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APPLYING A FIRST PRICE AUCTION MECHANISM FOR SUPPORTING MULTI-BILATERAL NEGOTIATIONS

Abstract

In this paper we consider a multi-bilateral negotiation problem from the perspective of all involved parties that we call the seller and the buyers. We model the negotiation process as a sequentially repeated first price auction. Since we consider a multi-issue negotiation, we do not operate with a bidding price as a single evaluation criterion but with a utility of the package (negotiation offer). To construct the optimal negotiation strategy we apply the notion of equilibrium bidding strategy. The parties' negotiation strategies are represented as vectors of bids for successive negotiation phases. The negotiation strategies are then used by a simple spreadsheet-based negotiation support tool for finding the most satisfying solution of the negotiation process. The software acts as a simple agent that converts the strategies into the values of the bids and then into the negotiation offers that maximize the payoffs of the buyer. The compromise is represented by the first bid that satisfies the current seller's aspiration level.

Keywords

Negotiation, utility, additive scoring system, first price auction, equilibrium strategy, negotiation support system

Introduction

Many economic situations can be described as a multi-bilateral negotiations. Selling a house, applying for a job, obtaining a building contract – all of these require interaction with many potential buyers or sellers who can submit various offers and change them during the negotiation process.

This makes the negotiation situation very uncertain. The party that negotiates with a multitude of counterparts does not know their negotiation strategies and can not foresee which of them will propose the most satisfying offer and when. That is because the shapes of the counterparts' concession curves can be very different. The ones that decrease fast at the beginning of the negotiations may never cross a negotiator's reservation level, and vice versa, the slowly decreasing ones may later quickly reach a negotiator's aspiration level. On the other hand, the party that competes with another for buying some goods or winning the contract from the sole seller cannot foresee the decisions of other competitors. By submitting an offer with tough conditions he risks that the offers of other competitors will meet the seller's aspiration level and they will win the contract. By submitting an offer with attractive conditions he increases the chance of winning the contract, but on very poor conditions for himself.

Negotiators can handle this uncertainty by applying multiple criteria decision making methods and tools that will support them in the evaluation and selection of their offers. Usually in negotiation processes this kind of support is given by a software negotiation support system (NSS). There are many negotiation support systems nowadays used in training, teaching and simulation of two-parties negotiations such as INSPIRE [4], Negoisst [9] or NegoCalc [11]But there are also NSSs solving real world problems such as RAINS [2] – used in negotiating air pollution limits within the Europeans countries, FamillyWinner [1] – used for solving divorce negotiation in Australia or SmartSettle [10] – used for structuring and analyzing negotiations between Canadian First Nations and the government of the Alberta Province. Moreover, the supply chain support systems proposed by IBM, SAP, Oracle or Ariba contain also simple components supporting negotiation between the cooperating companies. The multi-bilateral negotiation, however, are not so frequently considered in the research that leads to the construction of the method and software systems dedicated to support all the involved parties. They are usually structured and modeled as auctions with the single attribute of price. While the price usually is not a single criterion negotiators use to evaluate an offer, it is still important to develop a multi-bilateral negotiation methodology.

In this paper we focus on supporting the buyer parties in a multi-bilateral negotiation with a sole seller. We will build a mechanism that will help the buyers in selection of offers for subsequent negotiation phases based on their negotiation strategy formulated before in the pre-negotiation phase and assuming that the negotiation process is conducted by the negotiation support platform. This assumption is far form unrealistic since lots of transactions are conducted nowadays by means of electronic tools, such as auction services, e-shops etc., but it is methodologically required, since we need information about the preferences of all involved parties. The mechanism we apply is derived from the first price auction mechanism proposed for sequential first price symmetric auction based on a private value model [7]. Using the negotiators' aspiration levels declared in their evaluation spaces it computes the equilibrium bids [8] evaluated in the sellers' negotiation space and then transforms them into the best (the most preferable) offers evaluated again in the buyers' negotiation spaces.

The structure of this paper is the following. In the first section we give a brief statement of the multi-bilateral negotiation problem. Then in section 2 we introduce the basics: the first price symmetric auction based on a private value model with the idea of determining the equilibrium bids that will be used in the supporting algorithm we describe in section 3. In section 4 a short example is given to show the method of application of the mechanism for solving a hypothetical negotiation problem. To solve this problem we use a simple spreadsheet-based software support tool we had programmed to show the ease of software implementation of the mechanism proposed.

1. Multi-bilateral negotiation problem statement

To define the negotiation problem we will consider one seller offering a single good or service (a contract to win) and many buyers bidding for the object being sold. Furthermore, we assume this contract to be described multi-attributively, i.e. there is a list of negotiation issues whose resolution levels need to be agreed during the negotiation process between the seller and a single buyer. To evaluate the offers negotiators will use an additive scoring system with cardinal utility payoffs [3]. The application of this system requires a predefined list of all resolution levels (options) that could be used in the construction of the offers (packages of options). As the number of the options is usually big, only the most important of them are identified in the pre-negotiation phase (salient options). The algorithm of building an additive scoring system of the offers consists of two steps:

1. Distribution of scoring points between k negotiation issues to establish the importance of them (weights).
2. Assigning the scores to the options within each issue so that the least preferred option receives the score of 0, while the most preferred, the score of the issue weight w_i. All other options receive the scores from the interval $[0; w_i]$.

The score of the offer is the sum of the scores of the options that constitute the offer. A brief example of building the offers' scoring system for the negotiation between an employee and an employer is shown in Table 1.

Table 1

Scoring the issues and offers for a three-issue negotiation

Issue	Issue rating	Option	Option rating
Salary	50	3000 USD	0
		4000 USD	10
		5000 USD	40
		6000 USD	50
Holidays	30	20 days	0
		25 days	10
		30 days	30
Insurance	20	By employer	0
		By employee	20

From now on, we will denote the buyer's i scoring system as the function $s_i : R^k \to R$, transforming the vector of k options defined for the offer under evaluation into a scalar score.

We assume further that negotiators exchange the offers sequentially. The buyer submits his proposal, which can be accepted or rejected by the seller. If the proposal is rejected, the seller can propose his own counteroffer, which can be accepted or rejected by the buyer. Since the problem is multi-bilateral for the seller, he does not have to submit his own offers but can request another proposal from the buyer. The sub-process of submitting the offer and a possible counteroffer will be called a negotiation round.

In the multi-bilateral negotiation problem considered the buyers compete with each other by submitting at the subsequent negotiation rounds their proposals for agreement (offers). We assume that the first offer that exceeds the seller's reservation level defined for a particular negotiation round wins the contract[*]. The buyers compete with each other to win the contract by submitting the offer that gives relatively high score to the seller, which means they need to make concessions, i.e. to lower the score they achieve, but simultaneously they want to maximize their outcome, which means they are not willing to make huge concessions. In such a situation the problem of selection of the most competing offers (i.e. the offers that maximize the seller's score for the assumed buyer's payoff) arises. We will assume therefore that the negotiators do not define the exact offers (packages) for each negotiation round but prepare their negotiation strategies as the vectors of their aspiration levels, i.e. the scores they wish to achieve in subsequent negotiation rounds. In other words, they define their concession paths that say how much (in terms of utility scores) they can give in at each negotiation round. The idea of defining the strategies, transforming them into the offers and wining the contract is shown in Figure 1.

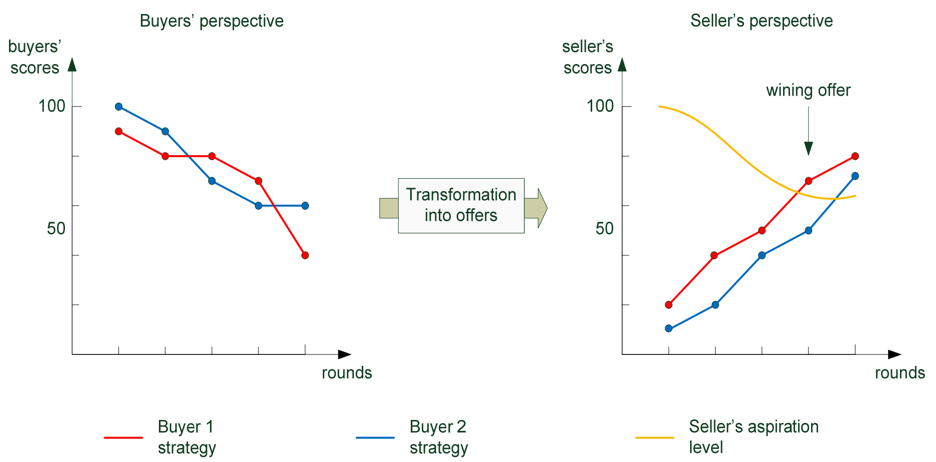

Figure 1. Definition of the strategies and their consequences in winning the contract

With the multi-bilateral negotiation problem defined as described above, each buyer needs a support for transforming his aspiration levels into offers that will best satisfy the seller, taking into consideration the fact that he is acting

[*] It is also possible that the seller's counteroffer will be accepted by the buyer as a negotiation agreement, but since the construction of this offer has not required any effort by the buyer's party it is trivial for us and we will not consider it in our analysis.

in a competing environment with many buyers. We will propose such a supporting mechanism in Section 3, derived from the first price auction theory and the equilibrium bid theory which we review briefly in the following section.

2. First price auctions and equilibrium bids

Following Milgrom and Weber [7] we consider the first price auction with n potential bidders (buyers). Let $X = (X_1, ..., X_n)$ be a vector of random information variables describing the private information of each buyer according to the value of the bidding object. Its value can be also determined by external factors described as a vector $S = (S_1, ..., S_m)$ of m different factors influencing the auction process. Each buyer i has his own evaluation of the bidding object, which is a random variable $V_i = v_i(S, X)$, where $v : R^{m+n} \to R$. The payoff of the buyer i can be described then as

$$g_i = \begin{cases} v_i - b_i & \text{if the buyer } i \text{ wins the auction} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where:

v_i is the *i*th buyer's evaluation of the bidding object,

b_i is the *i*th buyer's actual bid for the bidding object.

We will assume that each buyer knows the distribution of the bidding object evaluations $f(x)$ of all his competitors, and that $m = 0$, i.e. there are no external factors influencing the auction analyzed. Furthermore, we assume that the bidders are risk neutral and their decisions are reflected in an increasing decision function, which is also a random variable $B : R^n \to R$. The buyer i wins the auction if:

$$B(v_j) < b_i, \text{ for } j = 1,...,i-1, i+1,...,n \tag{2}$$

Following Riley and Samuelson [8] we can build now a formula for determining the optimal bid of buyer i, which is in fact an equivalent of the equilibrium strategy of this bidder. This formula can be denoted as:

$$b(v_i) = v_i - \frac{\int_{p_0}^{v_i} [F(x)]^{n-1} dx}{[F(v_i)]^{n-1}}, \quad \text{for} \quad i = 1, ..., n, \tag{3}$$

where:

$F(.)$ is the distribution function of the buyers' bidding object evaluations,
p_0 is the auction starting price.

The buyer's optimal offer can be computed with the formula (3) if $v_i \geq p_0$, otherwise the bid will be lower than the auction starting price p_0 and formally will not be taken into consideration as the auction proposal.

3. Buyers supporting mechanism

We will apply the first price auction approach described in section 2 for supporting the buyers in the process of construction of the negotiation offers. We propose a supporting mechanism for a multi-bilateral negotiation problem assuming that the whole negotiation process is conducted by means of software (electronic) support system, such as an e-auction service, which gathers the information about the users, including their preferences evaluation data and their scoring systems. We will regard each negotiation round as a separate first price auction. As we assumed in Section 1, the buyers define their strategies as the payoffs they want to achieve in the subsequent negotiation rounds. We will use these payoffs as the buyer's evaluation of the bidding object in each negotiation round. Therefore the negotiation strategy of the bidder i can be defined now as

$$N_i = \left(v_i^1,..,v_i^R\right) \tag{4}$$

where:
v_i^r is the payoff of the bidder i he wishes to achieve for the negotiation agreement settled in the round r.

Usually, to each desired payoff v_i^r there correspond several alternative offers that we can construct using the offer scoring system of the buyer i. The problem now arises: which of these offers should be chosen by the buyer as the bidding offer to best satisfy the seller. Since we have assumed that the negotiation support is given by means of electronic negotiation support system, acting as a facilitator, we know both the buyer's and the seller's preferences. Therefore within each negotiation round the system will look for an offer $\hat{a}_i^r \in A$, A being the set of all feasible offers, that gives the buyer i

the aspired payoff v_i^r and simultaneously maximizes the payoff of the seller. Knowing the seller's scoring system, the negotiation support system will consider the negotiation strategy of the buyer i as the vector

$$N_i^{seller} = \left(s_{seller}(\widehat{a}_i^1),\ldots, s_{seller}(\widehat{a}_i^R)\right) \tag{5}$$

The offers $\widehat{a}_i^r$ can be presented directly to the seller as the negotiation proposals, but the negotiation theory says [5] that to finish negotiation with a satisfying agreement, the concessions in the negotiation rounds should be made gradually. Therefore, we will not offer as much as $s_{seller}(\widehat{a}_i^r)$ to the seller, but a little less, taking into account the competing environment of many buyers. For each $s_{seller}(\widehat{a}_i^r)$ the optimal bid will be determined using the equilibrium strategy approach shown in the equation (3)* and we obtain the vector of optimal bids

$$O_i^{seller} = \left(b_{seller}^1,\ldots, b_{seller}^R\right) \tag{6}$$

where:
b_{seller}^r is the payoff the seller should receive in the negotiation round r.

The problem we are facing now is quite opposite to the one we had while finding the offers $\widehat{a}_i^r$. To each payoff b_{seller}^r there usually correspond several negotiation offers. Therefore, the system needs to find an offer $\breve{a}_i^r \in A$ that gives the seller the assumed payoff b_{seller}^r and simultaneously maximizes the payoff of the buyer i. If $s_i(\breve{a}_i^r) > s_i(\widehat{a}_i^r)$ then the system will recommend to the buyer i the alternative $\breve{a}_i^r$ as the one corresponding to his initial v_i^r, otherwise the recommendation will be the offer $\widehat{a}_i^r$ since it simply dominates $\breve{a}_i^r$.

The final product of the mechanism we propose is hence the list of offers (optimal bids) determined for the negotiation strategy defined by the buyer supported. The key steps of the entire procedure of supporting the negotiator i are presented as an algorithm in Figure 2.

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* Since the negotiation has been conducted by means of a software system, the number of the bidders required to make the calculations is determined automatically by the system, which will count the number of registered auction participants.

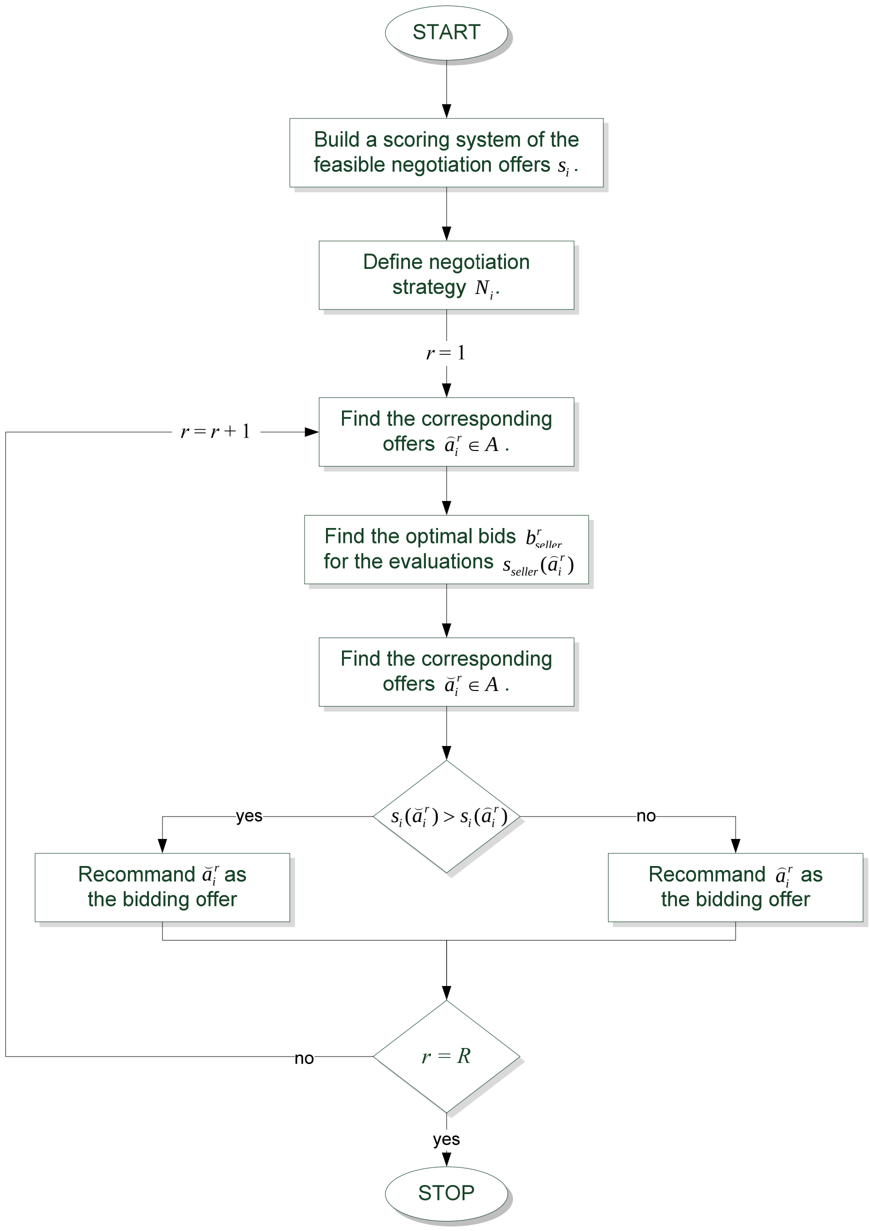


Figure 2. An algorithm for supporting *i*th buyer

Example

In this section we will present an application of the above mechanism to solve a hypothetical multi-bilateral negotiation problem. We will assume a situation with one seller and four buyers and will show the supporting process for one selected buyer party. We assume then that there is one contract to win in the negotiations supported –a business contract for supplying parts for production. Within the contract the parties need to agree on the resolution levels for four issues: unit price of the parts, time of delivery, time of payment and return conditions. We assume further that the parties agreed on some salient options for all the issues (the considered problem is discrete), which is required to apply an additive scoring system for offer evaluation.

Step 1

The first step of the supporting algorithm (see Figure 2) is conducted by means of the spreadsheet based negotiation support system called NegoCalc [11]. As described in section 1 the supported negotiator (a buyer) needs to assign weights to the negotiation issue first and then distribute the scores among all the salient options within each issue. These two steps are realized by means of Preference Elicitation Engine of the NegoCalc system (see Figure 3).

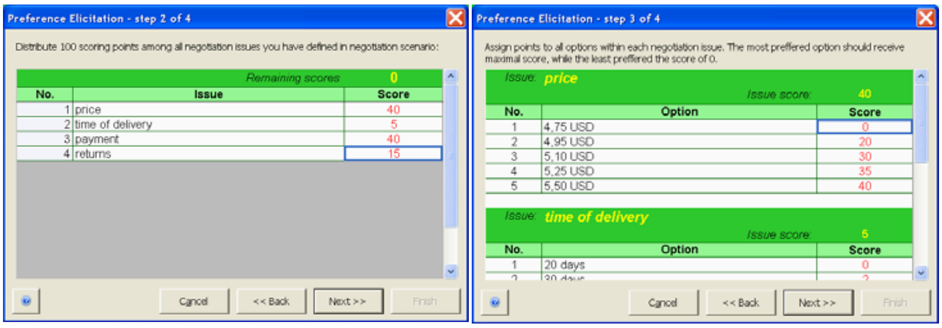
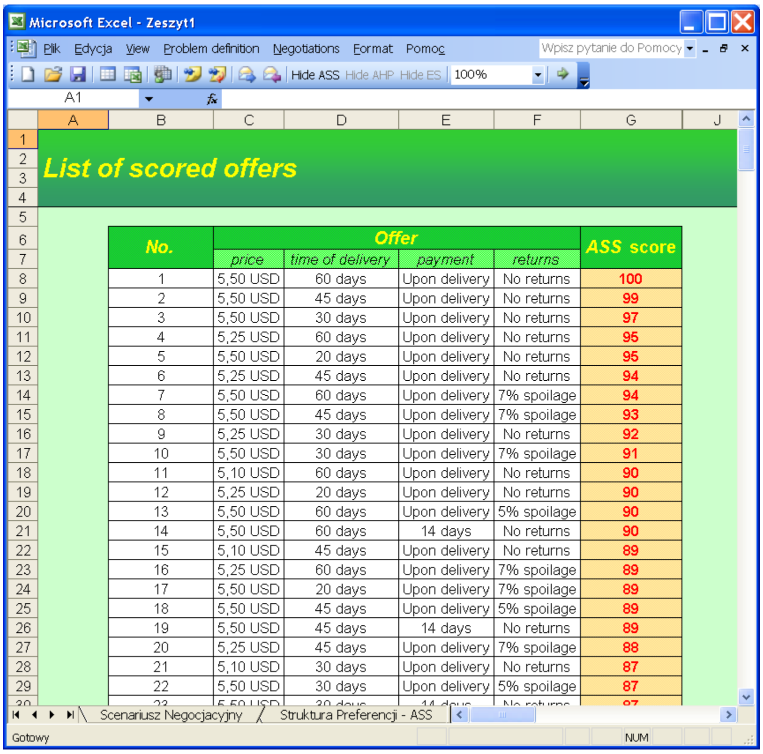


Figure 3. Building the offer scoring system (scoring issues and options) in NegoCalc

After preference elicitation the offer scoring system is ready, which allows to build the list of offers with the corresponding scores (see Figure 4).



List of scored offers

No.	Offer: price	Offer: time of delivery	Offer: payment	Offer: returns	ASS score
1	5,50 USD	60 days	Upon delivery	No returns	100
2	5,50 USD	45 days	Upon delivery	No returns	99
3	5,50 USD	30 days	Upon delivery	No returns	97
4	5,25 USD	60 days	Upon delivery	No returns	95
5	5,50 USD	20 days	Upon delivery	No returns	95
6	5,25 USD	45 days	Upon delivery	No returns	94
7	5,50 USD	60 days	Upon delivery	7% spoilage	94
8	5,50 USD	45 days	Upon delivery	7% spoilage	93
9	5,25 USD	30 days	Upon delivery	No returns	92
10	5,50 USD	30 days	Upon delivery	7% spoilage	91
11	5,10 USD	60 days	Upon delivery	No returns	90
12	5,25 USD	20 days	Upon delivery	No returns	90
13	5,50 USD	60 days	Upon delivery	5% spoilage	90
14	5,50 USD	60 days	14 days	No returns	90
15	5,10 USD	45 days	Upon delivery	No returns	89
16	5,25 USD	60 days	Upon delivery	7% spoilage	89
17	5,50 USD	20 days	Upon delivery	7% spoilage	89
18	5,50 USD	45 days	Upon delivery	5% spoilage	89
19	5,50 USD	45 days	14 days	No returns	89
20	5,25 USD	45 days	Upon delivery	7% spoilage	88
21	5,10 USD	30 days	Upon delivery	No returns	87
22	5,50 USD	30 days	Upon delivery	5% spoilage	87

Figure 4. List of scored offers in NegoCalc

Step 2

Having his preferences elicited the buyer needs to define his negotiation strategy. Let us assume that it is defined as follows: $N_i = (90;85;80;70;60;40)$. It means that the buyers is going to make a maximal concession of 10 points in the first negotiation round (within his first offer), 15 points in the second, etc. He would be then willing to accept as the negotiation agreement, for instance, the offer $a_1 = [5{,}50\ \text{USD}; 60\ \text{days}; 14\ \text{days}; \text{no returns}]$ in the first negotiation round. He introduces his negotiation strategy into the multi-bilateral negotiation support system (MB-NSS) (an add-in to the NegoCalc system) which is shown in Figure 5.

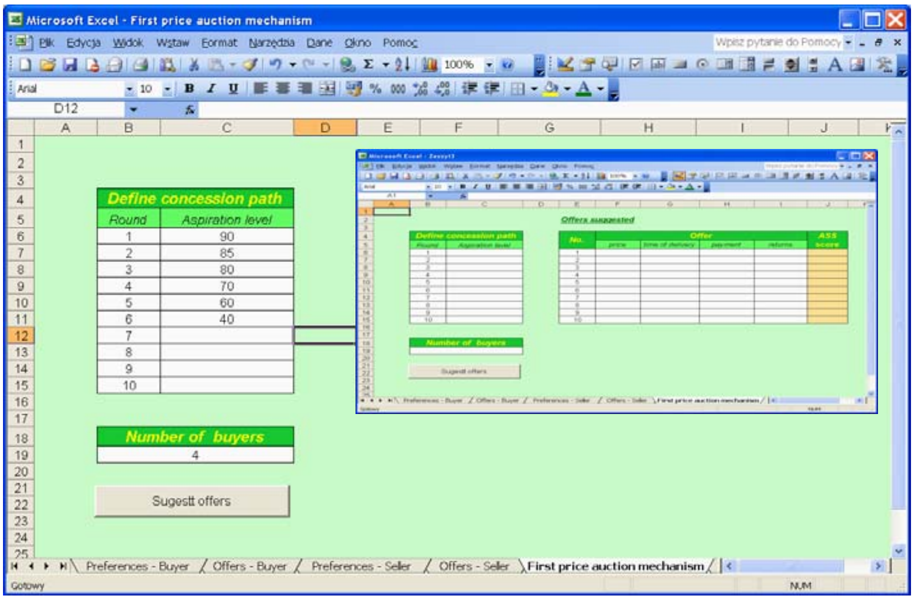


Figure 5. Defining the negotiation strategy in the MB-NSS

Step 3

The MB-NSS finds the offers corresponding to the first aspiration level of the buyer ($v_1^1 = 90$) and from the set of alternatives obtained it selects the one that maximizes the seller's payoff, $\hat{a}_1^1 = [4{,}95\ \text{USD}; 30\ \text{days}; 14\ \text{days}; 3\%\ \text{spoilage}]$, $s_{seller}(\hat{a}_1^1) = 52$. In Figure 6 there is a list of all alternatives satisfying the buyer at the level of 90 and their evaluation in the seller's scoring space (the scores of the seller are given in column I).

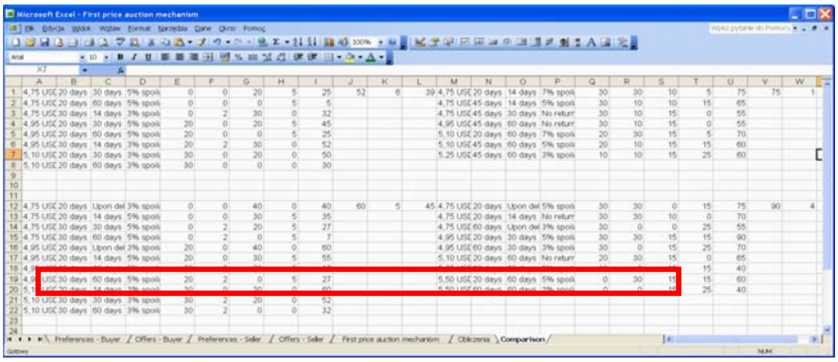


Figure 6. The analysis of the corresponding offers

Step 4

We use the evaluation of the maximizing offer $s_{seller}(\hat{a}_1^1) = 52$ to determine the optimal bid in terms of the seller's payoffs (equation 3), which, assuming there are four auction participants, equals $b_{seller}^1 = 39$.

Step 5

The system finds the offers corresponding to the seller's score $b_{seller}^1 = 39$. All the offers giving the score no better then b_{seller}^1 should be identified (see the list of 7 offers in Figure 7).

Step 6

The system finds the best corresponding offer which maximizes the buyer's payoff $\breve{a}_1^1 = [4{,}75\ \text{USD}; 20\ \text{days}; 14\ \text{days}; 7\%\ \text{spoilage}]$ (see Figure 7).

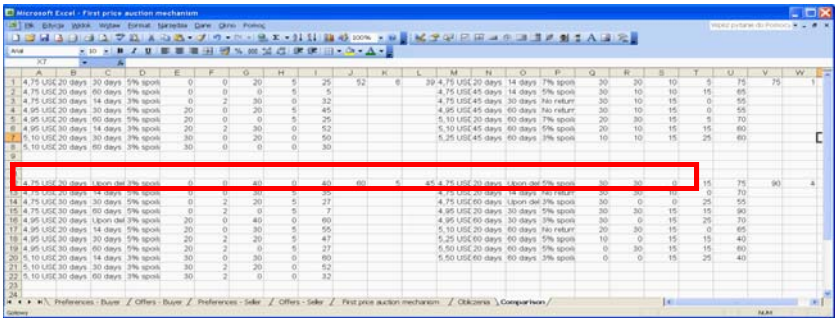


Figure 7. Corresponding offers and $\breve{a}_1^1$

Step 7

We have obtained $s_1(\breve{a}_1^1) = 75 < s_1(\hat{a}_1^1) = 90$; therefore the system will recommend $\hat{a}_1^1$ as the bidding offer.

As we can see, the supported mechanism proposed did not make any improvement in the first round of negotiation. The offer $\hat{a}_1^1$ corresponding directly to the buyer's aspiration level $v_1^1 = 90$ was recommended as the final bidding offer. Such a situation can appear during the negotiation process since the buyer's and the seller's scoring systems are not directly opposite, i.e. an increase of the scores assigned for the successive options in the buyer's scoring system is not equal to the decrease of the scoring points for these options in the seller's scoring system (and *vice versa*).

If we consider the second round of the negotiation process above we will find, however, that the mechanism proposed gives a significant improvement in the formulation of the bidding offer. We have $v_1^2 = 85$ and from the set of the corresponding alternatives (see the red rectangle in Figure 8) we select $\hat{a}_1^2 = [4{,}95\text{ USD}; 20\text{ days}; \text{upon delivery}; 3\%\text{ spoilage}]$, $s_{seller}(\hat{a}_1^2) = 60$. For $s_{seller}(\hat{a}_1^2)$ we obtain the optimal bid $b_{seller}^2 = 45$ and from the corresponding offers (see the green rectangle in Figure 8) we select $\breve{a}_1^2 = [4{,}95\text{ USD}; 20\text{ days}; 30\text{ days}; 5\%\text{ spoilage}]$ with the buyer's payoff $s_1(\breve{a}_1^2) = 90$. As we can see, thanks to the supporting mechanism the buyer will have recommended the offer that gives the seller the same payoff as for the declared aspiration level v_1^2, but simultaneously he will give himself a value greater than the aspiration level v_1^2 not allowing for leaving any gains on the negotiation table.

The mechanism repeats the steps of the algorithms, which finally leads to the identification of the full negotiation proposals corresponding to the negotiation strategy declared (Figure 9).

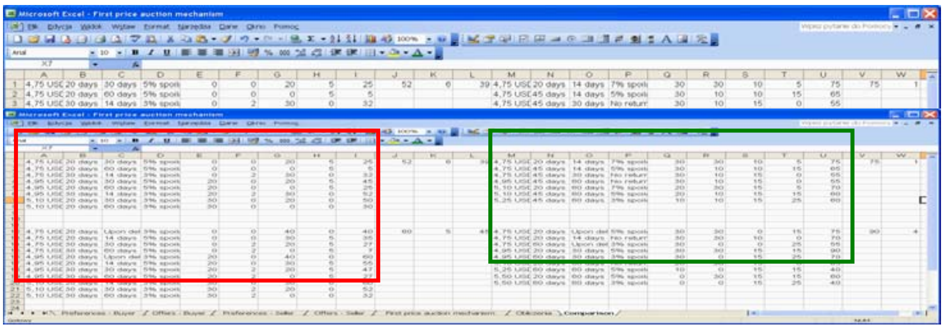
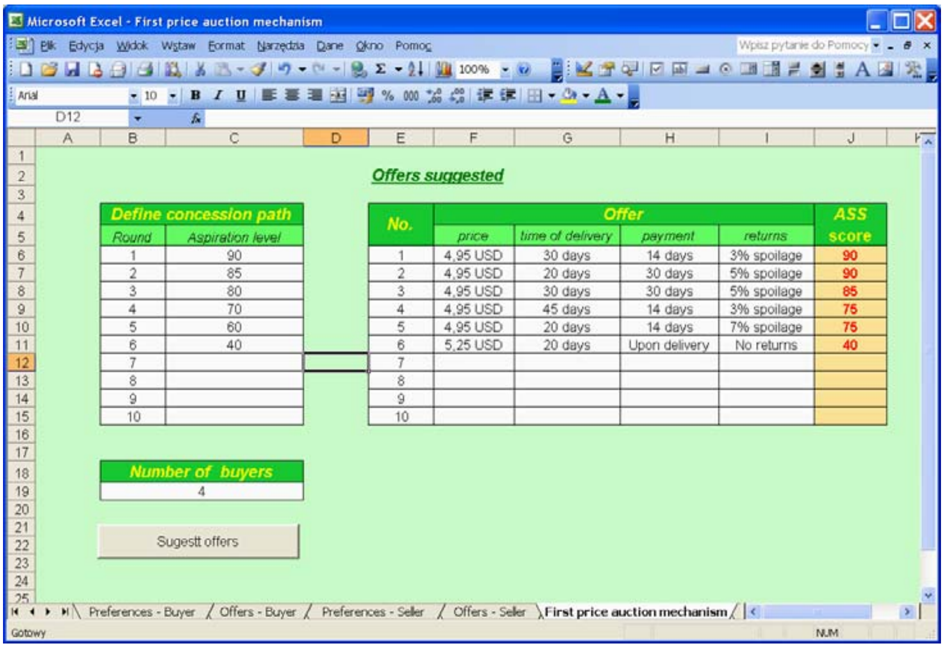


Figure 8. Finding the optimal bidding offer



Define concession path	
Round	Aspiration level
1	90
2	85
3	80
4	70
5	60
6	40
7	
8	
9	
10	

No.	Offer				ASS score
	price	time of delivery	payment	returns	
1	4,95 USD	30 days	14 days	3% spoilage	90
2	4,95 USD	20 days	30 days	5% spoilage	90
3	4,95 USD	30 days	30 days	5% spoilage	85
4	4,95 USD	45 days	14 days	3% spoilage	75
5	4,95 USD	20 days	14 days	7% spoilage	75
6	5,25 USD	20 days	Upon delivery	No returns	40
7					
8					
9					
10					

Figure 9. Recommendation of negotiation offers for full negotiation strategy

As we can see in the negotiation rounds number 2-5 the recommendations of the supporting mechanism allow for improvements for the buyer's party. Instead of having the payoffs: 85, 80, 70, 60 the buyer can assure for himself the outcomes: 90, 85, 75, 75 while offering to the seller the same level of payoffs as in the former case.

Summary

In this paper we have proposed a comprehensive proactive mechanism for supporting the selection of offers congruent with the buyers' negotiation strategy, defined as the maximal concession paths for successive negotiation rounds, and best satisfying the seller. Our approach can be implemented if the whole multi-bilateral negotiation process is conducted by means of an electronic negotiation system or is managed by an external facilitator. That is because we assumed we know the exact form of the distribution function of the values of the buyers' offers and the preferences of all parties (i.e. offer scoring systems). This information is confidential, and it is not transferred from the buyers to the seller or among the buyers but is only used to maximize the parties' payoffs. While building the supporting mechanism we have combined two different supporting elements. The first was a simple searching algorithm, which had to transform the total score of the offer (of the buyer or the seller respectively) into the set of corresponding offers and then select within the set the offers that maximize the payoff of the counterpart. We use this procedure to assure that the negotiators are not going to consider the non--efficient solutions and leave the gains on the negotiation table. The second element was the first price auction mechanism for determining the equilibrium (optimal) bid. In the competing environment of many buyers (bidders) the participants need to find a balance between their own profits from the winning the auction (here, the contract) and the risk of losing it. Therefore they need to declare how much they are willing to give in every negotiation round, but, to leave some extra point for themselves, if possible. The repeated first price auction mechanism fits precisely the situation we described here in multi-bilateral negotiation situation.

The mechanism we have proposed may be applied for the electronic commodity exchange or electronic auction services, especially when the bidding objects are described multi-attributively. Nowadays many business transactions are conducted via Web-based services, but they require the users to track the bidding or transaction process step by step, make decisions, prepare argumentations, etc. The software implementation of the mechanism we propose could make the transaction process a little bit easier and less involved for a decision maker, since it requires only preference elicitation and strategy formulation in the pre-negotiation phase while the actual negotiation phase can be conducted automatically.

Acknowledgements

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