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COMPLEMENTARITY OF THE GRAPHICAL ANALYSIS FOR INTERACTIVE AID AND DOMINANCE-BASED ROUGH SET APPROACH APPLIED TO THE CLASSIFICATION OF NON-URBAN MUNICIPALITIES

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Abstract

Graphical analysis for interactive aid (GAIA) and the dominance-based rough set approach (DRSA) are compared as methods of explaining the solution to a multi-criteria ranking problem obtained using the preference ranking organization method for the enrichment of evaluations (PROMETHEE). The classification of 52 municipalities in Northern Quebec in terms of the socioeconomic situation is based on three attributes: home conditions, employment and demographic potential. The classification provided to the decision maker is aggregated information. To facilitate decision-making, the problem is first considered as a sorting task, in which municipalities are distributed into three categories: best (B), worst (W) or intermediate (I), based on the PROMETHEE ranking. In order to improve the position of a municipality thus categorized, the decision maker needs information that will answer the questions: What criteria are relevant to the municipality? What criteria are in conflict? What are the critical values of the criteria? We show that GAIA and DRSA provide convergent and complementary information that allow enrichment of the answers to these questions.

Keywords: management decision support, multi-criteria analysis, GAIA, dominance-based rough set approach.

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1 Introduction

The dominance-based rough set approach (DRSA) proposed by Greco, Matarazzo and Slowinski (2001) is a mathematical tool that may be used to support decision-making processes in many fields such as medicine, banking and engineering (Pawlak, 2002). It has been applied also on a larger scale to feasibility studies and risk analyses for the purpose of facilitating the prioritization and selection of sustainable economic development projects in non-urban regions in the province of Quebec (Zaras, Marin, Boudreau, 2012; Marin, Zaras, Boudreau-Trudel, 2014).

In the present study, three socioeconomic indicators were measured using Canadian census data representing 52 of the 62 municipalities in Northern Quebec[1] (www 1). These indicators were: housing conditions, employment and demographic potential. The decision maker required a synthesis of information for the ranking of the municipalities.

To solve this multi-criteria classification problem, the PROMETHEE method (preference ranking organization method for enrichment evaluations) was used. First developed in 1982 by J.P. Brans (1982), it has since undergone several refinements (Brans, Mareschal, Vincke, 1984, 1986; Brans, Vincke, 1985; Mareschal, 1986, 1988; Brans, Mareschal, 1992, 1994). In order to decide how to improve the position of a municipality, the decision maker needed answers to the following questions: What criteria are relevant to the municipality? What are the critical values of the criteria for advancing to the next category?

The PROMETHEE method was used to rank the municipalities for sorting into one of three categories: best (B), worst (W) and intermediate (I). DRSA was then used to extract the decision rules. This method plays, in this context, the role of explaining the classification obtained by the multi-criteria method. Another method that can play this role is geometrical analysis for interactive assistance or GAIA. This is an interactive geometric normalization method that allows data to be written and interpreted.

Considering the position of all the municipalities projected in relation to the GAIA plan origin appears very helpful to the decision maker. The municipalities nearest to the origin are in the intermediate category (I). Decision rules are extracted for municipalities that are above and below the origin, which makes it possible to determine the critical values for specific criteria. In the present paper, we show that the GAIA and DRSA methods provide convergent and complementary information, thus enriching the answers to the questions being asked by the decision maker.

[1] Statistics Canada does not have data for municipalities inhabited by fewer than 200 individuals.

This paper is structured as follows. The problem is formulated in Section 2. Section 3 presents the multi-criteria method PROMETHEE and how ranking is obtained using this method. In Section 4, the GAIA and DRSA methods are applied to explain the classification. Section 5 provides a comparison of the usefulness of the two explicative methods for answering the questions asked by the decision maker.

2 Formulation of the multi-criteria problem

The first stage was the ranking of the 52 municipalities in northern Quebec. Since three indicators were used, this task is a multi-criteria ranking problem. It can be represented using the AXE model, where:

A is a finite set of actions (municipalities) a_i for $i = 1, 2\ldots 52$;

X is a finite set of criteria X_k for $k = 1, 2, 3$; and

E is the set of municipality evaluations $\mathbf{e}_{i,k}$ with respect to criterion X_k.

The main aim of the multi-criteria approach is to obtain an overall preference among the set of municipalities, which is based on performance evaluated with respect to each criterion. The municipalities were evaluated using Statistics Canada census data from 2012 (www 1) (results of the 2016 census were not all available).

3 The PROMETHEE II multi-criteria method

PROMETHEE II is a complete ranking method for solving multi-criteria decision problems. All actions are compared even when comparison is difficult to perform (Mareschal, 2013). The PROMETHEE II ranking is based on the computation of preference flows, which confirm the results of the pairwise comparisons of the actions and allows all actions to be ranked from the best to the worst. To achieve this, we need to compute three different preference flows:

- Φ^+ : the positive (or leaving) flow,
- Φ^- : the negative (or entering) flow,
- Φ : the net flow.

The positive preference flow $\Phi^+(a)$ gives an overall measurement of the strengths of action a by computing how much it is preferred over the $n-1$ others. The higher the computed $\Phi^+(a)$, the better the action:

$$\Phi^+(a) = \frac{1}{n-1}\sum_{b\neq a}\pi(a,b) \quad (1)$$

where $\pi(a,b) = \sum_{j=1}^{k} P_j\,(a,b)\cdot w_j \;\forall a,b \in A$ which aggregates the preferences $(0 \leq P_j \leq 1)$ by taking into account weights attributed by the decision maker to the various criteria (w_j). For our purposes, the same weight was used for each criterion.

The negative preference flow $\Phi^{-}(a)$ provides an overall measurement of the weaknesses of action a by computing how much the $n-1$ other actions are preferred. The smaller the computed $\Phi^{-}(a)$, the better the action:

$$\Phi^{-}(a) = \frac{1}{n-1}\sum_{b \neq a} \pi(b,a) \tag{2}$$

The net preference flow $\Phi(a)$ is the difference between the positive and the negative preference flows:

$$\Phi(a) = \Phi^{+}(a) - \Phi^{-}(a) \tag{3}$$

In summary, $\Phi(a)$ considers and aggregates both the strengths and the weaknesses of the action into a single score (Mareschal, 2013). The value of $\Phi(a)$ can be either positive or negative. As is the case with $\Phi^{+}(a)$, the greater the computed $\Phi(a)$, the better the action.

The PROMETHEE II ranking is based on the net preference flow. For example, action *a* is preferred to action *b* in the PROMETHEE II ranking if and only if it is preferred to *b* given that net preference flow:

$$aP^{II}b \text{ if and only if } \Phi(a) > \Phi(b) \tag{4}$$

where P^{II} means "is preferred to in the PROMETHEE II ranking".

3.1. Practical example

The data is from a real-life example, the North Quebec Development Plan. These data concern one of the most important issues related to the development of employment. In our example, we considered three selected criteria from among many that were taken in the analysis of this plan: employment, condition of housing in the municipality and demographic potential.

With respect to the three criteria, we used the measurement that come from the information available on the 2006 and 2011 censuses from Statistics Canada. They are defined by Statistics Canada as follows:

Demographic potential: Number of people aged 15 and under divided by the number of people.

Employment: Number of people employed divided by the number of people aged 15 and over.

Housing conditions: Number of private dwellings in need of major repair divided by the number of private dwellings.

A multi-criteria analysis of 52 municipalities in relation to the three above criteria using the PROMETHEE II method allowed to determine the ranking of municipalities presented in Table 1.

Table 1: Ranking of actions with PROMETHEE II

Rank	Actions	Φ(*a*)	Category	Rank	Actions	Φ(*a*)	Category
1	26	0,6078	B	27	48	0,0131	I
2	9	0,4771	B	28	18	−0,0131	I
3	31	0,4641	B	29	15	−0,0196	I
4	11	0,4052	B	30	20	−0,0261	I
5	6	0,3333	B	31	5	−0,0327	I
5	19	0,3333	B	32	14	−0,0523	I
7	13	0,3268	B	32	37	−0,0523	I
8	3	0,3137	B	34	44	−0,0654	I
9	25	0,2810	B	35	24	−0,1046	I
10	12	0,2745	B	36	38	−0,1111	I
10	39	0,2745	B	37	41	−0,1373	I
12	32	0,2484	B	38	16	−0,2026	I
13	22	0,2353	B	39	28	−0,2157	I
14	35	0,2157	I	39	34	−0,2157	W
15	33	0,2026	I	41	30	−0,2288	W
16	4	0,1765	I	42	46	−0,2614	W
17	1	0,1699	I	43	42	−0,2810	W
18	52	0,1569	I	44	49	−0,3203	W
19	8	0,1373	I	45	40	−0,3464	W
20	27	0,1242	I	46	47	−0,3595	W
20	17	0,1242	I	47	45	−0,3725	W
22	2	0,1176	I	48	43	−0,3791	W
23	7	0,0850	I	49	51	−0,4314	W
24	23	0,0458	I	50	36	−0,5163	W
25	10	0,0392	I	51	50	−0,7124	W
26	21	0,0261	I	52	29	−0,7516	W

This ranking helps us to determine which action is better than the other, which is the best or the worst, and to rank all actions between these two extremes. Although we have at this point no explanation for the ranking, we can distribute the municipalities among the three classes, namely the best (class B, i.e. those in the top quartile, n = 13), the worst (class W, i.e. those in the bottom quartile, n = 13) and the intermediates (class I, i.e. those in the two middle quartiles).

4 Explanatory methods

4.1 GAIA

The first explanatory method that we used was derived from Visual PROMETHEE, which represents the completed ranking obtained from PROMETHEE II. Developed under the supervision of the creator of PROMETHEE, Bertrand Mareschal, this software is available online (www 2). Compared to products like PromCalc and Decision Lab, it provides more visually appealing and informative representations, including GAIA.

4.1.1 Explanation of classification with GAIA

GAIA provides decision makers with a powerful tool for the analysis of the discriminating force between criteria and between their conflictual characters (Brans, Mareschal, 2002). We show our results in Figure 1. The plan is generated from principal component analysis.

In a GAIA plan, the discriminating force between criteria is indicated in terms of axis length. In our study, the longest axis is from the criteria employment. The orientation of the axes to each other indicates the level of similarity between the criteria. The closer they are, the more similar the criteria are in terms of preference (the cosine of the angle between them will be closer to 1). On the contrary, the more they are directed in opposite positions, the more the criteria express independence of preferences (the cosine of the angle between them will approach −1). As the axes become orthogonal, the preferences become independent. The view in the first two principal components (U-V) is the best quality. In our case it groups 87.1% of the information. With regard to the positioning of the actions, the closer these are in the GAIA plan, the more similar they are for the decision maker. When actions occur in clusters, they perform similarly based on all criteria. The closer an action is to the end of the axis of a criterion, the better this action is on the basis of this criterion. For example, action 26 in Figure 1 obtains the best evaluation on the basis of the employment criterion.

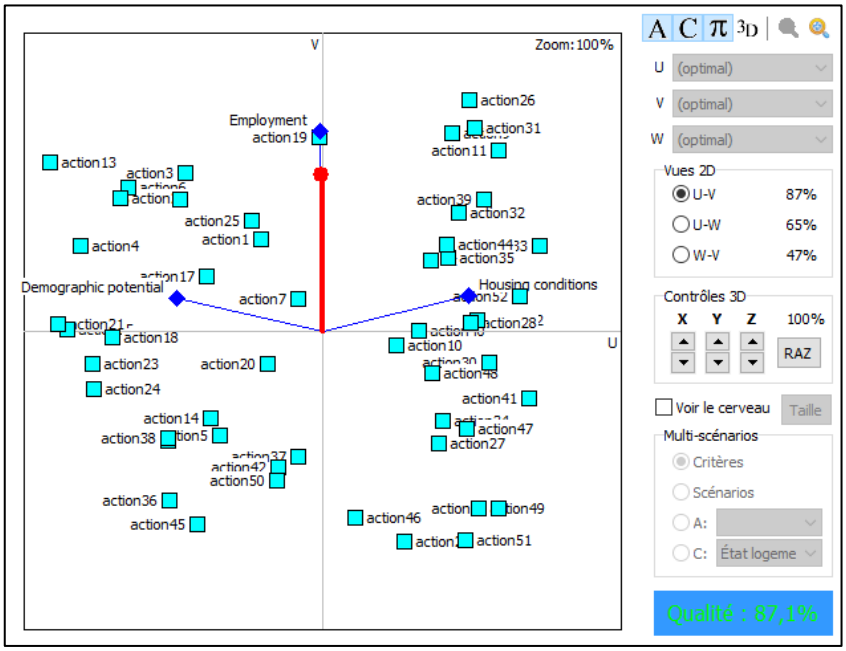

Figure 1: The GAIA plan

It is also possible to detect differences between actions by comparing their relative positions in the GAIA plan. Two actions differ if they are situated in different locations in the plan, for example, A19 and A46, as well as A28 and A21.

To obtain the explanation of the ranking provided by PROMETHEE II, we examine the decisional axis (π) on the GAIA plan, which appears in vertical axis in Figure 1. Representing the multi-criteria net flow, this axis indicates the criteria that are in agreement or not with the net flow. The reliability of this information increases with the length of the decisional axis. The best actions are thus the farthest possible in the direction of this axis. In our study, we see that the decisional axis is rather long and stuck on the axis of the employment criterion. We also see that the farthest action in this direction is action 26. This ranking thus represents the PROMETHEE II ranking presented in Table 1. In our multi-criteria problem, the most relevant criterion is employment, which is on the V axis as well. To be ranked the best, an action has to have the best score for that criterion, which was the case in our study. Complementary to the fact that the decisional axis is on the V axis, the remaining two criteria, namely demographic potential and housing conditions, are compensatory and influence the positioning of actions over the U axis. For example, action 13 scores strongly for demographic potential (39.9% versus an average of 24.14%), but below

average for housing conditions (50% versus 26.3%). For this reason, the position of action 13 is far on the U axis on the GAIA plan. Another example is action 7, for which both demographic potential (30.1%) and housing conditions (24.6%) are close to the averages (respectively 24.14% and 26.3%). This action is more balanced and therefore positioned nearly midway between both criteria axes on the GAIA plan.

The GAIA plan also helps the decision maker to classify the municipalities. For the first classification step (overall ranking based on the three criteria), municipalities in class B are preferred strongly and correspond to the first 13 actions starting from the upper side of the V axis on the GAIA plan. Class W municipalities correspond to strong non-preference and the first 13 actions starting from the lower side of V axis. Municipalities in class I correspond to weak preference, weak non-preference or indifference. They are found in the middle of the V axis.

4.2 The dominance-based rough set approach

The second explanatory method that we considered is based on the *rough set theory* proposed by Pawlak (1982, 1991) and developed by Greco, Matarazzo, Slowinski (2001) and Zaras (2004). Centered on the principle of dominance, this method is called the dominance-based rough set approach (DRSA). DRSA in effect helps decision makers identify a reduced set of criteria (reducts) that provides the same quality of classification of the original set of actions as obtained using (in our case) the PROMETHEE II net flow score.

In rough set theory, the decision problem is represented as a table in which the rows correspond to actions while the columns correspond to attributes (see Table 2). In our study, the actions are the municipalities. The attributes are of two types: conditional and decisional. The conditional attributes correspond to the three criteria, namely housing conditions, demographic potential and employment. The decisional attribute is the classification of the municipality on the basis of the PROMETHEE II net flow score to one of three categories: the best – class B, the worst – class W and the intermediate − class I.

Table 2: Decision table #1

	X_1	X_2	X_3	**D**
a_1	e[(a_1) 1]	e[(a_1) 2]	e[(a_1) 3]	e(a_1) = {B, I, W}
a_2	e[(a_2) 1]	e[(a_2) 2]	e[(a_2) 3]	e(a_2) = {B, I, W}
...	...	...	...	...
a_{52}	e[(a_{52}) 1]	e[(a_{52}) 2]	e[(a_{52}) 3]	e(a_{52}) = {B, I, W}

Then e[(a_1) 1] is the evaluation of municipality a_1 with respect to criterion $\mathbf{X_1}$ and e(a_1) = {B, I, W} is the classification of municipality a_1 corresponding to the appropriate class from the PROMETHEE II net flow score (B, I or W).

This first step will enable the decision maker to determine which criteria are the most relevant to getting a specific classification. Attribute reduction is one of major topics in the DRSA. In fact, this is not only a tool for identifying the most relevant criteria, but it also allows determination of the critical threshold value to be reached in order to upgrade the categorization.

4.2.1 The DRSA explanation of classification

To get an explanation of classification from DRSA, we extracted the rules using the 4eMK2 program (Greco, Matarazzo, Slowinski, 1999). Based on the rough set with dominance relation, 4eMK2 is another multi-criteria decision analysis method for classification problems. The rules explain the classification of actions by pointing out which condition(s) must be met in order to earn a specific classification. Our results are shown as decision rules as follows:

Rule 1. (Employment <= 32.3) => (Dec at most W); [6; 46.15%]
{29, 43, 45, 46, 49, 51}

This rule is confirmed by 6 of the 13 worst municipalities. This means that if the employment rate is at most equal to 32.3%, then the municipality can be classified as the worst.

Rule 2. (Home Conditions >= 61.5) => (Dec at most W); [2; 15.38%]
{36, 50}

This rule is confirmed by 2 of the 13 worst municipalities. This means that if the housing conditions rate is at least equal to 61.5%, then the municipality can be classified as the worst.

Rule 3. (Demographic Potential <= 10.4 & Employment <= 50.8) => (Dec at most W); [3; 23.08%]
{29, 30, 47}

This rule is confirmed by 3 of the 13 worst municipalities. This means that if the demographic potential rate is at most equal to 10.4% and employment at most equal to 50.8% then the municipality can be classified as the worst.

Rule 4. (Demographic Potential <= 8.1 => (Dec at most W); [2; 15.38%]
{29, 40}

This rule is confirmed by 2 of the 13 worst municipalities. This means that if the demographic potential rate is at most equal to 8.1%, then the municipality can be classified as the worst.

Rule 5. (Employment <= 48.0) & (Demographic Potential <= 28.9) => (Dec at most W); [8; 61.54%]
{29, 34, 36, 42, 43, 46, 49, 50, 51}

This rule is confirmed by 8 of the 13 worst municipalities. This means that if the employment rate is at most equal to 48.0% and the demographic potential rate is at most equal to 28.9% then the municipality can be classified as the worst.

Rule 6. (Employment >= 62.5) => (Dec at least B); [6; 46.15%]
{3, 9, 11, 19, 26, 31}

This rule is confirmed by 6 of the 13 best municipalities. This means that if the employment rate is at least equal to 62.5%, then the municipality can be classified as the best.

Rule 7. (Demographic Potential >= 39.9) => (Dec at least B); [1; 7.69%]
{13}

This rule is confirmed by 1 of the 13 best municipalities. This means that if the demographic potential rate is at least equal to 39.9%, then the municipality can be classified as the best.

Rule 8. (Home Conditions <= 1.07) => (Dec at most W); [1; 7.69%]
{12}

This rule is confirmed by 1 of the 13 worst municipalities. This means that if the housing conditions rate is at most equal to 1.07%, then the municipality can be classified as the worst.

Rule 9. (Demographic Potential >= 35.5) & (Employment >= 59.2) => (Dec at least B); [2; 15.38%]
{6, 22}

This rule is confirmed by 2 of the 13 best municipalities. This means that if the demographic potential rate is at least equal to 35.5% and the employment rate is at least equal to 59.2% then the municipality can be classified as the best.

Rule 10. (Employment >= 59.6) & (Home Conditions <= 25.6) => (Dec at least B); [1; 7.69%]
{25}

This rule is confirmed by 1 of the 13 best municipalities. This means that if the employment rate is at least equal to 59.6% and the housing conditions rate is at most equal to 25.6% then the municipality can be classified as the best.

Rule 11. (Employment>=59.6) & (HomeCond<=11.8) & (DemographPotenc>=28) => (Dec at least B); [6, 46.15%]
{9, 11, 26, 31, 32, 39}

This rule is confirmed by 6 of the 13 best municipalities. This means that if the employment rate is at least equal to 59.6% and the housing conditions rate is at most equal to 11.8% and the demographic potential rate is at least equal to 28% then the municipality can be classified as the best.

The municipalities which do not comply with the eleven rules mentioned above belong to intermediate class I.

The 4eMK2 software also makes it possible to identify the reducts. Reducts may be composed of single or multiple attributes, which allows us to classify the actions with the same quality. In other words, reducts of attributes lead to the same classification, but by taking into account reduced number of attributes in relation to the initial set. In our example, we have a reduct made up of two attributes: employment and demographic potential.

4.2.2 The DRSA explanation of the GAIA results

The municipalities belonging to classes B and W are presented in the GAIA plan in Figure 2. This figure shows a greater number of municipalities belonging to the intermediates class on the side of the potential demographic axis which represents the greatest uncertainty and this, perhaps, is an explanation of the reduct which is composed of two attributes: employment and demographic potential.

The rules listed in the previous section determine the critical values of the criteria which allow the sorting of municipalities on those which are the best, those which are the worst and those which are intermediate.

Decision-makers whose municipalities are in class W or I, are interested in the critical values which will allow their municipality to pass to class B. In relation to the employment criterion, as pointed by rule 6, the minimal value is 62.5%, which is confirmed by 6 of the 13 best municipalities (46.15%), circled between the first and second quadrant of the coordinates (see Figure 2). Here we can see a certain balance between two dimensions which are opposed to each other. In relation to the demographic potential criterion (rule 7), this is a value of 39.9%. In relation to the housing conditions criterion (rule 8), this is a value equal to 1.07%. It is possible to lower the critical value with respect to the employment criterion down to 59.2%, but in combination with other criteria, such as housing conditions critical value (rule 11) which should be at most 11.8%. This rule is confirmed by 6 of the 13 best municipalities (46.15%), circled in the first quadrant of the coordinates (see Figure 2). Here we can see all the six municipalities on the side of the housing conditions axis, which explain this combination. Both rules (11 and 6) are confirmed by 4 of the 13 best municipalities with the highest values in relation to the employment criterion.

From the other side, we have rule 9 which is the combination of two criteria. The critical employment criterion value equal to 59.2% and the demographic potential critical value equal to 35.5% which is confirmed by 2 of the 13 best

municipalities (15.38%), circled in the second quadrant of the coordinates (see Figure 2) on the side of the demographic potential axis.

Finally, we have rule 10 made of three criteria: employment whose critical value is equal to 59.2%, housing condition whose critical value is equal to 25.6% and demographic potential whose critical value is equal to 32%. This rule is confirmed by one of the 13 best municipalities (7.69%), namely municipality 25 (see Figure 2) on the side of the demographic potential axis.

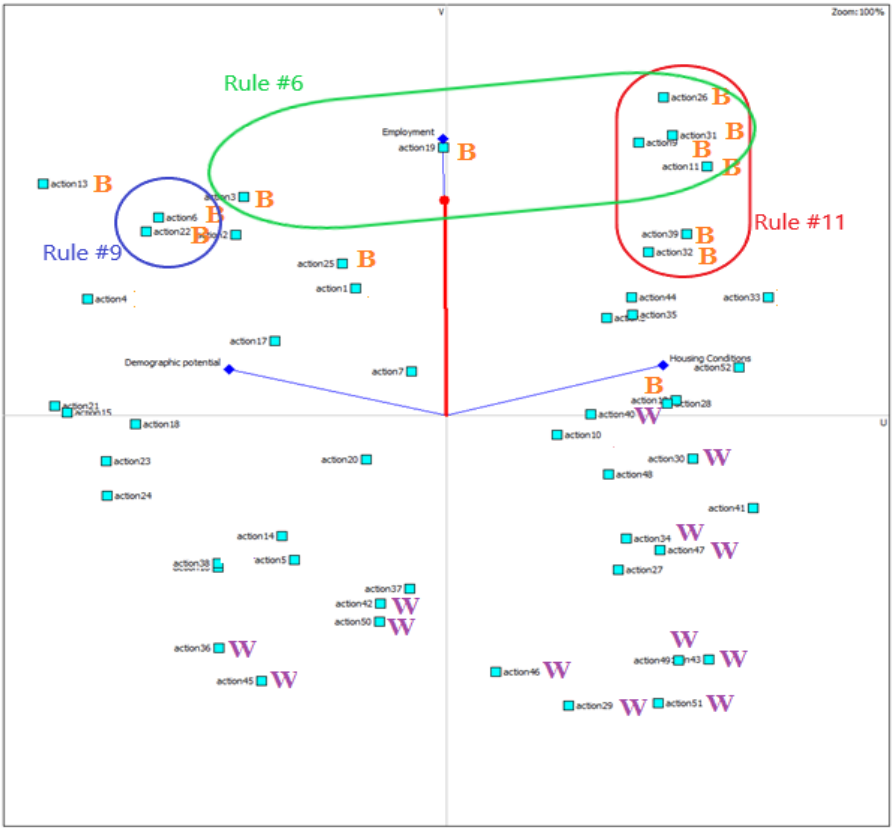

Figure 2: Municipalities belonging to classes B and W in the GAIA plan

5 Discussion

GAIA and DRSA are two methods that explain the ranking of potential actions obtained by the PROMETHEE multi-criteria method, each in its own way. The decision maker needs this explanation for a better understanding of the ranking of each action and to find a way to improve, if possible, the arrangement of the more distant actions in the classification.

The DRSA analysis of our case contains one reduct consisting of the employment rate and of the demographic potential rate. GAIA considers employment rate as similar to the housing conditions rate and the demographic potential rate when they are in balance. In the GAIA plan, it covers the decision axis marked as vertical. If the housing conditions rate and the demographic potential rate are unbalanced, then the points that represent municipalities are located in the GAIA plan above or below the center of the vertical axis, depending on which criterion is dominant. Obviously, this relationship is not linear, and the results can be seen on the GAIA plan for the municipalities, the increasing trend of the housing conditions rate being above the center of the vertical axis and the increasing trend of the demographic potential rate being below the center of vertical axis. For example, full balance is observed for belonging to the group of the best municipalities (action 19), located on the vertical axis of the employment in which the demographic potential rate is equal to 27.8% and the housing conditions rate is equal to 24.3%. The employment rate criterion (71.5% for this municipality) shows on the decision axis that this municipality has a very good performance.

6 Conclusions

We have compared GAIA and DRSA as approaches to assisting decision-making processes based on action ranking obtained using the multi-criteria method called PROMETHEE. The goal of using these approaches was to explain the ranking of 52 municipalities in northern Quebec in terms of employment statistics. The multi-criteria method provides aggregate information that is insufficient to answer the questions of the decision maker, such as how to upgrade the classification of a municipality categorized in a three-level scheme consisting of the designations ‘best’, ‘intermediate’ and ‘worst’, which criteria are relevant to the municipality, what critical values of a criterion determine the placement of municipality in one category or another, and so on. The application of GAIA and DRSA provides answers to these questions. GAIA allows visualization of a municipality and criteria positions on the initial main component plan, and DRSA allows determination of the critical values of the criteria. We have shown that the two methods complement each other, by explaining how three criteria can be reduced to two or by clustering the municipalities on the GAIA plan.

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