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Multi-Criteria Evaluation and Ranking of Suppliers - Case Study Analysis

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The article presents a coherent methodology of a multiple criteria evaluation of suppliers in furniture industry covering: the definition of a set of variants - laminated chipboards suppliers, the definition of a consistent family of criteria that allows for their comprehensive evaluation, modelling of decision maker's (DM's) preferences (including: the definition of the importance of criteria and the DM's sensitivity towards changes of criteria values), and finally computational experiments resulting in the final ranking of suppliers. Six suppliers have been taken into consideration. In the family of criteria evaluating the suppliers, 9 measures have been taken into account. These have included, among others: product price, product quality, timeliness and reliability of delivery or cost of delivery. In the computational phase a selected MCDM/A ranking method which is Electre III/IV has been applied.

Keywords: Suppliers selection problem, Ranking of suppliers, Multiple Criteria Decision Making/ Aiding (MCDM/A), Electre III/IV method.

1. INTRODUCTION

A procurement process in each business industry is mainly determined by the selection of the appropriate suppliers. Additionally, suppliers are responsible for the delivery of raw materials, components, finished products or services which are all necessary to conduct one's business activity, not only for manufacturing but also for service companies. In terms of suppliers selection process, a number of methods can be applied, including multiple criteria evaluation methodology. It consists of 5 main procedures: defining the set of variants (e.g. suppliers), defining a consistent family of evaluation criteria, structuring of decision maker's (DM's) preferences model in the given decision situation, carrying out computational experiments aiming at obtaining the final ranking and enabling the selection of the most desired variant. Conducting the effective process of selection may help to obtain fruitful cooperation between a potential supplier and a parent company, and may determine their future success on the market. The overall research goal of this paper is a multiple criteria evaluation and the ranking of the suppliers (laminated chipboards producers) for the company operating in the furniture industry. The evaluation criteria (crucial from the Vice President of the Management Board perspective - acting as decision maker) include 9 main criteria (further divided into their sub-criteria). In terms of computational procedures multiple criteria ranking method has been applied, which in this case is Electre III/IV.

2. METHODOLOGY IN THE SUPPLIERS EVALUATION AND SELECTION PROCESS

2.1. MULTIPLE CRITERIA DECISION MAKING/AIDING METHODOLOGY

A Multiple Criteria Decision Making, also known as a Multiple Criteria Decision Analysis is a field of study which derived from operational research (Hillier and Lieberman, 1990; Żak, 2010). It supports a decision maker with rules, methods, mathematical and programming tools in order to solve complex decision problems, considering - often contradictory - points of view (Figueira et al., 2005; Vincke, 1992). According to B. Roy (Roy, 1990) multiple criteria decision making is mainly an analyst's responsibility and one should indicate

the most desired solutions for various decision problems, taking into consideration all the criteria important from the decision maker's perspective. The evaluation and selection process comprises characteristics of all considered variants and it is based on the criteria which are hardly comparable.

The main components of multiple criteria decision problems are:

- a set of actions/ variants/ solutions A,
- a consistent family of criteria F.

The set of A can be defined as set of objects, decisions, solutions, variants or actions, which are analysed and evaluated in decision process. The set of A can be defined directly (in the form of a complete list) or indirectly (in the form of certain rules and formulas that determine feasible actions/variants/solutions, e.g. in the form of constraints). The consistent family of criteria F should provide a comprehensive and complete evaluation of all considered variants and the domain of each criterion in F should be disjoint with the domains of other criteria (Roy, 1990; Żak, 2014, p. 7141-7153; Galińska and Bielecki, 2017, p. 214). Each criterion in the family of criteria F is used to evaluate the A set, and represents the DM's preferences in relations to a proper aspect of a decision problem.

To solve multiple decision problems various tools, procedures or methods can be used. They can be generally divided into two groups (Figueira et al., 2005; Vincke, 1992; Żak, 2005; Żak, 2011):

- the methods of American inspiration based on the utility function (Keeney and Raiffa, 1993) referred to as the unique criterion of synthesis methods e.g. UTA (Figueira et al., 2005), AHP (Saaty, 1980; Saaty, 1995, p. 81-126);
- the methods of the European/French origin, based on the outranking relation, also known as outranking synthesis methods, considering incomparability relation e.g. Electre I–IV (Roy, 1990, p. 324-331), Promethee (Figueira et al., 2005) and Oreste.

In this paper – in the case study described – the Electre III/IV ranking method is applied.

2.2. CHARACTERISTICS OF ELECTRE III/IV METHOD

Electre III/IV method (Figueira et al., 2005; Roy, 1990; Żak, 2005) is the multiple criteria method of ranking the finite set of variants which are evaluated with the application of the set of criteria. The method is one of the universal multiple criteria ranking methods based upon the outranking relation (Figueira et al., 2005; Vincke, 1992; Roy, 1990; Żak, 2005). The procedures carried out with the application of Electre III/IV method aim at the construction of preference model on the basis of pair-wise comparisons of all decision variants, taking into account the thresholds which define the relation between these variants (Stachowiak, 2002, p. 132).

Computational algorithm of Electre III/IV comprises of three stages:

I. matrix evaluation construction and definition of the DM's preference model,
II. outranking relation construction,
III. outranking relation implementation.

Electre procedure starts from the definition of the set of solutions (variants) A and the consistent family of criteria F. Then, it is necessary to specify the value of particular criterion functions and wage indexes for each criterion (criterion wages). Finally, the DM's preference model is defined via the thresholds of indifference qj', preference pj' and veto vj', as well as the importance indexes. The thresholds define the sensitivity of the DM to the changes of the criteria values and the weight wj expresses the importance of each criterion. It is bound by a principle as follows: qj'<pj'<vj'.

On the second stage of the method, the consistency indexes C (a,b) are computed for every pair of variants (a,b). These are presented in the form of a consistency matrix. Their values indicate to what extent the a and b are consistent with the statement that a outranks b in relation to all other criteria. Subsequently, the inconsistency index Dj(a,b) is computed for every criterion j. The inconsistency index contradicts the statement that a outranks b. Finally, the outranking relation S (a,b) is structured which is defined as the outranking degree d(a,b) that is the aggregated measure of variants evaluation based on the consistency C (a,b) and inconsistency Dj (a,b) indexes. S (a,b) is an overall measure which specifies to what degree a outranks b. Outranking/Reliability degrees construct the credibility matrix.

On the third stage of Electre III/IV algorithm, the variants are ranked on the basis of the outranking degrees S (a,b). First it is a preliminary ranking structured with the application of descending and ascending distillations which rank the variants form the best to the worst. The intersection of two preorders (ascending and descending) gives the final ranking, which is

usually presented in a graphical form. It corresponds to a relation matrix that includes final, overall, mutual relations between variants, expressed in the following form: indifference (I); preference (greater than – „>"); non-preference or inverse of preference (less than – „<") and incomparability (R). Further details of the computational algorithm applied in Electre III/IV method can be found in the works of Roy B., Vincke P. or Figueira J. et al (Figueira et al., 2005; Vincke, 1992; Roy, 1990).

2.3. SUPPLIERS RANKING AND SELECTION PROCESS

The process of procurement belongs to the major categories of logistics activities, and has a critical impact on the operations of many manufacturing and service companies all over the world. Different entities, business units and companies order and purchase various categories of raw materials, components, semi-finished goods, final products, utilities and services. They carry out the sourcing of the required goods and services either on the local markets or internationally, which results in a different scale and organizational effort of the purchasing process.

Many authors determine the success of the procurement process from the selection of the appropriate supplier (Parniangtong, 2016; Baran and Żak, 2013; Coyle et al., 2010; Żak and Galińska, 2017; Galińska and Bielecki, 2017; Galińska, 2015). Unfortunately, it often happens that preliminary assumptions in the chain of deliveries are not well-respected and in the end the product obtained is different from the ordered one, the delivery fails to schedule and the quality of products does not comply with the requirements. Hence, both in the literature and in business practice more attention is being paid to the issue of suppliers selection and evaluation (Anders, 1992; Baran and Żak, 2013; Kleinau, 1995; Koppelmann, 2004; Pampel, 1993; Żak and Galińska, 2017). A certain role in this process is to create a beneficial cooperation by involving suppliers in the production and sale process of the buyer company (Appelfeller and Buchholz, 2011). Whereas suppliers evaluation aims above all to: create the structure of suppliers who will offer the desired products, safeguard supply sources, develop a trustworthy relationship between company and the supplier with reliability and trustworthiness in their partnership and finally to introduce the clear selection process and to maintain a sustainable advantage over competitors (Piontek, 1993).

In order to consider and analyse all aspects of evaluation, the selection process should be carried out at many stages, involving various business sectors. Also, it should be based on methodical, effective and comparable rules and should comprise: detailed analysis of manufacturing capacity, organisational and control capacities of the suppliers and an assessment of their experience, market position and flexibility. What is more, such a process, which is a very important economic decision, is particularly significant and should be implemented carefully. It should also be noted that it is an example of a multiple criteria decision problem, which means that evaluation is based on the various criteria, which can be both quantitative (deterministic) and qualitative (fuzzy). These include, in particular: product price offer, possibilities of deliveries and payment terms, frequency and reliability of deliveries or quality of the products offered (Lührs, 2010; Easton et al., 2014; Piontek, 1997; Mukherjee, 2017). Conducting the effective process of evaluation increases the chance of selection the appropriate supplier which will hopefully result in a fruitful cooperation between a potential supplier and a parent company in the future.

In conclusion, many authors demonstrate (Arnold, 1995; Janker, 2004; Kocój, 1997; Żak and Galińska, 2017; Galińska et al., 2015) that the issue of suppliers evaluation and selection is of a multiple criteria character. While analysing, it is essential to take into consideration the aspects of technical, economic, social, organizational, market-oriented and environmental character (Baran and Żak, 2013; Żak, 2010; Galińska, 2015) of the problem. In addition, the interests of different entities (stakeholders) should be well-considered, e.g. a manufacturer or a final client of the product. The practical aspect of MCDM/A methodology application has been further presented in the following part of the paper.

3. DESCRIPTION OF THE DECISION SITUATION

3.1. VERBAL CHARACTERISTIC OF THE DECISION PROBLEM

The issue considered in this paper is the evaluation and the ranking of suppliers for the Polish company operating in the furniture industry. The company specializes in office furniture manufacturing distinguished by wide range of

designs, colours, styling and finishing materials. The company's mission is finding innovative and timeless solutions. Nevertheless, the furniture offered is both elegant and functional, and also creates unique interior atmosphere. In 2016 the company reported sales of 14 million PLN, with the average employment of 24 workers. The manufactured furniture is dedicated to individual clients, both from the country and abroad. The furniture is exported to the Czech Republic, Germany and Slovenia.

The company belongs to furniture business operators which have been currently one of the fastest developing industry sectors, with one of the best positions on the market. It has been confirmed by dynamically growing manufacturing and exports, and according to estimates it will be still growing by several percent. Despite its good economic situation, the industry deals with two main problems - lack of workforce, and instantly growing labour costs (http://businessinsider.com.pl). Such situation forced companies to raise salaries in order to keep employees and stop the outflow of workers. The same applies to the respondent company whose authorities also decided to increase salaries gradually. Nonetheless, catalogue prices have been remaining still for many years which means the search for savings is in other areas (e.g. purchase of cheaper raw materials). Thus, the Vice President of Board, acting as a decision maker of this study, decided to analyse the ongoing suppliers of raw materials and enhance cooperation with the new ones. It has been presumed that those will be laminated chipboards producers (format of 2,800 x 2,070 x 18 mm) as this material is the basic construction material in the furniture production process. The process of chipboard manufacturing is done by refining them with decorative paper and creating the suitable surface structure. What is more, laminated chipboards are characterised by surface durability, scratch and stains resistance and great exposure to external factors. The DM indicated them as the most important in the manufacturing process, as any of their late deliveries lead to production downtimes. In addition, only local manufacturers, located not more than 150 km away from the company's plant, will be taken into consideration. Such a close distance between the supplier and the manufacturer contributes to reduction of delivery period and enables shipments of small but frequent parts of materials that form the manufacturing process. This kind of policy implements modern management concepts including i.e. Just in Time. Additionally, it reduces storage costs, improves logistics process and will provide calculable economic benefits. Moreover, company's plant location encourages cooperation on the local market, as in the wood sector there are many dynamically operating companies in the Łódź voivodship which have laminated chipboards in their offer.

3.2. DEFINITION OF VARIANT

Until now, the purchase choice of laminated chipboards was mainly determined by their availability. However, due to the necessity of cost reduction, it is vital to search for alternative sources with the utmost attention to products quality. The problem of suppliers selection has been defined as a multiple criteria of ranking variants, whereas considered variants are laminated chipboards suppliers of the 2,800 x 2,070 x 18 mm standard format, D1-D6 (table 1).

Table 1. Characteristics of variants - laminated chipboards suppliers - in the case study.

Suppliers	Characteristics
D1	Small production and service enterprise, located 15 km from the customer, existing 20 years on the market
D2	Large production and service enterprise, the subsidiary of Austrian Corporation, located 70 km from the customer, existing 60 years on the market
D3	Small production enterprise, located 25 km from the customer, existing 27 years on the market
D4	Medium-size production and service company, located 70 km from the customer, existing 26 years on the market
D5	Large production and service company, the subsidiary of Swiss Corporation, located 140 km from the customer, existing 50 years on the market
D6	Medium-size production and service enterprise, located 30 km from the customer, existing 25 years on the market

Source: *based on own research.*

Furniture industry situation, involving costs reduction with the main objective of maintaining existing clients and market position, resulted in decision maker's analysis of current and new suppliers of laminated chipboards. Such analysis comprises the ranking of suppliers indicating the most desired one: based on decision maker's (Vice President of the Management Board) preferences and expectations. It is of particular importance to

carry out the selection process, based on the number of criteria, relevant from the decision maker's point of view.

3.3. DEFINITION OF THE CONSISTENT FAMILY OF CRITERIA AND EVALUATION MATRIX CONSTRUCTION

The decision process of laminated chipboards suppliers evaluation and selection has been based on the analysis of six suppliers. The criteria have been constructed according to the model proposed by B. Galińska and J. Żak (Żak and Galińska, 2017), which distinguishes 9 main evaluation criteria. The importance wages of the criteria were formulated on the basis of the interview with the DM, his preferences and aspirations. Due to research limitations, criteria K1 - K9 and their sub-criteria have been only enumerated, without any detailed descriptions (table 2).

Table 2. Suppliers evaluation criteria in the case study.

Criterion	Sub-criterion
K1: Product price and payment conditions	K1.1: Unit cost of the product delivered
	K1.2: Payment conditions
K2: Timeliness of delivery/ supplier	
K3: Reliability of delivery	K3.1: Share of deliveries of products in appropriate quantity and conditions (undamaged)
	K3.2: Share of deliveries carried out as agreed
	K3.3: Quality of the product delivered
K4: Cost of delivery	
K5: Accessibility of supplier	K5.1: Time-oriented accessibility
	K5.2: Geographical accessibility
K6: Customer Service Quality (during the supply process)	K6.1: Level of customer support (info, monitoring, problem solving, reaction)
	K6.2: Flexibility of the supplier (in changing the order)
K7:Market position of the supplier	K7.1: Market experience of the supplier
	K7.2: Market share
K8: Performance of the supplier	K8.1: Efficiency of Human Resources (sales/ employee)
	K8.2: Assets turnover
K9: Modernity of the supplier	

Source: *Żak and Galińska, 2017*

On the basis of the nine suppliers evaluation criteria and the original raw data, the evaluation matrix has been constructed (Table 3).

In the described case study the raw data has been properly processed. Computational experiments are presented in detail in the following section of the paper.

4. COMPUTATIONAL EXPERIMENTS BASED ON THE ELECTRE III/IV METHOD

In accordance with the Electre III/IV method algorithm, described in detail in the second paragraph of this paper, the evaluation matrix has been constructed (Table 3) and the DM's preference model has been defined in the process of naming the wages of criteria and thresholds: indifference threshold q, preference threshold p and veto threshold v, which are the mode of expression the DM's sensitivity to the changing value of criteria. The model has been presented in table 4.

In the second stage of the algorithm the outranking relation has been constructed. To build the outranking relation, the matrix of concordance and discordance were generated. The concordance matrix comprises concordance indexes C (a,b) and the discordance matrix comprises the discordance indexes Dj (a,b). On that basis, the credibility matrix has been obtained which is presented in table 5. The matrix contains the outranking and credibility degrees d(a,b), which are the aggregated measure of the variants evaluation and representation of the outranking relation S (a,b). Each credibility degree specifies the extent to which globally 'a outranks b'. For example, the degree of credibility d (D2,D1) = 0,665 means that variant D2 is likely to outrank variant D1, whereas d(D3, D4) = 0,00 which demonstrates that variant D3 is unlikely to outrank variant D4.

Table 3. The Evaluation Matrix based on raw data in the case study.

Criteria		Suppliers					
		D1	D2	D3	D4	D5	D6
K1	K1.1 [PLN]	145	120	140	135	140	125
	K1.2 [Days]	7	21	0	14	30	14
K2 [%]		1	0.99	0.90	0.95	1	0.95
K3	K3.1 [%]	1	0.95	0.98	0.90	0.99	0.98
	K3.2 [%]	0.95	1	0.80	0.95	1	0.90
	K3.3 [%]	0.90	1	0.95	0.95	1	0.95
K4 [PLN]		37.50	175.00	62.50	175.00	350.00	75.00
K5	K5.1 [Days]	6	5	6	4	3	5
	K5.2 [KM]	15	70	25	70	140	30
K6	K6.1 [Points]	5	4	3	3	5	4
	K6.2 [Days]	3	1	5	2	1	3
K7	K7.1[Years]	20	60	27	26	50	25
	K7.2 [%]	0.005	0.095	0.002	0.060	0.085	0.050
K8	K8.1 [PLN]	25.000	53.000	13.000	49.000	55.000	42.000
	K8.2 [-]	No data; the criterion was omitted at the stage of computational experiments					
K9[Points]		3	5	2	4	5	4

Source: *based on own research.*

Table 4. Model of DM's preferences in the case study.

Preference information					
Criterion	Preference direction	Weight	Indifference threshold	Preference threshold	Veto threshold
K1.1.	Decreasing (Cost)	10,000	5	15	50
K1.2.	Increasing (Gain)	5,000	7	14	30
K2	Increasing (Gain)	6,000	0,03	0,1	0,3
K3.1.	Increasing (Gain)	7,000	0,03	0,1	0,3
K3.2.	Increasing (Gain)	3,000	0,03	0,1	0,3
K3.3.	Increasing (Gain)	9,000	0,03	0,1	0,3
K4	Decreasing (Cost)	9,000	50	100	400
K5.1.	Increasing (Gain)	5,000	1	2	4
K5.2.	Decreasing (Cost)	6,000	20	50	150
K6.1.	Increasing (Gain)	3,000	1	2	4
K6.2.	Decreasing (Cost)	8,000	1	2	4
K7.1.	Increasing (Gain)	5,000	5	10	50
K7.2.	Increasing (Gain)	2,000	0,005	0,02	0,1
K8.1.	Increasing (Gain)	4,000	5000	10000	30000
K9	Increasing (Gain)	3,000	1	2	3

Source: *based on own research.*

Table 5. Credibility matrix in the case study.

Credibility matrix						
Alternative	D1	D2	D3	D4	D5	D6
D1	1,000	0,001	0,946	0,140	0,000	0,299
D2	0,665	1,000	0,800	1,000	0,971	0,847
D3	0,484	0,000	1,000	0,000	0,000	0,018
D4	0,521	0,236	0,688	1,000	0,364	0,729
D5	0,028	0,298	0,050	0,494	1,000	0,108
D6	0,970	0,172	1,000	0,963	0,239	1,000

Source: *based on own research.*

In the third stage of the algorithm, the outranking relation S (a,b) has been applied and on the basis on the indexes of the variants, the ascending and descending distillations have been

performed, formulating the structure of complete pre-orders. Then, they have been averaged into the median ranking and the intersection of pre-orders resulted in the final ranking. The results of these suppliers' selection calculations are presented in the figure 1.

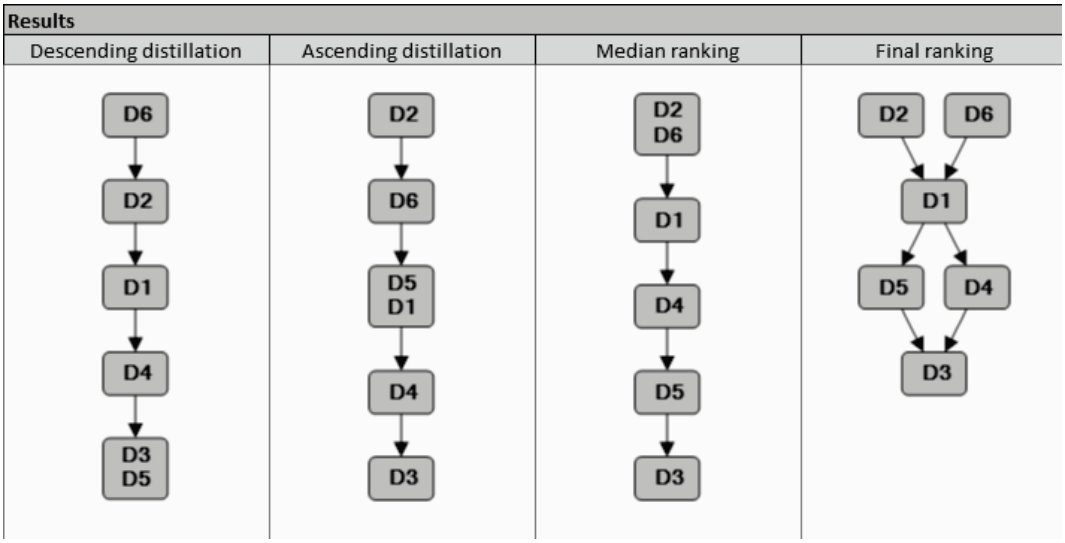

Fig. 1. The final ranking in the case study.
Source: *based on own research.*

The final ranking clearly indicates suppliers D2 and D6 as the most preferable variants, outranking the other ones. The most important advantages of the D2 supplier are: the cheapest raw material (K1), high quality of raw material (K3) and perfect delivery timeliness (K2). Variant D6 is featured by low price of raw material (K1) and relatively moderate cost of delivery. In addition, there are more distinguishing qualities of these two variants with a few disadvantages only. The least desired variant is D3, being sufficiently unattractive in a final overview. Its price of laminated chipboard is high (K1) with poor quality (K3) at the same time. What is more, the undertaking lacks modern technologies (K9) which implies not very suitable solutions such as cash payment during delivery of raw materials (K1).

5. CONCLUSIONS AND RECOMMENDATIONS

This paper presents the universal methodology for solving the problem selection and ranking of the suppliers for the company operating in the furniture industry. In the presented methodology the rules of multiple criteria decision making/aiding (MCDM/A) are implemented, as well as the traditional algorithm of proceedings in the situation of solving the multiple criteria decision problem. The decision problem was formulated as the multiple criteria problem of ranking variants. In the phase of computational experiments the Electre III/IV has been used, which resulted in constructing the final ranking of laminated chipboards suppliers.

The methodological part of the paper presents multiple criteria methodology characteristics with the implementation of Electre III/IV method. It indicates all stages of proceedings in order to construct the final ranking of the variants from the best to the worst in the multiple criteria sense. Also, the selection and evaluation process has been thoroughly analysed as it mainly determines the procurement process of the company.

The practical part of this paper includes the procedure of selection and ranking of chipboard suppliers for the furniture company. As a result, characteristics of six suppliers have been presented indicating their selecting criteria. Finally, the results of computational experiments pointed at the most desired suppliers which in this case study turned out to be variants D2 and D6. They are both featured by many advantages, and one of them should be considered for permanent cooperation.

In the authors' opinion further research should be carried out in two directions:

I. Application of alternative MCDM/A methods (Promethee, AHP, UTA) to the evaluation of different categories of suppliers;
II. Further analysis of suppliers' selection processes in different industries.

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