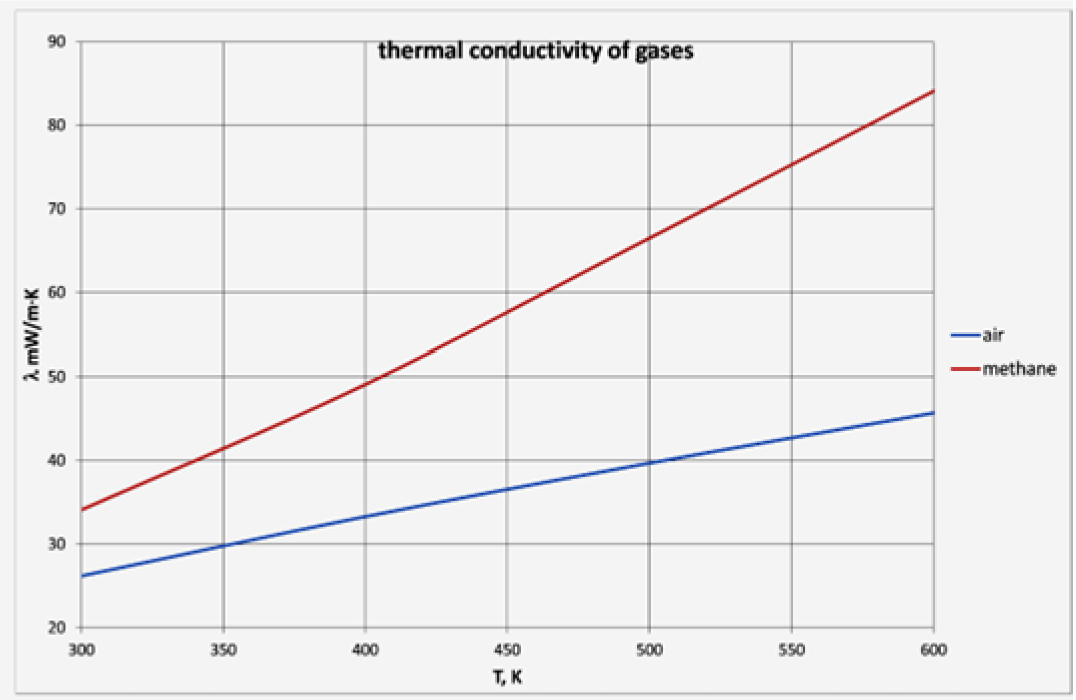


Fig. 10.4. Dependence of the thermal conductivity of methane and air on temperature [Engineers Edge]

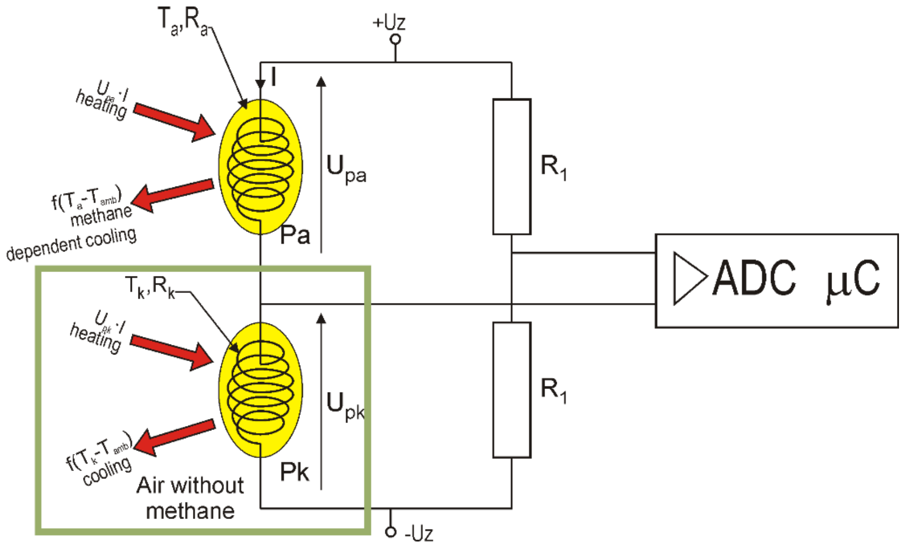


Fig. 10.5 Illustration of the operation of the conductometric bridge

Thermoconductometric sensor is built in the form of a bridge (Fig. 10.5), one arm of which is an active platinum spiral Pa (pellistor), placed in the measuring chamber, and the other arm is a compensation spiral Pk (pellistor) placed in a closed chamber containing the reference gas (air). The bridge is powered by a voltage of several volts, and the current flowing through the spirals heats them to a temperature of about 200°C.

If there is air in the measuring chamber, the bridge is in a state of equilibrium and the voltage on its diagonal is equal to 0. If there is air with methane in the measuring chamber, as a result of increased cooling, the temperature of the measuring spiral will decrease, its resistance decreases and on the diagonal of the bridge voltage appears depending on the methane concentration.

10.4.3. Infrared radiation absorption method

Infrared radiation passing through the gas is absorbed [Nowrot, 2011]. The radiation intensity after passing the optical path x in the gas is equal to [Sobków, 2010]:

$$I = I_o \cdot e^{-\alpha \cdot x} \tag{10.1}$$

Wher:

I_o – radiation intensity entering the layer,

α – absorption coefficient.

The relation (10.1) is called the Lambert-Beer law. We can transform it into the form:

$$lg\frac{I_o}{I} = A = \alpha \cdot x \cdot lge \tag{10.2}$$

Where:
a quantity *A* is called absorbance.

Value:

$$T = \frac{I}{I_o} \tag{10.3}$$

we call transmittance.

Both transmittance and absorbance at a constant geometric path depend on the type of gas and the wavelength. The dependence of transmittance T and absorbance A on wavelength is called the absorption spectrum. Fig. 10.6 and 10.7 show the absorption spectra of methane and carbon dioxide as a function of wave number (the wave number is the reciprocal of the wavelength and is given in w cm^{-1}).

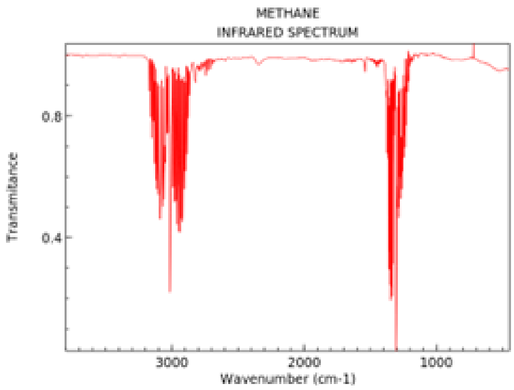


Fig. 10.6. Absorption spectrum of methane as a function of wave number for a geometric path of 5 cm [NIST]

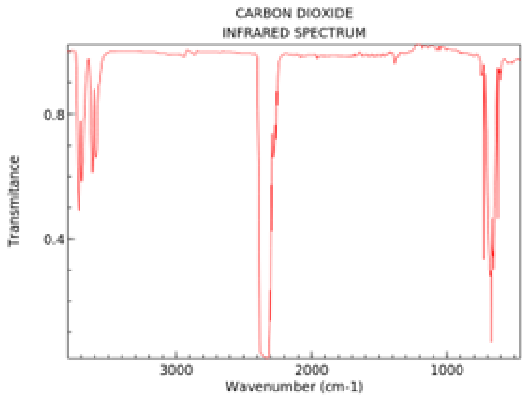


Fig. 10.7. Absorption spectrum of CO_2 as a function of wave number for a geometric path of 5 cm [NIST]

There are two minima in the absorption spectrum of methane:

– for a wave number of 3000 cm^{-1} (wavelength λ= 3.4 μm) – used in methane meters,
– for a wave number of 1300 cm^{-1} (wavelength 7.6 μm).

There are two minima in the absorption spectrum of carbon dioxide:

– for a wave number of 2300 cm^{-1} (wavelength λ= 3.3 μm) – used in carbon dioxide meters,
– for a wave number of 1300 cm^{-1} (wavelength 7.6 μm).

In the case of gas mixtures, the transmittance depends on the concentration of the gas being tested. This relationship is often non-linear [Sobków, 2010].

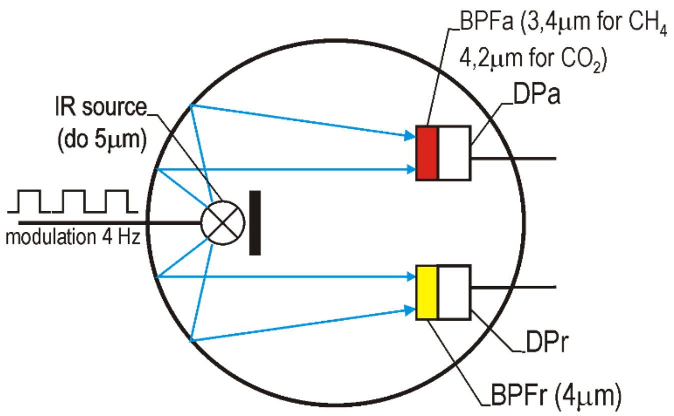


Fig. 10.8. Sketch of the IR sensor measurement chamber [RAE]

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In Fig. 10.8. an example of the construction of an IR sensor (made according to the technical specification RAE TN 169 [RAE]) using certain absorption properties of infrared radiation is shown. The measuring chamber contains a light source that also emits infrared radiation in the range of up to 5 µm. Infrared radiation is reflected from the inner surface of the measuring chamber and falls on the surface of two infrared radiation detectors: active DPa and reference DPr. These are pyroelectric detectors covered with optical filters. One of the filters (measurement BPFa) transmits radiation of a length corresponding to the maximum absorbance of the measured gas (CH_4 or CO_2), and the other (reference BPFr allows radiation of a different length (e.g. 4 µm) not attenuated by the tested gas. Comparing the signals from both pyroelectric detectors allows you to determine the concentration of the tested gas. Due to the properties of pyroelectric detectors, the light source is powered by a rectangular voltage with a frequency of 4 Hz.

The method of absorbing infrared radiation is abbreviated as NDIR (nondispersive infrared) [E2V].

10.4.4. Electrochemical method

An electrochemical sensor (electrochemical cell) is a low-voltage current source in which a chemical reaction of the measured gas takes place (cathodic reduction or anodic oxidation) and generates a current in the closing circuit of the cell electrode. This type of sensor is a fuel cell on a micro scale.

An illustration of the structure of an electrochemical cell (with anodic oxidation) for measuring the concentration of carbon monoxide CO is shown in Fig. 10.9. An electrochemical cell contains three electrodes:

– measuring electrode,
– auxiliary electrode,
– reference electrode.

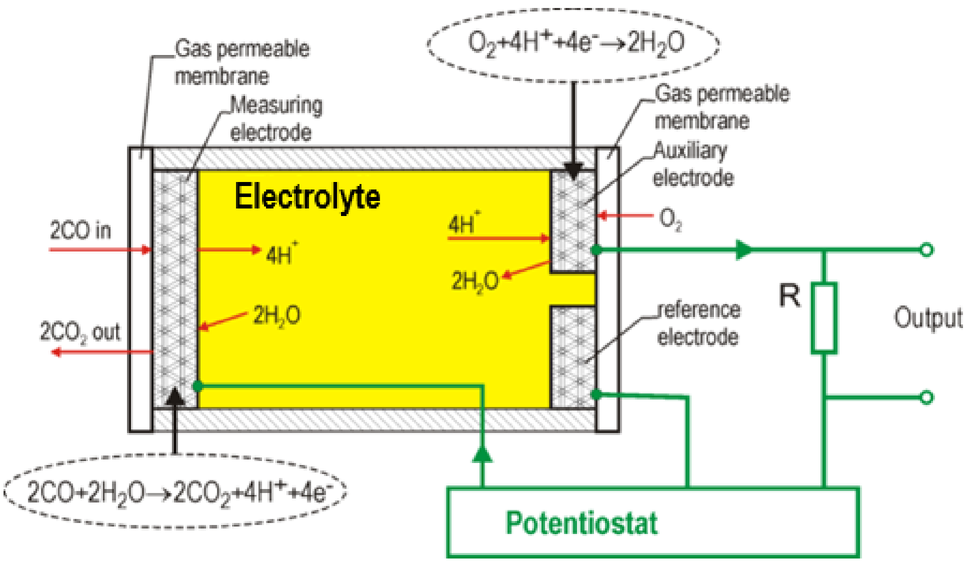


Fig. 10.9. Illustration of the principle of operation of the electrochemical CO sensor [NEMOTO]

The tested gas penetrates the measuring electrode through a hydrophobic (Teflon) membrane. The measuring electrode contains a metal catalyst that enables appropriate chemical reactions to occur with the tested gas. The structure of the measuring electrode (type of catalyst) and the required voltage at the reference electrode depend on the gas being tested.

In the case of a carbon oxygen (CO) sensor, an oxidation reaction takes place at the measuring electrode (anode):

$$2CO+2H_2O \rightarrow 2CO_2+4H^++4e^-$$

Positive hydrogen ions H^+ pass to the auxiliary electrode, and the electrons constitute charges flowing in the external circuit connected to the sensor. The reaction takes place at the auxiliary electrode (cathode):

$$O_2+4H^++4e^- \rightarrow 2H_2O$$

As a result of the described reactions, carbon monoxide is oxidized to carbon dioxide, and a low-voltage current source with a capacity of 55÷850 nA/ppm of the measured gas is created between the anode and cathode. The electrodes of the electrochemical sensor are connected to an electronic system called a potentiostat, which ensures the appropriate potential difference between the electrodes.

10.4.5. Comparison of gas concentration measurement methods

The measurement methods shown in section 10.4 are used to measure the content of various gases and in various measurement ranges. In Table 10.1. the properties of selected methods used to measure the concentration of gases in the air are shown.

Comparison of the properties of the methods used to measure gas concentration

Table 10.1.

	Catalytic combustion	**Thermoconductivity**	**IR (NDIR)**	**Electrochemical**
gas	CH_4	CH_4	CH_4, CO_2	CO, O_2, poisonous gases
measurement range	0–5%	0–100%	0– 00% CH_4, 0–5% CO_2	
T90	≈ 5 s	≈ 15 s	25–40 s	≈ 40 s
selectivity	Flammable gases	Sensitivity to CO_2	Good selectivity	Good selectivity
application in mining	CH_4	CH_4	CH_4, CO_2	CO, O_2,
sensitivity	10–30 mV/%CH_4	≈ 1 mV/%CH_4	Fa*=0.08 for 5%CH_4 Fa=0.3 for 5% CO_2	15 μA/1%O_2, 55-850 nA/1ppm
comments	range up to 5%	Dual-range methane meters, methane drainage pipelines		

*Fa – Fractional Absorbance

10.5. Methods of measuring air speed

Air speed in mine workings is measured with anemometers. The following types of anemometers are used in mines:

- mechanical anemometers,
- thermoanemometers,
- ultrasonic anemometers,
- vortex anemometers.

10.5.1. Thermoanemometers

Thermoanemometers (thermal anemometers, convection anemometers) use the dependence of the resistance of the measuring element on its temperature, which is related to the air flow near this element (or the thermistor). The measuring element (sensor) of such an anemometer may be a special thin wire ("hot wire") with a diameter of 1÷100 μm and a length of 0.2÷20 mm or a thermistor. With certain assumptions [Roszczynialski, 1992], a dependence on the amount of heat q transferred per unit time from the wire heated by electric current to the flowing gas can be expressed in the form:

$$q = \left(a + b \cdot \sqrt{v}\right) \cdot (T_d - T_o) \tag{10.4}$$

Where:

a, b – coefficients,

T_d – wire temperature,

T_o – wire ambient temperature (air),

v – air flow speed.

Heated wire anemometers are available as constant current and constant temperature [Biernacki, 1997]. Fig. 10.10 shows a view of the measuring element of a thermoanemometer, and Fig. 10.11 shows a simplified diagram of the constant temperature thermoanemometer system.

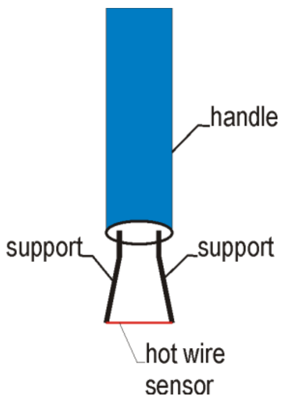


Fig. 10.10. View of the hot wire measuring element

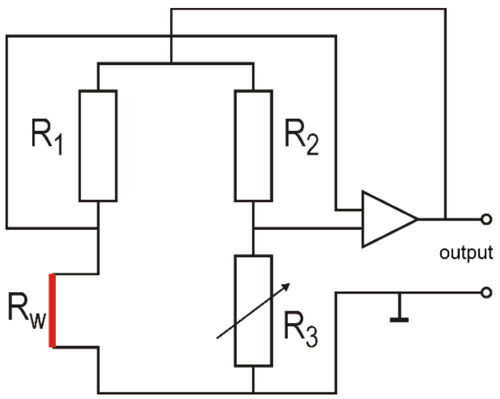


Fig. 10.11. Simplified diagram of a constant temperature thermoanemometer [Biernacki, 1997]

The constant temperature thermoanemometer sensor with resistance R_w is one of the branches of the bridge (the other branches are made up of resistors R_1, R_2, R_3). The bridge imbalance voltage is amplified in the amplifier and fed as the bridge supply voltage. The applied feedback keeps the bridge in a state of balance, which ensures constant resistance (including temperature) of the R_w sensor. The output voltage of the amplifier is a function of the air speed flowing around the sensor.

10.5.2. Ultrasonic anemometers

The principle of operation of this anemometer is shown in Fig. 10.12.

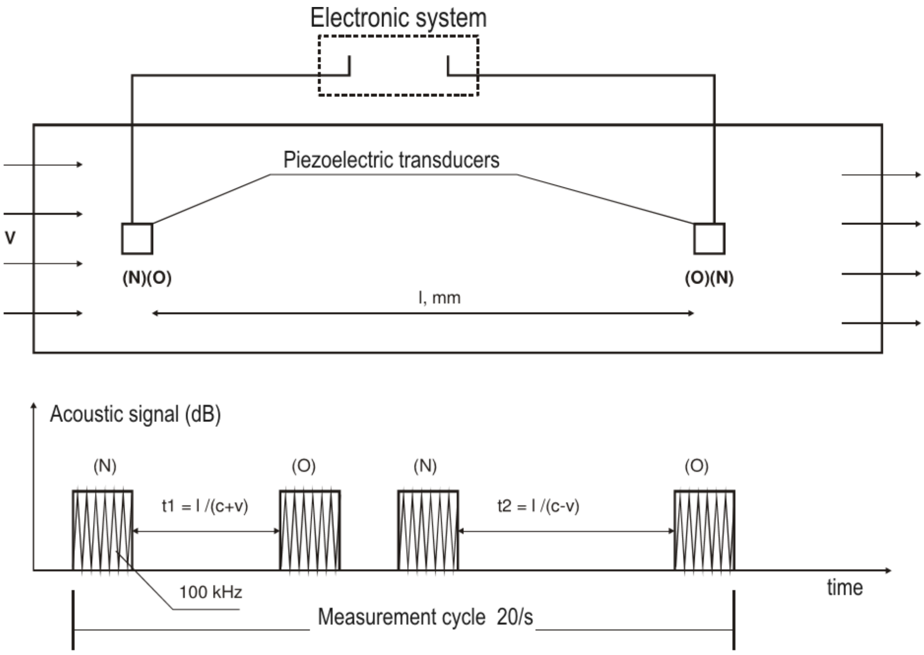


Fig. 10.12. Principle of operation of an ultrasonic anemometer

In this solution, two ultrasonic wave propagation times are measured: in the direction of air flow and against the direction of air flow. The block diagram of the AS-2s ultrasonic anemometer (EMAG) is shown in Fig. 10.13. [Cierpisz, 2007]

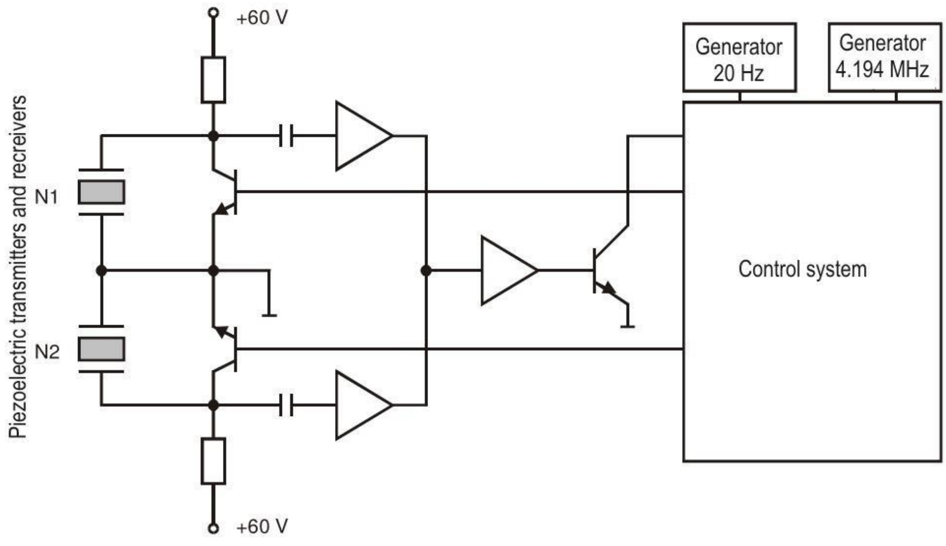


Fig. 10.13. Block diagram of the AS-2S anemometer

https://doi.org/10.32056/KOMAG/Monograph2024.2

Two piezoelectric transducers alternately emit ultrasound pulses with a frequency of 100 kHz. Switching of transducers acting alternately as a receiver and transmitter takes place at a frequency of 20 switches per second. The measurement result is averaged over the last ten measurements. The signal propagation times in the direction of air flow t_1 and against the air flow t_2 are:

$$t_1 = \frac{l}{c+v} \qquad t_2 = \frac{l}{c-v} \tag{10.5}$$

Where:

l – distance between piezoelectric transducers (approx. 30 cm),

c – speed of sound in air,

v – air flow speed.

The measurement result is the time difference:

$$\Delta t = t_2 - t_1 = \frac{2 \cdot l \cdot v}{c^2 - v^2} \approx \frac{2 \cdot l \cdot v}{c^2} \tag{10.6}$$

An important advantage of the ultrasonic method is the lower measurement range, which starts from 0 m/s. The maximum (measurable) air velocities in this method are approximately 20 m/s, above which turbulent air flow occurs.

10.6. Stationary gasometric meters

Stationary meters perform the following tasks:

- measurement of mine atmosphere parameters,
- transmission of the measurement result to the telemetry station,
- sending its own identification number to the telemetry station,
- possibility of carrying out the proper calibration procedure with protection against interference by unauthorized persons,
- support for relay contacts (also semiconductor) used to switch off the power in case of danger.

The meters can be constructed as separate devices (with battery backup) or as a set containing a transducer and a sensor, which allows you to create a meter by connecting various sensors to a universal transducer, depending on your needs. This chapter will present the characteristics of selected stationary meters used in gasometric systems. A broader review of blood gas meters is presented in the literature [Cierpisz, 2007; Wasilewski, 2014; Mróz, 2017].

The meters are powered remotely from the telemetry station or underground station. They can also be equipped with battery backup for a short time. They support a specific data transmission protocol to the telemetry center or underground station. The transmission of measurement results to the underground station most often uses the 0.4÷2 V standard. Data transmission to the telemetry center currently most often uses a digital (company) protocol. It is also possible to use the frequency protocol (5÷12 kHz) commonly used in Poland in gasometric central stations, as well as FSK modem transmission [Cierpisz, 2007].

10.6.1. Methane meters

The gasometric systems of JSW SA use methane meters to measure the concentration of gases in the workings from the following manufacturers:

- CSM-1, CSM-3, CSM-3i, CSM-3m methane meters manufactured by HASO,
- MM-4 and MM-4 methane meters with a raised measuring head on a cable, MM-2PW, MM-2PW with a raised measuring head on a cable, DCH, manufactured by EMAG SERWIS [Szczucki, 2013],
- CM-10c methane meters connected to the PSM transmitter, formerly produced by ZEG,
- CPC-2, SC-CH4 methane meters manufactured by Carboautomatyka.

Thermoconductometric method is used to measure methane concentration in methane drainage pipelines:

- CMW-10c (wraz z przetwornikiem PSM) produkcji ZEG,
- CSM-1R produkcji HASO.

Fig. 10.14 shows photographs of selected methane meters used at JSW SA.

CSM-1

CSM-3

CSM-3i

DCH

MM-4

MM-4 with a raised measuring head

https://doi.org/10.32056/KOMAG/Monograph2024.2

MM-2PW

MM-2PW with a raised measuring head


CPC-2

SC-CH4

CSM-3m


CMW-10c


CM-10cw


PSM-10cw


CSM-1R

Fig. 10.14. Photographs of selected methane meters used in gasometric systems [HASO, SEVITEL, CARBO, EMAGS]

The basic parameters of selected methane meters used at JSW SA are presented in Table 10.2. [HASO, SEVITEL, CARBO]. The following measurement methods are used in these methane meters:

– catalytic combustion method (range 0÷5%) and thermoconductometric method (range 5÷100%) - used in dual-range methane meters (TK),
– infrared radiation absorption method (NDIR).

The most important parameters of selected methane meters used in JSW SA

Table 10.2.

	CSM-1	**CSM-3**	**CSM-3i**	**CSM-3m**	**CM-10c**	**MM-4**	**MM-2PW**	**CPC-2**	**SC-CH4**
measurement method	TK	TK	NDIR	NDIR	TK	TK	TK	TK	TK
measurement range	0–100%	0–100%	0–100%	0–100%	0–100%	0–100%	0–100%	0–100%	0–100%
basic error									
0–2%	0.1% CH_4	0.1% CH_4	0.1% CH_4	0.1% CH_4		0.1% CH_4	0.1% CH_4	0.1% CH_4	
2%–2,5%	0.3% CH_4	5% rdg.	0.1% CH_4	0.2% CH_4		5% rdg.	0.1% CH_4	0.1% CH_4	
2,5%–5%	0.3% CH_4	5% rdg.	0.3% CH_4	0.2% CH_4		5% rdg.	10% rdg.	0.3% CH_4	
5%–10%	3% CH_4	3% CH_4	1% CH_4	5% rdg.		3% CH_4	10% rdg.	3% CH_4	
10%–60%	3% CH_4	3% CH_4	3% CH_4	5% rdg.		3% CH_4	10% rdg.	3% CH_4	
60%–100%	3% CH_4	5% rdg.	3% CH_4	5% rdg.		5% rdg.	10% rdg.	3% CH_4	
T90, s	<5	<5	<25	<7		<5	<6	<15	
repetition time, s	<2	<2	<2	<2	6	<2			
transmission	digital	digital	digital	digital	5–15 kHz digital	digital	digital	digital	5–15 kHz digital 0.4–2V
relay contacts	2	2	2	2	1	2		2	2
binary inputs	2	2	2	2		2			1
comments					with the PSM-10c transducer				

TK – thermocatalytic and thermoconductometric method
NDIR – infrared radiation absorption method
rdg. – reading

Methane meters are connected to the linear modules of telemetry control units (from the same manufacturer). From a formal point of view, the possibility of connecting a given type of methane meter to a telemetry control panel from another manufacturer is limited. It is possible after mutual sharing of transmission protocols and defining this fact in the exemption by the President of WUG in Katowice for this type of gasometric system. The T90 time of pellistor methane meters is usually below 5 s, while for NDIR methane meters the T90 time is below 25 s (for CSM-3i) or below 7 s (for CSM-3 m).

Methane meters have the ability to define two thresholds (warning and alarm) logically connected to binary outputs that perform the shutdown function. The contacts of binary outputs can also be controlled from the telemetry control panel and are equipped with a diode or resistor system to increase functional safety [Cierpisz, 2007]. Some methane meters are equipped with binary inputs to which an auxiliary contact of a switch turned off by a binary output can be connected.

10.6.2. Other gasometric meters

The gasometric systems of JSW SA use meters for measuring carbon monoxide from the following manufacturers:

- CSCO-1 and CSCO-2 carbon monoxide meters manufactured by HASO,
- CSTW-3 carbon monoxide meters with a range of 200 ppm and 1000 ppm connected to the Kx-2A transmitter manufactured by CARBOAUTOMATYKA,
- MCO carbon monoxide meter (dual range 0-200 ppm, 0-1000 ppm) developed by EMAG.

The meters mentioned above use an electrochemical method of measuring carbon monoxide.

Gasometric systems use meters to measure the concentration of dioxide from the following manufacturers:

- CSCD-3i carbon dioxide meters manufactured by HASO,
- UCS-1 carbon dioxide (CO_2) meters manufactured by SEVITEL.

The meters mentioned above use the infrared absorption method (NDIR) to measure carbon dioxide.

Table 10.3 shows the most important parameters of selected carbon monoxide and dioxide meters, and Fig. 10.15 photographs of selected carbon monoxide and dioxide meters [HASO, SEVITEL, CARBO].

The most important parameters of selected carbon monoxide and dioxide meters

Table 10.3.

	CSCO-1	**CSCO-2**	**CSTW-3**	**MCO**	**CSCD-3i**	**UCS-1**
measured quantity	CO	CO	CO	CO	CO_2	CO_2
power supply	telemetry station	underground station	telemetry station	underground station	telemetry station	hub MKS-2
measurement range	0–1000 ppm 0–200 ppm**	0–1000 ppm	0–200 ppm 0–1000 ppm*	0–200 ppm 0–1000 ppm	0–5%	0–5%
basic error, ppm 0–100 100–200 200–1000	 3 5 25	 3 5 25	 5 5 15	 5 5 25	 0.1%	
T90, p	<40	<40		<60	<25	
repetition time, p	<2				<2	
transmission	digital / 10–6 kHz	digital / 0.4–2V	5 – 12.5 kHz	2 exits 0.4–2V	digital	RS485
trip contacts	1				1	
comments			works with the Kx-2A transducer			

* depending on execution
** for frequency transmission

CO meter type CSCO-1

CO meter type CSCO-2

CO meter type CSTW-3
(without transmitter)

CO meter type CSTW-3 with
Kx-2A transmitter

CO meter type MCO

CO_2 meter type CSCD-3i

CO_2 meter type UCS-1

Fig. 10.15. Photographs of selected carbon monoxide and dioxide meters

Gasometric systems use meters to measure oxygen concentration from the following manufacturers:

- CSO-1 and CSO-2 oxygen meters manufactured by HASO,
- MO2 oxygen meters developed by EMAG,
- CST-3A oxygen meters connected to Kx-2A transmitters manufactured by CARBOAUTOMATYKA.

The meters mentioned above use an electrochemical method of measuring oxygen. Table 10.4 shows the most important parameters of selected oxygen meters, and Fig. 10.16 photographs of selected oxygen meters [HASO, SEVITEL, CARBO].

The most important parameters of selected oxygen meters

Table 10.4.

	CSO-1	**CSO-2**	**CST-3A**	**MO2**
power supply	telemetry station	underground station	telemetry station	underground station
measurement range, %	0–25	0–25	0–25	0–25 0–1000
basic error, %	0.5	0.5	0.3	0.5
T90, p	<20	<20		<45
repetition time, p	<2			
transmission	digital/10–5kHz	digital/0.4–2V	5–12.5 kHz	0.4–2V
comments			works with the Kx-2A transducer	

O_2 meter type CSO-2

O_2 meter type CSO-1

O_2 meter type CST-3A

O_2 meter type MO2

Fig. 10.16. Photographs of selected oxygen meters

Gasometric systems use meters to measure temperature, humidity, pressure and differential pressure from the following manufacturers:

- CSPD-4 differential pressure meter manufactured by HASO,
- DRC differential pressure meter manufactured by EMAG SERWIS,
- MCR differential pressure meter developed by EMAG,
- CSPA-2 temperature, humidity and pressure meter manufactured by HASO,
- THP-2 temperature and humidity meter developed by EMAG,
- temperature meter in the CSTK-2 duct pipeline manufactured by HASO.

Table 10.5 presents the most important parameters, and Fig. 10.17 shows photographs of selected temperature, humidity, pressure and differential pressure meters [HASO, EMAG/SEVITEL].

The most important parameters of selected pressure, humidity and temperature meters

Table 10.5.

	MCR	**DRC**	**CSPD-4**	**CSPA-2**	**THP-2**
measured quantity	differential pressure	differential pressure	differential pressure	pressure humidity temperature	pressure
power supply	underground station	telemetry station	underground station	underground station	telemetry station
measurement range	from ±250 Pa up to ±7500 Pa	from ±1000 Pa up to ±20000 Pa	from ±250 Pa up to ±7500 Pa	800÷1300 hPa 0÷100% -20 ÷ +50°C	800÷1300 hPa
basic error	2% of the range	1% of the range	2% of the range	2 hPa 3% 1°C	0.3 hPa
transmission	0.4÷2 V	digital	0.4÷2 V digital	3 exits 0.4÷2 V	digital

MCR differential pressure meter

DRC differential pressure meter

CSPD-4 differential pressure meter

CSPA-2 temperature, humidity and pressure meter

THP-2 temperature, humidity and pressure meter

temperature meter in the CSTK-2 duct pipeline

Fig. 10.17. Photographs of selected differential pressure, temperature, humidity and pressure meters

Anemometers from the following manufacturers are used in gasometric systems:

– SAT-1 anemometer manufactured by ZMUE,
– CSV-5A anemometer manufactured by HASO,
– AS-3 anemometer developed by the EMAG institute.

Table 10.6 shows the most important parameters and Fig. 10.18 presents photographs of selected anemometers [HASO, SEVITEL, ZMUE].

The most important parameters of selected anemometers

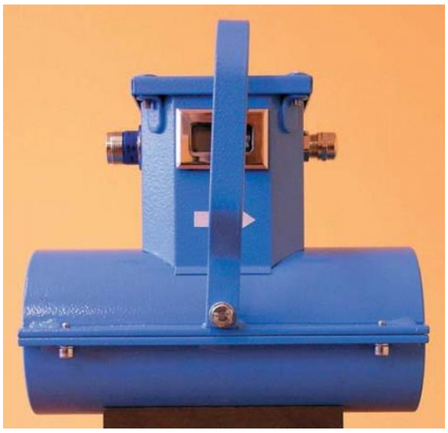
Table 10.6.

	SAT-1	CSV-5A	AS-3
type	windmill	thermoanemometer	ultrasonic
power supply	underground station	underground station or telemetry station	underground station
measurement range, m/s	from 0.2÷5 to 0.2÷20	0.01÷10 m/s	0.1÷10
basic error	1% rdg	2% rdg+0.1	5% rdg +0.1
transmission	0.4÷2 V 8÷12 kHz	0.2÷2 V or digital	0.4÷2 V

https://doi.org/10.32056/KOMAG/Monograph2024.2

SAT-1 anemometer

CSV-5A anemometer



AS-3 anemometer

Fig. 10.18. Photographs of selected anemometers

10.7. Underground stations

Depending on their configuration, underground stations perform the following functions:

- are powered from the telemetry line (except MKS-2 which has local power supply),
- receive analog signals (standard 0.4÷2 V) from low-power meters (CO, O_2, anemometer),
- they act as a specialized programmable controller that performs certain logical functions necessary for the construction of interlock and shutdown systems,
- they perform two-way communication with telemetry headquarters.

JSW SA uses the following underground stations in its gasometric systems:

- CSA-1, CSA-2 and CSD-1 analog switchboards from HASO,
- CSD control units, CSD-1 MCCD-01 developed at the EMAG institute,
- MKS-2 modem signal concentrators from SEVITEL.

Fig. 10.19 shows views of underground stations, and Table 10.7 shows the number and type of inputs and outputs used in mines by underground stations [HASO, EMAGS, SEVITEL].

Fig. 10.19. Photographs of selected underground stations

Configurations of selected underground stations

Table 10.7.

	MCCD-01	CCD-1	CSA-1	CSA-2	CSD-1	MKS-2
number of binary inputs	until 16	16		4	16	4
number of binary outputs	until 12	4		2	8	4
number of analog inputs 0.4-2 V	until 8	8	4	4		4

The transmission of binary signals to underground stations and from underground stations, blood gas meters and sensors is carried out in a way that ensures an appropriate level of functional safety. The solutions used (diodes or resistors) allow distinguishing a short circuit in the control contact from a short circuit in the transmission cable [Cierpisz, 2007].

10.8. Gasometric systems

Gasometric systems used in JSW SA mines perform the following functions:

- measurement and monitoring of methane concentration in workings and pipelines of the methane drainage network,
- measurement and monitoring of selected mine air parameters (e.g. CO concentration) enabling early detection of underground fires,
- monitoring physical parameters and air composition (O_2, CO_2 concentration, temperature, humidity, air speed) for the purpose of ongoing analysis of the ventilation condition and carrying out preventive actions,
- monitoring the condition of ventilation devices (ventilation dams, main ventilation fans, auxiliary and duct fans),
- implementation of automatic power shutdowns in hazardous areas,
- generating warnings, alarms and reports,
- time synchronization with the official time standard,
- transferring data to visualization systems and archiving them.

JSW SA uses two gasometric systems:

- SMP-NT system from EMAG/SEVITEL,
- HASO CST-40 system.

JSW SA mines are methane mines, so all underground elements of gasometric systems and underground connections of telemetry centers must meet the requirements of the ATEX directive [ATEX, RMR].

The configuration of a mine's gasometric system can be characterized by:

- number and types of telemetry stations,
- number of active telemetry lines (ML line modules with which the control panels are equipped),
- number of measures of individual physical quantities.

There are two types of telemetry control panels in the HASO CST-40 system:

- CST-40/A with a maximum capacity of up to 40 telemetry lines (ML modules),
- CST-40/C with a maximum capacity of up to 80 telemetry lines (ML modules).

There are three types of telemetry control panels in the SMP-NT system from EMAG/SEVITEL:

- CMC-3MS with a maximum capacity of up to 64 telemetry lines,
- CMC-4 or CMC-5 with a maximum capacity of 80 telemetry lines.

10.8.1. SMP-NT system in the Knurów-Szczygłowice Coal Mine, Szczygłowice Section

The block diagram of the SMP-NT system in Knurów-Szczygłowice Coal Mine, Szczygłowice Section is shown in Fig. 10.20. This diagram does not take into account the additional CST-40/C telemetry stations operated in the mine. In the drawing, the intrinsically safe underground telecommunications network is marked in blue, the links of interlock and shutdown systems are marked in red (in simple terms, without the necessary separators), and the separated computer network for data archiving and data transfer to the visualization system is marked in green.

The station part of the gasometric system is equipped with the following elements:

– 2 telemetry stations type CMC-3MS (total capacity 2x64 lines),
– 3 CMC-5 telemetry stations (capacity 3x80 lines).

As of the end of 2021, the following were connected to the CMC-3MS control panels:

– 26 anemometers type AS-1, AS-3,
– 2 high concentration methane meters type MM-2PW/A for measurements in methane drainage pipelines,
– 66 MM-2PW methane meters,
– 7 CCD control units to which 29 ACO-4B and MCO type CO meters were connected.

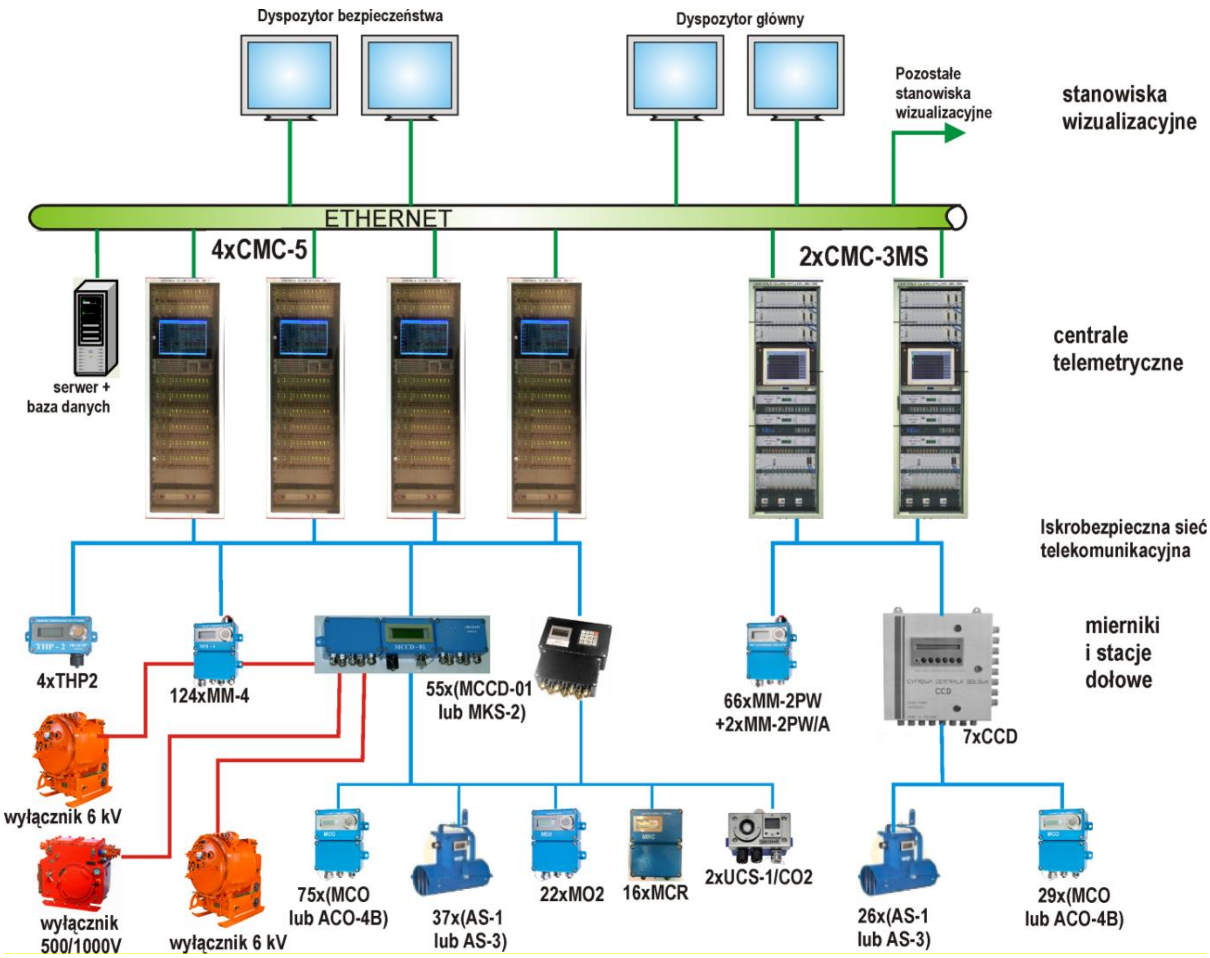


Fig. 10.20. Block diagram of the SMP-NT gasometric system in Szczygłowice Section

The following were connected to the CMC-5 gasometric stations:

– 124 MM-4 methane meters,

- 4 THP-2 type air physical parameter meters,
- 55 MCCD-01, MKS-2 control units – with appropriate meters:
  - 75 CO meters type ACO-4B and MCO,
  - 37 AS-3 and AS-1 type anemometers,
  - 22 MO2 oxygen meters,
  - 16 MRC differential pressure meters,
  - 2 CO_2 meters type UCS-1/CO2.

Therefore, in the underground part of the gasometric system of Szczygłowice Section (at the end of 2021), the following meters were operated:

- 190 methane meters,
- 104 carbon monoxide meters,
- 63 anemometers,
- 22 oxygen meters,
- 16 differential pressure meters,
- 2 carbon dioxide meters,
- 4 pressure, temperature and humidity meters,
- 2 meters of high methane concentrations,

giving a total of 403 meters. Additionally, 62 underground stations were installed.

The percentage share of individual types of meters in the total number of meters in use is as follows:

- 47% of methane meters,
- 26% of carbon monoxide meters,
- 16% of anemometers,
- 5% of oxygen meters,
- 4% of differential pressure meters,
- 2% other meters used in the mine.

10.8.2. CST-40 system in Coal Mine Borynia-Zofiówka-Bzie, Section Borynia

As an example of the second gasometric system used in the mines of JSW SA, Fig. 10.22 shows a block diagram of the CST-40 system by HASO in the configuration for the Borynia-Zofiówka-Bzie Coal Mine, Borynia Section, along with the number and types of meters used in this mine. In the Borynia Section, 11 CST-40 telemetry stations from HASO are used. All figures are from September 2022.

In the drawing, the intrinsically safe underground telecommunications network is marked in blue, the links in the interlock and shutdown system are marked in red (in simplified terms without the necessary separators), and the separated computer network for data archiving and data transfer to the visualization system is marked in green.

The station part of the system is equipped with 11 CST-40/x telemetry control panels.

The following are connected to the CST-40/x telemetry stations:

- 61 CM-10ca methane meters with PSM transmitters,
- 55 CSM-1 methane meters,
- 55 CSM-3 methane meters,
- methane meter for measuring methane in methane drainage pipelines CMW-10c,
- 8 methane meters for measuring methane in methane drainage pipelines CSM-1R,
- 12 CCO-1 carbon monoxide meters with PSM transmitters,
- 60 CSCO-1 carbon monoxide meters,
- 15 CSCO-2 carbon monoxide meters,
- 2 CSO-1 oxygen meters,
- 2 CSO-2 oxygen meters,
- 6 CSCD-3i carbon dioxide meters,
- 4 CSPA-2 pressure, temperature and humidity meters,
- 8 temperature meters in CSTK-2 flue pipes,
- 11 SAT-1F anemometers,
- 3 CSV-5 anemometers,

giving a total of 326 meters. In addition, 39 underground stations were installed. All types and numbers of meters in use are presented graphically (as views of individual devices) in Fig. 10.21.

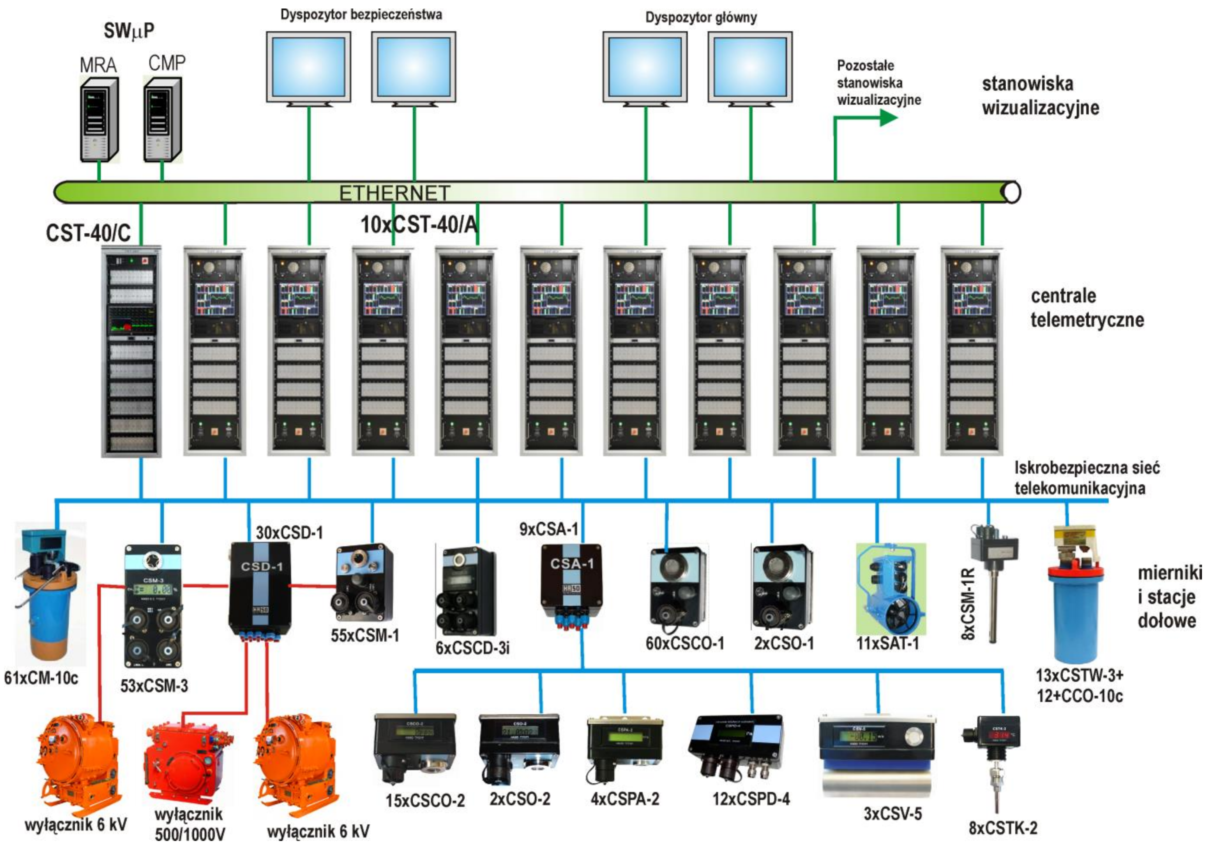


Fig. 10.21. Block diagram of the CST-40 gasometric system in Borynia Section

https://doi.org/10.32056/KOMAG/Monograph2024.2

The percentage share of individual types of meters used in Secton Borynia (in relation to all installed ones) is as follows:

- 52% are methane meters,
- 31% carbon monoxide meters,
- 5% anemometers,
- 12% other meters used in the mine.

10.8.3. Summary

In Table 10.8. the number of telemetry switchboards and the number of active telemetry lines (underground subscriber lines) of the SMP-NT and CST-40 systems in individual mines of JSW SA are shown. The least active telemetry lines are in Section Knurów (395), and the most in Coal Mine Pniówek (693). The number of active telemetry lines is not equal to the number of gasometric meters, because some of the telemetry lines are used to service underground stations (including binary ones that do not support meters), and some underground stations support several gasometric meters with analog outputs (0.4÷2 V).

A detailed analysis of the gasometric system equipment was carried out in the Borynia Section, where only the CST-40 system is used, and in the Szczygłowice Section, where the SMP-NT system is practically used (the CST-40 system has only 20 telemetry lines).

Structure of the station part of gasometric systems in individual JSW SA mines (as of September 2022)

Table 10.8.

Mine	Number of telemetry control panels	Number of active subscriber lines in individual systems	Total number of active subscriber lines in the mine
Coal Mine Borynia-Zofiówka **Section Borynia**	10xCST-40/A 1xCST-40/C	385	385
Coal Mine Budryk	7xCST-40/A 2xCST-40/C 2xCMC-3MS	379 for CST-40 128 for SMP-NT	507
Coal Mine Jastrzębie-Bzie	6xCST-40/A 2xCST-40/C	400	400
Coal Mine Knurów-Szczygłowice **Section Knurów**	6xCST-40/A 1xCST-40/C 1xCMC-3MS 2xCMC-5	257 for CST-40 138 for SMP-NT	395
Coal Mine Pniówek	6xCST-40/C 4xCMC-3MS	437 for CST-40 256 for SMP-NT	693
Coal Mine Knurów-Szczygłowice **Section Szczygłowice**	1xCST-40/C 2xCMC-3MS 4xCMC-5	20 for CST-40 388 for SMP-NT	408
Coal Mine Borynia-Zofiówka **Section Zofiówka**	6xCST-40/A 1xCST-40/C 3xCMC-3MS 1xCMC-4	257 for CST-40 266 for SMP-4	523

In total 2,295 lines are active in JSW SA's gasometric systems telemetry in CST-40 systems and **1,176 lines** in SMP-NT systems. A detailed analysis of the equipment of the gasometric system of two sections (Szczygłowice and Borynia) shows that approximately 50%

of the installed meters are methane meters, 25÷30% of the meters are carbon monoxide meters, and 5÷15% are anemometers.

10.9. Possibilities of developing gasometric systems

The introduction of gasometric systems was one of the conditions for the operation of methane mines. However, gasometric systems did not prevent methane explosions. An example is the methane explosion on April 20, 2022 in the Pniówek coal mine. As a result of the explosion and the rescue operation, nine miners and rescuers died.

Currently required arrangement of methane meters in the wall (§311 [RME]):

- the area where the longwall meets the tailgate,
- the area where the longwall meets the bottom gate,
- alternatively, one methane meter inside the longwall,

does not enable quick shutdown of power to electrical devices in the event of a sudden methane outflow inside the wall. This type of problem was analyzed as part of the research task entitled: "Development of a gasometric system causing immediate shutdown of longwall machines and electrical devices in the event of a sudden outflow of methane" of the strategic project on "Improvement of work safety in mines".

As part of this project, HASO SC created a prototype of a system that minimizes the system's reaction time to exceeding the methane concentration alarm threshold. The developed system includes methane meters located in the wall and a dedicated underground station, creating a new, autonomous subsystem for monitoring the methane hazard of the caving part of the longwall area (Fig. 10.22) [Dziurzyński, 2015; Dylong, 2016].

The system provides for the possibility of locating methane meters inside the longwall workings, including in hard-to-reach places, e.g. in the collapse zone behind the mechanized support. The need to minimize the effects of damage to the transmission network within the longwall workings was also taken into account. Therefore, it was assumed that data transmission from methane meters located in this area would take place via wireless link to the underground station located in the overhead gallery, from where information could be transmitted to the surface via copper or fiber-optic cables.

The executive element of this system (initiating automatic switch-off of electricity) is a control unit equipped with appropriate control outputs. The prototype of the developed system underwent experimental tests in the Budryk, Bolesław Śmiały and Borynia-Zofiówka Coal Mines. The subject of the research was to assess the correctness of its operation, in particular the wireless transmission of measurement data. According to the adopted concept, CR-1 sensors transmitted information about the methane concentration level to an underground station equipped with an RS422 interface.

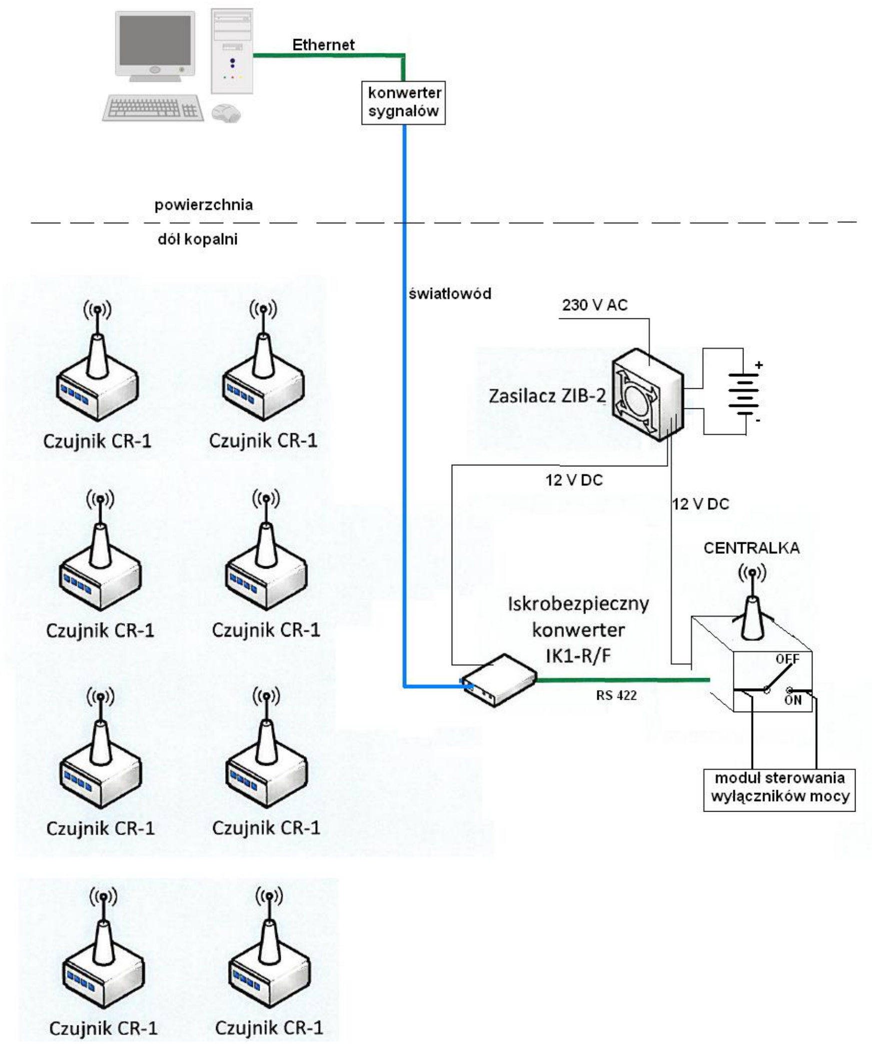


Fig. 10.22. Schematic diagram of the autonomous methane hazard monitoring subsystem

During the research, communication with the surface was carried out using copper and fiber optic lines, which ensured the integration of new devices with the mine-wide monitoring system. As a result of these studies, it was found that:

– the maximum time of polling a set of eight sensors operating in the MESH network by the control panel was (with no interference) approximately 1.5 s, with an assumed repetition time of 1.3 s; the measurement from the sensor was sent to the network every 2.5 s,
– the maximum transmission range was 200 m,
– the system response time in the event of transmission loss was 9 s,
– radio transmission was resistant to interference generated by electrical devices operating in mine workings.

Tests of this system allow us to conclude that it is possible to effectively monitor methane concentration in the mining wall using methane sensors with radio transmission.

One of the serious problems in the operation of pellistor methane meters is the contamination of the pellistors by various chemicals used in mining. Pellistor contamination causes temporary or permanent damage to the methane meter sensor and is only detected during calibration of the methane meter. To solve this problem, EMAG SERWIS has developed a prototype of the DCH-2 double-head methane meter (Fig. 10.23).

Fig. 10.23 View of the DCH-2 double-head methane meter

The methane meter has two measuring heads:

- using catalytic combustion and thermoconductometric methods,
- using the absorption of infrared radiation (NDIR).

The display shows the measurement result using the catalytic combustion method, while the surface on the telemetry station monitor shows both results (measurement using the catalytic combustion method and conductometric measurement) as well as the difference in the measurement results of both heads. Based on the difference in the measurements of both heads, the dispatcher may decide to check the methane meter and recalibrate it.

Assessment of the usefulness of such a methane meter will be possible after its trial operation in mine conditions.

https://doi.org/10.32056/KOMAG/Monograph2024.2

11. Monitoring the methane drainage network – effective implementation on the example of JSW SA

Artur Dylong

11.1. Introduction

The geological system of the Upper Silesian Coal Basin means that, at present, without effective methane drainage, coal mining would be very difficult, and in many cases even impossible. The mines of Jastrzębska Spółka Węglowa are characterized by coal seams with methane hazard classified by categories III and IV. That is why the role of methane drainage in JSW mines is so important to ensure an appropriate level of extraction. Effective methane drainage, in addition to properly performed mining works, also requires knowledge about the current condition of the methane drainage network, which includes many kilometers of pipelines located in underground workings. Real-time monitoring of air parameters in JSW mines has been in operation for a long time, but until recently monitoring of the methane drainage network was performed manually or semi-automatically. In the years 2000÷2005, the EMAG Institute conducted research, among others, in the Pniówek mine, aimed at confirming the possibility of implementing a monitoring system for the methane drainage pipeline network. At that time, a dedicated CPO-1 measuring device was developed, which allowed for the measurement of basic parameters of gas transported through the pipeline. The research and experiments carried out gave positive results, but they were never implemented in practice. In recent years, JSW SA has undertaken a number of activities aimed at developing and implementing an effective real-time monitoring system of the methane drainage pipeline network.

11.2. Methane drainage

Methane drainage is carried out primarily to improve safety in underground mine workings. The preceding removal of methane allows, in addition to the above-mentioned increase in the safety of mining crews, also to increase mining capacity. Due to changing mining conditions, gas discharged through pipelines is subject to fluctuations in composition and concentration, which is a problem when it is used to power devices, e.g. generating electricity. In order to ensure appropriate parameters, measuring and regulating devices installed on methane drainage pipelines are used. Until recently, network regulation could only be done manually, but in recent years technical possibilities for automatic regulation have emerged and currently preparatory work is being carried out to implement a fully remote automatic regulation system. JSW SA, among others, is working in this direction. Currently, underground measuring devices have been installed in JSW mines to monitor the concentration and flow of gas in the methane drainage network nodes. The next step will be to activate the regulation systems. The introduction of remote control systems will allow for increasing the efficiency of methane drainage and increasing the utilization rate of captured methane [Dziurzyński, 2015].

The methane drainage efficiency index is inherently related to methane drainage. This indicator shows how much methane we managed to capture in relation to the total methane released (absolute methane capacity). The efficiency of methane drainage is getting higher every year and in 2021 it was 41.8% for the Polish mining industry compared to previous years, where it was respectively: 2018 – 34.6%, 2019 – 37%, 2020 – 36.9% [WUG reports]. There is a slow increase in methane removal efficiency, which means that less methane is released into the atmosphere with ventilation air. The methane removal efficiency indicator does not provide information about the effectiveness of methane removal systems, but only informs us about the percentage relationship between the methane released and captured by methane removal systems, and does not provide information on how much methane captured has been managed. Moreover, to obtain a complete picture, the volume of extraction should also be taken into account in the analyses. From the point of view of safety, what happens to the gas after it is captured and removed from the workings is not important, because the essence of methane drainage systems is its removal from underground workings. As can be seen by looking at Table 11.1 [WUG reports], part of the captured gas is released into the atmosphere.

List of methane drainage parameters for 2017÷2021 [WUG raporty]

Tabela 11.1.

Specification	Year				
	2017	**2018**	**2019**	**2020**	**2021**
Absolute methane capacity [million m^3 CH_4/year]	948.5	916.1	803.8	819.6	815.3
Amount of methane captured [million m^3 CH_4/year]	337.0	317.0	301.6	302.8	340.9
Methane drainage efficiency [%]	35.5	34.6	37.5	37.0	41.8
Amount of methane utilized [million m^3 CH_4/year]	212.0	203.1	189.4	187.9	214.2
Efficiency of utilization of captured methane [%]	62.9	64.1	62.8	62.1	62.8
Hard coal mining [million Mg]	65.5	63.4	61.6	54.4	55.0
Relative methane capacity [m^3 CH_4/Mg]	14.5	14.4	13.0	15.0	14.8

Analyzing the data from Table 11.1, it can be seen that the efficiency index for the management of captured methane does not exceed 63%, which in the case of 2021 means that despite methane being captured through methane drainage systems, 126.7 million m^3 CH_4 was released into the atmosphere. Importantly, it can be noted that since 2017, the efficiency of the management of captured methane has fluctuated only minimally. With an increase of approximately 40 million m^3 CH_4 in 2021 compared to 2020, this means that the possibilities of installing methane drainage and its management are sufficient even in the event of a sudden increase in the amount of captured methane.

11.3. Use of methane in JSW SA

Since January 1, 2023 the JSW SA Capital Group includes four coal mines:

- Coal Mine Borynia-Zofiówka-Bzie,
- Coal Mine Budryk,
- Coal Mine Knurów-Szczygłowice,
- Coal Mine Pniówek.

In 2016, the Jas-Mos Coal Mine and in 2017 the Krupiński Coal Mine were transferred to Spółka Restrukturyzacji Kopalń SA (SRK). Currently, methane from these mines is still captured by the JSW methane drainage system and managed - in the “Krupiński” Coal Mine at the level of 86.9%, and in the Jas-Mos Coal Mine at the level of 99.4% [Szlązak, 2021].

JSW SA has been using methane from methane drainage systems to produce electricity and heat for over a dozen years. Table 11.2 [JSW odmetanowanie] presents a summary for the last few years.

Methane capture and use in JSW SA for 2016÷2021

Table 11.2.

Year	Amount of methane released in the exploitation process [million m³]	Methane drainage intake [million m³]	Utilization [million m³]	Percentage of methane use [%]
2016	482.92	210.21	114.93	54.70
2017	428.55	160.21	91.63	57.20
2018	406.36	131.66	74.75	56.80
2019	377.56	131.66	76.88	58.40
2020	362.83	142.45	86.03	60.03
2021	398.45	170.67	98.64	57.80

As can be seen, the efficiency of methane removal in the case of JSW SA mines ranges from approximately 34% to 43%. However, the use of captured methane has an increasing tendency, except for the years 2018 and 2021. The sudden changes in the amount of methane released in the years 2016÷2018 were related to the transfer of the Coal Mines Krupiński and Jas-Mos mines to SRK.

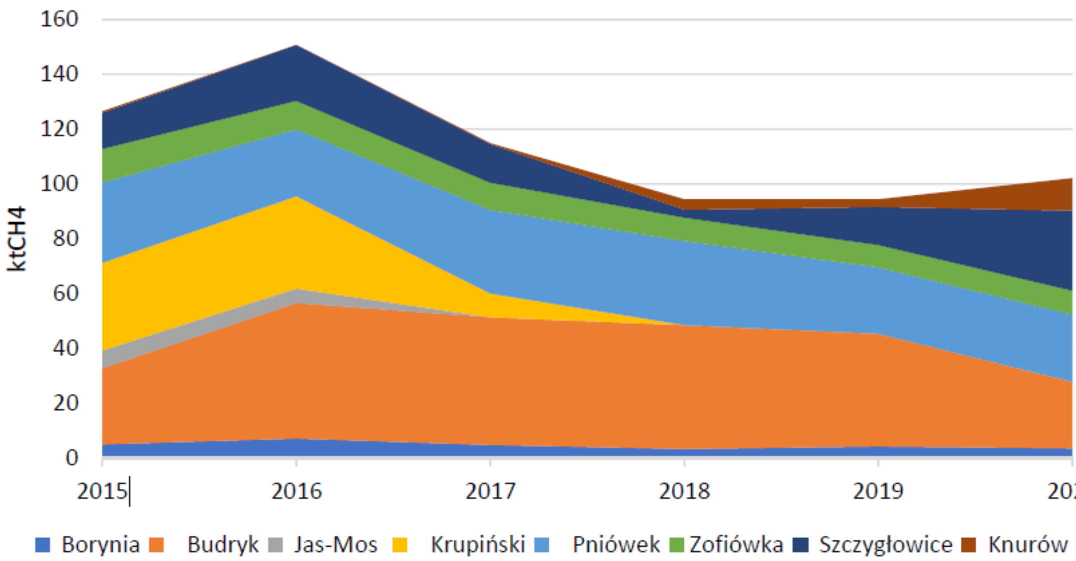


Fig. 11.1 Methane intake in individual JSW mines for 2015÷2020 [Szlązak, 2021]

In the period from 2015÷2020, the most methane was captured in the Budryk coal mine, a total of 234.1 kt (Fig. 11.1). This amount increased in 2016 compared to 2015 by 22 kt and remained at a similar level until 2018, from 41.1 kt to 49.4 kt. In 2020, however, it decreased to 24.2 kt. Large amounts of methane were captured in the Pniówek coal mine, a total of 163.3 kt of methane. The annual intake ranged from 24.4 kt to 30.4 kt. Active methane removal was also carried out in the Borynia-Zofiówka Coal Mine, where 98 kt of methane was captured. It should be noted that the lowest amount, only from 3.3 kt to 7.2 kt, was attributed to the Borynia Section [Szlązak, 2021].

JSW SA carries out activities aimed at increasing the efficiency of methane use included in methane drainage systems by expanding the existing infrastructure. The following investments have been completed in recent years:

- in the Budryk Coal Mine – July 2020 - an ECOMAX gas engine was launched with a total power of $2MW_{el}$, which in combination with the already installed JMS624GS-SL $2x4MW_{el}$ engines gives a total power of 10 MW_{el},
- Coal Mine Knurów-Szczygłowice Section Knurów - July 2020 CAT CG 260-16 3x4 MW_{el} gas engines with a total power of 12 MW_{el} were launched.

11.4. Modernization of the methane drainage system at JSW SA

In 2011, a Commission was established at JSW SA, the aim of which was to conduct an inventory of measuring devices used for mutual settlement of the amount of gas from methane drainage system sold by JSW SA to Spółka Energetyczna "Jastrzębie"[1] SA (SEJ).

The Commission proposed that the amount of gas captured by methane drainage stations and sold to customers should be measured by devices with a legalization or calibration certificate, and the composition and parameters of the gas should be measured by chromatographs. All measuring devices were also to be integrated and visualized in the dispatch systems of both JSW and SEJ. The facilities in which such systems should be installed were also indicated. These were to be JSW facilities: methane drainage station of the Borynia-Zofiówka Coal Mine, Borynia Section, methane drainage station of the Borynia-Zofiówka Coal Mine, Zofiówka Section, methane drainage station of the Jas-Mos Coal Mine, methane drainage station of the Pniówek Coal Mine, methane drainage station Coal Mine Krupiński and SEJ plants: Zofiówka Heat and Power Plant and Moszczenica Heat and Power Plant. In Fig. 11.2. [JSW odmetanowanie] shows the condition of the methane drainage network maintained by the "Zakład Odmetanowania Kopalń"[2] (ZOK).

11.4.1. Rules for gas settlement between JSW and SEJ

The composition and parameters of the gas mixture in the methane drainage network vary over time. For the purposes of gas settlement, it is necessary to convert the gas expenditure into the so-called normal conditions. For this reason, AGH Kraków developed a method for measuring gas parameters in the methane drainage pipeline and an algorithm for gas balancing and settlement in the so-called normal conditions, i.e. temperature 273 K and pressure 1013 hPa, which are the reference point when calculating the gas volume. The developed algorithm takes into account the exact composition of the gas (the content of individual components such as methane, ethane, propane, carbon monoxide, carbon dioxide, oxygen,

[1] Jastrzębie Energy Company
[2] Methane Drainage Plant

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nitrogen, hydrogen, hydrogen sulfide) and its physical parameters: temperature, pressure, humidity and atmospheric pressure.

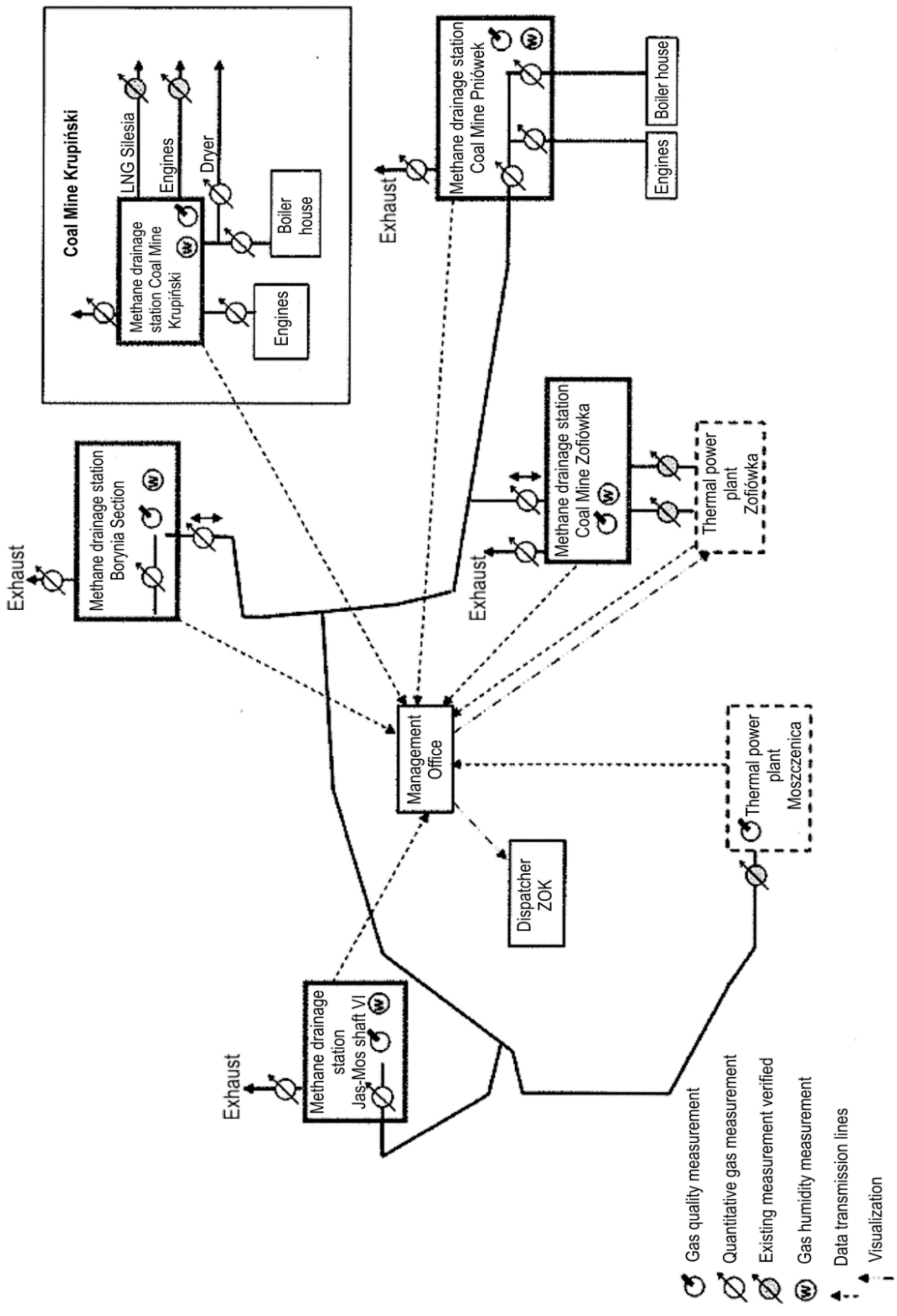

Fig. 11.2. Connection diagram of the methane drainage network within JSW SA

At that time, the so-called gas volume converters were available on the market, to which gas volume, temperature and pressure measuring transducers are connected. On this basis, the converter gives the volume of gas under normal conditions. These devices also made it possible to enter the composition of the gas for which calculations were made. Devices of this type work well in the gas industry, where the composition of the gas mixture is constant, while in the gas mixture from the methane drainage network, the composition of the mixture of gases changes dynamically, which eliminated the possibility of using available conversion factors [Berger, 2016]. In the gas mixture from the methane drainage network, the methane content varies from 30% to even more than 70%, and therefore, the concentrations of all other components in the mixture of gases also change. In the study prepared by AGH entitled "Methane balance in the methane removal network of JSW SA" describes the algorithm for converting the gas mixture from the methane removal network to normal conditions and the balancing method for individual plants and the entire gas network connecting JSW SA with SEJ.

11.4.2. Devices and measuring points

To ensure high measurement reliability and low measurement error, high-class devices with legalization certificates were selected. The measurement system was based on turbine gas meters from the Polish manufacturer COMMON SA and the Dutch Elster- Instromet. Fig. 11.3 shows a view of the CTG-02 turbine gas meter from COMMON SA.

Fig. 11.3. View of the CGT-02 turbine gas meter, manufactured by COMMON

Fig. 11.4. View of the PGC5000 gas chromatograph from ABB

In places where it was not possible to install turbine gas meters, it was decided to use thermal mass flow meters manufactured by FCI. ABB process chromatographs were selected to measure the gas composition. Fig. 11.4 shows a view of the components of the ABB PGC5000 chromatograph.

Additionally, pressure transmitters from the Polish manufacturer Aplisens, temperature transmitters from Bartec Polska and gas humidity transmitters were used. Each methane drainage station and the Moszczenica Heat and Power Plant have a set consisting of a chromatograph, a humidity meter and an atmospheric pressure transmitter. Each point measuring the volume of flowing gas was equipped with a gas meter or flow meter, a gas pressure transmitter and a gas temperature transmitter. This set of measurements allowed for the standardization of gas volume measurement, and thus for balancing and settling gas consumption.

The following elements were built at the “Borynia” methane drainage station:

- turbine gas meter in the station's force main,
- thermal flow meter in the station exhaust,
- bidirectional turbine gas meter in the gas network.

For monitoring purposes, measurements from existing thermal flow meters in the gas engine and the boiler room were used. Fig. 11.5 [JSW odmetanowanie] shows the gas network equipment in the Borynia-Zofiówka-Bzie Coal Mine, Borynia Section.

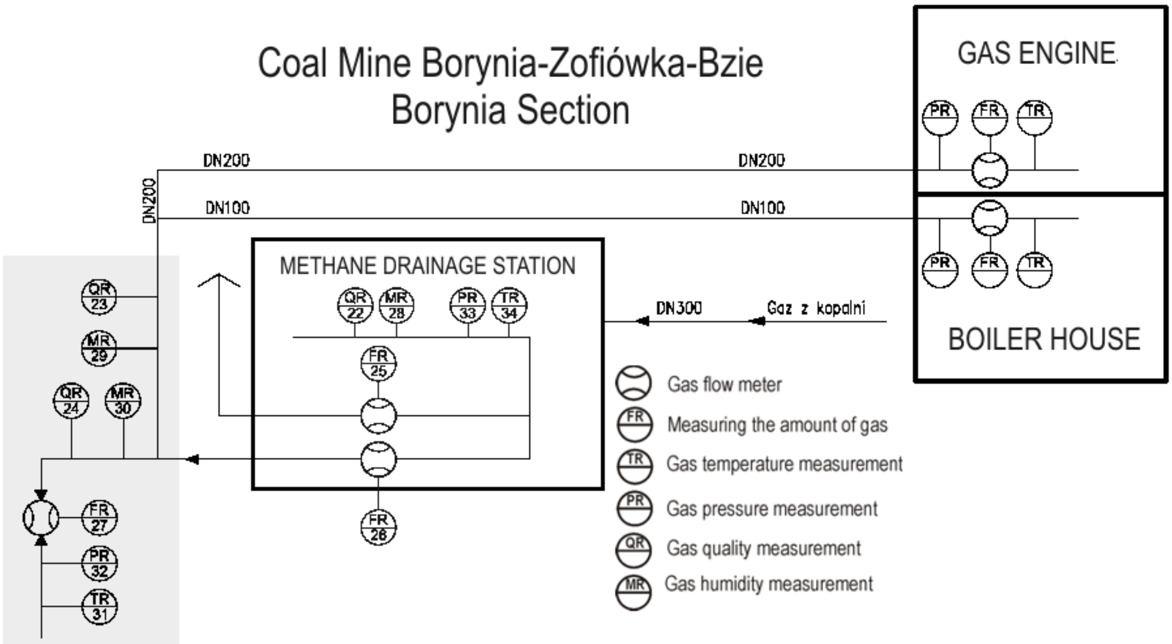

Fig. 11.5. Diagram of gas network instrumentation in Borynia Section

The following elements were built at the Zofiówka Section methane drainage station:
– turbine gas meter in the station exhaust,
– bidirectional turbine gas meter in a gas network.

For the purposes of monitoring the methane drainage network, measurements from three existing turbine gas meters at the Zofiówka Heat and Power Plant were used. Fig. 11.6 [JSW odmetanowanie] shows the gas network equipment in the Zofiówka Section.

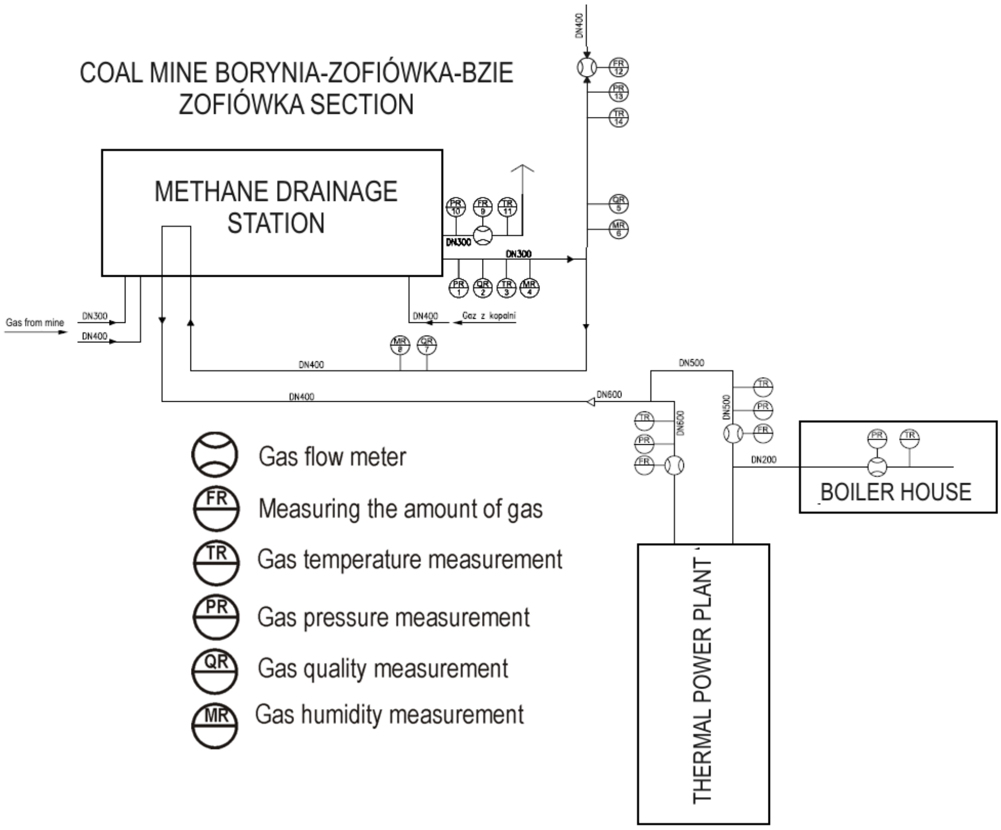

Fig. 11.6. Diagram of gas network instrumentation in Zofiówka Section

The following elements were installed in the methane drainage network of the Jas- Mos Coal Mine:

– thermal flow meter in the station exhaust,
– turbine gas meter in the gas network.

Fig. 11.7 [JSW odmetanowanie] shows the gas network equipment in the Jas-Mos Coal Mine.

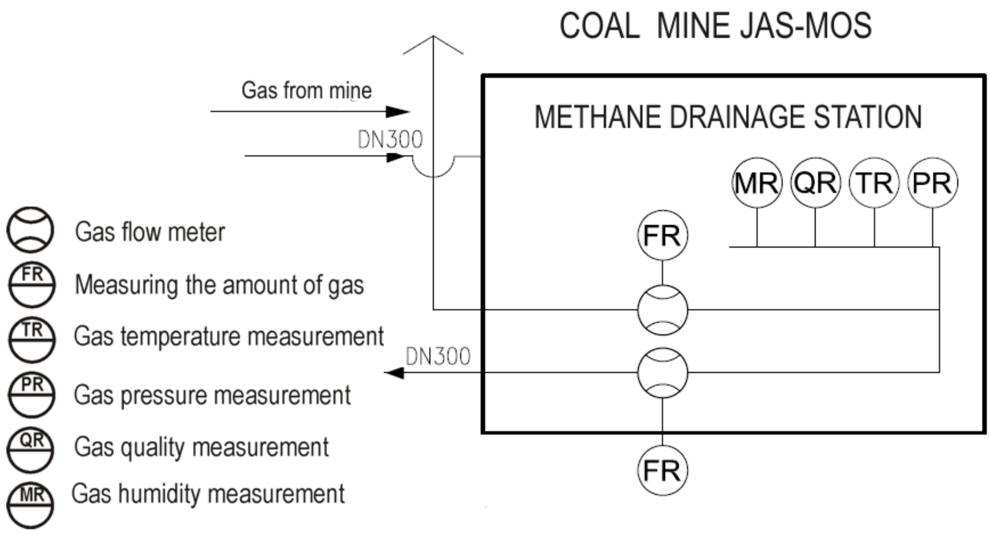

Fig. 11.7. Diagram of the gas network equipment of Jas-Mos Coal Mine

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The following elements were installed in the methane drainage network of the Pniówek Coal Mine:

– turbine gas meters on the 1st and 2nd exhaust stage of the station,
– turbine gas meter on the gas network,
– turbine gas meter at the Pniówek Heat and Power Plant,
– turbine gas meter on the gas engine of the Pniówek Heat and Power Plant.

Fig. 11.8 [JSW odmetanowanie] shows the instrumentation of the gas network in the Pniówek Coal Mine.

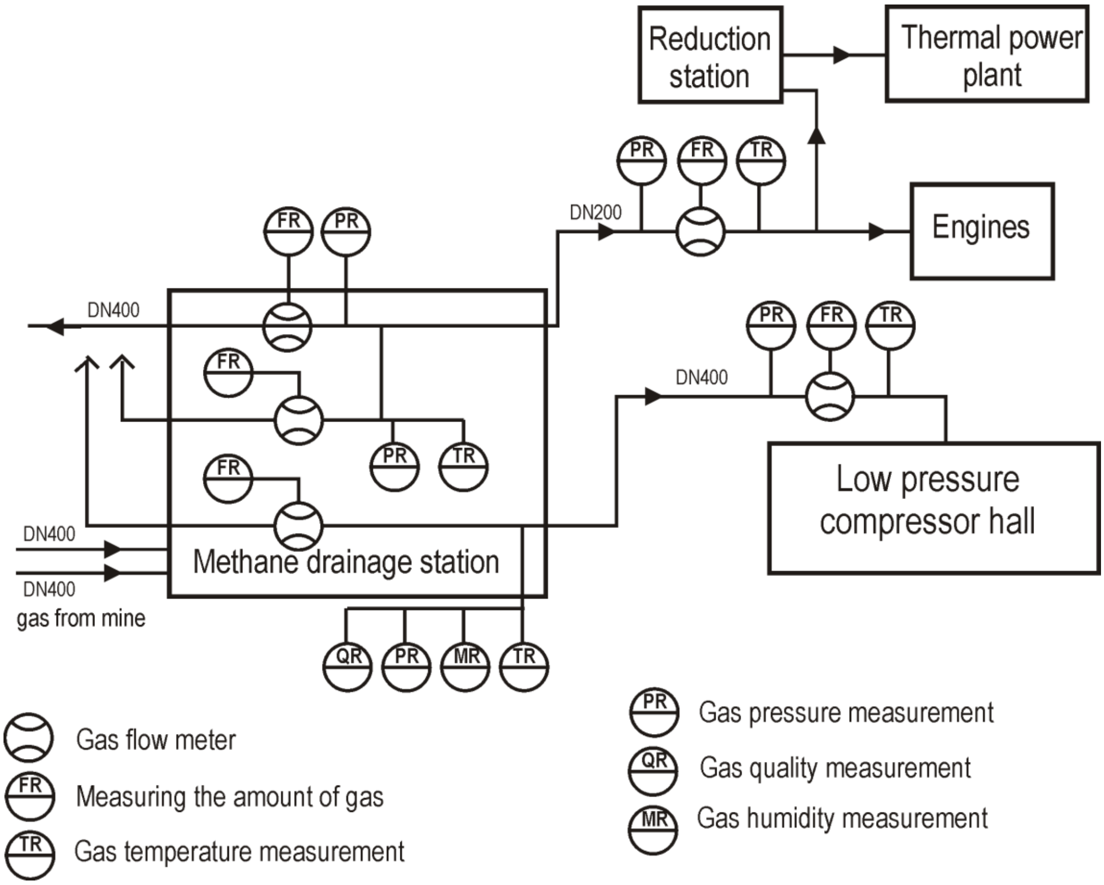

Fig. 11.8. Diagram of the gas network instrumentation of the Pniówek Coal Mine

The following elements were installed in the methane drainage network of Krupiński Coal Mine:

– thermal flow meter at the exhaust of the methane drainage station,
– turbine gas meter in the dryer,
– turbine gas meter in the boiler room of the Suszec Heat and Power Plant,
– turbine gas meter on the gas engine of the Suszec Heat and Power Plant.

For the purposes of monitoring the methane drainage network, measurements from existing turbine gas meters in the gas engine and the gas liquefaction installation were used. Fig. 11.9 [JSW odmetanowanie] shows the instrumentation of the gas network in the Krupiński Coal Mine.

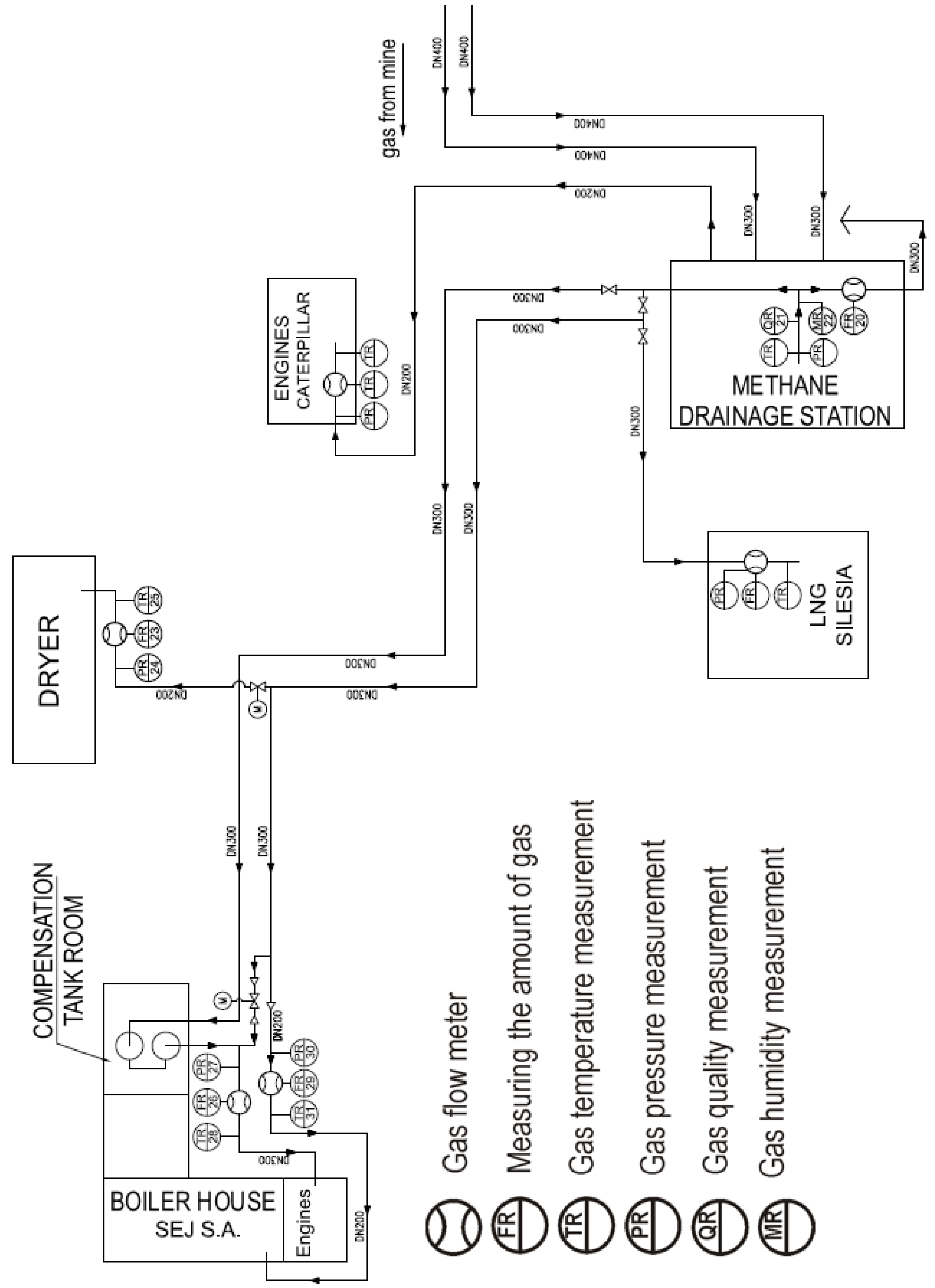

Fig. 11.9. Diagram of the gas network instrumentation of Krupiński Coal Mine

At the Moszczenica Heat and Power Plant, a turbine gas meter was installed in the gas network. For the purposes of monitoring the methane drainage network, measurements from existing turbine gas meters in the gas engine and gas boiler were used. Fig. 11.10 [JSW odmetanowanie] shows the gas network equipment at the Moszczenica Heat and Power Plant.

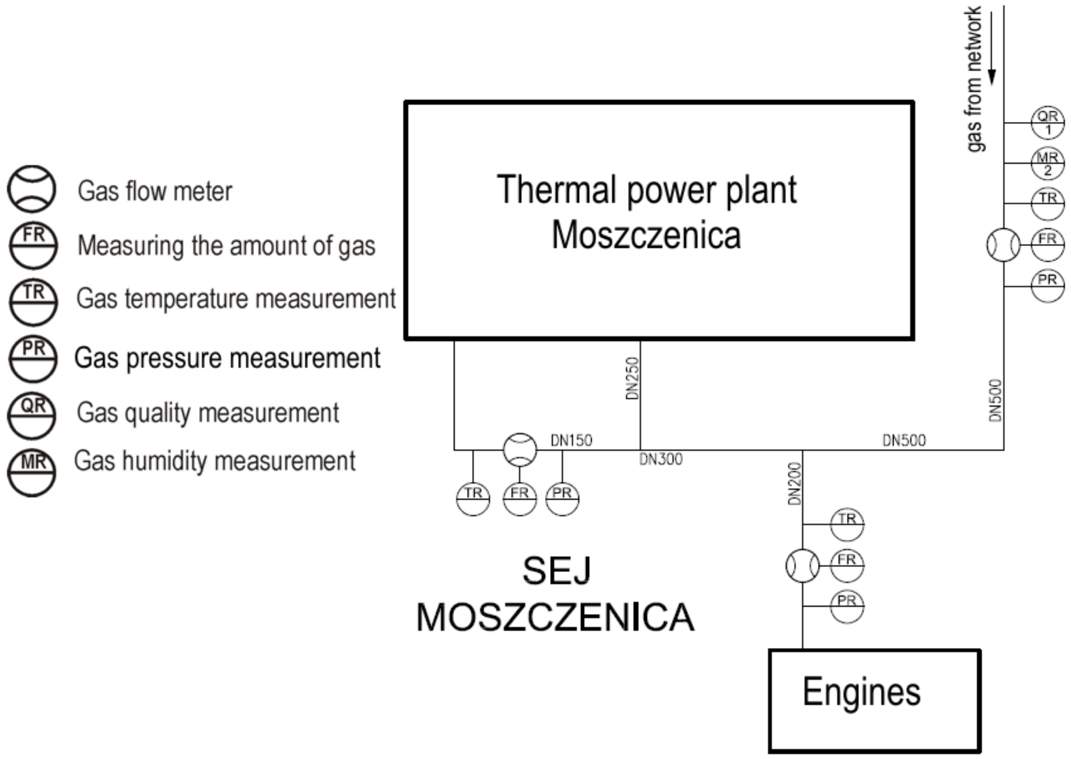

Fig. 11.10. Diagram of the gas network instrumentation of the Moszczenica Heat and Power Plant

In 2014, a new methane drainage station was put into operation at the “Budryk” Coal Mine. The Budryk gas network was equipped with the following elements:

– turbine gas meter for station exhaust,
– turbine gas meter for the gas recipient,
– turbine gas meter in the boiler room.

11.4.3. Monitoring of the methane drainage network

The modernization of methane drainage systems in individual mines also included appropriate monitoring (including the settlement part), which was intended to allow for the integration of information in the database and a global view of the methane drainage process. A computer system for visualization, registration, archiving and balancing of methane was designed and implemented at individual methane drainage stations and globally in the entire gas network connecting the gas supplier - JSW - with its recipient - SEJ. The system is based on the ASIX platform intended for the design and implementation of industrial IT systems for enterprises, processes, technological lines, machines and devices.

Local servers collecting and archiving data have been installed at individual methane drainage stations. The data was integrated on servers directly from measuring devices or via PLC programmable controllers. An algorithm was implemented in each server to convert the gas volume to normal conditions, so they also became gas volume converters. The servers use the ASIX platform.

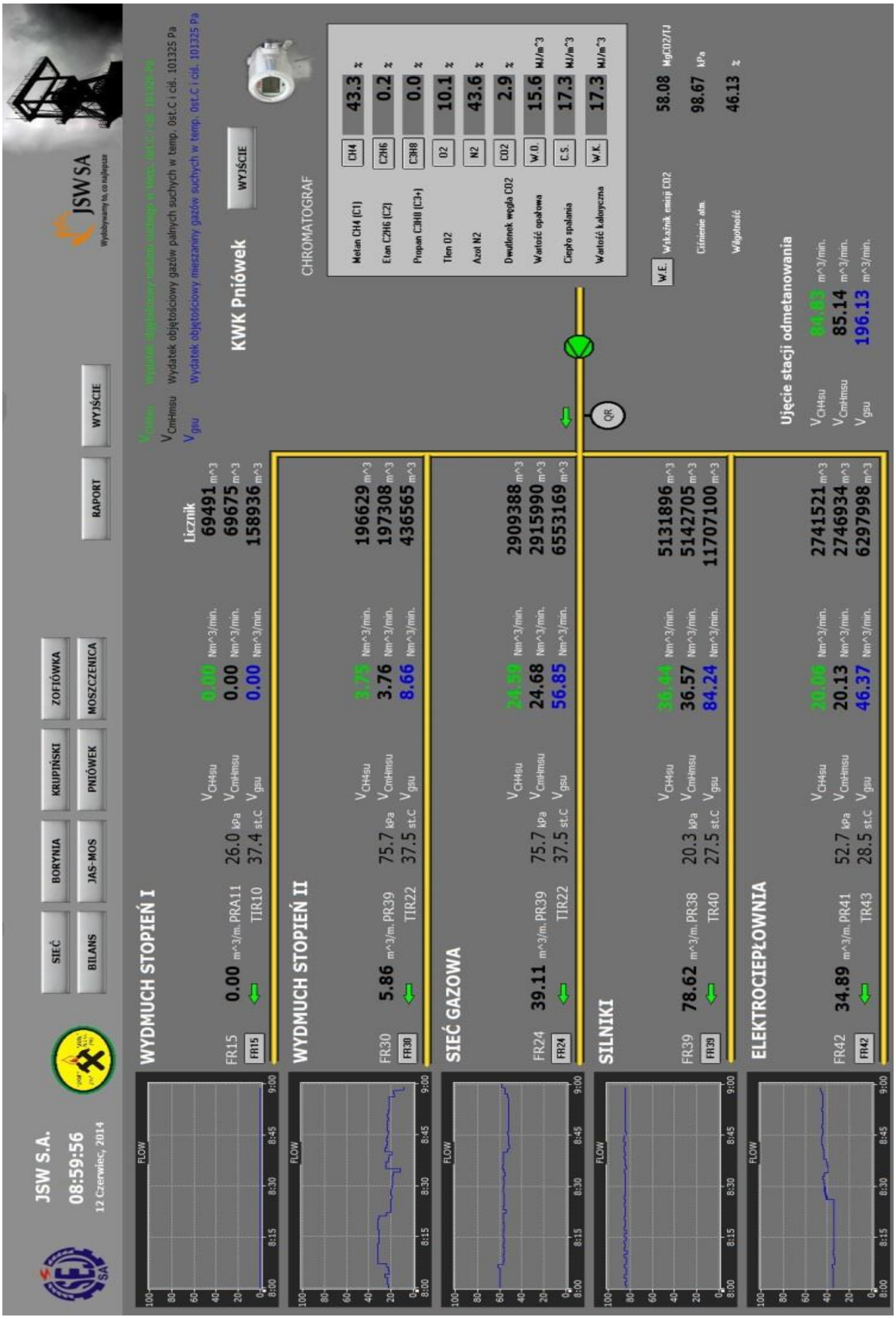

Fig. 11.11. Visualization screen of the gas network of the “Pniówek” Coal Mine

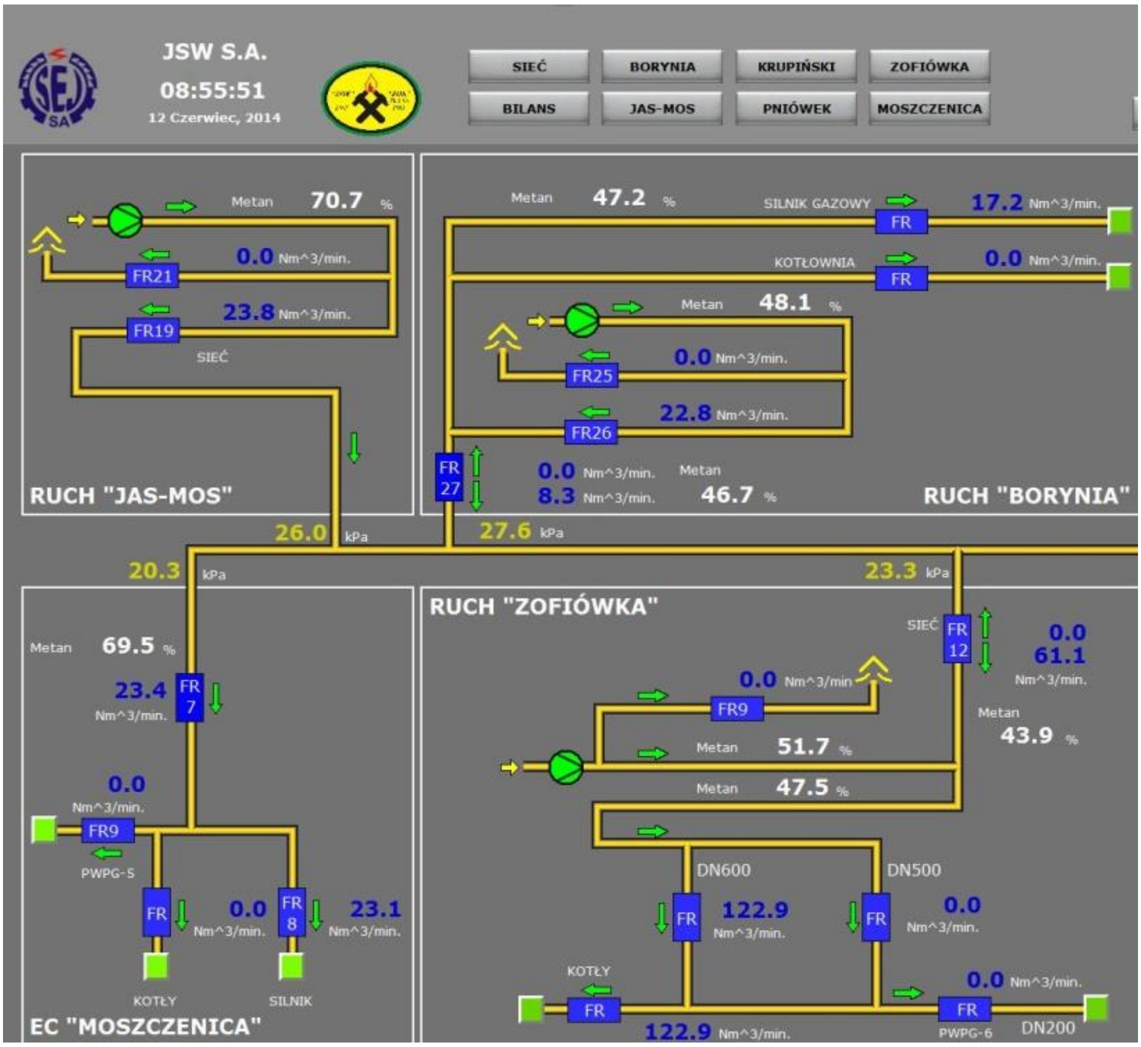

Fig. 11.12. Fragment of the visualization screen of the methane drainage network supervised by ZOK

Fig. 11.11 shows the visualization screen of the methane drainage network in the "Pniówek" coal mine. The screen shows the gas composition measured with a chromatograph and the flows, temperature and pressure in individual branches. At each station, a visualization of a given facility is available, along with access to archived data and an extensive reporting module. The visualization stations presented current current flow measurements, flows converted to normal conditions and other parameters, such as: gas composition, atmospheric pressure, pressures and temperatures in pipelines, etc.

A main server collecting current and archive data from all local servers was also installed. The server was installed in the server room of ZOK, which, under separate agreements, ran the methane drainage system in JSW mines and operated methane drainage stations in the initial period of implementation. Communication between local and central servers was carried out using the GSM mobile network. ZOK was also entrusted with the operation of the server and computer system as well as supervision of the entire gas network. A "gas dispatcher control room" was created at the ZOK headquarters, where visualization of all plants and the entire gas network was made available. The dispatcher continuously (24 hours a day) supervised the operation of the methane drainage station and gas recipients and decided on the flow of gas between individual plants. This was the first step towards effective management of gas from methane dewatering, leading to maximization of its use and minimization of emissions into the atmosphere. The duties of the gas traffic dispatcher also included reporting on current gas use and preparing monthly commercial balances for JSW and SEJ. The dispatcher also acted as a mediator in the event of any discrepancies and ambiguities arising during mutual settlements. Fig. 11.12 shows a fragment of the visualization screen of the methane drainage system supervised by ZOK. The visualization screen shows normalized gas flows and concentrations at measuring points of the methane drainage network.

11.5. Transferring monitoring of the methane drainage network to the HADES system

The ZOK dispatcher performed his role until July 2021. Therefore, it can be assumed that for a period of eight years from the commissioning of the methane removal system at JSW SA, the measuring systems for the quantity and quality of gas from methane removal, together with the computer system, fulfilled the tasks assigned to them. In 2019, by decision of the Management Board of JSW, the process of creating its own methane drainage structures began and as of August 1, 2021, the maintenance of the measurement system and operation was taken over entirely by JSW SA. The main system server from ZOK and local servers in individual methane drainage stations were taken over.

At the same time, the JSW SA capital group began implementing the "Standardization of data and SCADA systems" project. As part of the project, JSW ITS Systems launched an original SCADA system with the company name HADES based on the Asix.EVO platform. The system has a modular structure and allows you to successively connect subsequent devices or entire installations, visualize their operation and control devices and processes. The existing ZOK methane drainage monitoring system was incorporated into the HADES system. In mid-2020, the Methane Balance module was launched in the HADES system. After the testing period, on August 1, 2021, the Methane Balance module was fully ready for operation and from now on, this system is a module of the HADES system, and reporting and maintaining the gas balance from methane drainage remains the responsibility of the Methane Drainage and Methane Management Office of JSW SA. Supervision of the methane drainage network is carried out by the Orderly Engineer of the Jastrzębie Plant (Zofiówka Heat and Power Plant).

At the same time, for the needs of the Methane Balance module, fiber optic infrastructure was provided to each methane drainage station. The GSM network, which was previously used for data transmission, although it worked quite well in the existing system, was replaced with a fiber-optic network. The reason for its replacement was primarily due to certain transmission conditions related to changing weather conditions and frequent renovation works carried out by an external supplier of this service.

The application itself has gained new functionalities - access via a web browser from any computer in the JSW network has become possible, the reporting module has been expanded and adapted to new requirements, the reporting system available in older versions of the ASIX platform has been abandoned in favor of data export to Excel and enabling users to create personalized reports according to individual needs. This significantly improved reporting capabilities and comfort of working with data. The graphic design of the visualization itself was also changed. Fig. 11.13 [JSW odmetanowanie] shows the screen of the Methane Balance module in the HADES system.

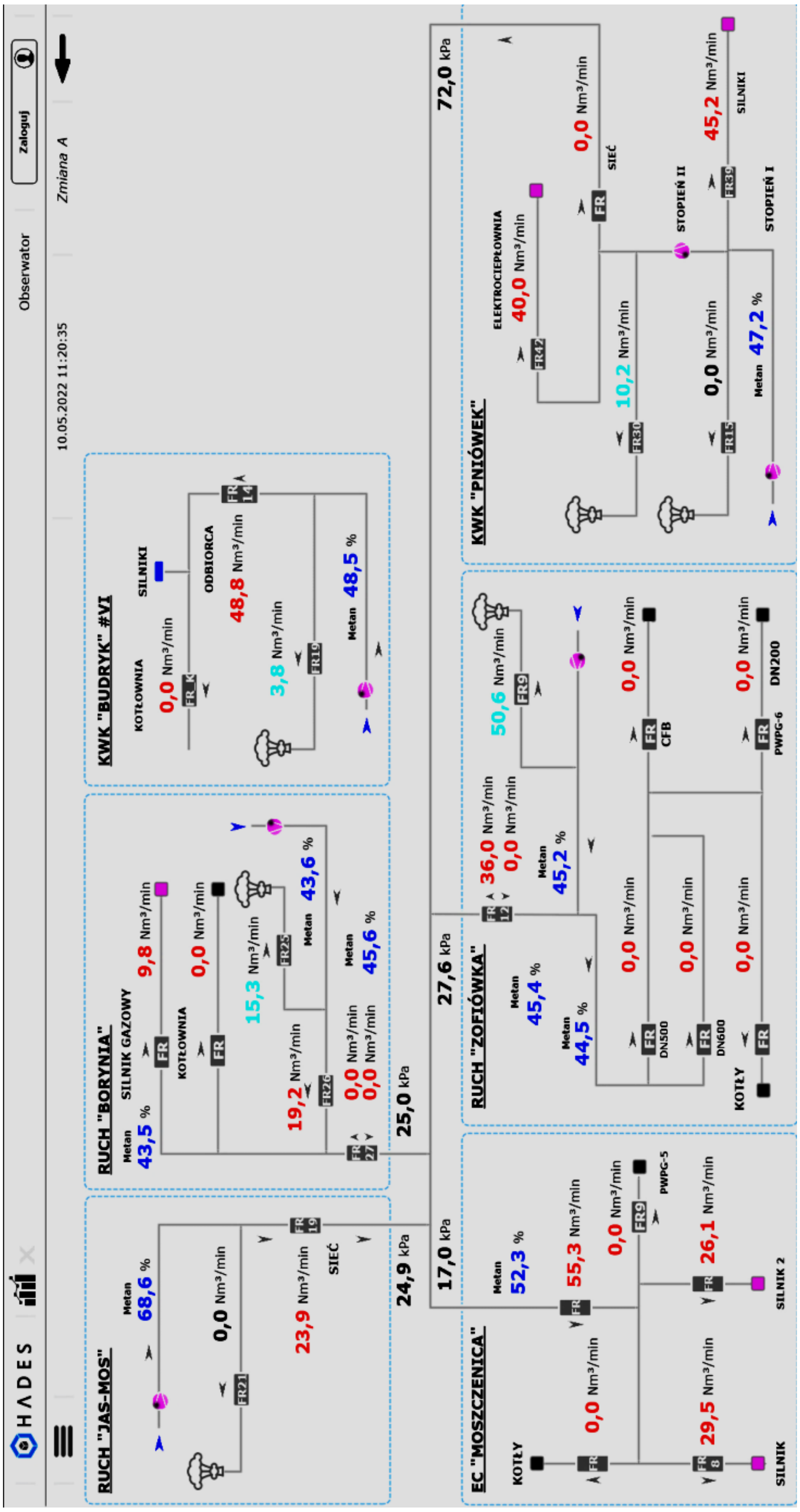

Fig. 11.13. Gas network screen of the Methane Balance module in the HADES system (screenshot inversion)

The visualization screen shows normalized flows, gas concentrations and pressures at the measuring points of the methane drainage network.

11.6. Monitoring of the underground part of the methane drainage network

Simultaneously with the migration of the settlement system to the HADES system, another innovative project was started in JSW mines involving the construction of a measurement system for underground main methane drainage networks and another module called Methane Dewatering was launched. First, key points in the underground main methane drainage networks were selected in every JSW mine where measurement systems should be installed. A total of 60 such points were identified in all JSW plants:

- in the Borynia Section - 8 measurement points,
- in the Zofiówka Section - 8 measurement points,
- Pniówek Coal Mine – 18 measurement points,
- Budryk Coal Mine – 8 measurement points,
- in the Knurów Section - 8 measurement points,
- in the Szczygłowice Section - 10 measurement points.

Each measuring point consists of an orifice meter with a differential pressure transducer, a methane meter adapted to measure methane in the pipeline, a pressure and a temperature transducers. All the works were carried out by the company's own methane drainage and communications departments, and the prefabricated pipeline elements to which the measurement converters are mounted were manufactured by a company from the JSW SA group - Jastrzębskie Zakłady Remontowe. Communication with underground devices is provided by the HASO CST system. Fig. 11.14 shows a fragment of the general screen of the Methane drainage [JSW odmetanowanie] module.

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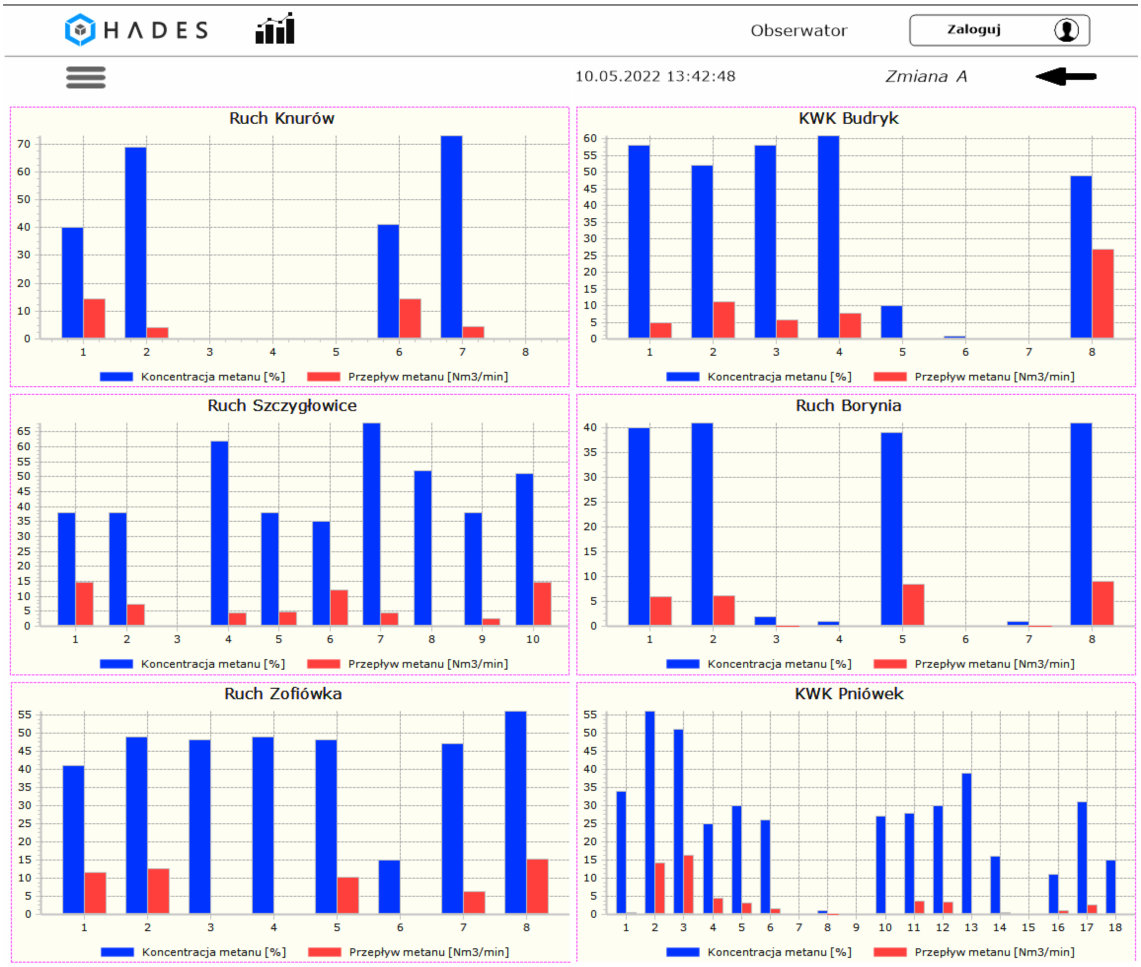

Fig. 11.14. Fragment of the general screen of the Methane Drainage module (screenshot inversion)

The screen shows the normalized gas flow and methane concentration at individual measurement points of the underground methane drainage network. Fig. 11.15 [JSW odmetanowanie] shows the detailed screen of the Methane drainage module for the "Knurów-Szczygłowice" Coal Mine.

The screen shows the values of normalized flow, methane content, pressure and temperature at individual measurement points of the underground methane drainage network.

All site works, including the assembly of prefabricated pipeline elements, installation and connection of measurement transducers, and programming works, consisting in creating the methane drainage module in the HADES system and obtaining measurement data, were completed before the end of 2020. As a result, a measurement system was created covering the methane drainage networks of all JSW mines.

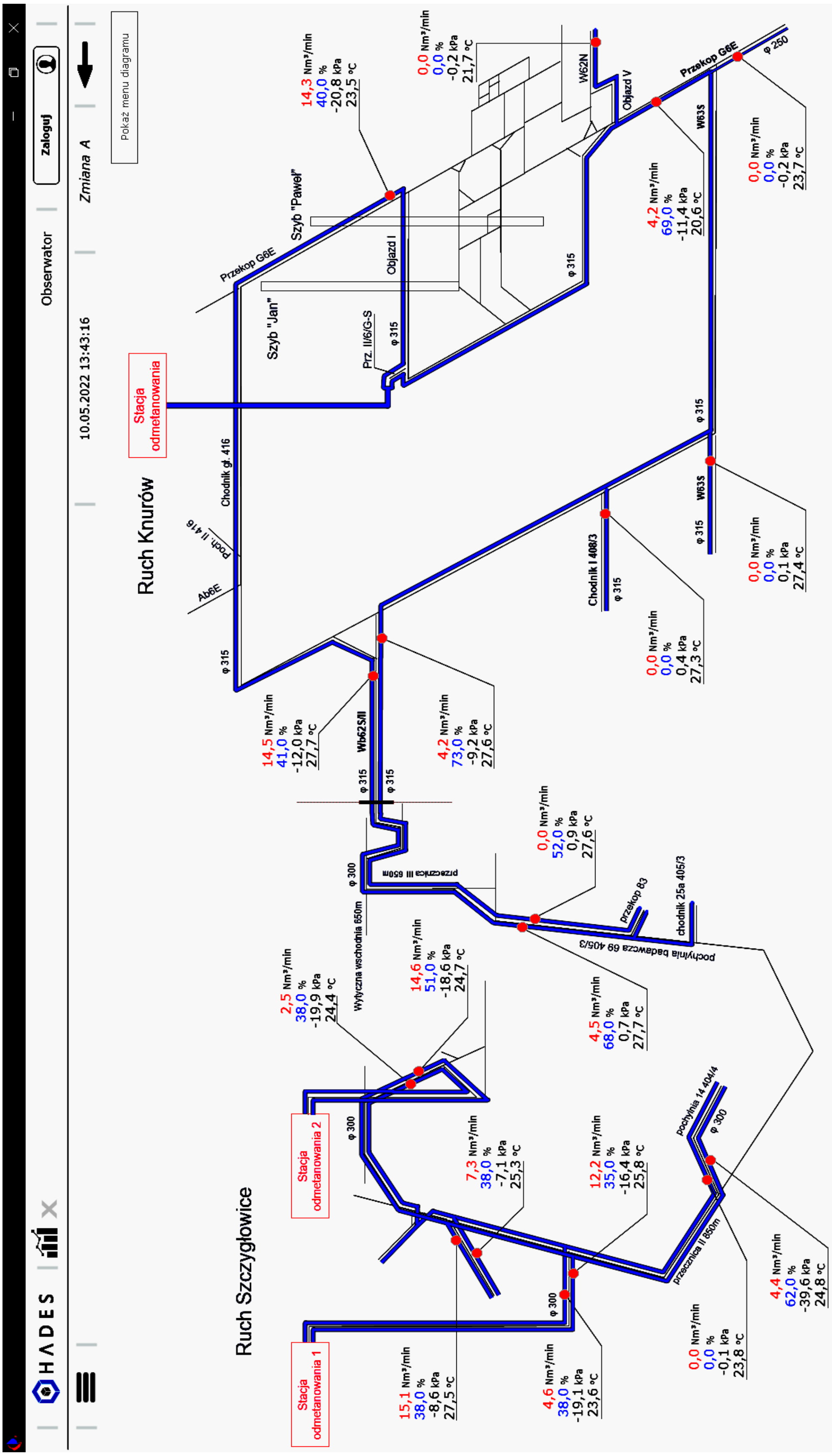

Fig. 11.15. Detailed screen of the methane drainage module for “Knurów-Szczygłowice” Coal Mine (screenshot inversion)

11.7. Summary

The implementation of a comprehensive monitoring system for methane drainage and methane balancing systems was successful. Initially, the ZOK Department was responsible for monitoring the methane drainage network. Methane drainage stations in all JSW mines were modernized and measurement systems were installed to calculate standardized gas flows in the methane drainage network. A methane drainage control room was built at the ZOK headquarters, equipped with monitoring of the methane drainage network. Measurement data was transmitted to the control room via the GSM mobile phone system.

In 2021, monitoring of the methane drainage network was transferred to the JSW network by expanding the HADES system with the Methane Balance module. The control room of the methane drainage system is operated by the Orderly Engineer of the Jastrzębie Plant (Zofiówka Heat and Power Plant). In the underground part of the methane drainage network, 60 measurement points were built and included in the Methane Drainage module of the HADES system.

Monitoring the underground part of the methane drainage network will make it possible in the future (after supplementing the measurement points with a control gate valve) to regulate the methane drainage network by obtaining a set gas flow in the pipeline with a methane concentration not lower than the set value [Dziurzyński 2015].

12. Monitoring of seismic phenomena

Adam Lurka, Grzegorz Mutke, Zbigniew Szreder

12.1. Introduction

The Central Mining Institute - National Research Institute (GIG) has been conducting research on the development of seismological equipment with appropriate interpretation methodology for several dozen years, allowing for the assessment of seismic and rock burst hazards [Barański, 2012; Dubiński, 2000; Lurka, 1998; Lurka, 2005; Mutke, 2015; Mutke, 2019; Kabiesz, 2015]. For many years, seismological equipment has been used and still is used in Polish mines, which, in terms of the electronic units used, allows the recording of seismic phenomena in the energy range from 10^2 J to even 10^{10} J, depending on the hardware settings and the type of seismic sensors. Unfortunately, with the significant improvement in the functional parameters of the seismological equipment itself, only the source location of the mining seismic events and seismic energy are routinely determined in mine geophysics stations. This is probably the result of a number of substantive, legal and technical conditions, but in fact, at present, nothing prevents mine geophysics stations from being equipped with seismic equipment allowing routine calculation of a number of other parameters characterizing seismic phenomena, and thus indirectly also characterizing the rock mass. subjected to exploitation. This is mainly about calculating seismic source parameters such as seismic moment, stress drop, apparent stress, focal radius, apparent volume, source displacement and spectral energy, as well as derived parameters such as energy index, seismic Schmidt number and seismic Deborah number [Mendecki, 1997] It should be emphasized that the parameters describing the seismic source, which have not been routinely calculated in the Polish mining industry so far, are determined by seismological systems installed in mining in South Africa, Australia, USA, China, Indonesia and Canada. This is therefore an area in which generally understood Polish mining seismology, which is not undoubtedly inferior to global mining seismology in terms of substantive level, but lags behind what is calculated in the best underground mines in the world. The possibility of routine calculation of these parameters is inextricably linked to the introduction of three-component seismic sensors with an appropriate frequency bandwidth. However, this is not only a hardware problem, but also a matter of appropriate software provided with the seismological equipment. Therefore, there is a very urgent need to introduce the possibility of routine or automatic calculation of additional seismological parameters directly in Polish mines. To achieve this goal, it is necessary for the seismological equipment to be provided with software that will allow for the calculation of these new parameters in a simple and uncomplicated way, just as currently the location of mining tremors and the determination of seismic energy are carried out. Based on the example of the latest version of the Seismological Observation System (SOS) designed and manufactured in the Mining Geophysics Laboratory of the Central Mining Institute - National Research Institute, Poland it can be concluded that it is now possible to easily extend the routine interpretation of seismological data in mines with the above parameters and, additionally, it is possible to more accurately calculate the location and energy of seismic tremors. From this point of view, a serious gap has arisen in the interpretation of seismological data, which prevents further development of mining seismology in Poland.

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12.2. Seismic equipment used in Polish mining - Mining Geophysics Station

The seismic and rock bursts hazard in the hard coal Polish mining industry has been present for at least several decades. As mining depth increases, this problem increases. Currently, most mines operate in seams classified as at high risk of rock bursts. The occurrence of seismic and rockburst hazard affects the level of work safety, requires the application of additional rigors in conducting mining works, and, above all, the need to monitor and assess the rockburst hazard and apply adequate rockburst prevention methods. Based on many years of experience, research and analysis of mining under rock burst hazard conditions, taking into account technical and technological advance, methods and means of assessing and combating this threat have been developed. A legal system and organizational forms of controlling and combating these threats have been created. The basic elements of rock burst hazard assessment systems are:

- station equipment installed in the Mine Geophysics Stations,
- underground equipment installed in underground workings,
- cable mine teletransmission network.

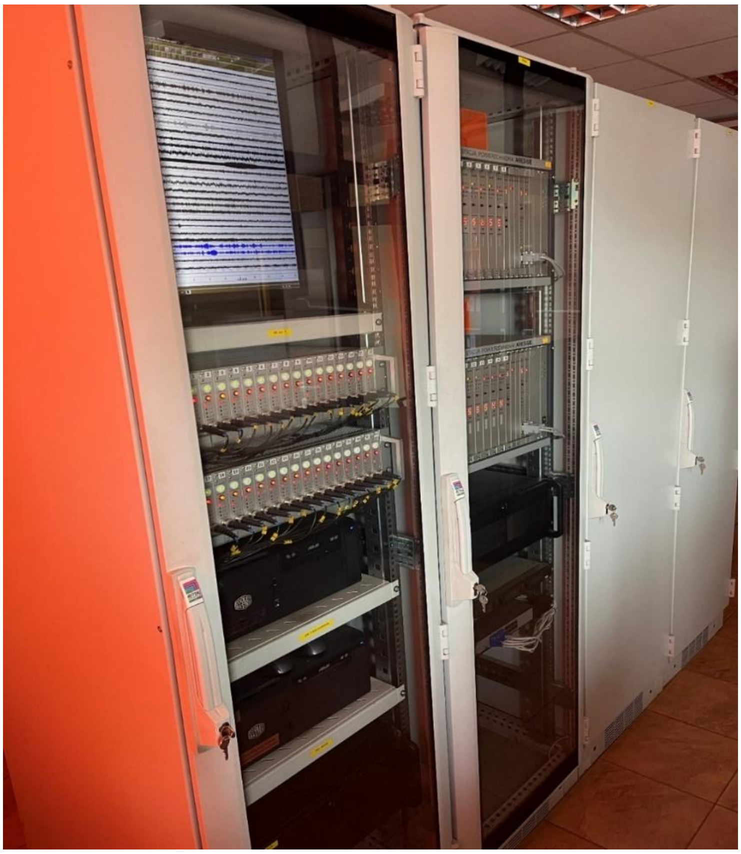


Fig. 12.1. An example of seismic equipment installed at the Mining Geophysics Station, SOS seismic system (left), Ares system (right)

In Fig. 12.1 the SOS seismic system (rack box on the left) and the Ares system (rack box on the right) installed in the Mining Geophysics Station are shown.

The legal basis for the need to use seismic monitoring and rock bursts hazard combating are included in the Polish Geological and Mining Law Act [PGG, 2023] and in the relevant implementing acts to this Act [RME, 2016; RMR, 2016]. They specify, among other things, that the entrepreneur is obliged to recognize hazards related to the operation of a mining plant, take measures to prevent and remove these hazards, and have appropriate material, technical means and services to ensure the safety of employees.

In a mining plant where a risk of rock bursts has been identified and seismic activity occurs, the Mining Plant Operations Manager (KRZG) classifies the seam or part of it as having an appropriate level of rock burst hazard. Then he is obliged to organize a technical service for combating rock bursts hazard in the mine and to launch the Mining Geophysics Station, in which the following systems should be installed:

- seismoacoustic,
- seismological.

The Mining Geophysics Station is classified as one of the so-called basic facilities of the mining plant. It is a separate room located most often near the plant's control room, in which station devices for geophysical systems, dispatcher's telephone and alarm communication systems are installed, and, above all, monitoring of mining induced seismicity and the current technological process in the mine are carried out, in which the dispatcher is particularly interested. The Mining Geophysics Station operates continuously in the mine 24 hours a day. It is headed by a mining geophysics engineer. In accordance with applicable regulations, he is responsible, among others, for [RME, 2016]:

- performing ongoing recordings and analysis of seismic activity of the rock mass in terms of its possible impact on mining excavations and surface objects,
- conducting measurements of:
  - geomechanical properties of the deposit and surrounding rocks, including measurements made using geophysical methods in boreholes,
  - seismic measurements in the deposit and in the surrounding rocks to assess the state of stress, in terms of assessing seismic and rock burst hazards,
  - resistivity of the rock mass to assess the crack distribution, porosity and other features of rocks mass,
  - other properties of the rock mass based on engineering geophysics methods to assess the impact of tremors on surface objects, including studies of shallow layers to determine site amplification coefficients.

In mining plants, the risk of rock bursts is assessed based on the analysis of the results of the following methods [RME, 2016]:

- mining seismology,
- recognizing the hazard of a rock burst due to the geomechanical properties of the coal seams and surrounding rocks and the technological mining conditions,
- observations and measurements of rock mass stress.

KRZG, based on the opinion of the panel of experts in the mine, may also recommend the use of other methods of assessing the rock burst hazard, such as [RME, 2016]:

1) seismoacoustic;

2) induced seismoacoustic activity;

3) seismoacoustic in the surrounding rocks;
4) seismic, including profiling, active and passive seismic geotomography;
5) resistivity;
6) gravimetric;
7) strain gauge;
8) convergence;
9) analytical.

Each Mining Geophysics Station has its own seismological system and seismoacoustic system. In most Polish mines, the mining seismology method is used based on the safety instructions developed by GIG in Katowice entitled **Principles of using the comprehensive method and detailed methods for assessing the hazard of rock bursts in hard coal mines.** The essence of the mining seismology method is to record seismograms of rock mass tremors occurring in the mine and then to analyze them. Examples of recordings of the mining tremors with the use of SOS seimsic system developed in GIG are shown in Fig. 12.2. Seismological monitoring should cover all areas of the mine with high seismic hazard and guarantee to record mining tremors with energy of the order of 10^2 J or higher.

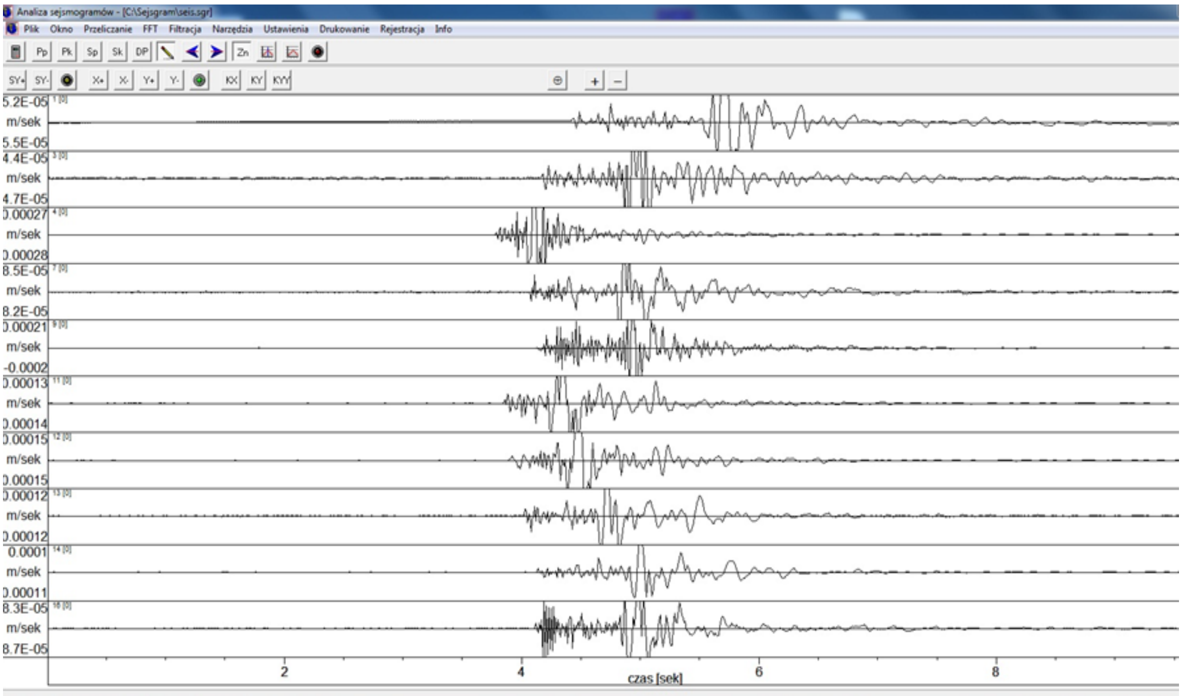


Fig. 12.2. An example digital recording of the mine tremor in the mine by the SOS system

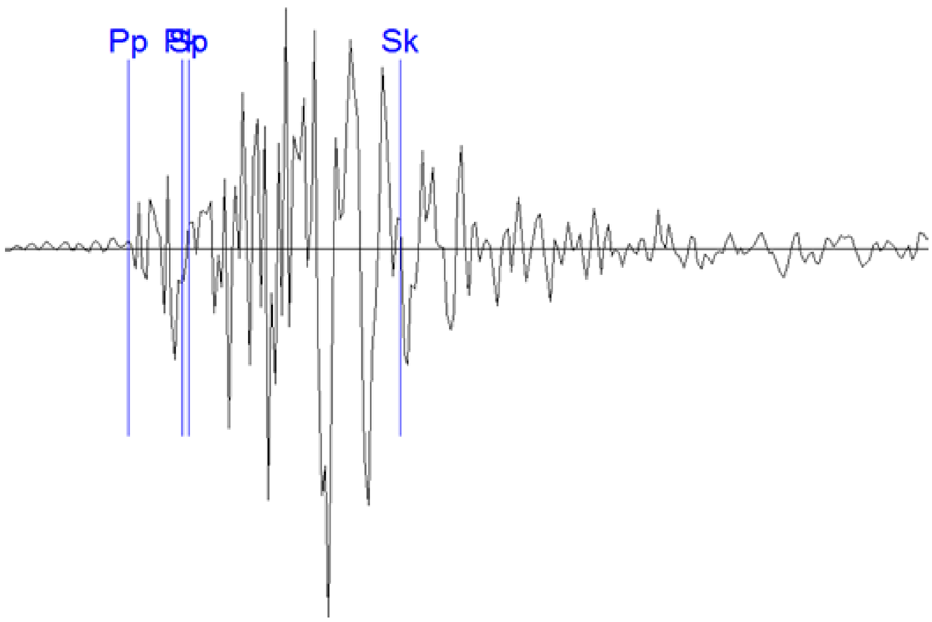
The essential work in the interpretation of recorded seismic tremors is to determine the coordinates of the tremors' foci, calculate the seismic energy and correlate the recorded seismic activity with geological and mining conditions, as shown in Fig. 12.3 and 12.4. In Fig. 12.3 a), the following features of seismic event are shown:

– Pp – the onset time of the seismic P body wave,
– Pk – the end of the duration of the P body wave,
– Sp – the onset time of the seismic S body wave,

– Sk – the end of the duration of the S body wave.

In Fig. 12.3 b), green squares mark the location of individual sensors, and the red circle indicates the location of the recorded seimsic event.

a)



b)

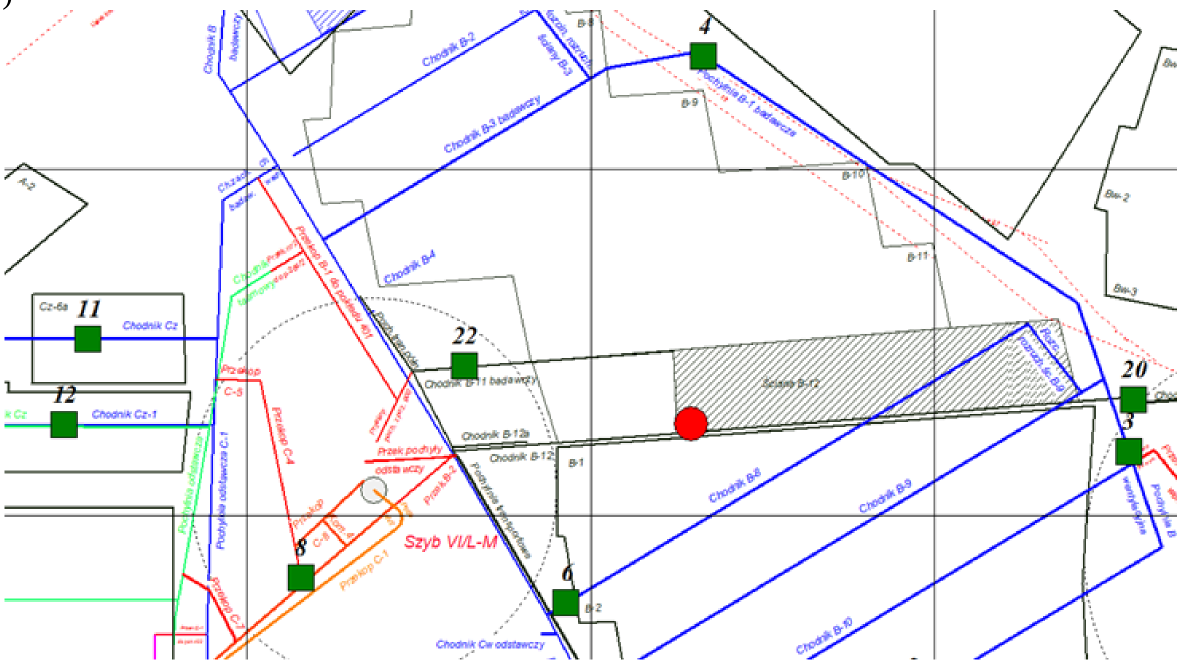


Fig. 12.3. An example of the location of a recorded seismic event using the SOS seismic system software

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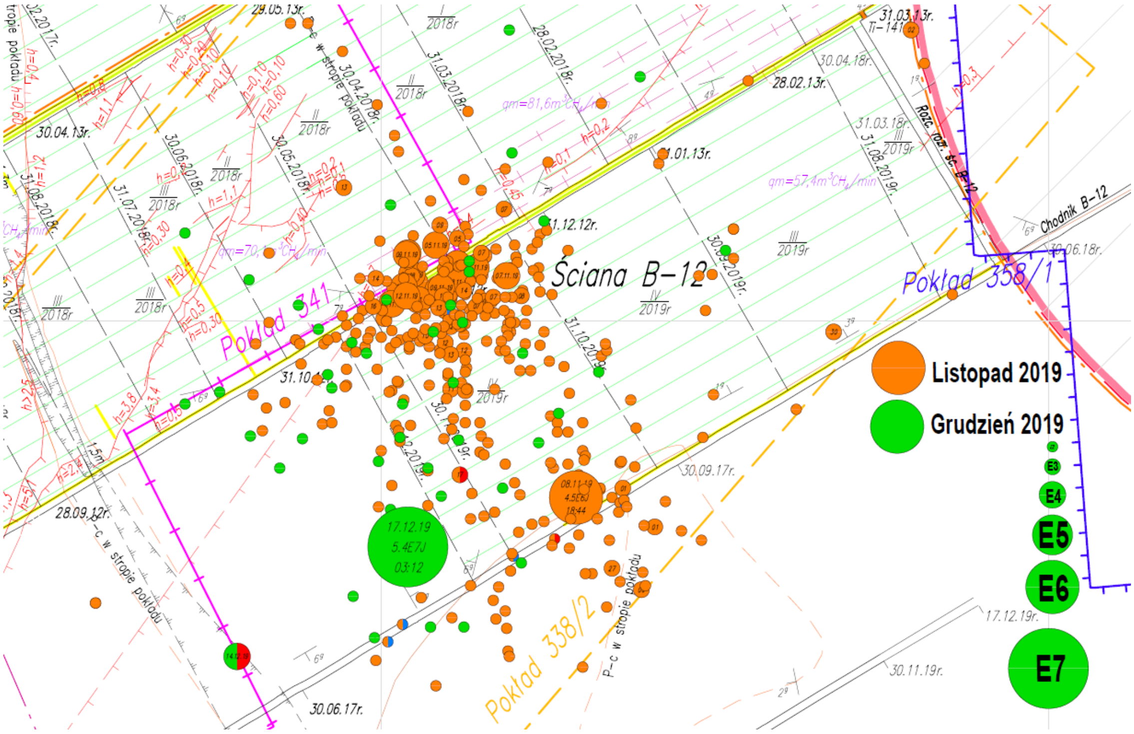

Fig. 12.4. An example of graphical presentation of the seismicity distibution with the edges of the old coal panels marked

To ensure correct interpretation of recorded mining tremors, each channel of the seismological system must have calibration frequency characteristics determined at least every two years. If possible, underground seismic stations should be built so that all areas at risk of rockfalls are located within the mine seismological network and are arranged in accordance with the seismological network optimization documentation, which determines the errors of mining tremors for the planned mining operations for various distribution of seimsic stations. The results of seismological monitoring and analysis are documented on an ongoing basis, at least once a day.

Each Mining Geophysics Station has an uninterruptible power supply: primary from the power grid and reserve from batteries buffered by a combustion generating set.

12.3. Seismological systems operated in Polish mines

Currently, there are two seismological systems installed in Polish mines:

– SOS Seismological Observation System developed by GIG in Katowice,
– ARAMIS M/E Seismic System manufactured by CTT EMAG in Katowice.

Older seismological systems may still be used in mines, such as: ARAMIS, SYLOK, AS-1, LKZ, Górnik-1 (most often these are the names of the manufacturers of these systems).

The surface part of the systems includes: seismic receiver stations, a recording server or seismological recorder with integrated software, a continuous recording server and computers with specialized software for the interpretation, archiving and analysis of seismic records, and a GPS clock. The recording server detects mining tremors and records them. The continuous recording server constantly records all phenomena and saves them on disk.

Receiver seismic stations consist of seismic receiver cassettes (Fig. 12.5 and Fig. 12.6) installed in typical IT racks intended for station equipment. The number of cassettes depends on the number of available channels of a given seismological system. Generally, there are 8, 16, 32 or more channels depending on the needs of the mine.

Fig. 12.5. DLM-SO receiver station with 16 SOS seismic receiver channels

Fig. 12.6. Receiver station with OCGA receivers of the ARAMIS M/E system

The receiver stations are connected to a recording server or seismological recorder. They cooperate, through the internal, independent IT network of the mine's Mining Geophysics Station, with other computers used to interpret and analyze recorded tremors at the Mining Geophysics Station.

For example, the receiver station of SOS system is built on the basis of 16 "OS" channel panels (seismic receivers) cooperating with 16 DLM 2001 probes. The receiver stations are panel-connected with the seismic SOS recorder, which makes it possible to use multiple of 16 seismic channels. The current-modulated signal in the DLM seismic probe is sent via the transmission line to the receiver and then to the transmission line current detection system. The current detection system, built based on an operational amplifier and two optocouplers, is intended to reproduce the transmission line current and convert it into a proportional voltage seismic signal. The receiver station also provides power to the system's underground equipment.

Selected technical data of the DLM-SO station:

- type of transmission – current modulation,
- frequency range – 1 Hz – 10000 Hz,
- dynamic range – 92 dB,
- gain – ×1, ×2, ×5, ×10,

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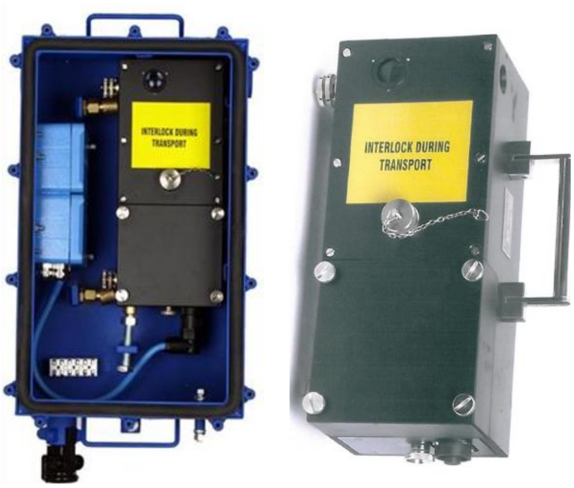
– sensors used – DLM 2001, geophones, accelerometers or others, depending on needs.

The underground part of geophysical systems consists of seismic sensors integrated with electronic transmitters of seismic signals. In the SOS system, these are DLM2001 probes (Fig. 12.7). The DLM2001 probe consists of a sensor and a transmitter, which are built in one housing. These probes can be mounted on anchors with M20 thread in a vertical position in the roof and floor of the excavation or in a horizontal position.

Fig. 12.7. Low-frequency broad band seismological probe DLM2001 of the SOS system

The ARAMIS M/E seismic system uses SPI-70 and SV*/DTSS seismometers or low-frequency geophones with NSGA transmitters shown in Fig. 12.8.

a)



b)

c)

d)

Fig. 12.8. Seismic sensors and transmitters used in the ARAMIS M/E system: a) SPI-70 seismometer, b) SV*/DTSS seismometer, c) NSGA transmitter, d) low-frequency geophone

12.4. Seismoacoustic systems

Currently, ARES-5/E seismoacoustic system is only available. A certain inconvenience of this system is that sensors only record vibrations above 10 Hz. This means that this equipment is not suitable for calculating the seismic energy of mining tremors, despite the possibility of recording digital seismograms of seismoacoustic phenomena. Older types of this equipment, ARES-4 and ARES-3, which are a modification of the older SAK system, may still be used in Mining Geophysics Stations. The ARES-5/E seismoacoustic system consists of a surface part and an underground part.

The surface part consists of the ARES 5/E surface station (Fig. 12.9) and a station computer with specialized software. The ARES 5/E surface station includes 8 OA-5/E receiver modules, a system module, a phenomenon recording module, a phenomenon detection module, a line listening module, and an extender module.

Fig. 12.9. Surface station of the ARES 5/E system

The underground part of the ARES-5/E seismoacoustic system consists of underground sensors (10 Hz geophone probes) and underground transmitters shown in Fig. 12.10. Geophone probes are installed on anchors in mining excavations.

a) b)

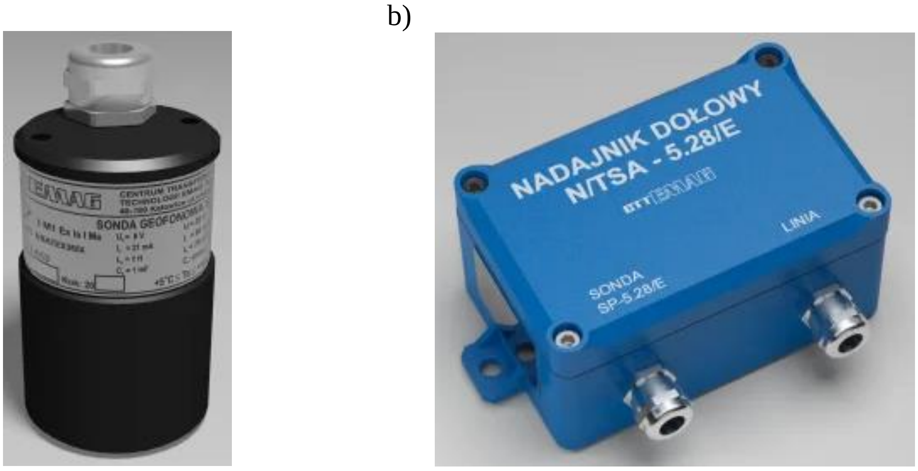


Fig. 12.10. Seismic sensors and transmitters used in the ARES system:
a) geophone probe, b) underground transmitter

12.5. SOS – Seismic Observation System

The basic diagram of the SOS system is shown in Fig. 12.12 a). The underground part consists of seismic geophones with an electronic unit that allows for recording frequency starting from 1 Hz and bandwidth 1÷600 Hz. This is extremely important in mining seismology, because a large part of seismic energy is contained in the low frequency below 10 Hz. Moreover, in the underground part there are transmitters of transmission lines where current modulation of seismic signals is carried out. In the surface part, five basic elements can be distinguished:

- the receiving part of the seismic signal transmission line implementing current demodulation,
- seismic recorder or seismic data logger that samples, analyses and detects seismic signals and saves them on a hard drive,
- GPS real-time clock allowing time synchronization with microsecond accuracy,
- LAN network, enabling on -line access to the recorder's data,
- PC computer for processing, analysis and interpretation of seismic data.

Standardowo As standard, the SOS system uses low-frequency broadband DLM 2001 sensors, which can be single- or three-component. The characteristics of these sensors are shown in Fig. 12.11. Additionally, these sensors are intrinsically safe and have a built-in current transmission transmitter system. Ease of installation and mobility in underground mining conditions is their large advantage. This is of great importance when using the probes in mines, where it is necessary to frequently change the location of the seismic sensor, and is a significant improvement compared to the SPI seismometers used in the past:

- type of transmission – current,
- sensitivity - selected from 50 to 15000 mA*s/m,
- range of recorded frequencie 1÷600 Hz,
- supply voltage range 18÷40 V,
- current consumption – 12 mA,
- current modulation depth in the transmission line ±5 mA,
- non-linear distortions ≤ 3%.

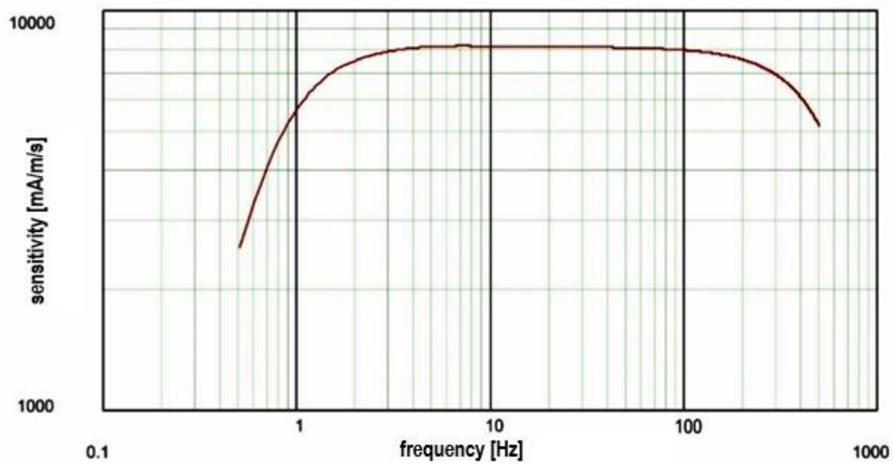


Fig. 12.11. Characteristics of the DLM 2001 sensor

It is also possible to use other types of sensors in the SOS system configuration, such as accelerometers, which means that the system can collect data recorded in various physical units and allow for the recordings of strong seismic vibrations using PPV sensors [Lurka, 2021; Mutke, 2007] or even rotational vibrations [Mutke, 2020]. An important feature of the SOS system is the internal storage in digital seismograms additional information such as:

- type of sensor for each seismic channel,
- coordinates of each seismic probe,
- real physical units are stored,

and there is a number of other basic information, such as precise date and time of the seismic tremor in one file with the digital seismogram. This gives complete flexibility in data analysis, because in the event of a change in the type of sensor, its characteristics or coordinates is stored independently in each digital seismic record. The SOS system is also adapted to data processing in single-channel or multi-channel mode (taking into account three-component sensors), where the amplitudes from individual components are displayed simultaneously, which, among other things, facilitates the analysis of longitudinal P and transverse S waves. The single-channel mode shows a digital seismogram from one sensor and usually contains recording only the vertical component of seismic vibrations, while the multi-channel mode shows three components seismic records: one vertical and two horizontal, e.g. east-west and north-south. An example of single-channel mode analysis is shown in Fig. 12.13, and in multi-channel mode in Fig. 12.14. Due to the possibility of configuring the SOS system in three-component and mixed versions, the recorder in the SOS system can analyze and record from 32 to 256 seismic channels. Each channel is sampled with a 16-bit word with an adjustable sampling frequency from 1 Hz to 10000 Hz, which allows for data processing and recording in a frequency band much higher than required for mining seismology systems, i.e. well above the range of 1÷500 Hz. This creates a unique possibility of processing seismic data, e.g. locating the earthquake focus and calculating seismic energy in bands considered seismoacoustic, which in fact allows the integration of two types of equipment, i.e. seismological and seismoacoustic.

The second variant of the SOS system is a significantly developed version of the SOS system in the first variant and is a system with a distributed architecture, where underground seismic hubs are used (Fig. 12.12 b), each of which independently analyses and collects digital seismic data. 32 or more seismic sensors can be connected to each hub, and due to the underground operation of the mine, the distance between the sensors and the recording system has been significantly shortened, resulting in a significant improvement in the seismic signal to noise ratio. Each underground SOS hub is connected via optical fiber to the LAN of the surface part of the SOS system and is time synchronized with an accuracy of 10^{-6} second utilizing the PTP (Precision Time Protocol), allowing for the integration of seismic data from all hubs. The task of the surface part of the distributed version of the SOS system is to integrate seismic data from underground hubs and their further processing.

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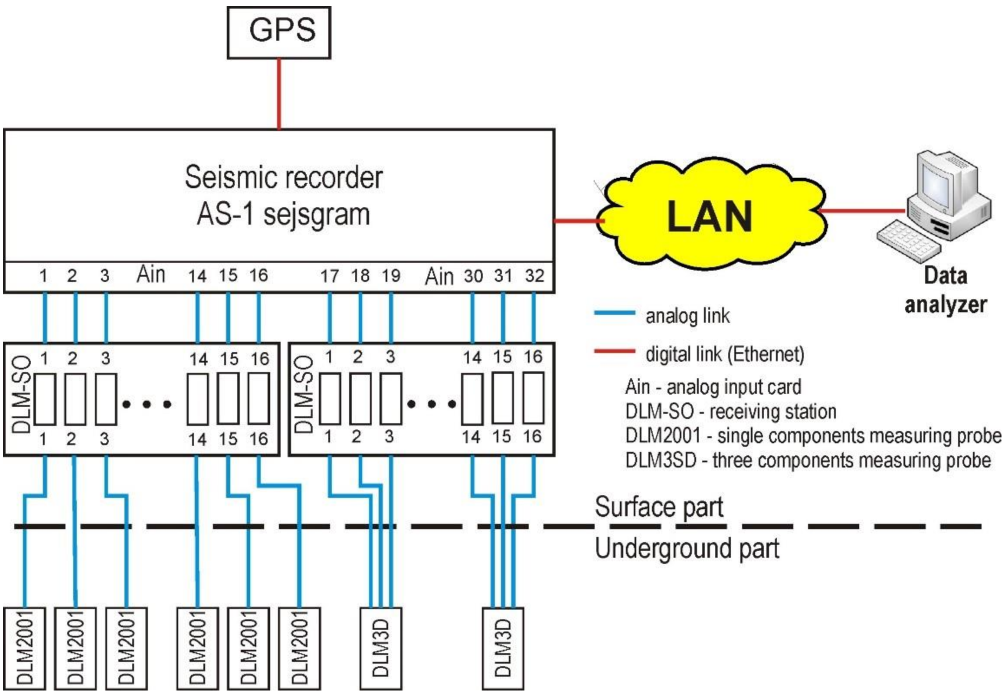
a)



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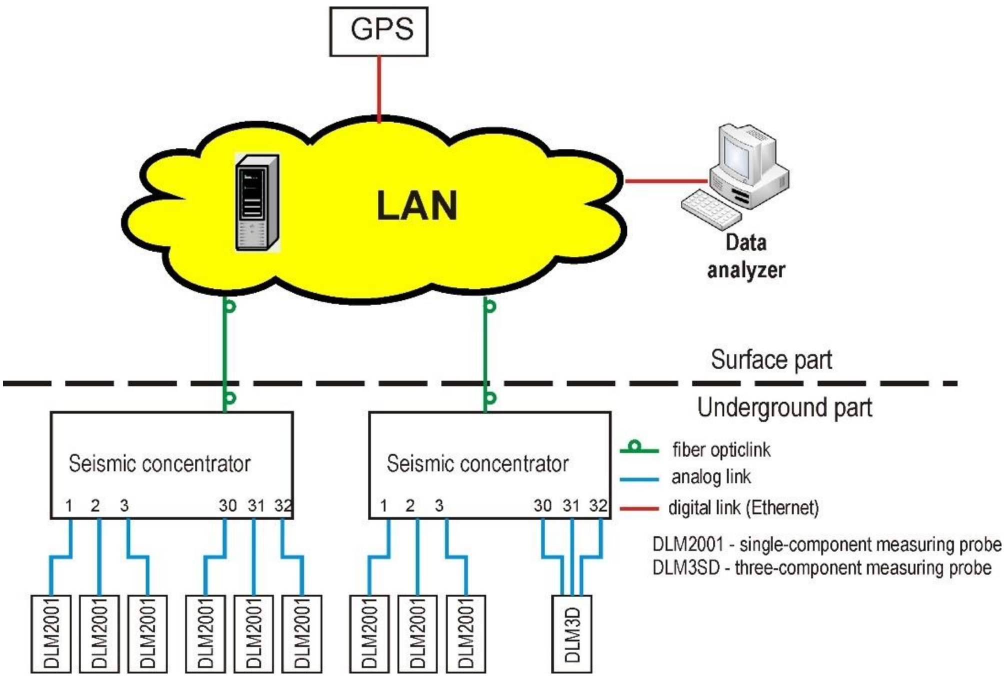

Fig. 12.12. Block diagram of the SOS system: a) SOS system with a single recorder, b) distributed SOS system with many underground hubs

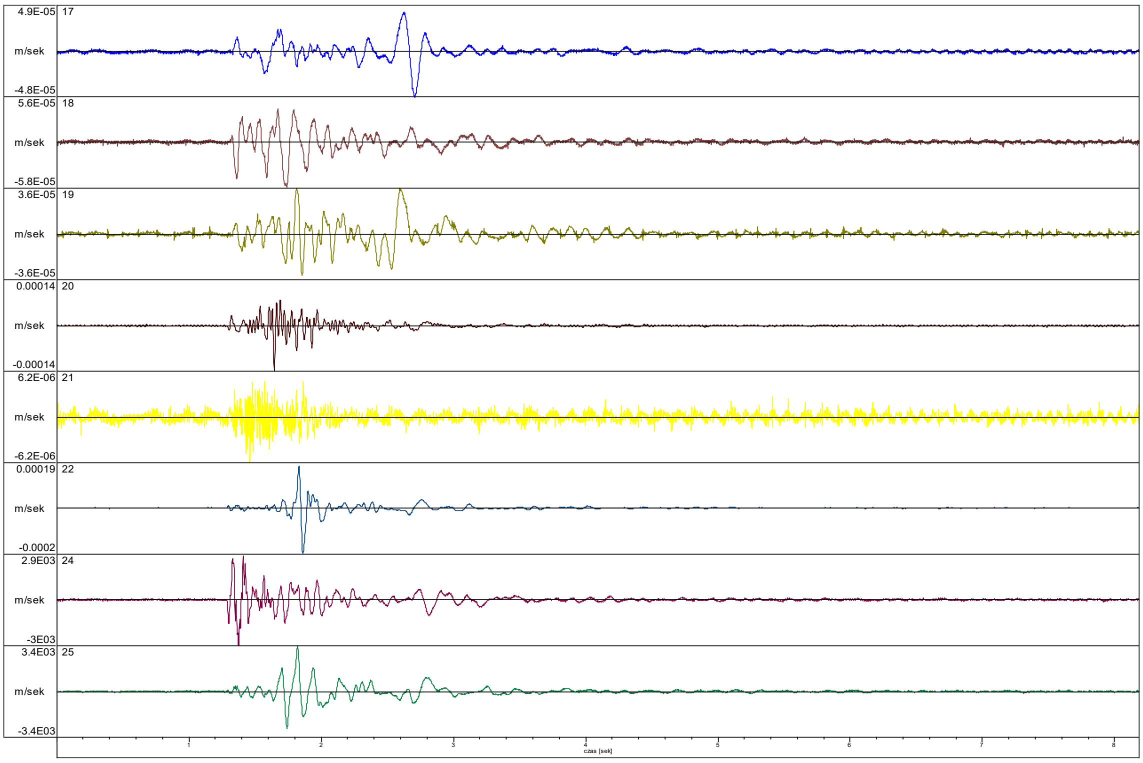

Fig. 12.13. Sample of digital seismogram of the mining tremor in single-channel mode

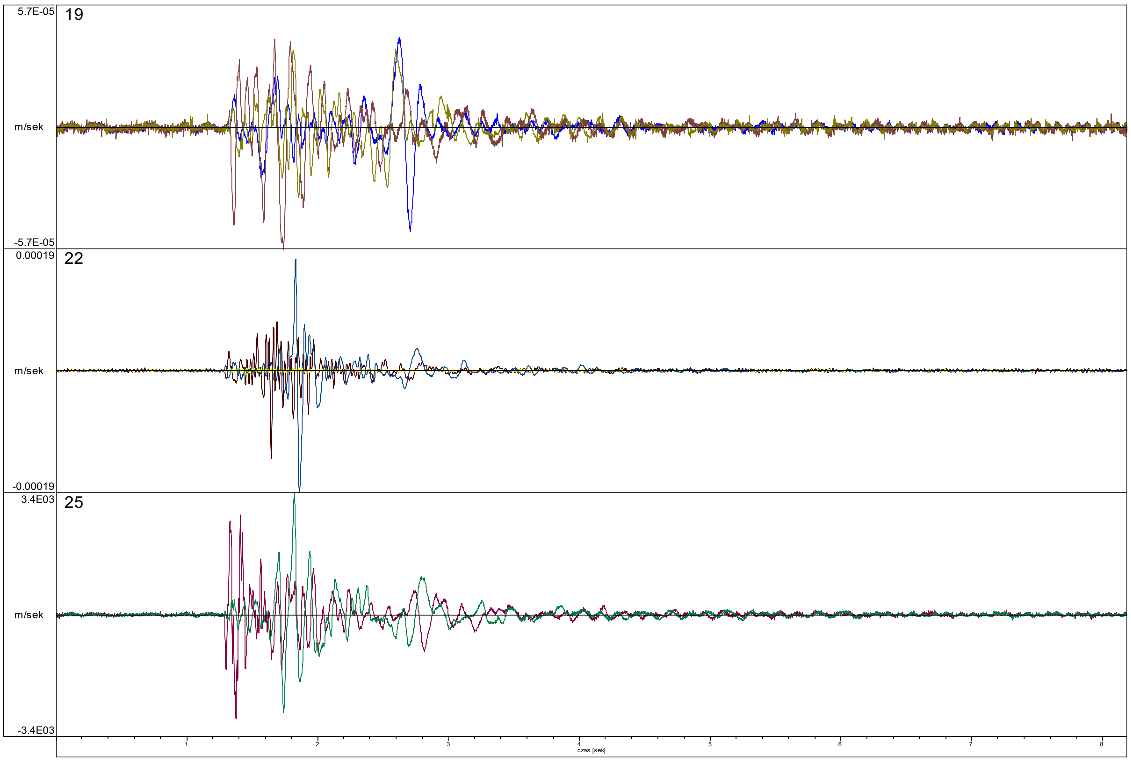

Fig. 12.14. Sample of digital seismogram of the mining tremor in multi-channel mode

12.6. Dynamic of seismic phenomena registration

Another important issue related to seismological monitoring systems is the dynamic range of seismic recordings (expressed in dB), defined as the logarithm of the ratio of the maximum to the minimum amplitude that the seismic system can record. This parameter, although extremely important in seismological observations, is often misunderstood. This is due to a number of factors that affect it, but the main reason for the misunderstanding of what we mean by the dynamic range of the entire seismic system is that the total dynamic range of the seismic system is not the dynamic range of the individual elements of this system. For example, we have the dynamic range of an analog-to-digital converter, the dynamic range of a sensor, the dynamic range of signal amplifiers or the dynamic range of transmission cables. Each of these elements, has its own dynamic range, but the true dynamic range of the seismological system should be understood as the dynamic range of the system treated as a whole. Additionally, it is necessary to take into account a problem inherent in the dynamic range of seismological systems, namely the problem of self-noise occurring in mine conditions. Based on numerous observations, it appears that seismic noise in mines is always greater than or equal to 10^{-7} m/s, which in practice means that we are unable to record vibrations from tremors with amplitudes smaller than this value. On the other hand, the gains on the seismic channels should allow for undistorted vibration recordings for mining tremors in the energy range from 10^2 J to 10^8 J. Both of these limitations cause that dynamic range of real digital seismic records vary in the range from 30 dB to 80 dB, and in many cases may be even lower. However, the dynamic range of electronic systems can be much higher. For example, for a 16-bit A/D converter it is approximately 96 dB, and for a 24-bit one it is approximately 144 dB. It is, of course, more advantageous to use transducers with higher dynamic range, but due to the above-mentioned limitations in terms of the noise level and amplification on seismic channels, this does not significantly affect the dynamic range of the obtained digital seismic records. Therefore, one should always consider the physical limitation of the dynamic range of digital seismic recordings and not confuse this with the dynamic range of the electronic systems themselves. Recently, a special seismic signal compression algorithm has been developed for the SOS system, which allows obtaining the current dynamic range of the real digital seismic records at the level of 90 dB for both weaker and stronger seismic phenomena. This allows, on the one hand, to significantly increase the dynamic range of recordings of weak tremors, and on the other hand, digital records of strong seismic phenomena will not exceed the measuring range of the devices. The principle of operation of this algorithm is analogous to the Dolby compression system used in audio devices.

12.7. Interpretation of data in the SOS system

The analysis of seismological data in the SOS system is based on two basic programs: Seisgram and Multilok. The Seisgram program is used for the preliminary analysis and processing of digital records of seismic tremors, while Multilok is used to obtain seismological parameters describing seismic source such as location and energy of seismic tremor as well the seismic source parameters. All these parameters are saved into the database management system. Both programs can exchange data with each other via Windows interprocess communication protocole (Interprocess Communication), which makes it possible to work on both programs at the same time. The SOS seismic system collects data in a way that facilitates the use of more advanced calculations, such as passive tomography [Lurka, 2009, 2005, 1998], which is an important advantage of the SOS system for research and advanced utilization in seismic hazard assessment.

12.7.1. Data processing and analysis in the Seisgram Program

Seisgram mainly operates on seismic data stored in its own internal format and this data format is best suited for further analysis of seismic data. The program additionally introduces the ability to manipulate seismic data from older versions of the AS-1 and ARAMIS seismic systems and enables the import of data from ASCII files. All data operations are carried out taking into account the physical units of the analyzed seismograms, which means that after opening a specific file, we can read the current values of velocity amplitudes, acceleration, displacements or derived units obtained, for example, from Fourier analysis. In newer versions of the program, you can also operate on mixed data sets, e.g. recordings from velocity and acceleration sensors as well as from one-, two- and three-component sensors with the appropriate display mode (Fig. 12.13 and 12.14). The general rule in the Seisgram program is to work in the multi-window mode, which allows for efficient comparison of various types of seismic data, such as, for example with those processed in the filtration process, Fig. 12.15.

The most important operations available in Seisgram include:

- Fourier spectrum analysis with the ability to calculate the amplitude and phase spectra, both for the entire seismogram and for selected wave groups,
- frequency filtering with the ability to select the filter type (low-pass, high-pass, band), filter order and its frequency limits,
- differentiation and integration of seismograms taking into account baseline correction, which allows to obtain acceleration records from velocity seismograms and the other way round,
- automatic calculation of P and/or S body wave onset times, taking into account the location of the seismic event,
- multi-level scaling of seismograms with the ability to scale amplitudes to the selected channel,
- various operations allowing cutting and selecting appropriate channels,
- data exchange with the Multilok program through the Interprocess Communication protocol,
- saving a displayed window into vector graphics such as windows metafile (a very useful option for reports preparation, e.g. in MS Word),
- securing the program settings with an access password.

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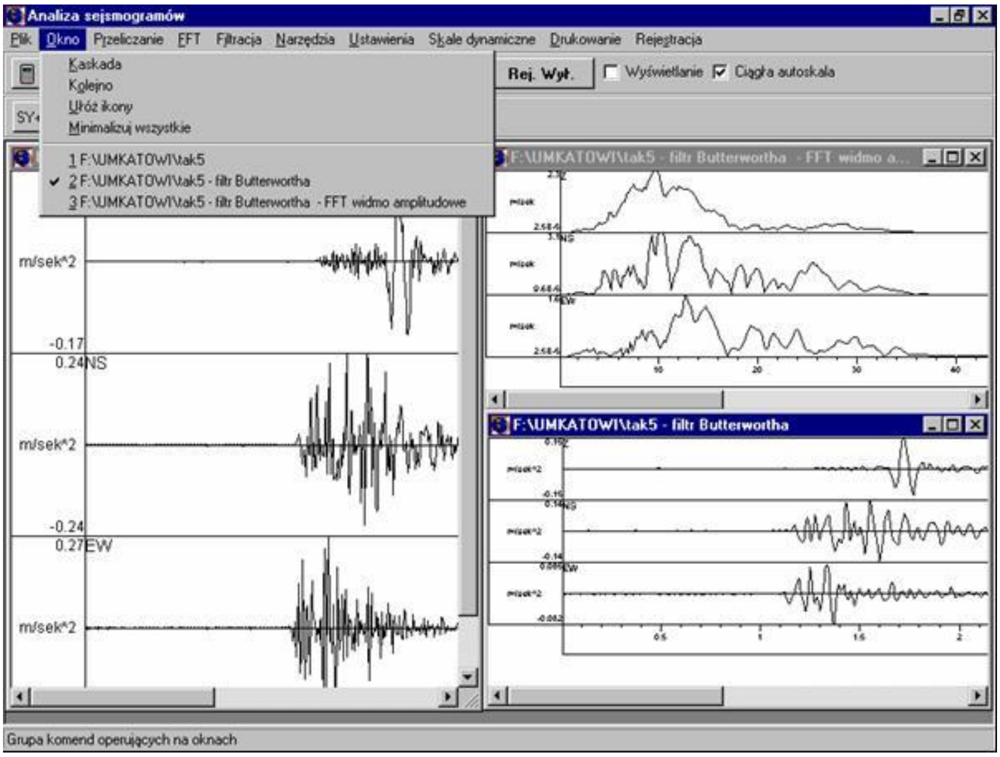

Fig. 12.15. An example image obtained during data analysis in the Seisgram program

12.7.2. Data analysis in the Multilok program

Multilok program allows to analyze seismic data in two modes. In the first one, seismic data is downloaded indirectly from the Seisgram program through the so-called mechanism of shared shared memory and in the second mode by direct reading from a selected file on the disk. The first mode is considered the most efficient, as it allows for the determination of onset times of seismic P and S waves and initial processing of digital seismic records in the Seisgram program. Working with the program takes place against the background of a graphic window with the most important geological and mining objects, such as wall outlines, faults, and seismic station locations. All graphic objects can be modified or new ones added as vector graphics objects, where data is described in the real coordinate system used by the mine. The basic features of the program include the calculation of location and energy of seismic tremors. In its latest version, Multilok also allows automatic calculation of seismic source parameters. All calculated parameters are continuously saved to the database management system so that subsequent analyses can be performed on groups of mining seismic events. Multilok is a program that utilizes a number of advanced numerical algorithms, but the program user finds it easy to use and most of the calculations can be performed automatically. It is also possible to save all the settings, which, similarly to the Seisgram program, can be password protected. Important feature of the program include the ability to use separate seismic station velocities for locating mining tremors and attenuation coefficients of longitudinal P and transverse S seismic body waves utilized in seismic energy calculation.

The most important operations available in Multilok include:

– searching for all minima in the seismic event location procedure,

- calculation of seismic location and seismic energy by selecting a separate group of seismic channels,
- seismic event location for various norms of the minimized objective function (including the L2, L1 norm) using various optimization algorithms (including the Simplex algorithm),
- location using the simultaneous use of longitudinal P and transverse S body waves onset times,
- location with the constrained vertical coordinate value,
- calculation of seismic energy using the integral method or maximum amplitudes,
- automatic calculation of seismic source parameters: seismic moment, source radius, seismi displacement, seismic stress drop, seismic source volume, apparent stress and spectral energy,
- displaying a coordinate system of the mine as grid on a graphic screen.

12.8. Parameters of seismic source

The seismic source parameters are determined by spectral analysis of the recorded seismic tremors [Snoke, 1987; Aki, 1980; Gibowicz, 1994]. In an inelastic medium, the amplitude of seismic vibrations is damped during seismic wave propagation and this parameter is very important in seismic source parameter calculations. The measure of attenuation is determined by attenuation coefficient or quality factor Q. Attenuation for direct body waves can be determined from the flat part of the displacement spectrum. The attenuation coefficient is assumed to be independent of the frequency below the corner frequency.

To calculate seismic source parameters the displacement spectrum of seismic P and S body waves are calculated first. From these displacement spectra, flat part of the spectrum and the corner frequency are determined. To obtain the displacement spectra the recorded velocity waveforms are integrated to obtain displacement waveforms. Then, a spectrum is calculated from the displacement waveforms and presented on a logarithmic scale. The calculation procedure of seismic source parameters is performed in the MULTILOK program automatically by calculating the integral of the square of the vibration velocity (J) and the integral of the square of the vibration displacement (K). This makes it possible to determine values for the low-frequency, flat part of the spectrum and the corner frequency in reliable and stable.

When calculating the seismic source parameters, the attenuation of seismic waves must be taken into account. In practice, this means introducing corrections related to the spread of the wave front between the seismic origin and the seismic station. In a non-homogeneous and inelastic medium, the amplitude of particle vibrations is suppressed during wave propagation as a result of energy absorption and dissipation, regardless of the seismic wavefront geometry. The attenuation of seismic waves depends largely on the inelastic properties of the rock mass.

As mentioned earlier, the SOS system software allows for the calculation of seismic source parameters in an automated manner. The required information that must be entered by the system user is the same as for the calculation of seismic energy, i.e. the location of the seismic tremor and markers defining the onset times and durations of longitudinal P and transverse S seismic body waves.

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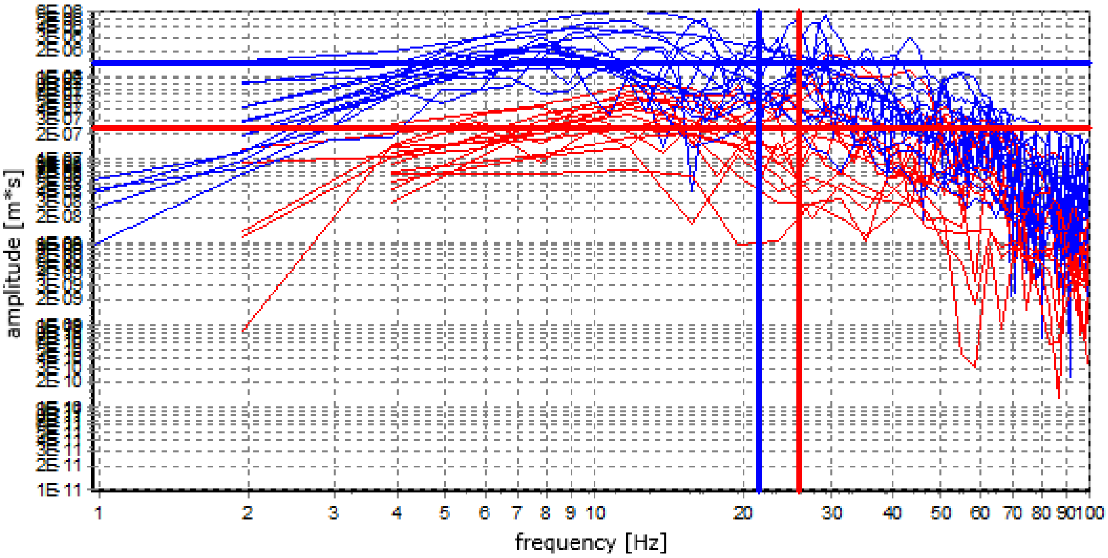

Fig. 12.16. An example of a displacement spectrum for a mining tremor with marked low-frequency levels and corner frequencies for longitudinal P and transverse S seismic body waves in MULTILOK program

MULTILOK program automatically calculates a displacement spectrum, such as in Fig. 12.16, and displays the results of calculated corresponding seismic source parameters. In this figure, the blue lines are the displacement spectrum for the transverse S seismic body wave, and the red lines are the displacement spectrum for the longitudinal P seismic body wave. Subsequently, these results are saved to the database management system. Collecting such information about mining tremors in databases allows the further use of new methods and analyses based not only on seismic energy, but also on source parameters [Mendecki, 1997]. In this way, the new version of the SOS system software becomes a tool for new analysis of seismological data in underground mining.

Digital seismograms contain more information than just location and the energy of the seismic event and additionally the seismic source parameters can be determined. For a specific coal panel, one can monitor, for example, the changes of the specific seismic source parameter, e.g. the value of the seismic moment.

12.9. Summary

The presented characteristic of the SOS seismic system, against the background of other existing seismic system solutions and mining regulations in Poland, allow for further, significant development of the mining seismology method in mines. The most important innovations in the SOS system include the possibility of using it in a distributed and mixed version, i.e. seismological systems consisting of various types of sensors, such as accelerometers and geophones, and the use of single-, two- and three-component sensors in parallel, depending on the needs of a specific mine. The SOS system now allows for increasing the dynamics of digital recordings of seismic phenomena, as well as increasing the bandwidth of the recorded frequencies. The latest version of the SOS system allows not only to determine the two basic parameters of seismic events, namely the location and seismic energy, but also to calculate the seismic source parameters and many other seismological parameters and automatically save this information in the mining tremor database for further processing purposes. Due to this, Mining Geophysics Stations in mines have the opportunity to integrate mining seismology and seismoacoustic methods in the near future. In addition to the introduction of new methods of analyzing seismological data, the location algorithms were also improved by applying the velocity model to individual seismicity regions in the mine by utilizing the results of seismic passive tomography method. The properties of the SOS seismic observation system shows that the hardware development of each seismological monitoring system in mines should go hand in hand with the development of software and appropriate interpretation methodology, because hardware improvement alone is not a sufficient condition to meet the increasingly growing requirements for improving safety in underground mines.

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13. Cybersecurity of the IT/OT systems in key functional areas of the mining plant operated according to the INDUSTRY 4.0 idea

Artur Dyczko

The second decade of the 21st century brought the events that led to a re-evaluation of the current thinking about security management in many domains, brutally verified additionally by the COVID-19 pandemic and the outbreak of the war in Ukraine.

Both of these events are equally important, considering that the armed conflict in Ukraine continues to negatively affect the level of security in neighboring countries, which have automatically become an arena of hybrid operations. This applies in particular to the Baltic states and Poland. As Microsoft reports show, in the contemporary hybrid war model, information influence operations based on social engineering techniques and supported by digital technology are becoming particularly important. Various events, including those taking place in the country, show that information operations can be as effective as complex attacks on industrial infrastructure, while being much cheaper. Currently, false information introduced into public space can be used to cause disruptions in the functioning of a sector that is important from the point of view of the security of an organization, community or state. For example, effective disruptions in the fuel sector can be achieved by causing social hysteria by introducing false information into the media about a significant increase in fuel prices or its limited stocks. A society susceptible to disinformation, subject to panic, will destabilize the situation on the fuel market. Such an operation will be much cheaper than the sophisticated actions of highly respected hackers. Examples of this type of activities make us look at the security of office computers, mobile devices, as well as industrial automation in a broader context.

The pandemic forced ICT system administrators to use solutions enabling remote work and learning in those areas where it was possible. A side effect of these then desirable actions was the emergence of new types of risk, related to the level of digital skills of the user who is outside the secure company network and uses important company data as part of his professional activity. In these circumstances, the issue of identity protection and the philosophy of authentication of IT system users become particularly important. During the epidemic, a similar situation was observed in industry. Pandemic restrictions on the movement of personnel, including service technicians, forced many companies to compromise in the area of OT security by allowing remote service and maintenance activities. Unfortunately, this meant additional system vulnerabilities and a potential threat to the continuity of operation of the infrastructure. As a result of these changes, certain risks have moved from the enterprise layer to lower layers, exposing OT to threats in a greater extent than before.

Cyberspace protection has become one of the most frequently discussed security topics. Countries, international organizations and other non-state entities understand that the stable functioning and development of the global information society depends on an open, reliable and, above all, safe cyberspace. The growing awareness in this area goes hand in hand with a sharp increase in the number of computer incidents and the emergence of new types of threats.

Poland faces technological, environmental, but also social challenges related to the supply of raw materials that underlie our industrial activities. The civilizational transformation of our economy cannot take place without ensuring the monitoring and safety of industrial processes, these processes cannot be supervised without efficient exchange of information and access to the latest technologies, ICT, automation and control systems, the construction and operation of which is already the subject of routine activities of specialized services.

Analyses of events and vulnerabilities - both reported by the power sector to the competent authority and included in subsequent reports of consulting and auditing companies, show that a new approach to managing security, resilience and enterprise continuity is needed. This is expressed, among others, by: recent legislative work at the European Union forum, as part of which, on December 27, 2022, amendments to two key directives were published, regarding the resilience of critical entities and measures for a common level of cybersecurity within the territory of the European Union.

The European legislative offensive, which cumulated at the end of 2022, led to the creation of a package of new directives and regulations that are extremely important for the regulated market that makes extensive use of digital technology. This is particularly important in the case of the NIS 2 Directive (Directive on measures for a high common level of cybersecurity across the EU) and the CER Directive (Critical Entity Resilience Directive). Both directives were created in response to new types of risks in cyberspace, which are based not only on events such as the pandemic or the war in Ukraine, but in particular on the models of functioning of modern supply chains. Nowadays, simple sequences of enterprise processes are becoming less common. Modern supply chains are often complicated connections of smaller or larger sub-processes, the interruption of which may lead to a cascading effect and pose negative consequences unknown in advance. This prompts us to re-examine the areas that should be protected, what protection model should be used and whether an object-oriented or process approach should be used.

Unlike the existing legal solutions, the need to cover an entity with the NIS 2 directive will not be signaled by a notification or the issuance of an administrative decision - the interested entrepreneur himself should check whether the subjective scope of the regulation applies to him. The obligations that will be associated with the implementation of directives into national law will mainly consortium the application of an approach to security based on risk analysis and the design of risk mitigating measures based on the zero trust rule. In practice, this will mean giving up on the current principle according to which all resources should be locked in a safe network in favor of protecting these resources under one central policy. This approach significantly hinders the penetration of company resources, typical of today's attack vectors, by obtaining subsequent credentials as part of the so-called lateral movements. The resources that should be constantly protected include identity, data, applications, networks, devices and digital infrastructure. Effective strengthening of resilience in this area is only possible with the involvement of all possible stakeholders - from the management board and administrators to serial users of end devices.

https://doi.org/10.32056/KOMAG/Monograph2024.2

13.1. IT/OT cybersecurity system in the JSW Group key functional areas as means for ensuring a functional continuity of the enterprise

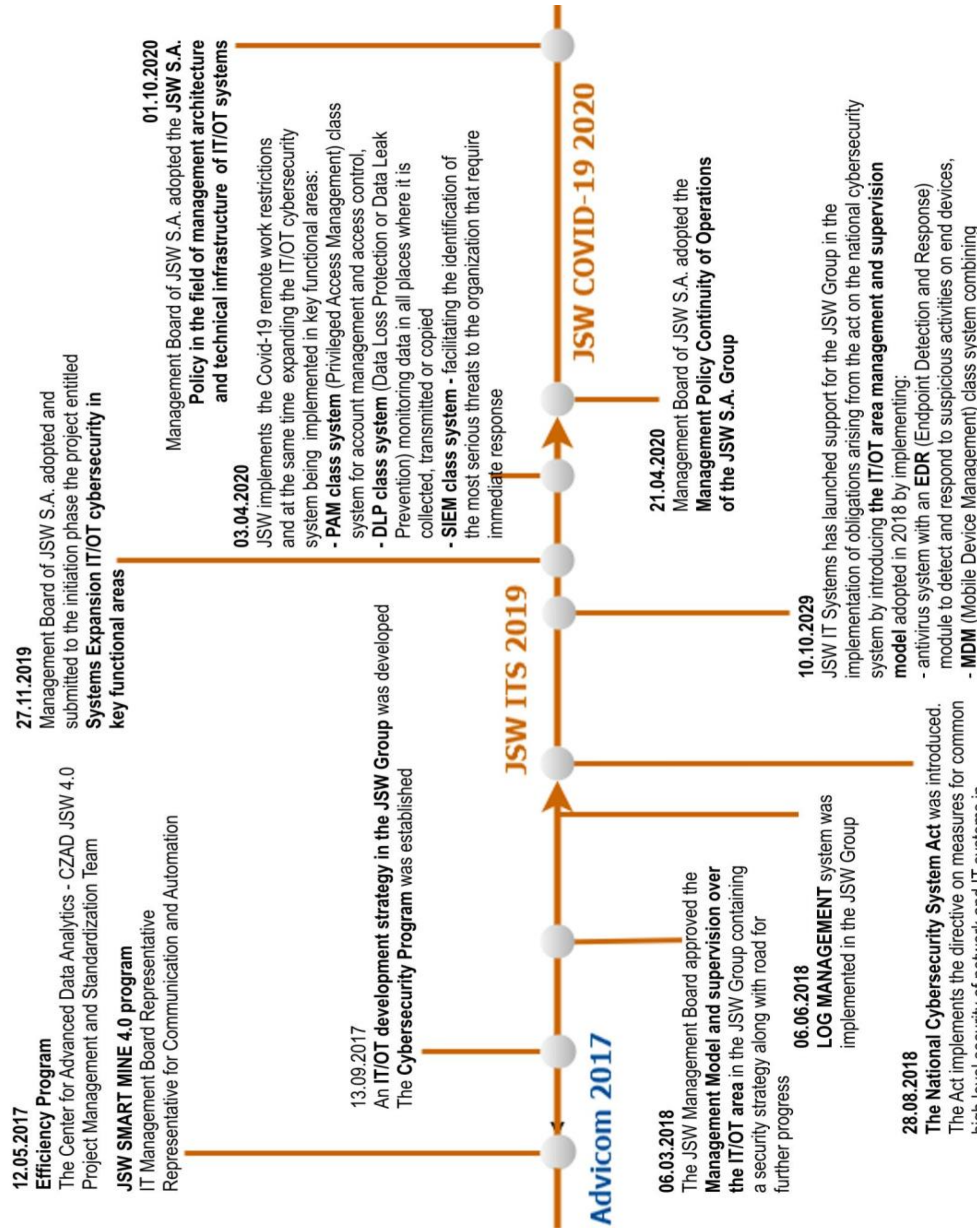
In the JSW Capital Group, a systemic approach to managing the security of IT/OT systems began to be created in mid-2017, when the “Strategy for the development of IT/OT systems of the JSW Group” was developed, in which the “Cybersecurity Program” was established. The next stage of strengthening the cybersecurity system being built was the adoption on March 6, 2018 by the Management Board of JSW SA of the "Model for management and supervision of the IT/OT area" in the Group, containing a security strategy along with a roadmap for further work. These activities were intensified with the recognition of the JSW Group as a Key Service Operator in accordance with the provisions of the Act of 5/07/2018 (Dz.U. 2018, poz. 1560) on the national cybersecurity system, which led to JSW IT Systems launching on October 10, 2019 a support for JSW Group in implementing the obligations arising from the Act on the national cybersecurity system by introducing the "Model of management and supervision over the IT/OT area" adopted in 2018 and implementing:

– antivirus system with the EDR module to detect and respond to suspicious activities on end devices; due to advanced technology that detects cyber attacks at an early stage, it is an effective weapon against hackers, detecting suspicious activities at their initial stage,
– MDM class system combining the functionality of comprehensive security and the Enterprise Mobility Management (EMM) tool, including traditional mobile application management (MAM) and a mobile content management tool (MCM),
– Log Management system for centralized storage, monitoring, visualization and analysis of server/application/machine logs.

These activities preceded the decision on November 27, 2019 by the JSW Group to launch a strategic project entitled: “Expansion of IT/OT cybersecurity systems in key functional areas”.

The historical context of the creation and supervision of the systemic security management of IT/OT systems by the author, along with the idea of establishing the Cybersecurity Information Exchange and Analysis Center for the mining sector, over the years 2017÷2023, is presented in Fig. 13.1.

a)


12.05.2017
Efficiency Program
The Center for Advanced Data Analytics - CZAD JSW 4.0
Project Management and Standardization Team
JSW SMART MINE 4.0 program
IT Management Board Representative
Representative for Communication and Automation
13.09.2017
An IT/OT development strategy in the JSW Group was developed
The Cybersecurity Program was established
27.11.2019
Management Board of JSW S.A. adopted and submitted to the initiation phase the project entitled Systems Expansion IT/OT cybersecurity in key functional areas
01.10.2020
Management Board of JSW S.A. adopted the JSW S.A. Policy in the field of management architecture and technical infrastructure of IT/OT systems
03.04.2020
JSW implements the Covid-19 remote work restrictions and at the same time expanding the IT/OT cybersecurity system being implemented in key functional areas:
- PAM class system (Privileged Access Management) class system for account management and access control,
- DLP class system (Data Loss Protection or Data Leak Prevention) monitoring data in all places where it is collected, transmitted or copied
- SIEM class system - facilitating the identification of the most serious threats to the organization that require immediate response
JSW ITS 2019
Advicom 2017
JSW COVID-19 2020
06.03.2018
The JSW Management Board approved the Management Model and supervision over the IT/OT area in the JSW Group containing a security strategy along with road for further progress
06.06.2018
LOG MANAGEMENT system was implemented in the JSW Group
28.08.2018
The National Cybersecurity System Act was introduced. The Act implements the directive on measures for common high level security of network and IT systems in the EU territory (NIS Directive)
10.10.2029
JSW IT Systems has launched support for the JSW Group in the implementation of obligations arising from the act on the national cybersecurity system by introducing the IT/OT area management and supervision model adopted in 2018 by implementing:
- antivirus system with an EDR (Endpoint Detection and Response) module to detect and respond to suspicious activities on end devices,
- MDM (Mobile Device Management) class system combining the functionality of comprehensive security and the EMM (Enterprise Mobility Management) too.
21.04.2020
Management Board of JSW S.A. adopted the Management Policy Continuity of Operations of the JSW S.A. Group

b)

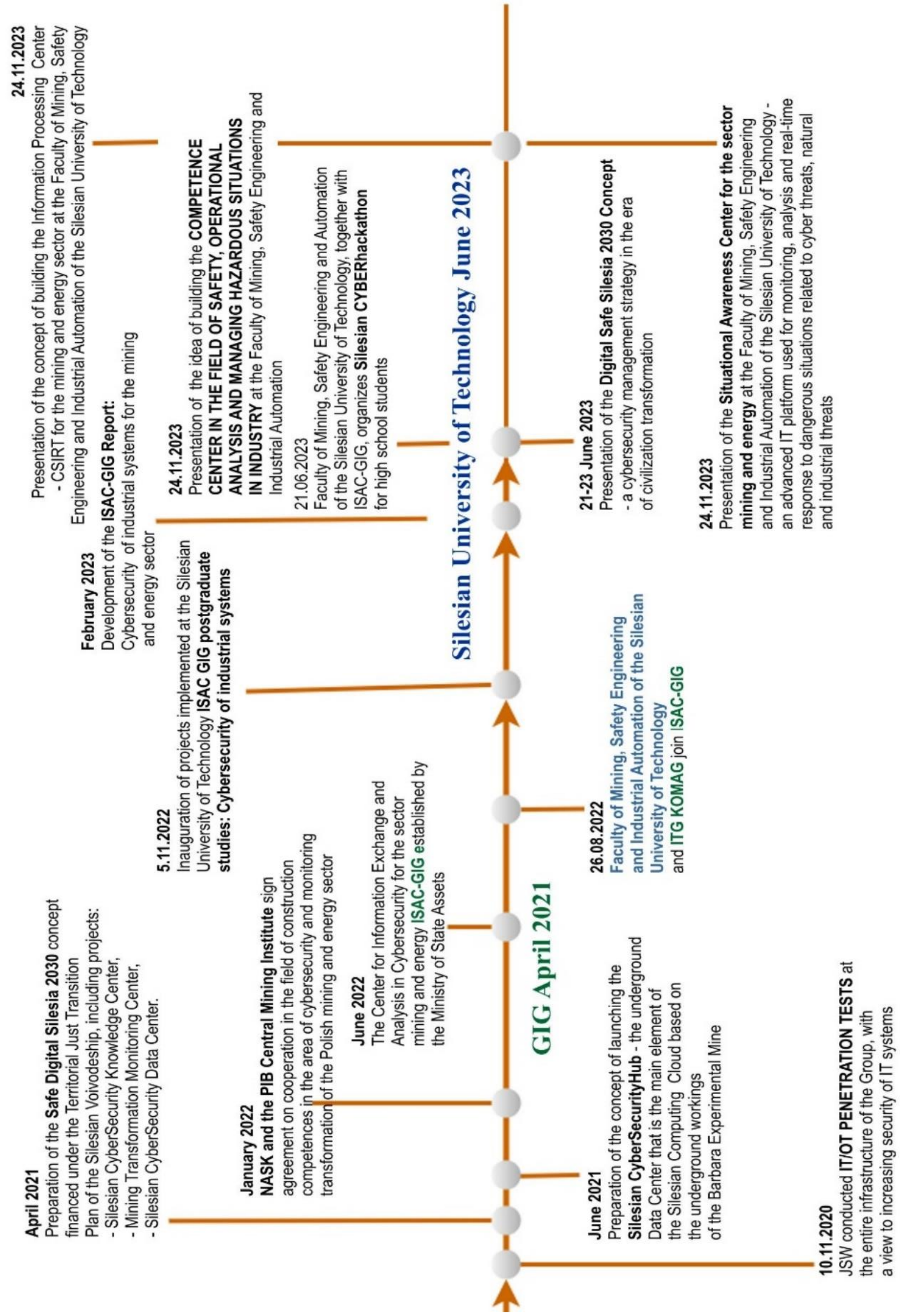


Fig. 13.1. Historical context of the author's creation and supervision of the systemic security management of IT/OT systems in the JSW Group, along with the development of the idea of establishing the Cybersecurity Information Exchange and Analysis Center for the mining sector over the years: a) 2017÷2020, b) 2021÷2023

The above-mentioned Act of 5/07/2018 on the national cybersecurity system imposed obligations on operators of essential services:

– systematically assessing the risk of incidents and managing this risk,
– implementation of appropriate technical and organizational measures proportional to the assessed risk, taking into account the latest state of knowledge,
– collecting information about cybersecurity threats and vulnerabilities to information system incidents,
– incident management,
– applying measures to prevent and limit the impact of incidents on the security of the information system,
– using means of communication enabling correct and safe communication in within the national cybersecurity system.

Taking the above into account, in November 2020, the Company performed a security audit of information systems used to provide the Key Service - mineral extraction. Its aim was to confirm the compliance of the security of the information system used to provide Key Services with the requirements of the Act on the National Cybersecurity System.

The audit consisted of sampling the implementation of system maintenance processes with the support of external suppliers (including software updates, change management, vulnerability testing, system monitoring, ensuring the continuity of system operation, making backup copies and testing their correctness, controlling access to systems, documenting service activities, etc.). The scope of work included:

– understanding the context of the organization's operation, including the impact of IT and OT Systems (SI_OUK) on Key Services;
– confirmation of the fulfillment of the obligations of the Key Service Operator in accordance with articles 8-16 of the Act on the National Cybersecurity System;
– analysis of documentation regarding cybersecurity of the information system used to provide Key Services;
– tests of the effectiveness of control mechanisms;
– preparation of a report containing a description of identified non-compliances along with recommendations;
– presenting the results of the Audit to the Top Management.

The results of the audit allowed for the issuance of a positive opinion and the identification of a number of recommendations, the most important of which included the implementation of the following tools in the Company:

– PAM *(Privileged Access Management)* class for managing privileged accounts, which allows for effective monitoring of activities carried out using accounts with "super user" rights, e.g. admin, root, accounts with elevated rights in databases, servers, etc. (Fig.13.2).

https://doi.org/10.32056/KOMAG/Monograph2024.2

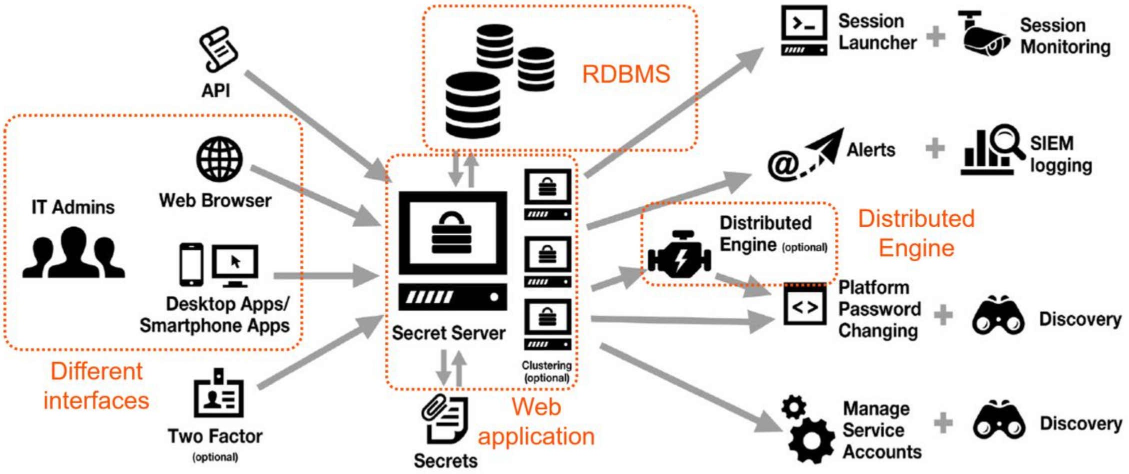


Fig. 13.2. Sample Privileged Access Management (PAM) System Architecture [IBM Redbooks, 2021]

– SIEM *(Security Information and Event Management)* systems provide comprehensive insight into what is happening on the network in real time and help IT teams actively fight threats. The uniqueness of SIEM solutions lies in the combination of security incident management with information management about the monitored environment (Fig.13.3).

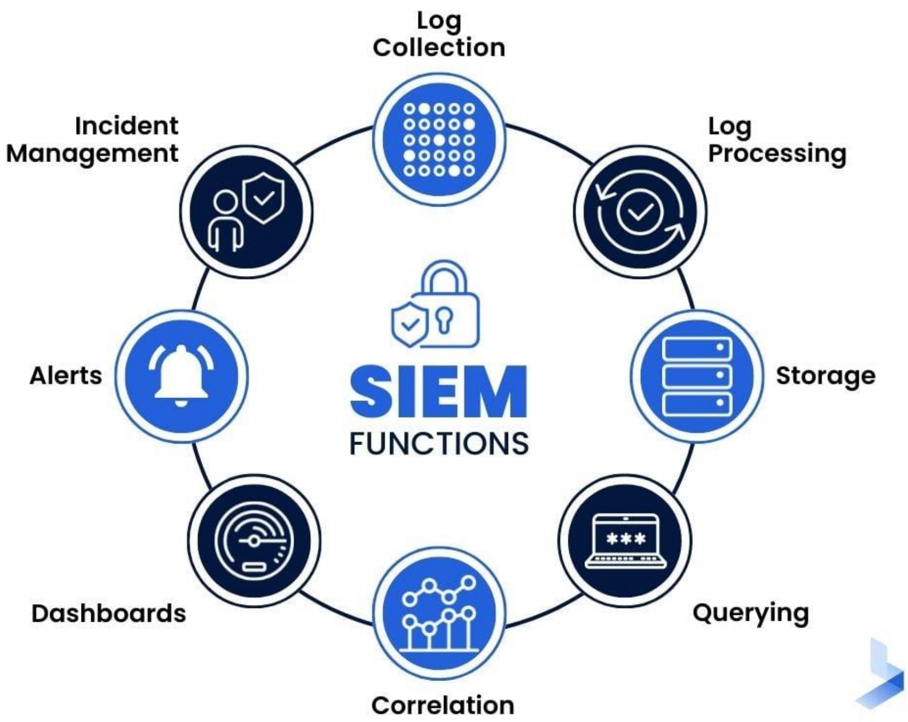


Fig. 13.3. Features of security information and event management (SIEM) systems, which are platforms that provide insight into the company's IT environment and help detect and respond to [Miller, 2021]

The tools used as a result of the implementation of the audit recommendations allowed the Company to provide a level of security adequate to the requirements and risk, ensuring that the protection of processed data is maintained at the highest possible level. They also allowed us to develop an optimal model of cooperation between the Privileged Access Management and Security Information and Event Management systems (Fig. 13.4 and 13.5).

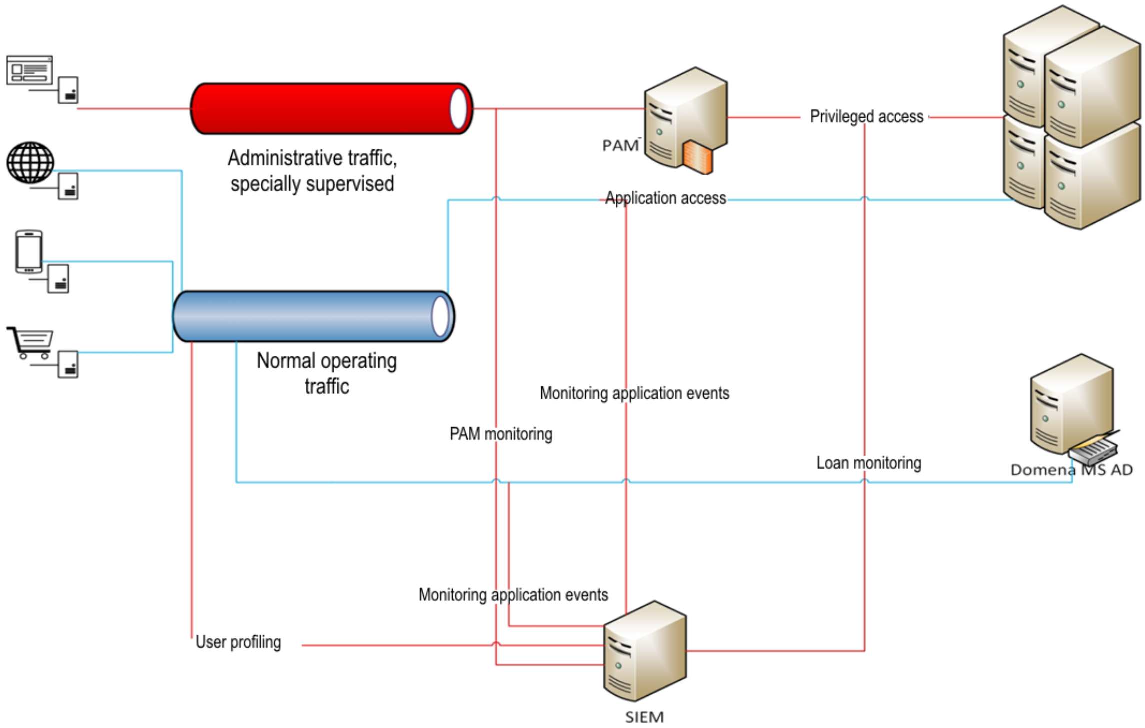


Fig. 13.4. Model approach for cooperation between SIEM and PAM class systems

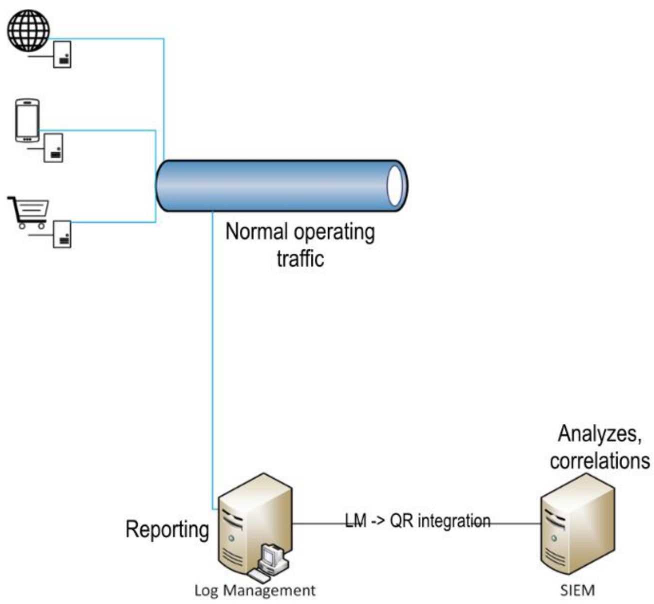


Fig. 13.5. Log Management SIEM model approach

– DLP *(Data Loss Protection lub Data Leak Prevention)* class system – monitoring data, searching data patterns, and in the event of an attempt to send or copy documents containing sensitive data (defined by the DLP System Administrator), blocking this action and notifying the administrator about irregularities. It is a tool that was created to tighten the information processing processes in the company. They effectively support enterprise and security departments in understanding how, where and by whom critical data is processed - Fig.13.6.

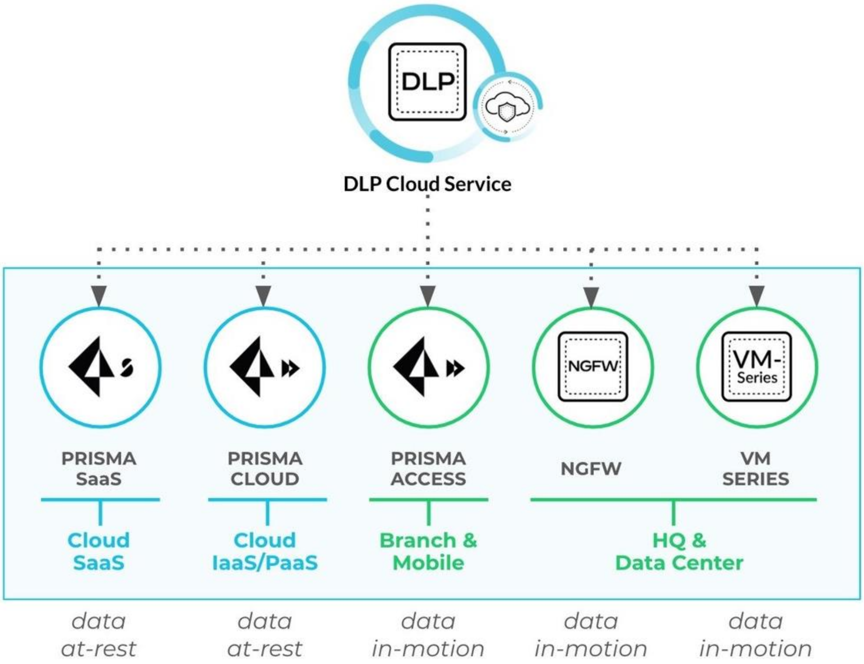


Fig. 13.6. Sample architecture of the Data Loss class system Protection DLP by Palo Alto Networks [Palo Alto Networks, 2020]

IT/OT cybersecurity system built in the years 2017÷2020 in key functional areas of the JSW Group allowed in 2020 alone to block approximately 900 domains that regularly harass the Company's IT network with phishing attacks, at the same time, the farms of JSW SA anti-spam and anti-phishing systems scanned and rejected approximately 1.3 million messages. Phishing currently accounts for approximately 49% of all cyberattacks and is sometimes difficult for an employee to identify. That is why it is so important to raise awareness and constantly train employees.

The year 2020 will always be associated with the COVID-19 pandemic. The Crisis Team at Jastrzębska Spółka Węglowa, established in March of that year, decided to start remote work for a significant number of employees, which created new challenges for the IT and OT services in the Company, forcing increased protection of the Company's IT infrastructure and blocking numerous attempts to infect workstations. Suffice it to say that in the second half of 2020 alone, JSW SA recorded approximately 8,000. domains showing "Malware behavior" and over 10,000 attempts to inject malicious code into workstations. These attacks were treated very seriously, bearing in mind the experience from December 2019, when the Ostrava- Karviná mines (OKD) were attacked by hackers, as a result of which, for security reasons, the entire OKD Company was interrupted in mining for almost a month. As it turned out, the hackers skillfully infiltrated the OT networks of Czech mines from the office network, using unsecured and infected end-user workstations for this purpose. The experience of the Czech OKD mines had a significant impact on the preparation of Polish mines for face attacks related to the CYBER area. An important activity was to conduct a continuous inventory of resources, IT/OT architecture, identify areas susceptible to threats and appropriate security. An essential element was to conduct cybersecurity training, which allowed a wide group of employees to be aware of the threats on the one hand and, on the other hand, allow us to operate in accordance with the adopted standards and Security Policies.

Currently, JSW SA together with JSW IT Systems is conducting a number of projects and implementations of systems that increase safety at work. The foundation of these projects is to increase the level of safety of crews and IT/OT processes and technologies. The cybersecurity strategy developed by JSW IT Systems in 2016÷2020 is based on stopping attacks (prevention), monitoring and determining undesirable events (detection), as well as implementing corrective actions (reaction). This is considered in relation to resources identified in the prism of protection of an extensive maturity model, extending the requirements of ISO 27001. Projects are implemented in cooperation with technological leaders in the field of IT/OT security on the market. The activities carried out strengthen the technical area of prevention by hardening the environment, controlling the tasks performed by employees and limiting the propagation of vulnerabilities in the internal network. In order to properly manage this infrastructure, the JSW SA Automation and IT Office was established at the Company's Headquarters, reporting directly to the President of the Management Board for Technical and Operational Affairs, which included the Automation and Teletransmission Team and the Advanced Data Analytics Team, closely cooperating with JSW IT Systems. This allowed the development and implementation on April 21, 2020 of the "Enterprise Continuity Management Policy of JSW SA" and on October 1, 2020 of the "Policy of Jastrzębska Spółka Węglowa SA regarding the management of the architecture and technical infrastructure of IT/OT systems", including: "Conditions of access to separate networks in JSW SA plants” and “Guidelines for IT/OT solutions for the created Specifications of Essential Procurement Terms at JSW SA”.

13.2. Ensuring a functional continuity of the enterprise

From the point of view of mining companies, it is critical to maintain enterprise continuity and rebuild service continuity after a failure. Therefore, it is recommended to follow the Recommendations on actions aimed at strengthening cybersecurity in the power sector and the sectoral guidelines on reporting incidents prepared by the Ministry of Climate and Environment in the field of cybersecurity for the Polish power sector. Enterprise continuity management is an activity whose aim is, among others, to: ensuring the operation of a given entity by protecting critical, key processes against the effects of incidents in the technological process area, as well as protecting information assets necessary to implement these processes. Enterprise continuity itself can be defined as the ability of an enterprise to anticipate and respond to enterprise process disruptions in order to maintain its operations at an acceptable, established level. Enterprise continuity management should be a priority for every company. Therefore, it is recommended that the organization develops methodologies for maintaining enterprise continuity, taking into account aspects that, according to the organizational specificity of a given enterprise, may affect this continuity, understood as maintaining key processes enabling the provision of a key service. It is recommended that a enterprise continuity plan be developed for each type of threat that may occur according to the risk analysis, as shown in Fig. 13.7.

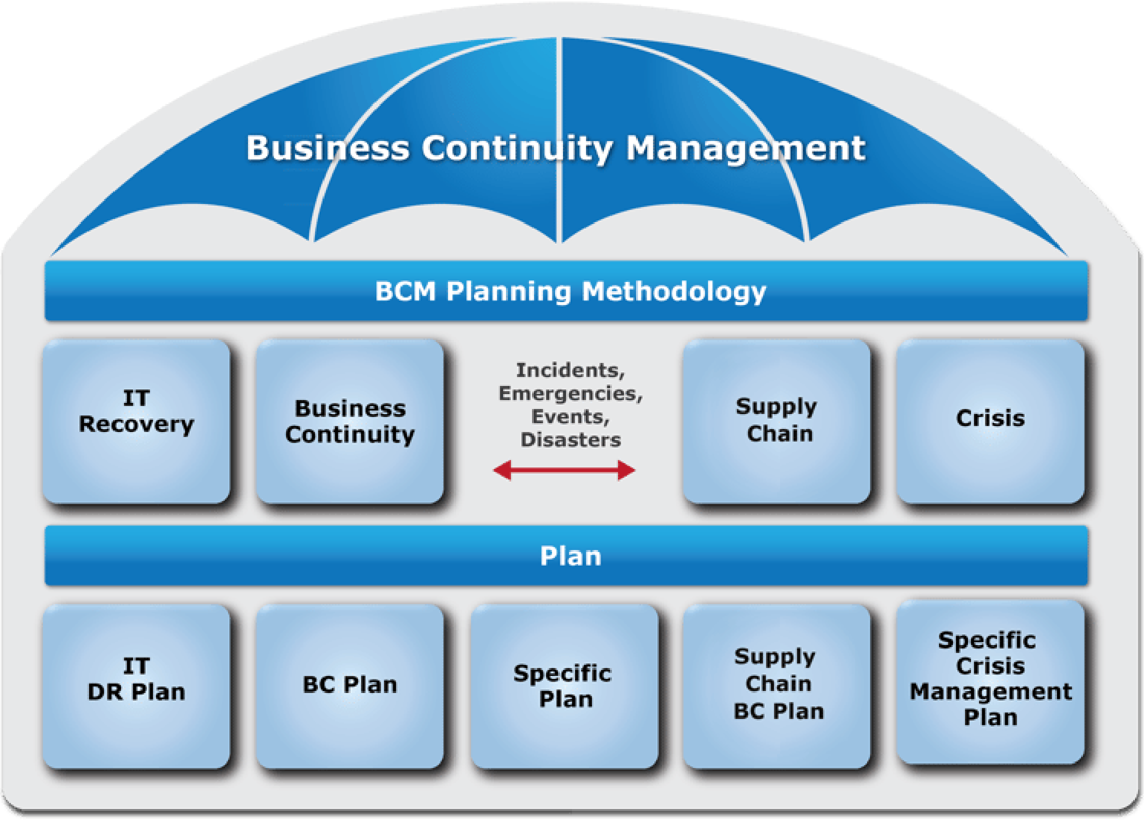


Fig. 13.7. Methodology for planning and managing enterprise continuity in an enterprise according to the Enterprise Continuity Management Institute [Moh Heng Goh, 2018]

Enterprise continuity management is a holistic management process aimed at identifying the potential effects of threats and developing response plans. The key goal here is to increase the organization's resilience to enterprise disruptions and minimize their effects. The definition of enterprise continuity management includes not only enterprise continuity (BC), but also crisis management (CM), crisis communication (CC), IT disaster recovery planning (DRP) and operational resilience (OR).

In the Jastrzębie mines, the "Enterprise Continuity Management Policy of JSW SA" was adopted on April 21, 2020. It is generally a set of procedures and information developed to assess risk and plan enterprise continuity in the event of any enterprise disruptions and minimize their effects to an acceptable level.

The primary goal of enterprise continuity management in the JSW Group is to protect the Company as effectively as possible against the negative consequences of critical events and to enable the restoration of original efficiency in the shortest possible time. By implementing the principles described in the Policy, the Company's Management Board expected to achieve the following goals:

– integration and coherence of contingency plans in the event of catastrophic disruptions in Critical Enterprise Processes,
– ensuring supervision over the effectiveness and adequacy of maintained emergency plans,
– providing policies and tools to support BCP Plan Owners in their development and maintenance.

The policy applies to all issues related to the identification, analysis and development of rules of conduct in the events that have a strong impact on the course of Critical Enterprise Processes. Enterprise continuity management is presented in two perspectives: the efficiency of the Company's Critical Enterprise Processes and the passage of time counted from the occurrence of events that result in a critical drop in this efficiency. The principles of conduct adopted in the Policy enable the development of effective response plans to the occurrence of an Extraordinary Event. The enterprise continuity management model in the JSW SA Group is presented in Fig. 13.8.

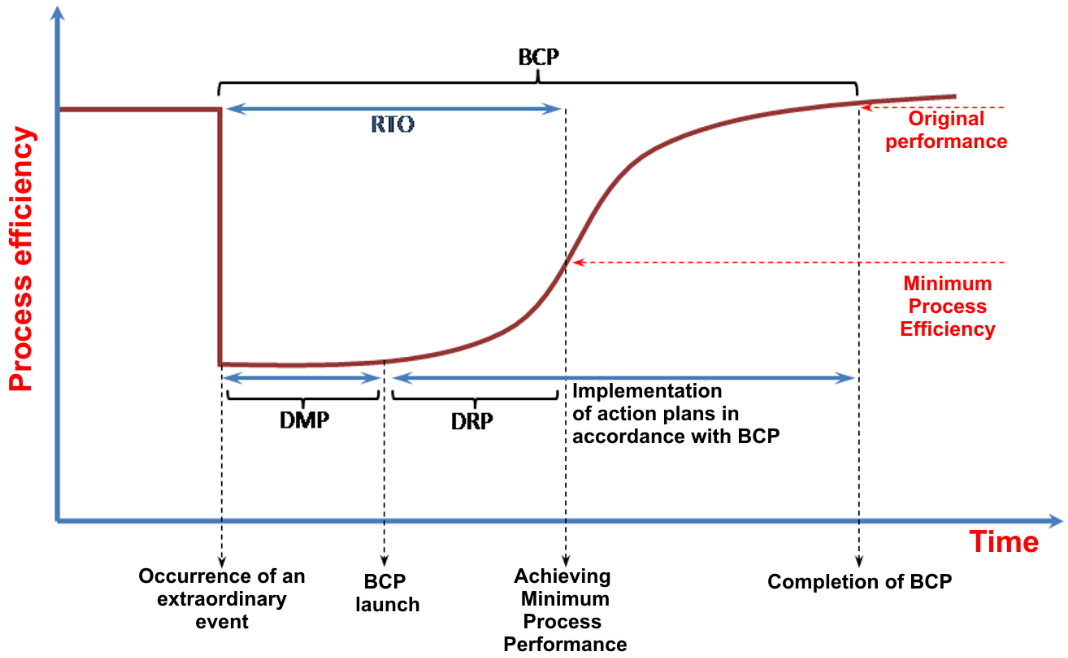


Fig. 13.8. Procedure diagram and main elements of the enterprise continuity management system in the JSW Group [Hereźniak, 2020]

The occurrence of an event that is considered in the context of loss of enterprise continuity causes a sharp decline in the efficiency of the entire process. In order to be able to restore the lost efficiency in an optimal time, it is necessary to plan actions that will be taken immediately after the occurrence of an Extraordinary Event. The procedure is divided into three stages:

– activities from the moment of occurrence of an Emergency Event to the moment of formal establishment of a enterprise continuity plan (DMP),
– activities undertaken as part of the announced and applicable enterprise continuity plan and leading to the restoration of the minimum expected efficiency of interrupted Critical Enterprise Processes (DRP), or the introduction of a maintenance mode,

- activities undertaken as part of the announced and applicable enterprise continuity plan leading to the restoration of lost performance (BCP).

The first step after an Emergency Event occurs is to take steps to formally announce and implement the BCP. The procedure defined as DMP is described directly in the BCP plan. The ssence of DMP is to use the shortest possible communication and decision path so that it is possible to effectively take actions aimed at maintaining Critical Enterprise Processes.

After establishing the BCP, which includes a course of action taking into account assigned roles, rights and responsibilities, the Company begins to operate in an emergency mode. The first actions are aimed at achieving the minimum efficiency of interrupted processes that will enable it to survive, or establishing a maintenance mode. The activities that are performed at this stage are described in the DRP, which is part of the BCP plan. DRP is constructed taking into account the critical time during which the lost efficiency must be partially restored, thus enabling the company to maintain its operations. The time counted from the moment of occurrence of an Extraordinary Event to the moment of achieving minimum survival efficiency is defined as RTO.

After the Company achieves efficiency at a level that guarantees the resumption of Critical Enterprise Processes or the introduction of the maintenance mode, activities related to restoring the state before the Extraordinary Event are carried out. In special cases, the nature of the disruption or the effectiveness of the solutions used so far justify making changes and restoring the lost functionality by using other methods.

After the loss of efficiency is achieved, the BCP operation is terminated, which is equivalent to the cancellation of the emergency mode. As in the case of introducing the BCP, in accordance with the described DMP procedure, the procedure for its cancellation must result from specific and described rules. The rules for canceling the BCP are described in each of the BCP plans prepared and adopted for use.

In the years 2020÷2023, Polish Ministry of Climate and Environment recommended mining enterprises to develop procedures for dealing with emergency situations, including:

- action plans in the event of a sudden loss of operational capabilities caused by the unavailability of a large number of employees at one time,
- establishing methods of communication between people involved,
- developing procedures for training employees with similar competences and transferring them, if necessary, to provide higher priority services, the aim of which should be to maintain the provision of the key service,
- developing shift work mechanisms, maintaining continuous monitoring of key systems,
- developing mechanisms for notifying key employees in the event of a serious failure or event related to CRP alert levels,
- developing remote work mechanisms, purchasing equipment enabling remote work and delegating employees (who can perform this type of work) to perform it at their place of residence,

– limiting access to the organization's headquarters by third parties, taking into account exceptions, such as people from CSIRT-type teams,
– controlling and monitoring third parties supporting the operation of key systems.

Integral to an organization’s ability to maintain enterprise continuity is the development of Disaster Recovery Plan (DRP). Developing such a plan is the process of formulating a strategy detailing the key actions required to restore IT services within the established recovery goals to be achieved following enterprise interruption due to a disaster.

For the key services provided, dependent on information systems, it is extremely important to include these systems in the post-disaster reconstruction plan. Taking the above into account, the possible threats leading to a disaster in their context include:

– criminal activity/cyber-attack/abuse,
– wiretapping/intercepting the session,
– physical attack,
– accidental damage (accident),
– malfunction/failure,
– interruption in supply (e.g. electricity),
– legal threats,
– natural disasters.

An important recommendation is also to raise awareness of employees in the field of cybersecurity, continuous training and education in the field of service continuity, and above all, OT/IT cybersecurity, with particular emphasis on the layering of security and implemented systems. One of the best means of protecting an organization's assets are employees who are aware of the threats and the importance of the information processed. An employee who is not fully aware of the consequences, such as disclosing certain information, may inadvertently take actions that negatively impact the organization. The process of periodic awareness and training can be a mean of creating preventive protection against such events. Training for new and existing employees should include at least relevant information on information security within the organization, as well as information specific to a particular job position. It is advisable to organize the training itself in a form that is interesting for the listener, which will not only enable passive acquisition of knowledge in a given area, but will also provide an opportunity for discussion. Additionally, where possible, examples of violations should be provided along with an indication of the consequences that occurred or could occur.

13.3. Reacting to incidents

With the increasing likelihood of incidents and attacks on small and large organizations in the mining and power sectors, it is essential to prepare the organization's ability to respond to incidents in order to secure the provision of services that are crucial to maintaining critical social or economic activities. Cybersecurity regulations, including: The Act on the National Cybersecurity System enforces the requirement to be able to respond to incidents.

Incident response requires thorough preparation as well as the ability to identify, contain and recover from cyberattacks. There are standards and guidelines for responding to incidents, e.g. ISO 27035:2016, SANS Incident Response in a Security Operation Center and NIST 800-61 Rev. 2 Computer Security Incident Handling Guide. The ISO 27035 standard proposes five phases of the incident management process. These are:

1. Planning and preparation.
2. Detection and reporting.
3. Assessment and decision.
4. Reaction.
5. Drawing conclusions.

NIST Guideline 800-61 Rev. 2, are one of the most detailed publicly available standards that describe in detail the process of responding to IT security incidents. According to the NIST document, there are four main steps in incident response:

1. Preparation.
2. Detection and analysis.
3. Reduction, elimination and recovery.
4. Post-incident actions.

In 2022, the Report "Cybersecurity in mining – 2022" prepared by the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology, ISAC-GIG Information Exchange and Analysis Center for the mining-and-power sector proposed the necessary guidelines and supplements to improve cybersecurity conditions in 2023 (Fig. 13.9).

Fig. 13.9. Principles influencing the improvement of enterprise cybersecurity conditions developed basing on the experience of the JSW IT Systems Ltd. [Raport ISAC-GIG, 2022]

Incident response requires a holistic approach to analyzing the situation and mitigating hostile actions taken against organizational assets. Threat analysis helps you realize how important it is to maintain constant dialogue and cooperation between IT and OT departments, cybersecurity and physical security experts, market entities and auditors. Therefore, in order to support active, early warning and rapid response to critical incidents, it is recommended to create a permanent and multidisciplinary task force within the organization, which must be able to select an appropriate strategy to mitigate the effects of incidents in order to minimize the impact on the continuity of key service.

To achieve this goal, the multidisciplinary task force should include:

- operational enterprise line experts who know the consequences of shutting down a system or communication channel,
- IT/OT experts who know the enterprise continuity specifications of the organization's infrastructure and who are in contact with suppliers and other partners during major incidents,
- incident response experts who are responsible for making decisions regarding actions determining the level of severity,
- analysts who can understand attack patterns and malware behavior, who should identify possible countermeasures.

Current practice shows that an incident may be various events, but in order for them to be considered a serious or critical incident, they must meet appropriate conditions. The Polish government regulated the issue of recognizing a given incident as serious by specifying these premises by way of a regulation on the thresholds for recognizing an incident as serious, according to the types of events in individual sectors and subsectors specified in Annex No. 1 to the KSC Act. Based on the thresholds indicated in this document relating to the effects that a given incident may cause, the following are listed:

- the number of users affected by the disruption of the provision of an essential service,
- time of impact of the incident on the key service provided,
- geographical scope of the area affected by the incident, other factors specific to a given subsector, i.e. circumstances such as: death of a person, serious damage to health, other serious damage to the health of more than one person, financial losses exceeding PLN 250,000.

The key service operator classifies the incident as serious and then, no later than within 24 hours from its detection, reports its occurrence to the appropriate CSIRT MON, CSIRT NASK or CSIRT GOV. When an incident occurs, the responsibility for appropriately classifying the incident as serious rests with the operator of the essential service. It should appropriately analyze the thresholds contained in the relevant regulation for a given essential service and, on this basis, submit the notification to the appropriate national level CSIRT.

13.4. Information Sharing and Analysis Center (ISAC) in the mining-and-power sector

Information Information Sharing and Analysis Center (ISAC) are non-profit organizations that provide the opportunity to exchange information about threats in the CYBER area. They enable the exchange of information on threats and vulnerabilities of IT systems and automation between enterprises, research institutes and local government units. This is especially important now that there is an armed conflict so close to our country's borders and the use of IT systems and the Internet in enterprises and offices has significantly increased as a result of the COVID-19 pandemic. It is the greater use of IT in the operation of industrial enterprises that has translated into a very large increase in related risks.

In counteracting CYBER threats, the key issue is access to expert knowledge. Therefore, enabling the exchange of experiences between people dealing with cybersecurity in different enterprises is particularly important and valuable, especially today, when there is such a shortage of specialists in this field. Cooperation within ISAC provides this opportunity and enables the education of new specialists, contributing to increasing resistance to all types of threats related to IT and automation systems.

The first Center for the exchange of knowledge and experience regarding cybersecurity incidents (ISAC) was established in the 1990s after the terrorist attacks in New York and Oklahoma City, when President Bill Clinton established the Presidential Commission for Securing Critical Infrastructure. The commission's task was to prepare a report recommending actions to secure American critical infrastructure in the future. In the report, the committee indicated the Internet and ICT systems as one of the greatest threats. The experts primarily recommended strengthening cooperation between government agencies and critical infrastructure operators and sharing information on potential threats. This recommendation was to be implemented through the establishment of the ISAC Center for the exchange of knowledge and experience regarding cybersecurity incidents. The Commission also emphasized the need to invest in research and development of modern technologies. In response to the Commission's recommendations, the first ISAC centers were created, and two years later, in accordance with the presidential recommendation, the obligation to create ISACs in each critical infrastructure sector was passed. The organization bringing together ISAC teams from all sectors in the USA is the National Council of ISACs. Its responsibilities include strengthening cooperation and exchanging cross-sectoral information.

There are currently over 20 ISAC organizations in the United States. In Europe, the first ISACs were established in the financial and power sectors. It is worth emphasizing that European organizations have different specifics than their American counterparts. They were created later, were built on a different cultural basis and are much more focused on government support, not just sector cooperation. This results from the belief deeply rooted in European culture that the state should ensure the security of both the public and private sectors.

European ISACs, compared to their American counterparts, are much more formalized, mainly due to the greater influence of government bodies on their functioning. They focus primarily on building partnership and trust. According to the nomenclature adopted by the European Network and Information Security Agency (ENISA), there are three ISAC models in Europe: national, sectoral and international. Each of these models has its own characteristics and specifics. Currently, there are over 20 ISACs operating in Europe, including: in Spain, Portugal, Poland, the Netherlands, Lithuania, Hungary, Greece, Ireland, France, Estonia, Austria, Belgium. ISAC-GIG is the first center for the exchange of information, experience and knowledge in the field of cybersecurity in the mining-and-power sector in Poland and even in Europe.

The rapid development of technologies used in the energy and mining industries has increased the number of dangers that may disrupt its smooth functioning. Effective cooperation, based on mutual trust between the public and private sectors, is necessary to ensure effective protection against new threats.

The idea of building an ISAC Center for the Exchange of Knowledge and Experience regarding cybersecurity incidents for the mining-and-power sector appeared for the first time in March 2020 during consultations between the heads of the crisis teams of JSW SA, Artur Dyczko, author of this exempt, and of KGHM Polska Miedź SA, Radosław Stach, vice-president responsible for copper production. Crisis teams were established to prevent, counteract and combat the threat of the SARS-CoV-2 virus. The editor of this monograph, organizing the work of the crisis team, which he then headed until March 2021, appointed as the team member, in addition to the directors of key production plants of the JSW Group, the President of JSW IT SYSTEMS Ltd., providing comprehensive IT services for Jastrzębie mines. It is this fact that led to intensive discussions until June 2020 at the level of the JSW SA and KGHM Polska Miedź SA crisis teams on the necessary procedures to ensure the Enterprise Continuity of the Mining Plants, also requiring the construction of the Knowledge and Experience Exchange Center regarding ISAC cybersecurity incidents.

It should be emphasized that the idea of creating ISAC, formulated in March 2020, during the work of the JSW SA Crisis Team for the mining-and-power sector was born from the need to exchange knowledge, information, experience, but above all, good practices in securing the Enterprise Continuity of Mining Plants. The past three years have clearly demonstrated the relevance and reasonableness of our idea. Today, no one disputes the thesis that cybersecurity of the entire mining-and-power sector depends on the security of individual entities, especially the smallest ones.

Currently, ISACs are becoming an increasingly popular cooperation model because they help improve the competences of operators in key sectors and build trust between the stakeholders of the cybersecurity system. Learning from each other, reducing costs and improving the level of cybersecurity - these are just some of the benefits of launching ISAC. Such knowledge exchange centers are built around various sectors of the economy (e.g. financial, aviation or energy). Their main task is to bring together institutions and enable an exchange of experiences about threats. ISAC is a form of public-private partnership (PPP) that is particularly effective in the area of cybersecurity. Operators of key services are private or public enterprises, and ICT threats rarely consortium only one institution or even one sector. Therefore, good cooperation and proper exchange of knowledge can significantly increase the level of cybersecurity. The data collected by ENISA shows that the creation of ISAC significantly contributed to increasing the level of knowledge about threats in a given country and to increasing the competence of companies and institutions in counteracting these threats.

As life has shown, despite several attempts and interventions of the Ministry of Climate, establishing the Knowledge and Experience Exchange Center regarding ISAC cybersecurity incidents by the State Treasury companies themselves was extremely difficult and fraught with the risk of divergent strategic goals - which consequently causes economically strong companies to operate alone, not taking advantage of the opportunities offered by working in a group, generating at the same time the costs of lost development opportunities that could be achieved by using the available resources more effectively. Not being discouraged by these problems, the author of this monograph, after almost a year of objective difficulties, in April 2021, together with several enthusiasts of the topic, proposed the organization of the Knowledge and Experience Exchange Center regarding ISAC cybersecurity incidents for the mining-and-power sector at the Central Mining Institute - National Research Institute (GIG), where the Institute's management, with great enthusiasm and ingenuity, took to create the necessary formal ISAC structures.

Formally, the agreements between the Central Mining Institute - National Research Institute and most representatives of State Treasury companies, playing a key role in the Polish mining sector, were signed in January 2022, while the ceremonial signing of the declaration of launching ISAC-GIG took place on June 3, 2022 at the Ministry of State Assets (Fig. 13.10).

Fig. 13.10. Signing of an agreement between the Central Mining Institute and representatives of most State Treasury companies that play a key role in the Polish mining sector. Piotr Toś from JSW SA was appointed as the first Managing Director of ISAC-GIG. – Warsaw June 3, 2022

The signatories of the agreement on cooperation within ISAC-GIG are currently:

– Central Mining Institute - National Research Institute,
– Jastrzębska Spółka Węglowa S.A.,
– JSW IT Systems Sp. z o.o.,
– KGHM Polska Miedź S.A.,
– TAURON Polska Energia S.A.,
– TAURON Wydobycie S.A.,
– Polska Grupa Górnicza S.A.,
– Lubelski Węgiel „Bogdanka” S.A.,
– Węglokoks Kraj S.A.,
– KOMAG Institute of Mining Technology,

– Silesian University of Technology, Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology.

In August 2022, in the presence of the Undersecretary of State at the Ministry of State Assets, Minister Piotr Pyzik, the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology and ITG KOMAG solemnly signed an agreement on joining the Information Exchange and Analysis Center in the field of cybersecurity for the mining-and-power sector ISAC - GiG. The accession of ITG KOMAG and the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology to ISAC GIG is the next step after the launch of elite postgraduate studies at the Faculty of Mining, Safety Engineering and Industrial Automation from October 2022 together with ITG KOMAG entitled: "Cybersecurity of industrial systems” (Fig. 13.11).

Fig. 13.11. Accession of the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology and ITG KOMAG to ISAC- GiG – Gliwice, August 2022

ISAC-GIG is one of the first projects of this type in the country, the first to bring together companies that play a key role in energy security. So far, only two such centers have been launched in Poland, i.e. ISAC-Kolej in the railway sector and the Reputation Center for Electronic Communications (ISAC-UKE) in the telecommunications sector. The idea of creating ISAC-GIG was born from the need to exchange knowledge, information, experience and good practices in the use of IT system security. The aim of ISAC-GIG Center is to, in accordance with the adopted principles, develop and promote standards and recommendations for the mining-and-power sector, as well as cooperate in handling security incidents and cyberattacks affecting entities in this sector.

The joint effort of each participant is to constantly analyze and share information about threats and incidents that occur in cyberspace. The main tasks of ISAC-GIG include:

– exchange and analysis of threat data in real time,
– creating reports on security incidents,
– exchange of technical and operational experiences along with the solutions used,
– sharing conclusions and experiences from incidents and threats.

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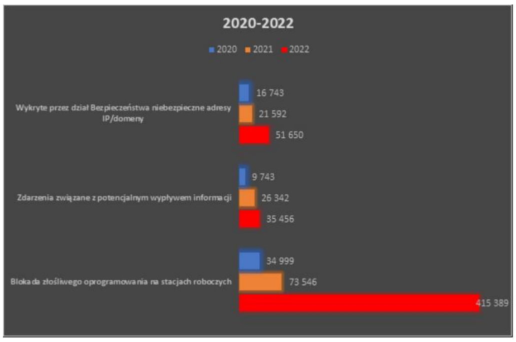
One of ISAC-GIG's cyclical initiatives is the preparation of the Report “Cybersecurity of industrial systems for the mining-and-power sector for 2022”. This document is an element of the Center's larger strategy related to conducting postgraduate studies entitled “Cybersecurity of industrial systems” at the Silesian University of Technology by the Faculty of Mining, Safety Engineering and Industrial Automation together with the KOMAG Institute of Mining Technology (Fig. 13.12).

Fig. 13.12. The architects of the creation of postgraduate studies entitled: “Cybersecurity of industrial systems” at the Silesian University of Technology, Dean of the Faculty of Mining, Safety Engineering and Industrial Automation, Franciszek Plewa, Prof. Ph.D.Eng. and the head of ISAC GIG, the CEO of JSW ITS Sp. z o.o., Piotr Toś – Gliwice, October 2022



Increased threat of cyberattacks - source: JSW IT Systems Sp. z o.o.

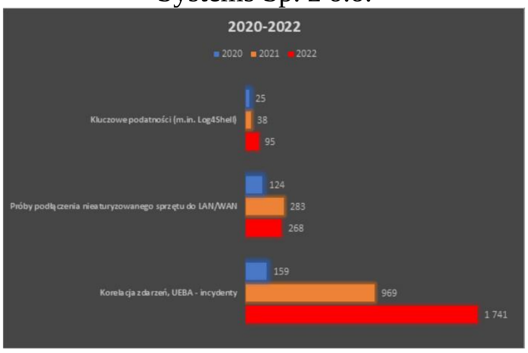


Fig. 13.13. Report “Cybersecurity of industrial systems for the mining-and-power sector for 2022” [Raport ISAC-GIG, 2022]

The report (Fig. 13.13) is ultimately intended to be an important element of ISAC-GIG's activities in the field of promoting and developing cooperation in the area of cybersecurity between science and enterprise, constituting a kind of alliance of innovative projects and research programs, disseminating their results in order to raise awareness of the management of the entire cybersecurity ecosystem for mining-and-power sector.

Learning from each other, reducing costs and improving the level of cybersecurity - these are just some of the benefits that come from reading the document, which will allow you to turn the data, observations and recommendations contained therein into actions that can ultimately improve security, among others, by building a new potential and capabilities in the area of the national cybersecurity system. The report, presenting the achieved goals and improvements that have been developed as part of developing a higher level of maturity and resilience of cybersecurity in the mining-and-power sector, also includes the effects of the amendment to the KSC Act, as well as proposals for the NIS 2 Directive introducing a number of challenges for entities of the national cybersecurity system in all sectors.

13.5. Silesians CyberSecurity Hub - a new way to build digital awareness and develop cybersecurity competences

As mentioned above, the idea of building the ISAC Center for the Exchange of Knowledge and Experience regarding cybersecurity incidents for the mining-and-power sector appeared for the first time in March 2020 during consultations of the heads of the JSW SA and KGHM Polska Miedź SA crisis teams. A little later, in April 2021, as a result of developing this idea, the main assumptions of the strategic research program entitled "Safe Digital Silesia 2030" were developed, an extremely ambitious initiative aimed at ensuring digital security for the inhabitants of Silesia in the era of civilization transformation.

The entire concept was based on the assumption that the primary goal of the "Safe Digital Silesia 2030" program will be the construction, in the "Barbara" Experimental Mine in Mikołów, belonging to the Central Mining Institute - National Research Institute, of the Center for the Development of Innovative Digital Competencies, whose task in the coming years will be:

- creation of the Center for the Exchange and Analysis of Information on vulnerabilities, threats and incidents to support entities of the national cybersecurity system, currently ISAC GIG,
- development of digital competences, especially in the field of cybersecurity, of local government units, large, small and medium-sized enterprises, construction of a training base in the field of cybersecurity, along with the launch of a program for discovering and training the most talented students of Cybersecurity Talent Identification and Assessment Program – CTIAP,
- creating technological security measures ensuring the continuity of operation of industrial IT/OT systems, enabling coordination and active response to incidents in cyberspace, creation of the Regional Transformation Monitoring Center based on obtaining source production and environmental data from mines undergoing the transformation process.

All this so that ISAC GIG, due to published reports, analyses and training, becomes an opinion leader and creator of ecosystems that increase resistance to cyberattacks.

All the author's ideas were strongly confronted with the prose of life, and especially with the financial reality of Polish science, in order to finally discuss the assumptions of the program with the Marshal's Office, which, after familiarizing itself with the proposed concept, included them in the Territorial Plan for the Just Transformation of the Silesian Voivodeship up to 2030, supporting activities aimed at increasing the level of innovation of the economy, developing new competences related to the need to adapt employees in the mining and mining-related industries to ongoing changes, and an effective and socially responsible transformation management system.

The finally prepared projects constituting the “Safe Digital Silesia 2030” research program were incorporated into the Territorial Just Transformation Plan of the Silesian Voivodeship, forming three main pillars (Fig. 13.14):

– Digital competence center – Silesian CyberSecurity Knowledge Center,
– Regional transformation monitoring center – Mining Transformation Monitoring Center,
– Technological security center – Silesian CyberSecurity Data Center.

Fig. 13.14. The idea of transforming the Barbara Experimental Mine into Silesian CyberSecurity Hub

The process of transforming the “Barbara” Experimental Mine, which had conducted normal mining activities in the past, into a modern IT center with a modern data processing center located underground, which will become a good example of the digital transformation not only of Silesia, but of the entire raw materials industry, has already been planned and financed in the National Reconstruction Plan of the Silesian Voivodeship.

The main advantage of locating the Data Center in underground mines is maintaining a high degree of security of stored data in an easier way than when using traditional server rooms. Data center customers demand server reliability and full availability. All IT and support devices located underground are not exposed to bad weather conditions or other random situations, not to mention war.

Internet service providers around the world have been cooperating with underground data processing centers for years. The most energy-efficient server room in Europe is located in Lefdal, Norway. It is located 150 m underground, in the workings of a former olivine mine, and has been operating since 2017 (Fig. 13.15).

Fig. 13.15. The most energy-efficient server room in Europe located in the Norwegian Lefdal olivine mine 150 m underground [Digital Report, 2022]

In the American city of Springfield, Missouri, in an old underground limestone mine, approximately 25 m underground, a data processing center with an area of over 7.500 m^2 was located. Similar underground server rooms operate in Pennsylvania and Kansas City. The Kansas City center is located 34 m below the surface and the Pennsylvania center is located 70 m below the ground (Fig. 13.16).

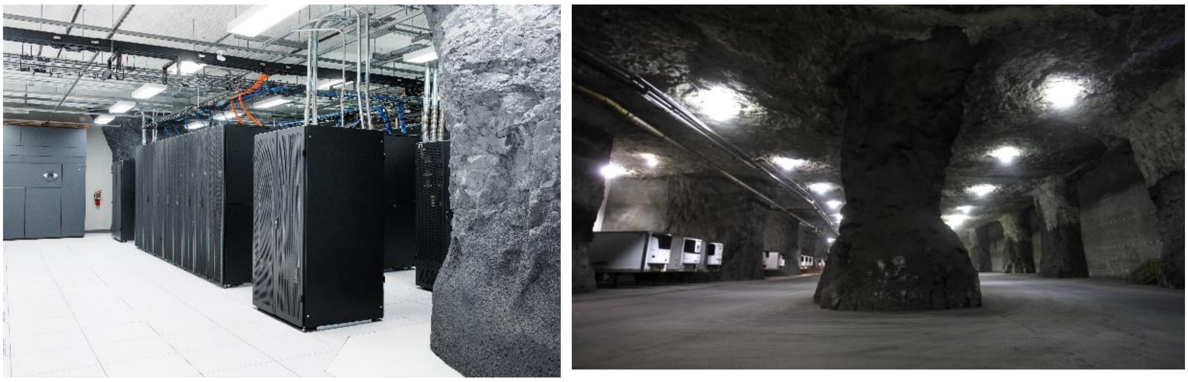


Fig. 13.16. Data processing center in the American Springfield, Missouri in an old underground limestone mine - DATA CENTER COMPANY EXPANDS UNDERGROUND IN MISSOURI [Missouri Partnership, 2018]

Data Center KD Barbara, through the use of existing underground workings, will help reduce the costs of data processing center operators, as it will not be necessary to build an entire

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server room building or rent expensive space. There will also be no huge costs associated with cooling the devices, because there is no sunlight underground and the temperature and air humidity are constant there.

According to the author of this chapter of the monograph, who is one of the creators of the concept of "Safe Digital Silesia 2030", Silesian CyberSecurity Hub can not only be an element of the Silesian Computing Cloud built, among others, based on the KD "Barbara" Data Center, but ultimately it should become an important element of the Government Computing Cloud in the area of monitoring the transformation of the national mining-and-power sector.

Fig. 13.17. A modern IT center in the “Barbara” Experimental Mine

As the reality around us shows, the "Safe Digital Silesia 2030" program prepared in April 2021 has not lost any of its attractiveness and relevance, and the war in Ukraine only confirmed the validity of the theses formulated by the authors a year before its outbreak, giving them additional meaning.

The past is in our heads and the future is in our hands - as folk wisdom says, the truth of these words was clearly confirmed by the past year 2022. This was the first year of operation of the Information Exchange and Analysis Center for the mining-and-power sector (ISAC GIG).

ISAC GIG works actively, integrating the entire environment of the Polish raw materials sector to raise awareness and digital responsibility, which is the foundation of the new face of the mining and energy industry in our country.

The writer of these words is particularly pleased that currently Silesian CyberSecurity Hub is not only GIG and the idea of building a Center for the Development of Innovative Digital Competencies in the "Barbara" Experimental Mine with the only modern server room in Poland located in underground mines. Today, after a year of operation, ISAC GIG, Silesian CyberSecurity Hub is primarily an ALLIANCE between the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology, the Central Mining Institute - National Research Institute and the KOMAG Institute of Mining Technology for the benefit of State Treasury companies playing a key role in the Polish mining-and-power sector.

Today Silesian CyberSecurity Hub is also, and perhaps above all, an agreement between the worlds of science and industry - an industry that is exceptionally important for the security of our country's functioning - to permanently secure an elementary node of concentration of the main data streams of our critical infrastructure in many fields. As Piotr Toś, Chairman of the Management Committee of the Information Exchange and Analysis Center ISAC-GIG, said: *"... today Silesian CyberSecurity Hub is working to create a training base to support all existing and emerging new ISACs throughout Poland. We have experience and great achievements in building efficiently operating Information Exchange and Analysis Centers in the field of cybersecurity, we want to become an important element of the Government Computing Cloud in the area of monitoring the transformation of the Polish energy industry, we want to launch, together with the Silesian University of Technology, a program for searching and training the most talented students Cybersecurity Talent Identification and Assessment Program - CTIAP, we want, together with the KOMAG Institute, to build a fast certification path in the field of cybersecurity of IT/OT products that will be recognized in Europe. I believe that our cooperation in Silesia will bring a new quality. There is no doubt that we play as one team, and our team is not a group of people who just work together! Our team is a group of people who trust each other in the context of science, new and innovative ideas, research projects and initiatives that are aimed at developing and modernizing the Polish scientific sector...* ".

THE ALLIANCE of the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology, the Central Mining Institute - National Research Institute and the KOMAG Institute of Mining Technology breathed life into the idea of building Silesian CyberSecurity Hub! Through organized postgraduate studies, training and information exchange, as well as ensuring an appropriate response to emerging threats, it has made it possible to build and develop new competences in the field of cybersecurity for State Treasury Companies, Local Government Units and other participants of the National Cybersecurity System.

This alliance also focused the efforts of the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology around the idea proposed by the Author to launch six laboratories at the faculty by 2025, constituting a COMPETENCE CENTER IN THE FIELD OF SAFETY, OPERATIONAL ANALYTICS AND MANAGING HAZARDOUS SITUATIONS IN INDUSTRY.

The Alliance for building a DIGITAL ECONOMY as a factor in the technological development of the mineral resources sector and a fair energy transformation of Silesia was established on December 11, 2023 in Gliwice.

The Silesian University of Technology and the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences from Krakow have concluded an agreement on cooperation in the implementation of research programs, project initiatives and commissioned works aimed at improving innovation, technical and economic efficiency of the mineral resources management in Europe.

The agreement was solemnly signed by the Silesian University of Technology – Vice-Rector for Science and Development, Marek Pawełczyk, Prof. Ph. D. Eng. and on the part of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences – Krzysztof Galos, Prof. Ph. D. Eng., Director of the Institute (Fig. 13.18).

Fig. 13.18. Signing an agreement on cooperation between the Silesian University of Technology and the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in Krakow by the Vice-Rector for Science and Development, Marek Pawełczyk, Prof. Ph. D. Eng. and Krzysztof Galos, Prof. Ph. D. Eng., Director of the Institute

The CENTER, based on the latest achievements in automation and IT using artificial intelligence, will enable simulation of industrial and technological processes and crisis situations, as well as connecting distributed monitoring, control and security systems responsible for the operation of the enterprise.

AI, OPERATIONAL ANALYTICS AND INFORMATION PROCESSING Laboratory - will constitute the heart of the CENTER being built, serving as a research ground for ensuring the security and cybersecurity of industrial automation systems in the mining-and-power sector. This will fill the gap in testing the cyber resistance of automation systems and devices used in industry. A complement to the activities presented by the Author, originator and initiator of activities aimed at involving the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology around the idea of: Digital Economy as a Factor in the Technological Development of the Mineral Sector, will be the creation of a SITUATIONAL AWARENESS SYSTEM - constituting, as it were, the brain of the CENTER being built. The situational awareness system for industry is an advanced platform for real-time monitoring, analysis and response in an industrial environment. The main assumptions of this system include, among others, the integration of data from various sources, such as sensors, monitoring systems, databases and measuring devices, which will allow to obtain a comprehensive picture of the situation. This knowledge provides the opportunity to counteract and respond appropriately to emergency situations.

Fig.13.19. The construction of the CENTER will be managed by the Dean, Franciszek Plewa, Prof. Ph. D. Eng. and Artur Dyczko, Ph. D. Eng.

The author of this chapter of the monograph believes that the COMPETENCE CENTER IN THE FIELD OF SAFETY, OPERATIONAL ANALYTICS AND MANAGEMENT OF HAZARDOUS SITUATIONS IN INDUSTRIES being built at the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology will be an excellent development and complement to the Silesian concept of CyberSecurity Hub, at the same time becoming a new quality on a European scale in the field of research and training, using simulation and virtualization in laboratory conditions of dangerous situations related to cyber threats, natural and industrial threats.

In recent years, cyberspace has become a new security environment, which has introduced significant changes in both the practical, and legal and organizational aspects of the operation of global security systems. In this context, it is particularly important to understand the dynamics of this environmental change (both in the provisions of the NIS 2 directive and the KSC Act). Building a legal system as a national response to the opportunities and challenges related to its presence in cyberspace was an extremely complex task. This results not only from the pace of technological change, but also from the specificity of the environment and its "interactivity". The trend in international law that has emerged during COVID-19 and the current geopolitical situation is to treat organizations from the mining-and-power sector as one of the important actors in national and international relations.

The new regulations introduce and expand international cooperation between individual entities and regulate security strategies and policies, which should take into account the recommendations of the Ministry of Climate and Environment, with particular emphasis on, among others, ensuring the continuity of system operation, handling security incidents and constantly increasing awareness of cybersecurity and cyber threats. It should not be forgotten that threats in cyberspace represent a different class of organizational challenges, largely similar to those posed by other asymmetric threats such as terrorism. Their common feature is that they require less hierarchical and more flexible solutions on state structures. Cybersecurity, both socially and technologically, with all its consequences, emerges as one of the most important concepts of the security paradigm at the national and international level.

14. Summary

Artur Dyczko

The DIGITAL TRANSFORMATION of the JSW Group presented on the pages of this monograph took place in the years 2016÷2020. Its scope included the digitalization of processes related to underground radio communications, monitoring work safety conditions, automation of entire production lines and the use of advanced data analytics to manage the company. These activities were carried out primarily with an aim to increase the efficiency and thus the competitiveness of the JSW Group's operations on the dynamically changing global market of mineral raw materials.

In 2017, the Management Board of JSW SA, while analyzing the premises for verifying the Group's Business Strategy until 2030, which was currently being prepared, noticed a group of conditions and limitations - with particular emphasis on the resource base - that may threaten the security of the Company's operations in the future. As stated on the basis of the conducted analyses, potentially the greatest limitation to the implementation of the assumed strategic goals will be the geological and mining conditions deteriorating with increasing mining depth, as well as the accompanying risks and threats. The situation was so serious that it could prevent the JSW Group from maintaining the status of the largest producer of high-quality hard coking coal in Europe in the near future. Being aware of the seriousness of the situation, the Company's Management Board decided, in the years 2017÷2020, to base the Company's development on technical and technological diversification of the production process based on knowledge, innovations, research projects and cooperation with industry leaders not only in Poland but also abroad. The extraordinary determination accompanying the implementation of the **JSW 4.0** and **JSW 4.0 Smart Mine programs** was seen as an unique opportunity to quickly transform the Polish coal company based in Jastrzębie Zdrój into a modern European raw materials consortium with 4.0 ambitions.

The digital revolution of the JSW Group described in this monograph explains, presents and documents the digital transformation that took place in the Jastrzębie mines in 2016÷2020. The book covers processes related to underground computerization, radio communication, monitoring of occupational safety conditions, automation and the use of advanced data analytics to make management decisions. It presents the experience gained by entire research teams during strategic projects implemented over the period of nearly four years, documenting the greatest technological breakthrough in the Polish mining industry in years.

As it turned out, the key element of the Company's digital transformation was **the centralization and consolidation of IT activities,** both in the field of IT and OT, of the entire JSW Capital Group. The activities carried out since 2010, centralizing IT and OT functions in JSW SA in a dedicated IT special purpose company, were intensified in 2017÷2020, ultimately leading to full service of entire business processes in the field of IT and OT of subsequent JSW Group companies. A breakthrough stage of the digital revolution at JSW SA was the implementation of a uniform IT/OT infrastructure in the Company. The process was complicated and long-lasting, but due to the full determination of the entire project teams,

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consistent work to eliminate the technological gap and unify and standardize the infrastructure and data layers was carried out.

First, the work covered the IT area, and then also OT. The main projects related to the construction of LAN and WAN network infrastructure, construction of the primary and reserve Data Processing Center, implementation of the IT Data Warehouse and Business Intelligence tools along with the construction of a platform for consolidating data from JSW Group companies at the level of the Management Office and the Shared Services Center were completed by 2017. In this year, the network infrastructure started developing underground and in areas directly related to the production of JSW mines. Company's own technical OT data warehouse was built, tools for advanced data analytics were implemented, and at the Company Management Board level**, the JSW Group Project Management and Standardization Team** was established, as well as the **JSW 4.0** and **JSW 4.0 Smart Mine** programs, together with **the JSW SA Management Board Plenipotentiaries for IT, Communication and Automation** and **CZAD**.

Standards have been developed for underground communications, transmission and data security. The process of digitalization of key IT/OT processes in the JSW Group has begun.

Since 2018, the Company's digital transformation has included the digitalization of key functional areas supporting basic business processes and activities aimed at increasing the level of security. The main projects implemented during this period include: deposit modeling and production scheduling implemented in all JSW SA mines and the Management Office (the world's largest implementation of this type of IT tools in mining in 2018÷2019), Electronic Document Circulation, expansion of CZAD, launch of ERP systems , launch of tools supporting project and program management, standardization of SCADA systems, Planning Model in the JSW Group, Safety of Mining Crews, expansion of cybersecurity systems.

For the years 2021÷2025, projects are planned to be implemented in the field of integration of individual functional areas in order to enable process and financial optimization and process automation leading to increasing the company's value. The projects implemented at this stage were assumed to aim at integrating safety management and the integration and monitoring of production processes of the entire JSW Group, which should enable in the future the launch of projects leading to the implementation of systems optimizing and automating entire business processes in the key strategic areas of the Company.

The implementation of the activities described above, which constitute the current implementation of a kind of digital revolution of the JSW Group in the years 2016÷2020, would not be possible without taking over 100% control over the IT area in the JSW Group. The decision to take over full ownership control over the Advicom company in 2018 and then rename it to JSW ITS was made in order to protect the JSW Group's investments in ICT and automation, widely presented on the pages of this book, which comprised the adopted in 2017 JSW SA IT/OT Strategy updated in 2019.

It was the establishment of JSW ITS in 2018, along with a significant increase in financing for the IT/OT area throughout the Group, that allowed for a number of investments to be made both in ICT infrastructure and the development of IT/OT systems, allowing for:

- increase of the safety of mining crews and data in systems, among others by building new standards in the field of cybersecurity of the industrial systems used, developing a new policy and selecting technologies for locating employees in particularly dangerous underground zones,
- implementation of strategically important programs for JSW mines: **JSW 4.0 Smart Mine** and **JSW 4.0**,
- Construction of company's own resources in the field of cybersecurity and protection of investments in IT/OT development.

The DIGITAL TRANSFORMATION of the JSW Group, carried out in 2016÷2020 and described in the monograph, on the one hand allowed for the implementation of strategic efficiency programs such as QUALITY and EFFICIENCY, but what is equally important, allowed for the elimination of the huge **technological debt** that JSW SA had been dealing with basically since the beginning of the Company's establishment in 1993 and subsequent years of its operation. This debt, growing year by year, choked JSW SA's technological innovation, especially in the years 2000÷2015, paralyzing the implementation of a few advanced IT projects and not recognizing the OT area at all, the implementation of which could have significantly improved the production monitoring and control processes in the JSW mines.

The actions launched in 2016 aimed at changing the management and supervision model of the IT/OT area in the Company, generally centralizing IT and OT functions throughout the JSW Group, accelerated the process of **eliminating technological debt in the field of technical infrastructure and communications**, enabling the use of the most modern technologies in the world in JSW SA mines. During that period JSW SA:

- expanded the network infrastructure by building in its mines:
  - 170 km of fiber optic cables,
  - 165 km of radiating cable, launching the digital radio communication in underground workings of JSW SA mines (handing over nearly 400 radiotelephones to the maintenance services of mining plants and the headquarters),
  - thermal imaging (non-contact) temperature measurement systems for employees,
  - CCTV video monitoring (especially underground), enabling the observation of particularly endangered places and strategic points of technological lines of JSW SA mines,
- developed assumptions for an intrinsically safe system for localizing employees in underground mines,
- launched continuous monitoring of gas parameters in methane drainage pipelines, and also reconstructed, after nearly 30 years of operation of JSW SA, their own methane drainage services and took real control over their own methane drainage infrastructure,
- modernized LAN and WAN networks in all JSW SA mines,

- modernized existing server rooms and launched the ability of providing private cloud services,
- developed their own communication standards and technological data collection tools and launched the IT and OT Technical Data Warehouse as well as analytical and reporting systems; a project was also developed to replace the central data backup system and IT/OT systems,
- built their own resources and standards in the field of cybersecurity and data protection in accordance with the adopted technological security architecture model of the JSW Group.

A similar digital transformation was carried out in the field of applications supporting the business areas of the JSW Group. The years 2017÷2020 are the culminating period of technical and organizational changes and the accompanying investments, due to which **the technological debt in the field of applications supporting business areas and data processing was eliminated**. It was during this period that activities were launched, which allowed for:

- consolidation and analysis of financial data of the entire JSW Group,
- integration of data from process acquisition systems (SCADA) with business systems (ERP); Company implemented, among others:
  - Center for Advanced Production Data Analytics (CZAD),
  - unified Digital Deposit Map - a digital deposit model with integrated planning and scheduling of mining production (the largest in the world implementation of this type of IT tools in mining in 2018÷2019),
  - Explosion-Proof Equipment Registration System “Ewidencja EWEX” (the EWEX system device database currently includes nearly 70 million devices),
  - optimization of the resource management and material logistics process at JSW SA; a new version of the “Wozy” software system supporting the area of material logistics in mines was launched (for the first time, underground transport control rooms were equipped with industrial computers),
  - Project Portfolio Management System – Microsoft Enterprise Project Management,
  - Electronic Document Circulation (EOD) – at first the implementation covered the investment area and the main office of the JSW Group,
  - analytical and reporting management information system (MIS dashboards),
  - standardization and acquisition of technological data in the central technological data server (using it as a base platform meeting the requirements for building CSDT PISystem by OSIsoft,
  - own SCADA system software called HADES for dispatcher support of production processes,

  and started:

  - construction of the Central Reactive Power Compensation System,
  - implementation, at CLP-B, of a system supporting laboratory work in order to optimize the coal and coke quality testing process (LIMS). It was launched as a part of the JSW

QUALITY 4.0 program – system supporting comprehensive quality management and automation in the field of continuous measurement of quality parameters of mined material in the JSW Group.

Only in hindsight it can be seen how the DIGITAL TRANSFORMATION of the JSW Group presented in this monograph, carried out in the years 2016÷2020, contributed to changing the old operating model of the Company, how it dynamized the process of building a new, effective operating model of the entire JSW Group, and how it finally secured the Company against new digital threats, actively influencing the increase in the Company's value and efficiency, and safety of JSW Group employees.

Due to the new management and supervision strategy over the production area in the JSW Group, which assumed an increased integration and automation of entire production processes and applying innovative IT/OT solutions throughout the entire production and commercial cycle, several decades of technological debt in the field of technical infrastructure, communications, applications supporting business areas, and data processing were eliminated.

Automation and IT Office (TA) and **the Automation Divisions (EDA)** reporting to the Superintendent of Teletechnical Devices, Methanometry and Geophysics at JSW SA mining plants, established to coordinate cooperation between the Group companies and JSW SA (the parent company) and JSW ITS, was a foundation of the digitalization process. The Automation and IT Office (TA), established at the Company's headquarters, until 2021 was responsible for coordinating all activities related to the ongoing digital transformation in the Group. Its tasks included:

- supervision of the implementation of the IT/OT strategy adopted in 2018,
- development, updating and maintenance of IT/OT standards of the JSW Group,
- establishing automation departments (EDA) in JSW SA plants,
- supervision and expansion of the scope of analyses of CZAD telecommunications data,
- coordination of the work of IT and Cybersecurity Coordinators at mining plants,
- 24-hour monitoring of the operation of JSW SA plants by CZAD (in 2020÷2021, CZAD employees, in cooperation with JSW SA mine operations dispatchers, monitored the operational situation in the Company on an ongoing basis, including reporting on extraordinary events, such as accidents or epidemiological threats),
- development and supervision (together with JSW ITS services) of key information for the Management Board presented on management dashboards (panels) that transparently aggregate daily key information on the Company's operational activities,
- supervision of the CCTV video monitoring system (in March 2021, 397 cameras were activated at the plants in the Milestone system),
- launching and supervision of systems for measuring gas parameters in methane drainage pipelines of JSW SA mines,
- modernization and supervision of functioning of FOD-900 multiple transmission systems (the FOD-900 system is designed to collect and transmit information - most often two-state, about the technological process of mines to the supervision point - traffic dispatcher),

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- supervision and development of the Central Server for Technological Data (CSDT), which is used to create reports based on machine operating parameters,
- standardization of data transmission, cybersecurity, monitoring of reporting processes of main production lines and safety of mining crews,
- coordination of key efficiency projects implemented at mining plants,
- optimization of service costs under SLA service agreements,
- obtaining funds to finance efficiency projects from the National Fund for Environmental Protection and Water Management and the Voivodeship Fund for Environmental Protection and Water Management.

The consequence of establishing the Automation and Information Technology Office (TA) was the organization of Automation Departments (EDA) from scratch in all mining plants of JSW SA and the employment of 13 employees in each of them to maintain the full operation of machinery and equipment supervision systems, including teletransmission networks and IT systems supporting operation of machines and devices. In total, by the end of 2018, nearly one hundred people worked in EDA branches of all mines. Their tasks included:

- cooperation with external entities - suppliers of control and measurement equipment (AKP),
- coordination, cooperation and supervision of companies responsible for servicing production process supervision systems and teletransmission networks,
- implementing new solutions to improve the functioning of broadly understood mining automation,
- creating specifications of essential terms of the commission for investments related to the implementation of new and expansion of existing ICT systems,
- coordination of tasks related to ensuring the appropriate level of IT security of JSW SA plants.

The establishment of Automation Divisions (EDA) allowed the company to perfectly control the dynamic development of hardware and software infrastructure in the area of industrial automation used in the production processes of JSW SA mines.

The changes introduced in the organizational structure of the mines, consisting in the creation of a new organizational unit in the Power Mechanical Department (Electrical Department) subordinated to the Superintendent of Teletechnical Devices, Manometry and Geophysics, employing specialists to maintain the operation of systems monitoring the operating parameters of machines and devices in full efficiency, forced the construction of a CSDT ensuring a continuous, central access to structured data generated in the production process, which became one of the main milestones of the digital transformation process at JSW SA mining plants.

Being aware of the changes taking place, and especially the pace of the transforming economy, the Management Board of JSW SA noted in the Company's Strategy for 2018÷2030 that the digitalization of the mining sector, as an element of the industrial revolution in mining, is an unique opportunity for the JSW Group to increase the resilience of national industrial supply chains, improve the environmental performance of the minerals sector and increase transparency and dialogue with citizens and communities affected by mining activities.

We believed that computerization, digitalization and integration of key economic processes could allow to start building an effective and modern operating model for the entire JSW Group. That it would enable to think boldly about taking advantage of the unique opportunity to quickly transform the Polish coal company based in Jastrzębie Zdrój into a modern, effective and competitive European raw material consortium with 4.0 ambitions. We believed that we could make JSW SA a learning organization, using its own experience and available information resources in a systematic and active way, optimizing its business model to withstand the growing needs and requirements of a dynamically changing market. We finally believed that we could set new, ambitious development directions and become a part of an intelligent vision of the functioning of the Polish mining sector 4.0.

Mining automation is a discipline with enormous potential. However, a fully automated mine with machines endowed with hypothetical intelligence is a rather distant vision. In the long run, it is worth ensuring real support for processes that are and will most certainly continue to be implemented in the future by people. The situation on the energy raw materials market and the increasing depth of deposits make the ability to use the correct methods to solve heterogeneous, complex planning and optimization problems an essential issue.

The constantly changing environment means that information exchange and processing constitute an increasingly important element of business activities and have a significant impact on the market position of a mining company. In its Strategy for 2018÷2030, the JSW Group defined strategic directions of development, in accordance with the theory of "creative destruction". The company has developed its own communication standards in mining plants, organized procedures and guidelines for the transmission, storage, and protection of OT data, and proposed a completely new model of IT development within the JSW Group, involving entire teams of engineers in mines in its implementation. In short, it started changing the perception of the organization's automation and IT.

The Management Board made the Deputy President of the JSW SA Strategy, Investment and Development, responsible for implementing the digital transformation process of the JSW Group by 2030. His task was to prepare the Strategy, create organizational conditions for its implementation and build entire project teams in accordance with the principle*: Team is not a group of people who work together. A team is a group of people who trust each other.* It is the expertise of these people, their determination and diligence that enabled to achieve results that now place Jastrzębska Spółka Węglowa among European pioneers in the automation and monitoring of the production process in underground mines, in accordance with the INDUSTRY 4.0 paradigm.

Assessing the implementations carried out in the JSW deep hard coal mines from today's perspective, the validity and effectiveness of the implementation of the Digital Transformation process of the JSW Group should be confirmed. The Digital Transformation of the JSW Group presented in this monograph was, and I believe still is, the Jastrzębie miners' response to the challenges awaiting the entire Polish mining industry in the coming years and should constitute a valuable inspiration for its further transformation.

https://doi.org/10.32056/KOMAG/Monograph2024.2

15. Literature

Aki K., Richards P.G.: Quantitative Seismology. Theory and Methods, Freeman, San Francisco, 1980.

ATEX (RMR, 2016). Dyrektywa 2014/34/UE Parlamentu Europejskiego i Rady z dnia 26 lutego 2014 r. w sprawie harmonizacji ustawodawstw państw członkowskich odnoszących się do urządzeń i systemów ochronnych przeznaczonych do użytku w atmosferze potencjalnie wybuchowej. Dziennik Urzędowy Unii Europejskiej L96 z 29.03.2014, str. 309. (RMR 2016). Rozporządzenie Ministra Rozwoju z dnia 6 czerwca 2016 r. w sprawie wymagań dla urządzeń i systemów ochronnych przeznaczonych do użytku w atmosferze potencjalnie wybuchowej Dz.U. 2016 poz. 817. Do 19 kwietnia 2016 r. obowiązywała poprzednia Dyrektywa ATEX nr 1994/9/WE w sprawie ujednolicenia przepisów prawnych państw członkowskich dotyczących urządzeń i systemów ochronnych przeznaczonych do użytku w przestrzeniach zagrożonych wybuchem.

ATUT. Specyfikacja produktów i wyrobów. https://www.atutnet.com/pl/platforma-oprogramowania-at-visio2-system-wspomagania-procesow-produkcji. [Access: 11.07.2022].

Barański A., Dubiński J., Lurka A., Mutke G., Stec K.: Metoda sejsmologii górniczej oceny stanu zagrożenia sejsmicznego i tąpaniami. Zasady stosowania metody kompleksowej i metod szczegółowych oceny stanu zagrożenia tąpaniami w kopalniach węgla kamiennego. Wydawnictwo GIG, Seria Instrukcje Katowice 2012, nr. 22.

Bazan Ł., Diederichs R., Gajda W., Lubryka J., Ptak K.: Monitorowanie podporności elementów obudowy zmechanizowanej - system EH-PressCater. Monografia pod redakcją A. Wojaczka i A. Dyczko: Monitoring wybranych procesów technologicznych w kopalniach podziemnych. Wydawnictwo Katedry Elektryfikacji i Automatyzacji Górnictwa Politechniki Śląskiej, Gliwice, 2015.

BECKER. Materiały firmy BECKER (http://www.becker-mining.com.pl/) dotyczące informacji o produktach firmy BECKER – Becker Mining Systems: https://www.becker-mining.com.pl/do_pobrania/WALLTECH.pdf [Access: 11.07.2022].

Bentley T: Information Systems Strategy for Business, 1998.

Berger J., Markiewicz J., Badylak A., Olszewska M, Berger-Kirsz J.: Doświadczenia zakładu odmetanowania kopalń „ZOK” Sp. z o.o. w Jastrzębiu-Zdroju, w projektowaniu i budowie powierzchniowych i podziemnych stacji odmetanowania. Systemy Wspomagania w Inżynierii Produkcji, 2016.

Biernacki Z.: Sensory i systemy termoanemometryczne. WKŁ. Warszawa, 1997.

Bieszczad P., Lasek M.: Wizualizacja pracy kopalni, monitoring i telekomunikacja w JSW S.A. KWK „Pniówek” – wczoraj, dziś i jutro. International Mining Forum, Jastrzębie, kwiecień 2019.

Blaschke W.: Przeróbka węgla kamiennego – wzbogacanie grawitacyjne. Wydawnictwo IGSMiE PAN. Kraków, 2009.

Borowicz A., Duczmal M., Ślusarczyk G., Frankowski R.: Wykorzystanie Jednolitej Bazy Danych Geologicznych do tworzenia cyfrowego modelu geologicznego złoża węgla brunatnego Złoczew, [in:] Górnictwo Odkrywkowe 2–3, 2014, p. 111–115

Brzychczy, 2006. Brzychczy E.: Metoda modelowania i optymalizacji robót górniczych w kopalni węgla kamiennego z wykorzystaniem sieci stochastycznych. Część 3. Model matematyczny. Inst. Gospod. Surowcami Miner. Energią PAN Kom. Zrównoważonej Gospod. Surowcami Miner. PAN, t. 22, nr 3, Art. nr 3, 2006.

Brzychczy, 2008. Brzychczy E: Tradycyjne metody optymalizacji a nowoczesna heurystyka w wybranych zagadnieniach modelowania robót górniczych w kopalniach węgla kamiennego. Gospodarka Surowcami Mineralnymi., t. 24, nr 2/1, Art. nr 2/1, 2008.

Brzychczy, 2009. Brzychczy, E.: Analiza wyposażenia przodków ścianowych na podstawie reguł asocjacyjnych. Wiadomości Górnicze 2009, nr 3.

Brzychczy, 2012. Brzychczy E: Pozyskiwanie wiedzy w przedsiębiorstwie z wykorzystaniem technik inteligentnych. Wiadomości Górnicze 2012, nr 10.

Burczyk A., Marcisz J.: Zarządzanie jakością złoża i produktu w GK JSW S.A. w oparciu o nowoczesne narzędzia informatyczne. Geomatyka Górnicza 2021 – rola geoinformatyki w cyfrowej transformacji górniczych danych przestrzennych. Konferencja online, 24-25 lutego 2021. https://www.youtube.com/watch?v=ttBX5zyfsJU [Access: 11.07.2022].

Campbell. G., Geophysical contributions to mine development planning: A risk reduction approach in Anhausser. C.R.EC1.15th CMMI Congress, vol. 3 Geoloay, 1994.

CARBO. Materiały firmy CARBOAUTOMATYKA S.A. Katalog wyrobów dla górnictwa oraz strony internetowe dotyczące informacji o produktach tej firmy. Tychy.

Cichy T., Sekta A.: Monitorowanie ciśnienia w stojakach obudowy zmechanizowanej w wybranych ścianach w Jastrzębskiej Spółce Węglowej. Mining – Informatics, Automation and Electrical Engineering. No 4 (540) 2019.

Cierpisz S., Miśkiewicz K., Musioł K., Wojaczek A.: Systemy gazometryczne w górnictwie. Monografia. Wydawnictwo Politechniki Śląskiej, Gliwice, 2007.

Cook M. A.: „Building Enterprise Information Architectures. Reengineering Information Systems. Englewood Clif", Prentice Hall, 1996.

Cortada J. W.: „Best Practices in Information Technology." 1998. Access: 9 wrzesień 2022. https://dl.acm.org/doi/abs/10.5555/272978. [Access: 22.07.2022].

Danihelka P., Schreiberova L., Jurasek J.: Kyberneticky utok jako hrozba pro BOZP v podnicich. Cyber attack as OHS threat in enterprices. Casopis vyzkumu a aplikaci v profesionalni bezpecnoscti (JOSRA) JOSRA 4 – 2020 roc 13.

De Wet. J.A.J., Hall. D.A., Campbell. G., Interpretation of the Oryx 3D seismic survey, in Anhausser. C.R.Ed. 15th CMMI Congress, VoL3 Geology, 1994, p. 259-270.

https://doi.org/10.32056/KOMAG/Monograph2024.2

Digital Report Norwegian Datacenter Industry, 2022. https://static1.squarespace.com/static/6129463e215bea534c574c7f/t/6290ae900166be6bbfdc03db/1653649062074/Report-NorwegianDataCentre-June2022.pdf [Access: 24.03.2023].

Dorman A.: Franken SOA. Network Computing, Innovations in Information Systems Modeling: Methods and Best Practices. 2007.

Dubiński, 1989. Dubiński J.: Sejsmiczna metoda wyprzedzającej oceny zagrożenia wstrząsami górniczymi w kopalniach węgla kamiennego. Prace GIG, Katowice seria dodatkowa.

Dubiński, 2000. Dubiński J., Konopko W.: Tąpania. Ocena. Prognoza. Zwalczanie. Prace GIG. Katowice, 2000.

Dyczko, 2014. Dyczko A., Galica D., Kudlak Ł., Wybrane aspekty zastosowania narzędzi informatycznych w projektowaniu i harmonogramowaniu produkcji górniczej. Wiadomości Górnicze, 9, 2014.

Dyczko, 2013. Dyczko A., Galica D., Sypniowski S., Szot M. (2013): „Planowanie i harmonogramowanie produkcji górniczej w LW „Bogdanka" SA, Wiadomości Górnicze 2013, nr 7-8; s. 422-426.

Dyczko, 2020. Dyczko A., Malec M., Prostański D.: The efficiency of longwall systems in the case of using different cutting technologies in the LW Bogdanka. Acta Montanistica Slovaca, 2020, 25(4), str. 504–516.

Dyczko, 2021. Dyczko A.: Construction of a heuristic architecture of a production line management system in the JSW S.A. Mining Group in the context of output stabilization, quality improvement and the maximization of economic effects. Mineral Resources Management 37(4), 219–238. Kraków, Poland. doi: 10.24425/gsm.2021.139746.

Dyczko, 2009. Dyczko A.: Інформаційні технології у польському гірництві – від ідей до практичної реалізації, Школа підземної розробки - 2009

Dyczko, 2022a. Dyczko A.: Methodology for Run-of-Mine Quality Management in a Hard Coal Mine. KOMAG Institute of Mining Technology, Gliwice 2022. ISBN 978-83-65593-24-5 https://doi.org/10.32056/KOMAG/MONOGRAPH2022.1.

Dyczko, 2022b. Dyczko A.: Modeling of quality parameters of the coking coal as a process of adapting the output to the contracted parameters. Acta Montanistica Slovaca, Volume 27 (1), 11-26 ISSN 1335-1788. https://doi.org/10.46544/AMS.v27i1.02.

Dyczko, 2023. Dyczko A.: Production management system in a modern coal and coke company based on the demand and quality of the exploited raw material in the aspect of building a service-oriented architecture. Journal of Sustainable Mining: Vol. 22: Iss. 1, Article 1. https://doi.org/10.46873/2300-3960.1371.

Dylong A.: Monitorowanie i prognozowanie wydzielania metanu w ścianie a możliwości sterowania kompleksem ścianowym. Mechanizacja i Automatyzacja Górnictwa, 2016, nr 1.

Dzedzej, 2013. Dzedzej C., Nowicki K.: Komputerowe wspomaganie zarządzania w przedsiębiorstwie górniczym. Część 2. Wspomaganie informatyczne procesu planowania i harmonogramowania produkcji górniczej. Wiadomości Górnicze, Tom R. 64, nr 1, 2013, p. 34-40.

Dzedzej, 2008. Dzedzej C., Nowicki K.: System planowania i harmonogramowania w kopalniach węgla kamiennego. Materiały Szkoły Eksploatacji Podziemnej. Wydawnictwo IGSMiE PAN. Sympozja i Konferencje nr 72, Kraków, 2008.

Dziemdziora M, Skirtun Sz.: Monitoring maszyn i urządzeń, automatyzacja procesów technologicznych kompleksów ścianowych i chodnikowych – prezentacja. International Mining Forum JSW S.A. kwiecień 2019.

Dziurzyński W., Krach A., Pałka T., Krawczyk J., Wasilewski S.: Podstawy budowy i regulacji rozpływu sieci odmetanowania. Przegląd Górniczy 2015 nr 7.

E+H. Materiały firmy Elgór+Hansen S.A. Chorzów.

E2V. Infrared Sensor Application Note 1, A Background to Gas Sensing by Non-Dispersive Infrared (NDIR).

ELEKTROMETAL S.A Cieszyn. Katalog produktów i wyrobów; np. DTR System lokalizacji i ewidencji pracowników EMLOK-16; DTR Stacja lokalna RSS-1.

ELSTA ELEKTRONIKA Sp. z o.o. Katalog produktów i wyrobów. Wieliczka, 2022.

EMAGS Materiały firmy EMAG SERWIS Katowice.

EMC. (Ustawa EMC). Dyrektywa 2014/30/UE Parlamentu Europejskiego i Rady z dnia 26 lutego 2014 r. w sprawie harmonizacji ustawodawstw państw członkowskich odnoszących się do kompatybilności elektromagnetycznej (wersja przekształcona). Dz. Urz. UE z 29.03.2014 (L96) USTAWA z dnia 13 kwietnia 2007 r. o kompatybilności elektromagnetycznej. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 7 lutego 2018 r. w sprawie ogłoszenia jednolitego tekstu ustawy o kompatybilności elektromagnetycznej. Dz.U. 2018 poz. 397.

Endrei M. (red.): Patterns: service-oriented architecture and Web services, 1st ed. United States: IBM, International Technical Support Organization, 2004.

Engineers Edge: https://www.engineersedge.com/heat_transfer/thermal-conductivity-gases.htm [Access: 22.07.2022].

Erickson J., Siau K.: Service Oriented Architecture: A Research Review from the Software and Applications Perspective. Innovations in Information Systems Modeling: Methods and Best Practices, 2009, pp. 190-203.

Erl T., Tost A., Plunkett T., Roy S., Thomas P.: SOA with Java: Realizing Service-orientation with Java Technologies. Pearson Education. 2014.

ETSI 102361-1 ..do.. ETSI 102361-4. Technical Specification 102398. Electromagnetic Compatibility and Radio Spectrum Matters (EMR); Digital Mobile radio (DMR) Systems. Part 1: DMR Air Interface (AI) Protocol. Part 2: DMR Voice and Generic Services and Facilities. Part 3: DMR Data Protocol. Part 4: DMR Trunking Protocol.

https://doi.org/10.32056/KOMAG/Monograph2024.2

FAMUR S.A. Katowice. https://www.slideserve.com/elia/grupa-famur-nowe-kierunki-modernizacji-podziemnej-eksploatacji-węgla [Access: 22.07.2022].

Farjow W. F.: Leaky Feeder System Optimisation in Underground Mines ana Tunnels. Teses and dissertations. Ryerson University 2009.

Finkenzeller K.: RFID Handbook. Fundamentals and Applications in Contactless Smart Cards and Identification. Second Edition. John Wiley & Sons Ltd.

Firganek B., Gralewski K.: System VENTURON – doświadczenia eksploatacyjne, dalszy rozwój. Mechanizacja i Automatyzacja Górnictwa 1999, nr 4-5.

Fitowski K., Jankowski H., Jaszczuk M., Jenczmyk D., Krzak Ł., Pieczora E., Stankiewicz J., Szczurkowski M., Rogala J., Warzecha M., Worek C.: RFID nowa metoda identyfikacji elementów w podziemiach kopalń. Napędy i Sterowanie 2006 nr 2 s. 82-88.

Flakiewicz W.: Od systemu informatycznego do systemu informacyjnego wspartego technologią komputerową. Informatyka 1991 nr 8, s. 3. http://delibra.bg.polsl.pl/Content/7054/Nr%208_91__AB.pdf [Access: 22.07.2022].

Gast S. M.: 802.11. sieci bezprzewodowe. Przewodnik encyklopedyczny. Wyd. Helion. Gliwice, 2003.

Gibowicz S. J., Kijko A.: An Introduction to Mining Seismology. Academic Press. Wyd. Elsevier 1994.

Grzesica D.: Harmonogramowanie produkcji na przykładzie górnictwa węgla kamiennego. Logistyka, 2014.

Gumiński A.: Zakres stosowania narzędzi informatycznych wspomagających transfer wiedzy w kopalni węgla kamiennego, [in:] Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie, Z. 70, 2014, p. 177-188.

Hall, 1997. Hall R. A.: Analysis of mobile equipment maintenance data in an underground mine. Unpublished master’s thesis. Queen’s Univ. Kingston Ont., 1997.

Hall, 2000. Hall R. A., Knights P. F., Daneshmend L. K.: Pareto analysis and condition-based maintenance of underground mining equipment. Mining Technology, 2000 No. 109/1, 14-22.

HASO. Materiały firmy HASO S.C. Tychy.

Herbaleb J., Carleton A., Rozum J., Siegel J., Zubrow D. 1994. Benefits of CMM-Based Software Process Improvement: Initial Results., Carnegie Mellon University, 1994.

Hereźniak W., Dyczko A.: Działania podejmowane w celu ograniczenia rozprzestrzeniania się zakażenia wirusem SARS-COV-2 w Jastrzębskiej Spółce Węglowej S.A., [in:] Monografia: Zagrożenie wirusem SARS-CoV-2 w kopalniach podziemnych – wybrane zagadnienia. GIG, 2020.

Hołubowicz W., Płóciennik P., Różański A.: Systemy łączności bezprzewodowej. Wydawnictwo EFP, Poznań, 1996.

HYTERA: PD715 Ex/PD795 Ex. Intrinsically Safe Digital Portable Two-way Radio, HYTERA XPT. https://www.hytera-mobilfunk.com/pl/blog/nowe-wiadomosci/2018/informacje-dotyczace-technologii-dmr-xpt-pseudo-tranking/, HYTERA DMR Conventional Series Pseudo Trunk Application Notes. https://www.hytera-mobilfunk.com/pl/blog/nowe-wiadomosci/2018/informacje-dotyczace-technologii-dmr-xpt-pseudo-tranking/ [Access: 22.07.2022].

IBM Redbooks, 2021, Privileged Access Management for Secure Storage Administration. https://www.redbooks.ibm.com/redpapers/pdfs/redp5625.pdf [Access: 23.03.2023].

IEC 62264-1. INTERNATIONAL STANDARD Enterprise-control system integration – Part 1: Models and terminology.

ITU-R V.662-2 RECOMMENDATION ITU-R V.662-2. Terms and definitions.

J122 ITU-T Recommendation: Interactive System for Digital Television Distribution. Second-generation Transmission System for Interactive Cable Television Services – IP Cable Modems.

Jamroży Sz.: Zarządzanie danymi jakościowymi w JSW S.A. na przykładzie złóż Bzie-Dębina. Materiały konferencyjne XXVIII Szkoły Eksploatacji Podziemnej, 25-27 lutego 2019, Kraków.

Jaszczuk M., Jenczmyk D., Pieczora E., Rogala J.: Use of RFID technology to increase operational safety of powered roof supports. Materiały na konferencję: "High Performance Mining", RWTH Aachen, June 3rd and 4th, 2009 s. 91-102.

Jordan R.: Integracja i modernizacja sieci OT. International Mining Forum, Jastrzębie, 2019.

JSW IT SYSTEMS Sp. z o.o. Dokumentacja techniczna systemu Hades KWK „Pniówek" Dokumentacja nr: DT/PN/HDS/7/2022-1.

JSW odmetanowanie. Materiały wewnętrzne JSW nie publikowane 2016-2021.

Kabiesz J., Lurka A., Drzewiecki J.: Selected Methods of Rock Structure Disintegration to Control Mining Hazards. Archives of Mining Sciences. 2015, No 3 p. 807-824.

Kaiser P.K., Henning J.G., Cotesta L.: Innovations in mine planning and design utilizing collaborative immersive virtual reality (CIRV), [in:] Proceedings of the 104th CIM Annual General Meeting, May 2002, Vancouver.

Kapageridis I. K.: The Future of Mine Planning Software – New Tools and Innovations. The 19th International Mining Congress and Fair of Turkey 1MCET2005 Izmir Turkey, 2005.

Kępski P., Barszcz T.: Application of Vibration Monitoroing for Mining Machinery in Varying Operational Conditions, in Fakhfakh T., Bartelmus W., Chaari F., Zimroz R., Haddar M.: Proceedings of the Second Conference Condition Monitoring of Machinery in Non-Stationary Operations CMMNO, 2012.

Ketterling A.: Introduction to Digital Professional Mobile Radio. Artech House. Boston London 2004.

https://doi.org/10.32056/KOMAG/Monograph2024.2

Kicki, 2008. Kicki J., Dyczko A.: A Mining Software System at “Bogdanka” S.A. Underground Coal Mine – an Important Implementation of an Integrated Mineral Deposit Management System in the Polish Mining Industry, International Mining Forum 2008, ss. 141-147, Taylor & Francis Group, London, UK 2008; ISBN 978-0-415-46126-9.

Kicki, 2010. Kicki J., Dyczko A.: The concept of automation and monitoring of the production process in an underground mine.” Publisher: Taylor & Francis Group, London. Journal: New Techniques and Technologies in Mining-Proceedings of the School of Underground Mining, R. Dychkovskyy (eds.), Volume R. 72, Issue nr 8, strony 245-253 London 2010. ISBN 978-0-415-59864-4.

Kicki, 2011. Kicki J., Dyczko A., Kamiński P.: The Future of Information Solutions in Polish Mining Industry”. [In:] Eskikaya Ş. (ed.) – Proceedings of the 22nd World Mining Congress & Expo, 11-16 September, Volume-IV, Istanbul-2011, Turkey.

Kicki, 2013. Kicki J., Dyczko A.: System ewidencji, kontroli, analizy efektywności maszyn i urządzeń górniczych EKSPERT – inteligentna platforma analityczna w KGHM Polska Miedź SA. Przegląd Górniczy 2013. 69 (5), 94-103.

Kijanka D.; Wróbel D.: Projektowanie i harmonogramowanie robót górniczych w LW Bogdanka S.A. z wykorzystaniem narzędzi IT drugiej generacji. Inżynieria Górnicza, 2017.

Klakus J., Krzystolik P.: Rozwój aparatury metanometrycznej na tle zmian przepisów. Mechanizacja i Automatyzacja Górnictwa 1985, nr 2, s. 27-31.

KOMAG Instytut Techniki Górniczej KOMAG; Instytut Badawczy. Gliwice. http://prass3.komag.eu/results-2/ [Access 28.07.2022].

Kokesz Z., Mucha J.: Metody geostatystyczne w rozpoznawaniu i dokumentowaniu złóż oraz w ochronie środowiska, [in:] Studia i Rozprawy nr 19, Kraków: CPPGSMiE PAN, 1992.

Kopacz, 2018. Kopacz M., Sobczyk E. J., Galica D.: The impact of variability and correlation of selected geological parameters on the economic assessment of bituminous coal deposits with use of non-parametric bootstrap and copula-based Monte Carlo simulation, Resources Policy, Volume 55, March 2018, Pages 171-183.

Kopacz, 2019. Kopacz M., Kulpa J., Galica D., Dyczko A., Jarosz J.: Economic valuation of coal deposits – The value of geological information in the resource recognition process. Resources Policy, 2019, 63, 101450.

Kopacz, 2020. Kopacz M., Kulpa J., Galica D., Olczak P.: The influence of variability models for selected geological parameters on the resource base and economic efficiency measures - Example of coking coal deposit. Resources Policy, vol. 68. 2020.

Kosydor P., Warchala E., Krawczyk A., Piórkowski A.: Determinants of large-scale spatial data processing in Polish mining. In AIP Conference Proceedings (Vol. 2209, No. 1, p. 040007). AIP Publishing LLC. 2020, March.

Krawczyk, 2018. Krawczyk A.: A concept for the modernization of underground mining master maps based on the enrichment of data definitions and spatial database technology. E3S Web of Conferences 2018. doi: 10.1051/e3sconf/20182600010

Krawczyk, 2019. Krawczyk A.: Geomatyka i geoinformacja górnicza - ich praktyczne zastosowania i bariery rozwoju Wydawnictwa AGH Kraków, 2019.

Krodkiewski J.: Kontrola podporności obudowy zmechanizowanej na podstawie danych z systemu FAMAC RSPC. Dotychczasowe doświadczenia i perspektywy rozwoju. International Mining Forum, Jastrzębie, kwiecień 2019.

KSC, 2018. Ustawa z dnia 5 lipca 2018 o krajowym systemie cyberbezpieczeństwa. Dz. U. 2018 poz. 1560 z późniejszymi zmianami.

KTPCz, 2022. (RRM, 2022). Rozporządzenie Rady Ministrów z dnia 27 grudnia 2013 w sprawie Krajowej Tablicy Przeznaczeń Częstotliwości. Obwieszczenie Prezesa Rady Ministrów z dnia 22 sierpnia 2022 r. w sprawie ogłoszenia jednolitego tekstu rozporządzenia Rady Ministrów w sprawie Krajowej Tablicy Przeznaczeń Częstotliwości. Dz. U. 2022 poz. 1988.

Kurose J., Ross K.: Sieci komputerowe. Ujęcie całościowe. Wydawnictwo Helion Gliwice, 2019.

Kurytnik I. P., Karpiński M.: Bezprzewodowa transmisja informacji. Wydawnictwo Pomiar Automatyka Kontrola. Warszawa, 2008.

Kuśmirak-Brudnicki J.: Rozwój kopalnianych transmisyjnych sieci technologicznych. International Mining Forum, Jastrzębie, kwiecień 2019.

Kwaśnica J.: Centralny Serwer Danych Technologicznych w JSW S.A. (unpublished)

Li L., Mechefske C. K., Li W.: Electric motor faults diagnosis using artificial neural networks, Insight - Non-Destructive Testing and Condition Monitoring, 2004, 46(10), 616-621.

Lewandowski A., Kiełb T.: Planowanie strategiczne w JSW S.A. z wykorzystaniem narzędzi do cyfrowego modelowania złoża na przykładzie złoża „Borynia” – studium przypadku. Materiały konferencyjne XXX Szkoły Eksploatacji Podziemnej, 27-29 września 2021, Kraków.

Lubryka J., Opielka K., Stojek M., Wojaczek A.: Systemy monitoringu i wizualizacji grupy EH-VIEW typu EH-MINEVIEW. Monografia pod red. A. Wojaczka i A. Dyczko.: Monitoring wybranych procesów technologicznych w kopalniach podziemnych. Wydawnictwo Katedry Elektryfikacji i Automatyzacji Górnictwa. Gliwice, 2015.

Lurka, 1998. Lurka A.: Rozwiązanie zagadnienia tomografii pasywnej z wykorzystaniem algorytmów ewolucyjnych. Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie nr 4, s. 44 - 47. 1998.

Lurka, 2005. Lurka A.: Location of Mining Induced Seismicity in Zones of High P-wave Velocity and in Zones of High P-wave Velocity Gradient in Polish Mines, 6th Int. Conf. on Rockbursts and Seismicity in Mines, Balkema Pub. 2005.

Lurka, 2009. Lurka A.: Wybrane teoretyczne i praktyczne zagadnienia tomografii pasywnej w górnictwie podziemnym. Prace Naukowe GIG. nr 879. Katowice, 2009.

Lurka, 2021a. Lurka, A., Mutke, G., Małkowski, P.: Dynamic Influence of Near-Source Seismic Ground Motion on Underground Mine Working Stability Using Time-Frequency Analysis. Shock and Vibration. Hindwai, ID 9023550. 2021.

Lurka, 2021b. Lurka, A.: Spatio-temporal hierarchical cluster analysis of mining-induced seismicity in coal mines using Ward's minimum variance method. Journal of Applied Geophysics, vol.184, 104249. 2021.

Łukaszczyk, 2018. Łukaszczyk Z., Koszowski Z.: Górnictwo węgla kamiennego. Informatyzacja. COIG SA., Systemy Wspomagania w Inżynierii Produkcji 7, 2018.

Łukaszczyk, 2019. Łukaszczyk Z.: Projektowo-zadaniowe podejście w planowaniu i monitorowaniu działalności przedsiębiorstwa górniczego z wykorzystaniem informatycznego systemu SZYK2, [in:] Systemy wspomagania w inżynierii produkcji. Górnictwo – perspektywy i zagrożenia, Vol. 8, issue 1, 2019, p. 185-191.

Majchrzyk Ł.: Jak fale innowacji wpłynęły na gospodarkę od 1785 do 2021 roku?" MIT Economics MIT SLOAN SCHOOL OF MANAGEMENT. https://mobirank.pl/2021/07/04/jak-fale-innowacji-wplynely-na-gospodarke-od-1785-do-2021-roku/ [Access: 22.07.2022].

Marcisz M., Ignacok D., Knapik D., Ostrowska-Łach M.: 3D solutions in documentation of geological structure of hard coal deposit in upper silesian Coal Basin (Poland), [in:] Conference proceedings of 17th international multidisciplinary scientific GeoConference SGEM 2017, Geoinformatics and Remote Sensing, 17 (21), 2017, p. 761-767.

Martin D.: A General Study of the leaky feeder principle. The Radio and Electronic Engineer. Vol 45, No 5, May 1975.Marcisz M., Probierz K., Ostrowska-Łach M., 3D representation of geological observations in underground mine workings of the Upper Silesian Coal Basin, [in:] Journal of Sustainable Mining, Volume 17, Issue 1, 2021, p. 34-39.

Mendecki A. (red.): Seismic Monitoring in Mines, Springer Dordrecht Chapman & Hall, 1997.

Mielimąka R.: Effect of the observed variability of a topographical surface on the precision of its realization at different densities of recognition points in the network, [in:] Proceedings of the Mining and Geodesy Commission Polish Academy of Science-Kraków Section Geodesy 36, p. 91-117, 1991.

Mikuła S., Warzecha M., Rogala-Rojek J., Latos M.: Zarządzanie flotą wielozadaniowych terminali mobilnych jako niezbędny element efektywnej strategii zarządzania majątkiem trwałym w zakładzie górniczym. KOMTECH 2012, Innowacyjne techniki i technologie dla górnictwa. Bezpieczeństwo - Efektywność - Niezawodność, Instytut Techniki Górniczej KOMAG, Gliwice, 2012, s. 555-568.

Miller J., 2021, Is Elastic Stack (ELK) the Best SIEM Tool? https://www.bitlyft.com/resources/is-elastic-stack-elk-the-best-siem-tool [Access: 21.03.2023].

Missouri Partnership, 2018, Data center company expands underground in Missouri. https://www.missouripartnership.com/data-center-company-expands-underground-missouri/ [Access: 21.03.2023].

MinSearch. Odbiornik lokacyjny typu MinSearch-15. Instrukcja obsługi. Cieszyn, 2018. Odbiornik lokacyjny MinSearch-09 (250 kHz) Instrukcja obsługi. ELEKTROMETAL S.A. Cieszyn, 2009.

Miśkiewicz, 2010. Miśkiewicz K., Wojaczek A.: Systemy radiokomunikacji z kablem promieniującym w kopalniach podziemnych. Wydawnictwo Politechniki Śląskiej. Gliwice, 2010.

Miśkiewicz, 2011. Miśkiewicz K., Wojaczek A. Wojtas P.: Systemy dyspozytorskie kopalń podziemnych i ich integracja. Wybrane problemy. Wydawnictwo Politechniki Śląskiej. Gliwice, 2011.

Miśkiewicz, 2012. Miśkiewicz K., Wojaczek A., Wojtas P.: Eksploatacyjna zmienność właściwości metrologicznych metanomierzy. Mechanizacja i Automatyzacja Górnictwa. 2012, nr 5.

Miśkiewicz, 2018a. Miśkiewicz K., Wojaczek A.: Telekomunikacja w górnictwie. Wybrane zagadnienia teletransmisyjne. Wydawnictwo Katedry Elektrotechniki i Automatyki Przemysłowej Wydziału Górnictwa i Geologii Politechniki Śląskiej. Gliwice, 2018.

Miśkiewicz, 2018b. Miśkiewicz K., Wojaczek A.: Telekomunikacja w górnictwie. Systemy łączności telefonicznej, alarmowej i rozgłoszeniowej. Wydawnictwo Politechniki Śląskiej. Gliwice, 2018.

Miśkiewicz, 2020. Miśkiewicz K., Wojaczek A.: Radiokomunikacja w kopalniach podziemnych. Wydawnictwo Politechniki Śląskiej, Gliwice, 2020.

MODBUS Standard - http://www.modbus.org. [Access: 22.07.2022].

Moh Heng Goh, 2018**.** What Exactly is BCM? https://blog.bcm-institute.org/bcm/what-exactly-is-business-continuity-management [Access: 23.03.2023].

Motorola. Mototrbo Digital Trunking System http://komtek2006.com/en/mototrbo-digital-trunking-systems [Access: 22.07.2022].

Mróz J., Felka D., Broja A., Małachowski M.: Urządzenia pomiarowe parametrów wentylacyjnych i stężenia metanu oraz koncepcja kompleksowego monitorowania zagrożenia metanowego w rejonie ściany wydobywczej. Mining – Informatics, Automation and Electrical Engineering 2017, No. 1.

Mucha J., Wasilewska-Błaszczyk M., Cieniawska M., Chudzik W.: Ocena wiarygodności prognozy jakości kopaliny na podstawie modelu 3D (na przykładzie fragmentu złoża wapieni i margli Barcin-Piechcin-Pakość), [in:] Górnictwo Odkrywkowe, R. 58, nr 4, Wrocław, p. 10-17, 2017.

Mutke, 2007. Mutke G.: Charakterystyka drgań wywołanych wstrząsami górniczymi w odległościach bliskich źródła sejsmicznego w aspekcie oceny zagrożenia tąpnięciem, Prace Głównego Instytutu Górnictwa. Katowice, 2007.

Mutke, 2015. Mutke G., Dubiński J., Lurka A.: New Criteria to Assess Seismic and Rock Burst Hazard in Coal Mines. Archives of Mining Sciences. 2015, No 3. p. 743-760.

Mutke, 2019. Mutke G., Kotyrba A., Lurka A., Olszewska D., Dykowski P., Borkowski A., Araszkiewicz A., Barański A.: Upper Silesian Geophysical Observation System A unit of the EPOS project. Journal of Sustainable Mining. 2015, No 18(4), p. 198-207.

Mutke, 2020. Mutke G., Lurka A., Zembaty Z.: Prediction of rotational ground motion for mining-induced seismicity – Case study from Upper Silesian Coal Basin, Poland. Elsevier Engineering Geology, vol. 276.

Narkiewicz J.: GPS. Globalny system pozycyjny. WKŁ Warszawa.

Naworyta W.: Zastosowanie symulacji geostatystycznej do oceny deficytów rozpoznania złoża, [in:] Górnictwo Odkrywkowe, 3, p. 21-28, 2016.

NEMOTO Technologies: Column No.9 Safety and Nemoto - (7) "Electrochemical CO gas sensor".

Nieć M. (red.): Metodyka dokumentowania złóż kopalin stałych. Ministerstwo Środowiska, Wydawnictwo IGSMiE PAN, Kraków, 2012.

Niknejad N., Ghani I., Hussin A. R. C., Jeong S. R.: A systematic literature review towards service oriented architecture adoption from 2009 to 2015. International journal of advanced smart convergence, 7(3), 79-91, 2018.

NIST. https://webbook.nist.gov/chemistry [Access: 22.07.2022].

Nowrot A.: Detektor gazów z wykorzystaniem absorbcji fal elekromagnetycznych w zakresie środkowej podczerwieni. Mechanizacja i Automatyzacja Górnictwa, 2011, nr 5.

OOSW. Ognioszczelne optyczne stanowisko wizualizacji DTR. Firma Timler, Zakład Elektrotechniki Budowlanej i Przemysłowej. Nowy Sącz.

OPC Standard - https://opcfoundation.org/ [Access: 22.07.2022].

Owczarek, 2020. Owczarek D., Przontka K.: Prognozowanie jakości węgla koksowego w programie Deswik. Materiały konferencyjne XXIX Szkoły Eksploatacji Podziemnej, 24-26 lutego 2020. Kraków.

Owczarek, 2021. Owczarek D., Przontka K.: Narzędzie do kontroli pożądanego poziomu produkcji oraz ograniczeń poszczególnych elementów procesu produkcyjnego. Materiały konferencyjne XXX Szkoły Eksploatacji Podziemnej, 27-29 września 2021. Kraków.

Ozga-Blaschke U.: Gospodarka węglem koksowym Instytut Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk. Wydawnictwo IGSMiE PAN, Kraków, 2010.

Ozon, 2017. Ozon D., Dyczko A.: W kierunku inteligentnej kopalni przyszłości – JSW 4.0. Materiały konferencyjne XXXI Konferencji z cyklu: Zagadnienia Surowców Energetycznych i Energii w Gospodarce Krajowej. Instytut Gospodarki Surowcami Mineralnymi i Energią PAN, Zakopane, 15-18 października 2017.

Ozon, 2019. Ozon D., Dyczko A.: Strategia IT/OT w GK JSW – NOWE WYZWANIA. Materiały konferencyjne International Mining forum 2019: Safety and efficiency of exploitation against the challenges of industry 4.0. Kraków-Katowice-Jastrzębie Zdrój 2019.

Palo Alto Networks, 2020. https://www.paloaltonetworks.com/company/press/2020/palo-alto-networks-reimagines-data-security-with-an-easy-to-implement-cloud-delivered-enterprise-data-loss-prevention-service [Access: 23.03.2023].

Paszek A.: Systemy transmisji danych i wizualizacji firmy HASO w zakładach górniczych. Warsztaty Nowe rozwiązania IT/OT– prezentacja. International Mining Forum JSW S.A. kwiecień 2019.

PBE. Pyott Boone Electronics (PBE): PAS-Z Proximity Alert. https://pbegrp.com/wp-content/uploads/2019/02/eng_ts-0011-003_pas-z_zr-tech-sheet_a4-1.pdf [Access: 22.07.2022].

Perrey R., Lycett M.: Service-oriented architecture. [In] 2003 Symposium on Applications and the Internet Workshops, 2003. Proceedings., Orlando, FL, USA, 2003, s. 116–119. doi: 10.1109/SAINTW.2003.1210138.

Petersen K., Wohlin C., Baca D.: The waterfall model in large-scale development. Frank Bomarius, Markku Oivo, P¨aivi Jaring, Pekka Abrahamsson, redaktorzy, ProductFocused Software Process Improvement, s. 386–400. Springer Berlin Heidelberg, 2009.

PGG, 2023. Ustawa z dnia 9 czerwca 2011 r. Prawo geologiczne i górnicze. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 27 stycznia 2023 r. w sprawie ogłoszenia jednolitego tekstu ustawy. Dz.U. 2023 poz. 633.

PN-EN IEC 60079-0:2018-09 Explosive atmospheres. Part 0: Equipment. General requirements.

PN-EN 60079-1:2014- Explosive atmospheres. Part 1: Equipment protection by flameproof enclosures "d".

PN-EN 60079-11:2012 Explosive atmospheres. Part 11: Equipment protection by intrinsic safety "i".

PN-EN 60079-18:2015-16 Explosive atmospheres. Part 18: Equipment protection by encapsulation "m".

PN-EN IEC 60079-25:2023-02 Explosive atmospheres. Part 25: Intrinsically safe electrical systems (IEC 60079-25:2020 + COR1:2020).

PN-EN 60079-26:2015-04 Explosive atmospheres. Part 26: Equipment with Equipment Protection Level (EPL) Ga.

PN-EN 60079-28:2015-12 Explosive atmospheres -- Part 28: Protection of equipment and transmission systems using optical radiation.

PN-EN 60300-3-3:2017-07 Dependability management. Part 3-3: Application guide. Life cycle costing

PN-EN 62264-5:2017-02 Enterprise-control system integration. Part 5: Business to manufacturing transactions.

Podsumowanie zarządcze Strategii IT/OT w GKJ SW S.A., 2017.

Polak, 2011. Polak R.: Koszty cyklu życia urządzeń energomechanicznych w kontekście oceny efektywności ich pracy w podziemnych zakładach górniczych. Wiadomości Górnicze 2011 nr 10, strony 569-578.

Polak, 2014a. Polak R.: Systemy przetwarzania danych - ich rola i znaczenie w realizacji idei Inteligentnej Kopalni". Wiadomości Górnicze 2014, nr 10, strony 512-522.

Polak, 2014b. Polak R.: Adaptacja kluczowych miar efektywności strategii TPM w warunkach kopalni węgla kamiennego. Journal: Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN, Volume R. 87, Issue nr 87, strony 49-68. Kraków, 2014.

Polak, 2014c. Polak R.: Koncepcja i uwarunkowania zintegrowanego systemu zarządzania majątkiem produkcyjnym przedsiębiorstw górniczych. Mechanizacja i Automatyzacja Górnictwa 2014 nr 5, strony 36-48.

Polak, 2015. Polak R.: Dynamiczny szacunek kosztów cyklu życia maszyn i urządzeń górniczych - przykład zastosowania dla kompleksu ścianowego. Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN nr 89. Kraków, 2015, strony 93-110.

Polak, 2016a. Polak R.: Karta miar efektywności jako narzędzie oceny pracy kompleksu ścianowego. Przegląd Górniczy 2016, nr 5. s. 79-85.

Polak, 2016b. Polak R., Dyczko A.: Rola systemu wsparcia produkcji w przedsiębiorstwach górnictwa podziemnego. Wiadomości Górnicze 2016, nr 2. s. 75-83.

Polityka Jastrzębskiej Spółki Węglowej S.A. w zakresie zarządzania architekturą i infrastrukturą techniczną systemów IT/OT. JSW S.A. Jastrzębie Zdrój, październik 2020.

PORTAS. Dokumentacja techniczno-ruchowa. SYBET Katowice, 2019.

Pretorius, 1987. Pretorius C. C., Jamison. A. A., Irons C., Seismic exploration in the Witwatersrand Basiu. Republic of South Africa: Proc. of Exploration 87. Ontario Geological Survey, Special Volume 3 (1989), 1987, p. 214-253.

Pretorius, 2003. Pretorius C. C., Muller M. R.. Larroque, M., Wilkins. C.: A Review of 16 years of Hardrock Seismics on The Kaapvall Craton, in Eaton, D.W., Milkereit, B., Salisbury, M.H., Eds, Hardrock seismic exploration, Geophysical Developments No. 10. Society of Exploration Geophysicists, 2003.

Pretorius, 1994. Pretorius C. C., Steenkamp, W. H., Smith, R. G.: Developments in data acquisition, processing, and interpretation over 10 years of deep vibroseismic surveying in South Africa in Anhausser, C.R., Ed. 15th CMMI Congress. VoL3 Geology, 1994, p. 249-258.

Probierz, 2017. Probierz K., Marcisz M., Ignacok D.: Trójwymiarowy model złoża węgla kamiennego z zastosowaniem środowiska CAD na przykładzie SW części Górnośląskiego Zagłębia Węglowego, [in:] Górnictwo Odkrywkowe, 3, 2017, p. 84-85.

Probierz, 2004. Probierz K., Marcisz M.: Metoda konstrukcji cyfrowych map geologicznych, [in:] Sborník z 13. semináře Moderní matematické metody v inženýrství (3mi), Dolní Lomná, 2004, p. 143-149.

Probierz, 2007. Probierz K., Marcisz M.: Nowe szanse i możliwości wykorzystania programów AutoCAD i Surfer do konstrukcji map górniczo-geologicznych – ich znaczenie w procesie kontroli jakości węgla i planowania produkcji kopalni, Gospodarka Surowcami Mineralnymi, 4, 2007, p. 259–195.

Probierz K., Marcisz M.: Zastosowanie kombinacji programów AutoCAD i Surfer do konstrukcji map jakości węgla, Wyd. Politechniki Śląskiej, 246, 2000, p. 439–450.

PTEL, 2022. Ustawa z dnia 16 lipca 2004 r. Prawo telekomunikacyjne. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 23 czerwca 2022 r. w sprawie ogłoszenia jednolitego tekstu ustawy - Prawo telekomunikacyjne. Dz.U. 2022 poz. 1648.

Puzik K.: System SZYK2 - informatyczna perspektywa dla górnictwa. Wiadomości Górnicze Tom R. 63, nr 5, 2012, p. 261-266.

RAE System Inc. Technical Note TN-169. Theory and Operation of NDIR Sensors.

Rajwa, 2012. Rajwa S., Bulenda P., Masny W., Chowaniec A., Skrzyszowski P.: Określenie istotnych wymagań konstrukcyjnych dla obudowy zmechanizowanej przeznaczonej do pracy w warunkach silnego zagrożenia tąpaniami. Bezpieczeństwo Pracy i Ochrona środowiska w Górnictwie. 2012, nr 4, 2012.

Rajwa, 2014. Rajwa S., Pieszczek M., Guzera J.: Dobór obudowy zmechanizowanej dla ściany prowadzonej w złożonych warunkach geologiczno-górniczych w KHW S.A. KWK „Wieczorek". Przegląd Górniczy nr 5/2014. s. 58-63.

Raport ISAC-GIG, 2022. Cyberbezpieczeństwo systemów przemysłowych dla sektora wydobywczo-energetycznego. Materiał niepublikowany.

RFS. Radiaflex Cables. http://www.rfsworld.com [Access: 22.07.2022].

RMC, 2022. Rozporządzenie Ministra Cyfryzacji z dnia 9 lutego 2022 r. w sprawie urządzeń radiowych nadawczych lub nadawczo-odbiorczych, które mogą być używane bez pozwolenia radiowego. Dz.U. 2022 poz. 567.

RME, 2017. Rozporządzenie Ministra Energii z dnia 23 listopada 2016 w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych. Dz. U. 2017 poz 1118.

RMR, 2016. Rozporządzenie Ministra Rozwoju dnia 6 czerwca 2016 r. w sprawie wymagań dla urządzeń i systemów ochronnych przeznaczonych do użytku w atmosferze potencjalnie wybuchowej. Dz.U. 2016 poz. 817.

RMX. DTR Koncentrator światłowodowy RMX. REDNT SA Katowice.

Rogala-Rojek J., Latos M., Piecha A., Mikuła S., Warzecha M.: Gospodarka majątkiem przedsiębiorstwa z wykorzystaniem systemu iRIS. KOMTECH 2012, Innowacyjne techniki i technologie dla górnictwa. Bezpieczeństwo - Efektywność - Niezawodność, Instytut Techniki Górniczej KOMAG, Gliwice 2012 s. 541-554.

Roszczynialski W., Trutwin W., Wacławik J.: Kopalniane pomiary wentylacyjne. Wydawnictwo Śląsk. Katowice, 1992.

https://doi.org/10.32056/KOMAG/Monograph2024.2

Royce Walker W.: Managing the development of large software systems: concepts and techniques., IEEE WESCON, 1970.

RRM, 2004. Rozporządzenie Rady Ministrów z dnia 30.04.2004 r. w sprawie dopuszczania wyrobów do stosowania w zakładach górniczych. Dz.U. 2004 nr 99 poz. 1003.

Saganiak K.: Zarządzanie danymi przestrzennymi w oparciu o narzędzia informatyczne jako ważne wsparcie procesu decyzyjnego. Konferencja online, 25.02 2021. https://www.youtube.com/watch?v=QHUhbxk87BQ

SAURON - opis systemu wizualizacji. RNT Sp. z o.o.

Serafin R., Zastosowanie algorytmów ewolucyjnych do harmonogramowania zadań produkcyjnych. [in:] Komputerowo Zintegrowane Zarządzanie, t. 1, R. Knosala (red.). WNT, Warszawa, 2007.

Sermet E., Góreck J., Nieć M.: Tradycja, nowoczesność i pułapki modelowania złóż. Kraków, Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk, nr 100, 2017.

SEVITEL Materiały firmy SEVITEL Sp. z o.o. Katowice.

Snoke J. A.: Stable determination of (Brune) stress drops, Bull. of Seismol. Soc Am., 1987, No. 2, p 530 - 538.

Sobków Z.: Optyczny detektor metanu w szerokim zakresie zmian koncentracji gazu. Praca doktorska wykonana w AGH. Kraków, 2010.

SOMAR. www.somar.com.pl, Specyfikacja produktów i wyrobów dla górnictwa.

Sosnowski P.: Zarządzanie jakością w modelu geologicznym 3D – wiarygodność przewidywanych parametrów jakościowych węgla. Materiały konferencyjne XXX Szkoły Eksploatacji Podziemnej, 27-29 września 2021. Kraków.

Spišák J., Zelko M.: The Advanced Technologies Development Trends for the Raw. Material Extraction and Treatment Area, Products and Services; from R&D to Final Solutions, Igor Fuerstner (Ed.), ISBN: 978-953-307-211-1.

SWTx. Aneks nr 1 do instrukcji obsługi Szkieletowego Węzła Transmisyjnego typu SWTx. JSW IT Systems. Jastrzębie, 2021.

Szczucki J., Kołodziejczyk M.: Uniwersalne czujniki pomiarowe parametrów środowiska. Mechanizacja i Automatyzacja Górnictwa. 2013, nr 8.

Szczurkowski M., Jankowski H., Worek C., Maksymowicz L. J.: RFID reader designing for identification of industrial metallic objects, Optoelectronic and Electronic Sensors VI, Tadeusz Pisarkiewicz, Editor, Proceedings of SPIE Vol.6348 0T, October 2006.

Szlązak N., Swolkień J.: Metan z kopalń JSW S.A. Realne zagrożenie dla klimatu? Wydawnictwo AGH. Kraków, 2021.

Szot M.: Projektowanie procesów eksploatacji w kopalniach podziemnych z wykorzystaniem technik informatycznych-system harmonogramowania produkcji w LW" Bogdanka" S.A. Wiadomości Górnicze, 61.2, 2010, p. 97-100.

Szóstka J.: Mikrofale. WKŁ Warszawa, 2008.

Szurgacz D., Bazan Ł., Trzop K., Diederichs R.: Bezprzewodowy system wizualizacji parametrów ciśnienia zmechanizowanej obudowy ścianowej na przykładzie polskich kopalń. Mining – Informatics, Automation and Electrical Engineering No 2 (542) 2020.

Szyguła M.: Rozwój konstrukcji sekcji obudowy zmechanizowanej w górnictwie węgla kamiennego w Polsce. Maszyny Górnicze nr 2/2013. s. 30-38.

Tąpała D., Koj K.: Wdrażanie nowych technologii telekomunikacyjnych i informatycznych w kopalni KWK Knurów-Szczygłowice, International Mining Forum, Jastrzębie, kwiecień 2019.

TF-KABLE. TELE-FONIKA Kable S.A Katalog wyrobów. Myślenice.

Timler, 2006. Timler M.: Optoelektroniczne stacje przetwornikowe ALFA I - IV. Karty katalogowe. Firma Timler, Zakład Elektrotechniki Budowlanej i Przemysłowej. Nowy Sącz, 2006.

Timler, 2019. Timler M.: Infrastruktura systemów nadzoru i sterowania procesów technologicznych w JSW S.A. kiedyś, dziś, kierunki rozwoju – prezentacja. International Mining Forum JSW S.A., kwiecień 2019.

TRANZTEL. MCA-1000digi Radio Communications System Central Unit. User’s Manual. 2015.

Varis Mine Technology Ltd.: Smart Com Ethernet Training Manual.

Warchoł G.: Realizacja procesów technologicznych obejmująca wizualizację maszyn i urządzeń SJW S.A. KWK Budryk, International Mining Forum, Jastrzębie, kwiecień 2019.

Warzecha M., Stankiewicz K., Jasiulek D., Rogala-Rojek J., Piecha A.: iRIS - system elektronicznej ewidencji środków trwałych w zakładach górniczych. Maszyny Górnicze 2011 nr 3 s. 92-96.

Wasilewska-Błaszczyk M., Mucha J.: Jakościowy model 3D złoża wapieni i margli Barcin-Piechcin-Pakość, Archiwa Lafarge Cement S.A., 2014.

Wasilewski S., Krawczyk J., Janus J.: Ocena przydatności danych zbieranych przez czujniki systemu gazometrycznego dla celów modelowania numerycznego przepływu powietrza w kopalnianej sieci wentylacyjnej. Prace Instytutu Mechaniki Górotworu PAN. Tom 16, nr 3-4. Kraków, 2014, s. 3-21.

Waye C., Farjow W.: Docsis over Leaky Cable (CMTS). Mine radio System. August 2007.

Wesołowski K.: Systemy radiokomunikacji ruchomej. WKŁ Warszawa, 2003.

Wilkinson W.A.: Benefits of building an efficient mine planning process. Mining engineering, 2010.

Wodzyński B.: Radiotelefony. WKŁ. Warszawa 1978.

Wojaczek, 2011. Wojaczek A., Dyczko A.: Systemy telekomunikacyjne, monitoring wizualizacja podziemnej eksploatacji złóż. Kraków, Wydawnictwo Fundacja dla AGH.

https://doi.org/10.32056/KOMAG/Monograph2024.2

Wojaczek, 2014. Wojaczek A.: Wpływ środowiska technicznego kopalń podziemnych na transmisję sygnałów w dołowych sieciach telekomunikacyjnych. Gliwice, Wydawnictwo Politechniki Śląskiej. Gliwice.

Wojaczek, 2016. Wojaczek A., Wojaczek Ad.: Systemy monitoringu w kopalni podziemnej. Systemy wspomagania w inżynierii produkcji. Górnictwo – perspektywy i zagrożenia. 2016 z. 1

Wojaczek Ad.: Dyspozytorski system monitoringu i wizualizacji THOR dla podziemnego zakładu górniczego. in: Wojaczek A., Dyczko A. (red.): Monitoring wybranych procesów technologicznych w kopalniach podziemnych. Wydawnictwo Katedry Elektryfikacji i Automatyzacji Górnictwa Politechniki Śl. Gliwice, 2015, s. 115-139.

Worek C., Szczurkowski M., Kałuski M.: Zagadnienia propagacji fal radiowych w podziemnych zakładach górniczych w aspekcie gospodarki widmem radiowym. Rozprawy i Monografie – Wybrane obszary infrastruktury systemowej kopalń podziemnych – Praca zbiorowa pod redakcją Piotra Wojtasa, Instytut Technik Innowacyjnych EMAG. Katowice.

WUG raporty. Stan bezpieczeństwa i higieny pracy w górnictwie raporty WUG za lata 2016-2021.

Zieliński R. J: Satelitarne sieci teleinformatyczne. WNT Warszawa, 2009.

ZMUE. Materiały firmy Zakład Montażu Urządzeń Elektronicznych.

ZPAS. Synoptyczne tablice mozaikowe. Katalog. Zakład produkcji automatyki sieciowej, Przygórze, 1999.

Żymełka K.: Monitorowanie procesów technologicznych i stanu bezpieczeństwa w dyspozytorniach polskich kopalń węgla kamiennego. Wyd. Instytutu Systemów Sterowania. Chorzów, 2000.

Automation and monitoring of the production process in underground mines – Polish experience in implementing the INDUSTRY 4.0 paradigm

Abstract

The monograph is dedicated to a wide range of recipients interested in the digital transformation of traditional branches of economy into learning organizations, i.e. those that, in a systematic and active way, using their own experience and available information resources, optimize their business model in accordance with the industry 4.0 paradigm, maintaining competitiveness in the changing, dynamic market.

The digital revolution of the raw materials consortium described in the monograph explains and documents the digital transformation that took place in the JSW mines in the years 2016÷2020. The book covered processes related to underground computerization, radio communication, monitoring of occupational safety conditions, automation and the use of advanced data analytics to make management decisions. It presents the experience gained by entire research teams in the result of realizing strategic projects for nearly four years, documenting the greatest technological breakthrough in the Polish mining industry in years.

The DIGITAL TRANSFORMATION of Poland's key raw material consortium – extensively described on the pages of the monograph – on the one hand allowed for the implementation of strategic efficiency programmes such as QUALITY and EFFICIENCY, but what is equally important, it allowed for the elimination of the huge technological debt with which Jastrzębska Spółka Węglowa S.A. has been dealing with it basically since its establishment in 1993 and in the subsequent years of its operation. This debt, growing year by year, strangled the technological innovativeness of the JSW S.A., especially in the years 2000÷2015, paralyzing the implementation of advanced IT projects and not recognizing the OT area at all, the implementation of which could have significantly improved the production monitoring and control processes in the JSW mines.

The book presents the Polish experience of entire teams of engineers: IT specialists, automation specialists, miners, geologists and economists, transforming the traditional branch of the economy, which is mining, into a European raw material consortium with ambitions, showing, among others:

- how to build a management and supervision strategy over the production area of a modern raw materials company,
- how to design the integration and automation of entire production processes and innovative IT/OT solutions in the production and commercial cycle in the field of technical infrastructure, communications, applications supporting security areas and data processing,
- how to monitor the area of cybersecurity, security of systems and automation devices used in production,
- how to create planning for the desired future, based on the analysis of past experience and functioning in the present and future.

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The systems for locating people and equipment, gasometric systems, monitoring of methane drainage networks and seismic phenomena, described in the monograph, have a significant impact on ensuring the appropriate level of safety.