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APPLICATION OF THE MULTI–CRITERIA DECISION MAKING IN THE PRODUCT DEVELOPMENT PROCESS

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Abstract: The quality of products in machine industry is determined by numerous criteria from the group of technical, economic or other elements of the quality. When developing products, product engineers often face the problem of selecting the optimal component, subassembly or the entire assembly. This is reflected primarily in the fact that along with a large number of alternatives there is also a large number of criteria for their evaluation. For solving complex problems of evaluation and selection of the optimal solution, methods of multi–criteria decision making are used. This paper presents the application of the AHP method for the selection of the optimal set of motoreductors as elementary components of the transportation system within a single production system. As a result, the output gives the comparative view of the obtained results of multi–criteria decision making with the order of alternative motoreductors sorted by importance.
Keywords: Multi–criteria decision making, Motoreductor selection, AHP method

1. INTRODUCTION

Manufacturing system will function well, achieve growth and continue to develop only if meets market requirements, i.e. if the products are usable, cost–effective, well–designed, environmentally–friendly, competitive and marketable [1]. Mutually conflicting requirements have never been more expressed because the product development team have to design and manufacture a product at low cost and the shortest possible time. Good accuracy, quality and other attributes that are maximally adapted to changing customer demands and needs also have to be taken into account [2]. Product designers very often face with the need to select the optimal alternative among products, processes, resources, components, etc. In these situations, apart from a large number of alternative solutions, there is also a large number of criteria which makes the selection problem more complex. In order to solve these complex selection and evaluation problems, methods of multi–criteria decision making are proposed [3].

This paper presents the problem of selecting a set of motoreductors for design and manufacturing of the transportation system using the AHP multi–criteria decision making method as well as the corresponding Expert Choice software. The output provides a comparative view of the obtained results with ranked alternatives of motoreductors of different manufacturers.

2. THE MULTI–CRITERIA DECISION MAKING AND THE AHP METHOD

— Basics of the multi–criteria decision making

Multi–criteria decision making (MCDM) falls within the field of the decision theory whose main goal is to consistently overcome difficulties that decision makers face when solving problems with a large amount of complex information [4]. The MCDM covers a number of various techniques and methods which differ in approach to a problem or in the way of aggregating data for particular measurable criteria. The goal is to determine the total performances of alternatives with respect to a set of explicitly defined objectives.

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These techniques and methods can be used for: identifying a single most suitable alternative, ranking of selected alternatives, selecting a limited number of alternatives or simply for choosing acceptable from unacceptable alternatives.

Multi–criteria decision making refers to those situations in which a large number of very different criteria is present. As with the definition of the concept of decision making, the division of decision making process into stages also expresses some similarities and differences. However, these methods can generally boil down to the following stages [3, 5, 6]:

» Identifying and defining a problem,
» Determining a set of alternative solutions,
» Determining a set of criteria for evaluation of the alternatives,
» Determining weight coefficients,
» Evaluating and selecting the best alternative.

The existence of several alternatives and criteria, some of which should be maximized and some minimized, means that the decisions are made in conflicting conditions and in order to solve multi–criteria tasks, instruments that are more flexible than the mathematical techniques of basic optimization should be used. For this purpose, numerous methods of multi–criteria decision making have been developed, of which the following ones can be emphasized: AHP (Analytic hierarchy process), PROMETHEE, ELECTRE and TOPSIS.

— The application of the AHP method

The Analytic hierarchy process (AHP), a method developed by Thomas Saaty in early 1970s, was designed to help decision makers in solving complex decision making problems [7]. The field of application is multi–criteria decision making where, based on a defined set of criteria and attribute values, the selection of the most acceptable alternative and a complete order of importance of all alternatives in the model are performed.

The application of the AHP method is carried out in the following four phases [7]:

(1) Building the hierarchy of a problem / structuring a decision–making problem.

Structuring a problem consists of dividing a complex decision–making problem into a series of hierarchies, where each level assumes a smaller number of controlled attributes. They are further divided into another set of elements that corresponds to the next level, etc. The hierarchical model of a decision making problem is developed so that the objective function is at the top, criteria and sub–criteria are at lower levels and alternatives are at the bottom of the model.

(2) Data collection and relative evaluation

The second phase of the AHP method starts with the collection of data and their evaluation. Decision makers assign relative evaluations in pairs of attributes of one hierarchical level and for all levels of the entire hierarchy. Relative evaluations of decision makers are assigned using Saaty's scale of 9 points of relative importance which have 5 degrees and 4 middle degree of verbally described intensities and the corresponding numerical values for them ranging from 1 to 9.

Following this ranking method, decision makers compare, i.e. assign weights for each pair separately, as a measure of showing how one pair of attributes is more important than the other. If we possess objective data than it can be used when assigning weights, and if not, then our own estimations, beliefs or information should be considered. Upon completion of this process, appropriate pairwise comparison matrices that match each level of hierarchy are obtained. That is, comparison matrix for mutual criteria comparison and comparison matrix for mutual comparison of alternatives for each criteria individually are obtained.

(3) Calculating weight coefficients and consistency check

The evaluation, i.e. the calculation of weight coefficients of all elements of the hierarchy is the third phase of the AHP method. Based on the comparison matrices from the previous phase, the synthesis of all evaluations is performed. Also, weight coefficients of criteria within a model and weight coefficients of alternatives within each criterion are determined according to a strictly defined mathematical model. The sum of weight coefficients of elements at each level of the hierarchy is equal to 1, which allows a decision maker to rank all elements in a horizontal or vertical way.

The AHP method has the ability to identify and analyse the inconsistency of a decision maker in the process of reasoning and assessing elements of the hierarchy. A man as a decision maker is rarely consistent when assessing values or relations among qualitative elements in the hierarchy. The AHP alleviates this problem in a certain way by measuring the degree of inconsistency and informing a decision maker afterwards. Consistency ratio (C.R.) provides a measure of inconsistency when filling the matrix, i.e. it tells how many errors were made when giving assessments. If the consistency ratio is less than 0,10 (10%), the result is sufficiently accurate and there is no need to correct the comparisons and repeat the calculations.

(4) Ranking and sensitivity analysis

Within this phase, the final calculation and ranking of alternatives according to importance (quality) as well as the sensitivity analysis of the obtained results are performed.

The Expert Choice is a software tool designed for solving semi–structured and unstructured decision making problems on the basis of the AHP method. It is a very robust application for multi–criteria decision making at the level of organizations/teams and individuals as decision makers. It consists of the following activities [8]:

» Priority sorting of criteria and alternatives,
» Reliable decision making or assessment for achieving the desired goals,
» Simulation and prediction of events when planning „what–if" situations,
» Graphical representation of the decision making results and results of the sensitivity analysis,
» Possibility of applying group decision making,
» Possibility of applying internet technologies.

The Expert Choice is based on the sensitivity analysis or determination of sensibility (stability) of solution (the selected alternative). Using this tool, experienced decision makers are able to carefully analyze the stability of solutions, because very often the phase of sensitivity analysis is very significant in the entire decision making process.

3. SETTING THE DECISION MAKING PROBLEM – THE SELECTION OF MOTOREDUCTOR CASE STUDY

The project team had the task to select the best alternative reductor with an electric motor – a motoreductor which is available on the market for installing in a transportation system in the form of a conveyor belt system. The transportation system contains a total of 12 reductors which perform a similar function with 10% deviation of the speed of the conveyor belt and a very small deviation of the conveyor belt load. Regulation of the speed is achieved using the frequency regulator so that the output rounds per minute should be as low as possible while the torque at the output shaft should be as high as possible. Assuming the design needs, a variant of motoreductor with worm transmission is adopted. In order to reduce the manufacturing cost and the cost of exploitation and maintenance, the need for unification of motoreductors is defined. Based on the required data and adopted characteristics, offers from 4 reductor manufacturers are collected.

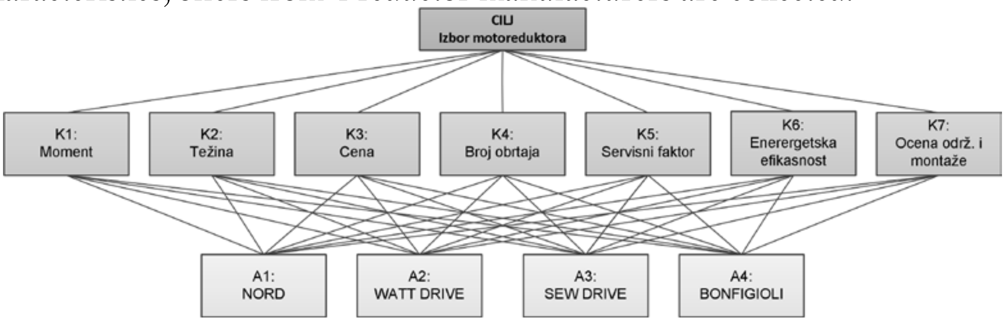

Figure 1. Hierarchical structure of the problem of selecting motoreductors

Table 1. Basic data about alternative motoreductors

Criteria	Desired characteristic of the criteria	Units	Alternative motoreductors			
			NORD A1	WATT DRIWE A2	SEW DRIVE A3	BONFIGIOLIO A4
K1: Torque	max	Nm	54	53	70	52
K2: Mass	min	kg	19	24	27	20
K3: Price	min	EUR	610	625	645	600
K4: Rounds per min	min	o/min	110	112	125	117
K5: Service factor	max	–	2.4	2.66	2	2.7
K6: Energy efficiency	max	–	0.83	0.89	0.77	0.79
K7: Maintenance and assembly factor	max	–	8	7	6	8

Figure 1 presents the defined hierarchical structure of the problem of selecting motoreductor according to the set input conditions. Based on the necessary functional characteristics of motoreductors, manufacturing conditions and economic parameters, decision makers defined the typical criteria. Table 1 gives the basic data needed for the decision making process, i.e. the data for 4 alternative motoreductors (A1–A4) with 7 selected criteria (K1–K7).

4. APPLYING THE AHP METHOD IN THE SELECTION OF MOTOREDUCTOR

— Applying the approximation approach of the AHP

This approach refers to the analytical table calculation of weight coefficients and alternatives within the criteria as well as the final solution in the form of ranking alternatives according to the importance. Table 2 shows the prioritization matrix of criteria obtained by comparing criteria by the decision maker, whereby the values in brackets represent the reciprocal ratio of preferences. Table 3 shows the final steps of calculating the weight coefficients of the criteria whose values are given in the column „Average“ and the coefficient CR whose values within the allowed limits are given at the bottom of the table.

Table 2. Prioritization matrix of the criteria within the model

	K1	K2	K3	K4	K5	K6	K7
K1	1	4	1/6	2	1/5	1/4	1/3
K2		1	1/9	1/3	1/8	1/7	1/6
K3			1	7	2	3	4
K4				1	1/6	1/5	1/4
K5					1	2	3
K6						1	2
K7							1

Table 3. Determination of the weight coefficients of the criteria

	K1	K2	K3	K4	K5	K6	K7	SUM	Average
K1	0,05063	0,10526	0,06656	0,07895	0,04624	0,03525	0,03101	0,41390	0,05913
K2	0,01266	0,02632	0,04437	0,01316	0,02890	0,02014	0,01550	0,16105	0,02301
K3	0,30380	0,23684	0,39937	0,27632	0,46243	0,42296	0,37209	2,47380	0,35340
K4	0,02532	0,07895	0,05705	0,03947	0,03854	0,02820	0,02326	0,29078	0,04154
K5	0,25316	0,21053	0,19968	0,23684	0,23121	0,28197	0,27907	1,69247	0,24178
K6	0,20253	0,18421	0,13312	0,19737	0,11561	0,14099	0,18605	1,15987	0,16570
K7	0,15190	0,15789	0,09984	0,15789	0,07707	0,07049	0,09302	0,80812	0,11545
	λ_{max}=7,44131		CI=0,0735		RI=1,35		CR=0,054		

Table 4. Overall synthesis of the problem of selecting motoreductors

Alternative		W_K – Weight coefficients of the criteria	W_A – Weight coefficients of the alternatives	Product of W_K and W_A	Alternative importance	Alternative rank
A1	NORD	0,0591	0,16253	0,0096	0,25955	3
		0,0230	0,36364	0,0084		
		0,3534	0,28840	0,1019		
		0,0415	0,35071	0,0146		
		0,2418	0,17148	0,0415		
		0,1657	0,26417	0,0438		
		0,1154	0,34522	0,0399		
A2	WATT	0,0591	0,16253	0,0096	0,25965	2
		0,0230	0,18182	0,0042		
		0,3534	0,15445	0,0546		
		0,0415	0,35071	0,0146		
		0,2418	0,28401	0,0687		
		0,1657	0,50561	0,0838		
		0,1154	0,21011	0,0243		
A3	SEW	0,0591	0,52329	0,0309	0,10998	4
		0,0230	0,09091	0,0021		
		0,3534	0,08132	0,0287		
		0,0415	0,10933	0,0045		
		0,2418	0,07365	0,0178		
		0,1657	0,08677	0,0144		
		0,1154	0,09945	0,0115		
A4	BONFIGIOLIO	0,0591	0,15166	0,0090	0,37082	1
		0,0230	0,36364	0,0084		
		0,3534	0,47584	0,1682		
		0,0415	0,18925	0,0079		
		0,2418	0,47086	0,1138		
		0,1657	0,14345	0,0238		
		0,1154	0,34522	0,0399		

After that, the determination of the influence of the alternatives within each criterion is carried out. The weight coefficients of the alternatives within each criterion are therefore obtained. Finally, the overall synthesis of the problem is made and the final orders of alternatives within the model are given in Table 4. From the results shown above it can be clearly noticed that the conditionally optimal alternative is A4– BONFIGIOLIO motoreductor and the order of alternatives is A4, A2, A1, A3.

— Applying the Expert Choice software

In the proposed case, the Expert Choice software with the comparative assessment of the alternatives within the criteria performed by the decision maker are applied. First, the basic data such as the objective, alternatives and criteria are entered. Then, the mutual assessments of the importance of the criteria within the model are entered (Figure 2). On the basis of the comparison among criteria, weight coefficients of the criteria within the model are obtained (Figure 3). Coefficient CR equals 0,04 which concludes that the comparison among criteria is satisfactory. The alternatives are further compared for each criteria individually. According to the carried comparisons and the synthesis of the results, the final solution with ranked alternatives of motoreductors and the total CR=0,03 is obtained (Figure 4).

As previously noted, the software allows the sensitivity analysis to be performed in several ways (Performance Sensitivity for nodes below, Dynamic Sensitivity for nodes below, Gradient Sensitivity for nodes below, Head–to–Head Sensitivity for nodes below, etc.). Figure 5 shows the Performance Sensitivity for nodes below, where performances of the alternatives of motoreductors can be seen for each criterion.

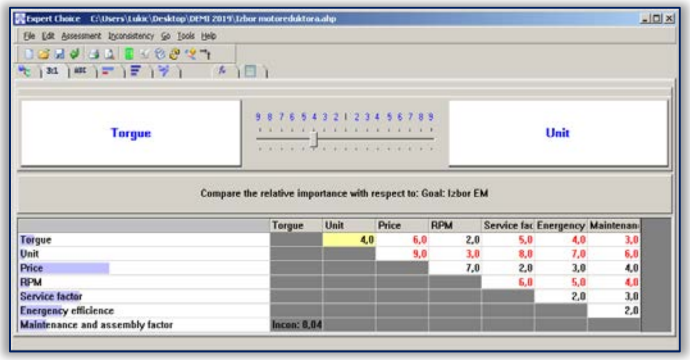

Figure 2. Assessment of the criteria comparison

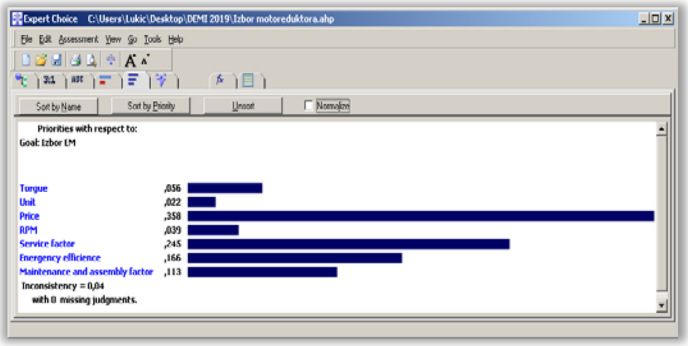

Figure 3. Weight coefficients of the criteria in the model

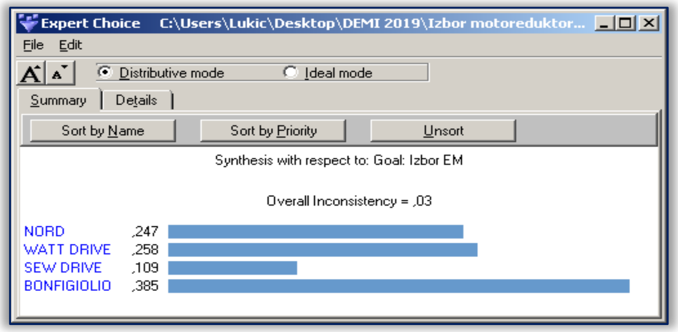

Figure 4. Final order of the alternative motoreductors

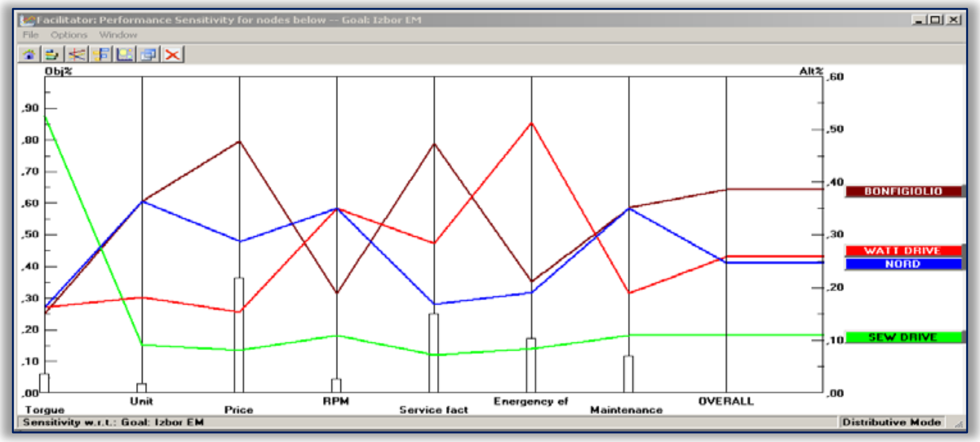

Figure 5. Sensitivity analysis window – Performance Sensitivity for nodes below

5. ANALYSIS OF THE RESULTS AND CONCLUSION

Multi–criteria decision making methods have become an indispensable tool in the development, planning, control, organization, techno–economic analysis and many other activities within a business system. They are methodologically consistent, easy to use and software–supported. These methods constantly draw attention from modern engineers and other decision makers, while science continues to explore the most efficient ways of their use and analyzes their reliability and robustness.

The described AHP method as a powerful tool is used to obtain a clear image of the overall quality and importance of the selected alternatives that are assessed on the basis of a large number of different criteria. Decision makers who used this method had the opportunity to articulately explain their decision making steps, i.e. the steps in the optimization on the basis of the obtained output results and the sensitivity analysis that this method provides as well as the corresponding software.

Table 5. Comparative view of the results of multi–criteria selection of the motoreductor

Method		Alternative			
AHP – Approximation approach	Rank	A4	A2	A1	A3
	Result	0.371	0.2596	0.2595	0.110
AHP – Expert Choice software	Rank	A4	A2	A1	A3
	Result	0,385	0,258	0,247	0,109

The detailed comparative view of the results of selecting the motoreductors which is obtained using the AHP multi–criteria decision making method is given in Table 5. It can be concluded from this information that the model is well set, consistent and robust, and that solutions are very similar for both methods. The BONFIGIOLIO (A4) alternative is ranked first by both of these methods, the alternatives WATT (A2) and NORD (A1) are the second and the third, while the alternative SEW (A3) is the worst alternative.

Note:

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