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APPLICATION OF THE MULTIPLE CRITERIA DECISION-MAKING FOR COMPARISON OF CUTTING WHEELS FEATURES *

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Abstract. *Families of cutting wheels for processing infrastructure profiles are developed as part of the technological development project entitled "Integrated Development of the Process of Simultaneous Design of Specific Products for Variant Processing of Infrastructure Profiles". A simple additive weighting method is used to position the product on the market at the moment of comparison, which can serve as the basis for establishing possibilities for the product's quality improvement.*

Key words: *Cutting Wheels, Simple Additive Weighting Method, Product Quality Improvement*

1. INTRODUCTION

Families of cutting wheels for processing infrastructure profiles are developed as part of the technological development project entitled "Integrated Development of the Process of Simultaneous Design of Specific Products for Variant Processing of Infrastructure Profiles" at the Faculty of Mechanical Engineering in Kraljevo. These products represent assembly subsystems of the system for processing infrastructure facilities. They contain a very wide range of cutters which are placed around the wheel with respect to a definite arrangement and type. Cutting wheels are developed and examined on the basis of an extremely large number of functional requirements and restrictions defining a whole range of variants. For the purpose of achieving the world level of competitiveness of these subassemblies, and taking into account their outstanding complexity, their design could not be imagined without the application of modern computer technologies. In addition to development of families of these products, the modeling of the technology of manufacturing as well as that of the assembly structure of cutting wheels are carried out.

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In this phase of development, it is necessary to evaluate the quality level of the designed product and compare its features to those of the products made by leading manufacturers in this field in order to position it at the moment of comparison, which can serve as the basis for improvement of the product-s crucial features. *The simple additive weighting method* is used for comparison.

2. Systems of Cutting Wheels in Processing Infrastructure Facilities

Cutting wheels [6] are the systems of milling tools which are designed to enable processing of profiles that have a relatively small width in relation to the depth. The cutting wheel systems have a broad range of application. They are used as connecting devices in mini excavators, mini loaders and other construction machines.

The cutting wheel systems have compact dimensions, they are easily manipulated and used in relatively small machines so that they do not represent a big problem in operation in the traffic environment. These systems of different diameters and widths, with a relatively large diameter in relation to the width, are suitable for digging trenches for placing optical cables, pipes, electrical installation, etc.

Fig. 1 Examples of cutting wheel systems' application

The cutting wheel system [7] consists of:

1) A wheel with cutters placed around the wheel in a precisely appropriate arrangement defined by the kinematics of the cutting process,
2) A holder by means of which the system is connected to the working machine,
3) The carrying structure which has the role of wheel holder and hydromotor, and,
4) A hydromotor as the driving body which is supplied with oil under pressure through the hydraulic system of the working machine.

Based on the functional requirements defined through the size, profile shape and quality of the surface which is processed, a family of the cutting wheel system is adopted (conceptually). The family covers three sizes of cutting wheels, for three diameters, whose exploitation and technical parameters are presented in Table 1.

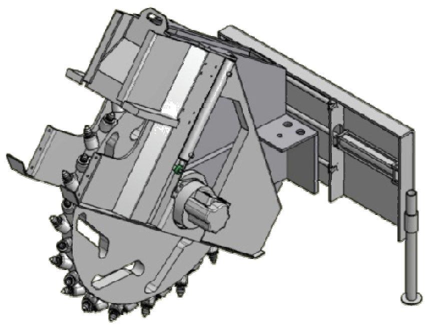


Fig. 2 Cutting wheel system

Table 1 Features of the cutting wheel system

		SGD 300	SGD 450	SGD 600
Excavation depth	mm	300	150-450	200-600
Width	mm	80	130	130
Possible wheel widths	mm	50	80-160-200	80-160-200
Working pressure	bar	160-300	160-300	160-300
Oil flow	l/min	60-80	70-110	90-130
Number of revolutions of the cutting head	min^{-1}	75-95	60-90	52-72
Cutting speed	cm/min	50-600	50-500	40-400
Mass	kg	615	1150	1250

The modeling of the main elements in the hierarchical structure of the cutting wheel system (in Solid Edge) is followed by the definition of the assembly structure of subassemblies as the elements of a higher level as well as the assembly structure of the whole product (Fig. 3).

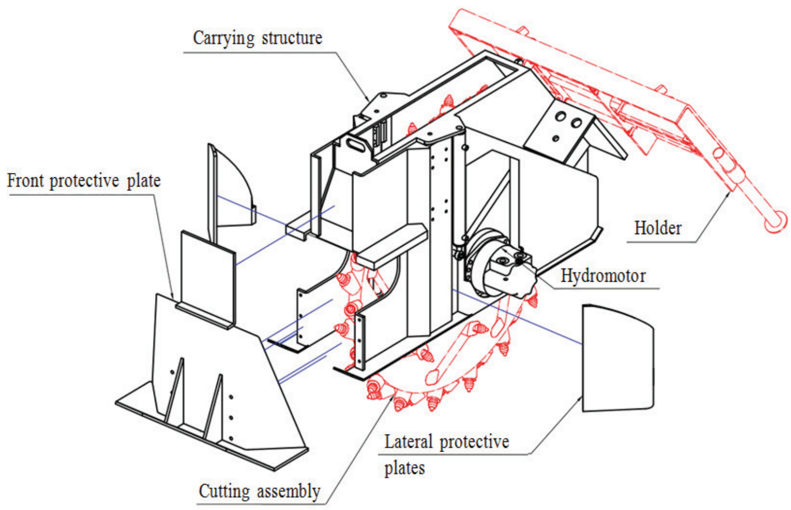


Fig. 3 Assembly structure of the cutting wheel system

Cutting wheels are the elements of assembly structure of the cutting wheel system, which are variant- and parameter-designed as befits the customer's requirements. They are designed for various depths and widths of the trench profile that is processed, with a different number of cutters placed around the wheel. The number of cutters directly influences the distance between the cutter tips and it is determined depending on the required quality of the processed surface as well as on the type of the material which is processed. The variant design is connected with the number of cutters on the shroud of the milling head, while in the parameter modeling the diameter and width of the wheel are changed.

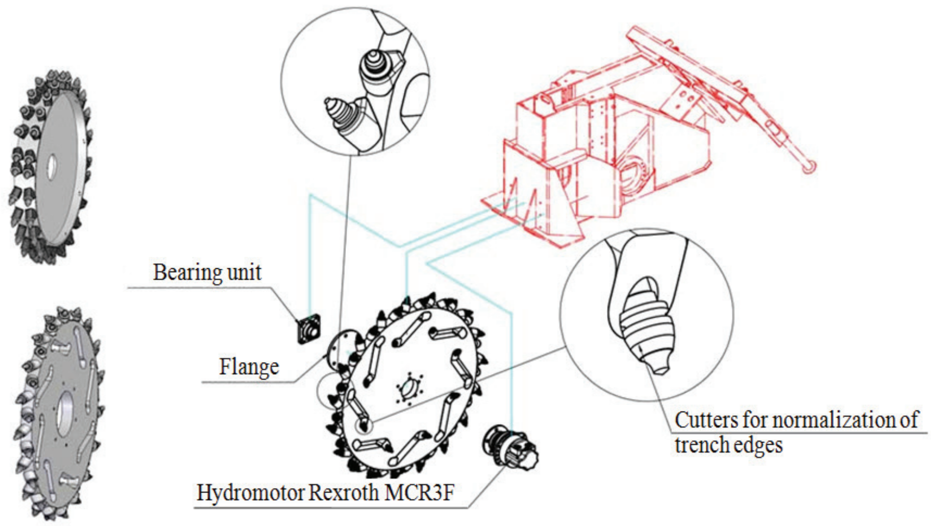


Fig. 4 Subassembly of the cutting wheel as an element of the assembly structure

Cutter holders are the elements which enable rotation of cutters and they provide the cutter with the necessary spatial position in the cutting process (Fig. 5).

Fig. 5 Cutter holder on the shroud of the milling head, welded

Hydromotor (Fig. 6) is a device which is used for driving the system of cutting wheels. The hydraulic system of the working machine on which it is installed provides it with power for operation. The output shaft of the hydromotor is connected to the input shaft of power transmission. The hydromotor's assembly structure is not defined at the level of components because of the possibility of selection of a large number of hydromotors on the basis of features designed by the manufacturers such as: PPT, Rehroth, Sauer Danfoss, etc.

Fig. 6 Subassembly of the hydromotor manufactured by Rexroth

The subassembly of the carrying structure with protective plates represents a connection between the subassembly of the cutting wheel and the holder. It has the function of a wheel holder, wheel housing, hydromotor and a connection with the holder. It possesses a system for vertical moving of the subassembly of the cutting wheel, which allows adjustment of the desired depth of the trench which is processed.

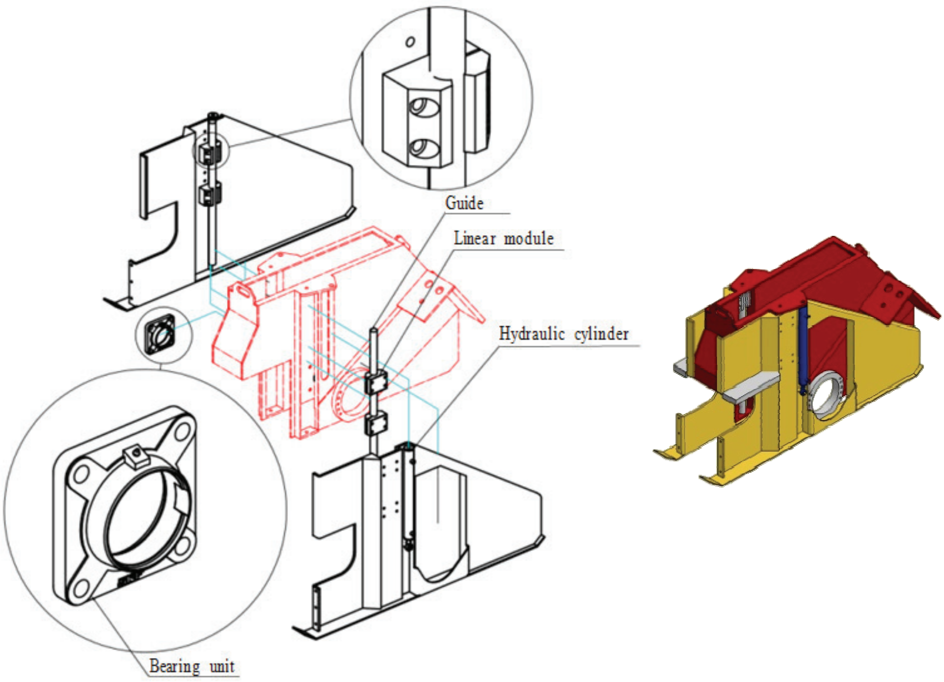


Fig. 7 Subassembly of the carrying structure

The subassembly of the holder represents a subsystem for connection with the working machine. In this subsystem, there is a system for lateral movement of the subassembly of the carrying strycture, which allows milling of the trench profile at different distances from the edge of the infrastructure facility.

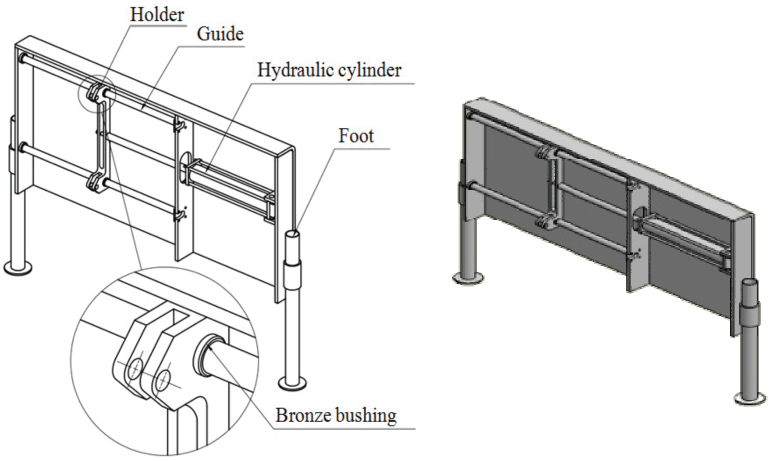


Fig. 8 Subassemably of the holder

The cutting wheel systems are complex products with relatively small overall dimensions. As they are composed of several components of various shapes, dimensions and material, there is a need for different technologies of their production. Therefore, the design of the manufacturing technology as well as that of the mounting of parts and assemblies represents the next segment of integration. The dominant technologies for production of the cutting wheel systems are as follows: 1) Cutting technology, 2) Plasma cutting technology, 3) Deformation technology, 4) Welding technology, and 5) Chip removal technology.

Cutter holders are made by forging, cutter tips are made of hard metal by sintering, the carrying structure is made of plates that require cutting, bending and punching operations as well as joining components by welding. The component that sets the highest requirements with respect to geometrical precision is the cutting wheel (Fig. 9). It has openings for positioning the tool holder. For realizing the required position of the cutter in relation to the base which is processed, respecting the kinematics of the cutting process, it is necessary to drill holes in the appropriate arrangement along the perimeter of the wheel and on the lateral surfaces. The same manner is used for manufacturing the other components that participate in the assembly structure of the cutting wheel. Upon manufacturing the components, the next step is manufacturing of the subassemblies.

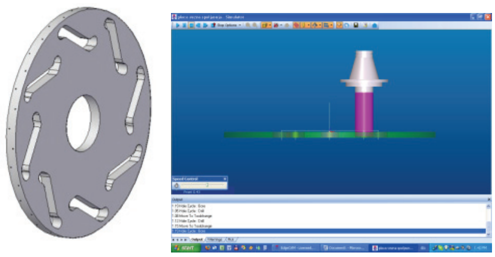


Fig. 9 Cutting wheel

Realization of the project provides the preconditions for realization of the production process in distributed production circumstances in several different small companies (Fig. 10), which are capable of performing only certain technological operations, with the production that is monitored, controlled, inspected and coordinated from one place. All this enables employment of a certain number of small and medium companies which could manufacture components, subassemblies and the assembly of the system of cutting wheels.

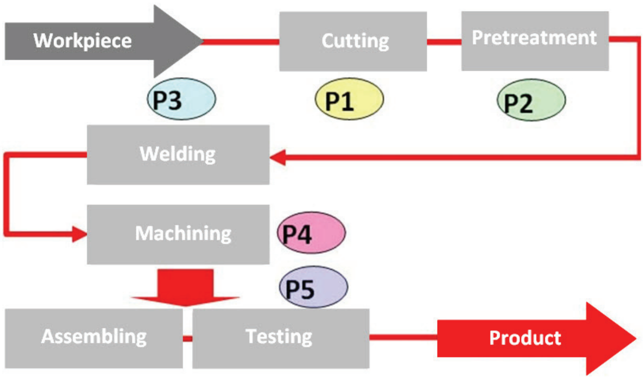


Fig. 10 Flow of the workpiece through technological operations in several different companies

3. Comparison of Features of the Designed Product

In this phase of development of the system of cutting wheels for processing infrastructure facilities it is necessary to evaluate the level of quality of the designed product and compare its features with those of the products made by leading manufacturers in this field in order to position it at the moment of comparison, which can serve as the basis for improving the product's crucial features.

The most frequently used technique is ***Comparison of features***, which is based on the methods of the Multiple Criteria Decision-Making (MCD). The following points should be taken into account [2]:

- instead of selection of an alternative which appears in MCD problems, alternatives (comparison objects) are ranked in order to establish the position of the observed product in relation to the competition,
- upon evaluating the position, individual values of each selected attribute are compared to adequate attributes of the best product selected to be the leader in that branch,
- attributes – product features that have the highest deviation are identified so that the manner for their improvement could be found in a later phase.

Some methods of the Multiple Criteria Decision-Making that can be used are [1]:

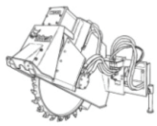
- Dominance method
- Maximin method
- Maximax method
- Lexicographic method
- Simple additive weighting method, etc.

The simple additive weighting method is used for comparison because the decision-maker has the possibility of *active participation* in the procedure of problem solving, by assigning weighted coefficients to the criteria. They *express their preferences* in that way, i.e. importance of each individual criterion based on their own aspirations.

3.1 Selection of objects (alternatives) of decision-making

The products presented in Table 1 are selected to be the representatives of products (alternatives) with which the features of the designed product are compared. The mentioned alternatives are denoted by A1 – A4, and the alternative of the domestic product is denoted by A5.

Table 2 Products by leading manufacturers selected for comparison of features

Alternative	Manufacturer	Product	Type	
A1	Simex Engineering s.r.I. Italy	Wheel Excavator	T300 T450 T600	
A2	AFT Trenchers LTD, England	Wizz Wheel	WW 55 WW 75	
A3	Bobcat, Czech Republic	Wheel Saw	15.2-61cm	 
A4	Vermer Corporation, USA	Concrete Cutter	CC 155	

3.2 Definition of the attributes which are holders of criteria for establishing values

The characteristics of product quality for the attributes necessary to evaluate the accomplished level are adopted and classified into four groups (Table 3):

- design characteristics Q_I
- production characteristics Q_{II}
- exploitation characteristics Q_{III} , and
- other characteristics Q_{IV}.

The mentioned groups are further divided into 19 main subgroups which are then divided into elementary characteristics of quality. The subgoups of indicators denoted by ($q_1 \ldots q_{19}$) are adopted for the main indicators of quality.

Table 3 Characteristics of product quality

Group of characteristics	Subgroup of characteristics
Design characteristics of product Q_I	q_1 – Quality of designed concept q_2 – Productibility q_3 – Quality of design documentation
Production characteristics Q_{II}	q_4 – Quality of production documentation q_5 – Quality of input material and finished goods q_6 – Quality of manufacturing parts and assemblies q_7 – Quality of product mounting q_8 – Quality of product testing q_9 – Economical manufacturing and mounting
Exploitation (functional) characteristics Q_{III}	q_{10} – Operating characteristics q_{11} – Safety in operation q_{12} – Effectiveness q_{13} – Economical utilization q_{14} – Ergonomic characteristics q_{15} – Ecological characteristics
Other characteristics Q_{IV}	q_{16} – Assortment (variety) of products q_{17} – Aesthetic characteristics q_{18} – Product price q_{19} – Patent-legal characteristics

3.3 Data collection and analysis

The data necessary for comparison are collected by direct contact, from professional literature and available catalogues issued by competitive manufacturers. The available data are analyzed and then presented in the table of characteristics (attributes) and alternatives (Table 4).

Table 4 Values of attributes for the selected alternatives

Attributes		Alternatives				
		A1	A2	A3	A4	A5
Group of characteristics	Subgroup of characteristics	Simex Engineering s.r.l. Italy	AFT Trenchers LTD, England	Bobcat, Czech Republic	Vermer Corporation, USA	Observed product
QI	q_1	9	8	8	7	8
	q_2	8	8	8	8	6
	q_3	8	8	8	7	8
QII	q_4	8	8	8	8	8
	q_5	9	9	9	9	9
	q_6	8	8	8	9	7
	q_7	9	8	8	9	8
	q_8	9	7	8	9	7
	q_9	9	8	9	7	8
QIII	q_{10}	9	8	8	9	8
	q_{11}	8	7	8	9	8
	q_{12}	9	8	8	9	8
	q_{13}	9	8	9	8	8
	q_{14}	8	8	8	8	8
	q_{15}	8	8	8	7	7
QIV	q_{16}	9	7	8	7	7
	q_{17}	8	7	8	7	8
	q_{18}	8	7	9	7	8
	q_{19}	9	9	9	9	7

3.4 Creation of the mathematical model

The general mathematical model of MCD is:
It is necessary to find the maximum value of the criterion function:

$$Max\left\{ f_1(x), f_2(x), ..., f_n(x), \qquad n \geq 2 \right\} \tag{1}$$

at the given restrictions:

$$x \in A \; \left[A1, A2, ..., Am \right], \tag{2}$$

where:

n – the number of criteria (j=1,2,...,n)
m –the number of alternatives (i=1,2,...,m)
f_j – the criteria Kj (j=1,2,...,n)
A_i –the alternatives for consideration (i=1,2,...,m)
A –the set of all alternatives.

Values f_{ij} of each considered criterion f_j for each of possible alternatives A_i are known:

$$f_{ij} = f_j(A_i) \quad \forall(i,j); \quad i = 1,2,...,m; \quad j = 1,2,...,n \tag{3}$$

The model of multicriteria analysis can be shown by the corresponding matrix of values of criteria for individual alternatives of the matrix, which is called *the decision-making matrix.* For the concrete problem, the decision-making matrix possesses 19 attributes and 5 alternatives and looks as follows:

$$\begin{array}{c} \\ K1 \\ K2 \\ K3 \\ K4 \\ K5 \\ K6 \\ K7 \\ K8 \\ K9 \\ K10 \\ K11 \\ K12 \\ K13 \\ K14 \\ K15 \\ K16 \\ K17 \\ K18 \\ K19 \end{array} \begin{array}{c} \begin{array}{ccccc} A1 & A2 & A3 & A4 & A5 \end{array} \\ \begin{bmatrix} 9 & 8 & 8 & 7 & 8 \\ 8 & 8 & 8 & 8 & 8 \\ 8 & 8 & 8 & 7 & 8 \\ 8 & 8 & 8 & 8 & 8 \\ 9 & 9 & 9 & 9 & 9 \\ 8 & 8 & 8 & 9 & 7 \\ 9 & 8 & 8 & 9 & 8 \\ 9 & 7 & 8 & 9 & 7 \\ 9 & 8 & 9 & 7 & 8 \\ 9 & 8 & 8 & 9 & 8 \\ 8 & 7 & 8 & 9 & 8 \\ 9 & 8 & 8 & 8 & 8 \\ 9 & 8 & 9 & 8 & 8 \\ 8 & 8 & 8 & 8 & 8 \\ 8 & 8 & 8 & 7 & 7 \\ 9 & 7 & 8 & 7 & 7 \\ 8 & 7 & 8 & 7 & 8 \\ 8 & 7 & 9 & 7 & 8 \\ 9 & 9 & 9 & 9 & 7 \end{bmatrix} \end{array} \begin{array}{c} \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \\ \max \end{array}$$

3.5 Definition of relative importance of each individual attribute

Relative importance of each individual attribute (*attribute ponder*) is determined by a set of ponders which are normalized in such a way that their total sum is equal to one. For the case of *n* attributes, the set of ponders is given as:

$$t_j = (t_1, t_2, ..., t_j, ..., t_n), \tag{4}$$

where:

$$\sum_{j=1}^{n} t_j = 1 \quad ,i \quad 0 < t_j < 1 \tag{5}$$

In the given case, as they are the attributes which are divided into subgroups, pondering is also performed on the group of characteristics and on the subgroups of considered characteristics (Table 5). The total weight of the attributes is obtained as the product of ponders of the group and ponders of the subgroup of the characteristic, i.e.:

$$G_i = \prod K_i \tag{6}$$

Table 5 Relative importance of the analyzed attributes

		Level of Significance		Weight Gi	
Attributes		1	2	Gi	Gi (%)
QI	q_1	0.3	0.40	0.120	12.0
	q_2		0.40	0.120	12.0
	q_3		0.20	0.060	6.0
		$\Sigma qi=$	1.00	0.300	30.0
QII	q_4	0.28	0.10	0.028	2.8
	q_5		0.17	0.048	4.8
	q_6		0.20	0.056	5.6
	q_7		0.20	0.056	5.6
	q_8		0.15	0.042	4.2
	q_9		0.18	0.050	5.0
		$\Sigma qi=$	1.00	0.280	28.0
QIII	q_{10}	0.3	0.20	0.060	6.0
	q_{11}		0.20	0.060	6.0
	q_{12}		0.17	0.051	5.1
	q_{13}		0.18	0.054	5.4
	q_{14}		0.13	0.039	3.9
	q_{15}		0.12	0.036	3.6
		$\Sigma qi=$	1.00	0.300	30.0
QIV	q_{16}	0.12	0.25	0.030	3.0
	q_{17}		0.20	0.024	2.4
	q_{18}		0.30	0.036	3.6
	q_{19}		0.25	0.030	3.0
		$\Sigma qi=$	1.00	0.120	12.0
SQi=QI+QII+QIII+QIV=		**1**	**$\Sigma Gi=$**	**1**	**100**

3.6 Establishing the position–rank of the alternative

The alternatives are ranked by using the MODIPROM method developed at the Faculty of Mechanical Engineering in Kraljevo, which is based on modification of the family of methods for multicriteria ranking Promethee[5]. The software bearing the same name is used for procession of the results. It allows ranking of 10 alternatives on the basis of 25 criterion functions. The appearance of the input mask with the entered data is presented in Fig. 11.

The results obtained by this method show that the best ranked alternative is A1, i.e. the product of the Italian company Simex Engineering (Table 6 and Fig. 12) and it is further used for comparison of the analyzed attributes.

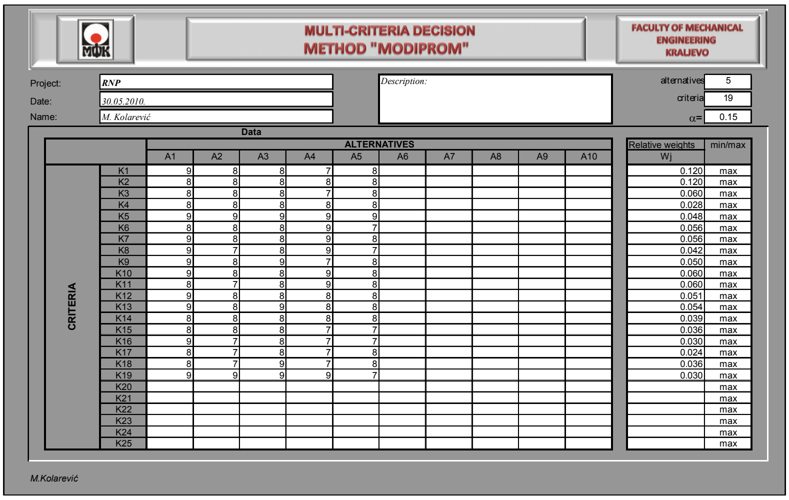


Fig. 11 Software MODIPROM

Table 6 Results of the analysis obtained by the MODIPROM method

Promethee I		Promethee II		Promethee III	
Rank		Rank		Rank	
4	A1	4	A1	4	A1
2	A3	3	A3	3	A3
1	A2	2	A4	2	A4
0	A4	1	A2	0	A2
0	A5	0	A5	0	A5

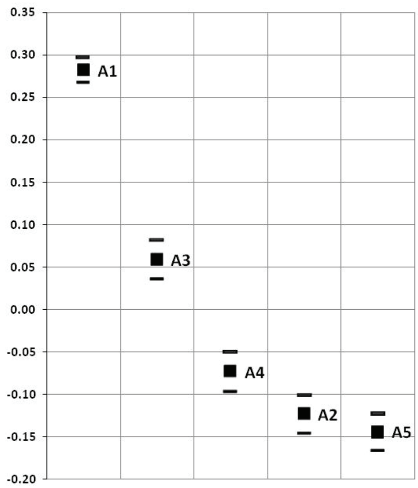


Fig. 12 Graphical presentation of the interval order of the alternatives

3.7 Identification – selection of attributes with the largest deviation

A simple additive weighting method [2] is used for comparing the values of attributes of the new product with the values of attributes of the leader. The obtained results are presented in Table 7.

The denotations in the table have the following meanings:

N_i – The ordinal number of the attribute

G_i – The weight of the attribute

B_i – The quantitative value of the attribute from Table 4

P_i – The importance of the attribute which is calculated as the product:

$$P_i = G_i \cdot B_i \tag{7}$$

The total value of the evaluated alternative of the new product is Σ P_i =785.36, and for the leader Σ P_i =854.10, where the maximum possible value is 1000. Differences between individual values of the attribute ΔP_i are presented in the last column of Table 7. If the attributes are ranked, it can be seen that attributes *A*1 and *A*8 have the highest values (Fig. 13) and it is necessary to pay particular attention to the improvement of these attributes, i.e. characteristics of the product.

Table 7 Calculated values of importance of the attributes

		Level		Weight G_i		NP		Leader		
Attributes		1	2	G_i	G_i (%)	B_{1i}	P_{1i}	B_{2i}	P_{2i}	ΔP_i
QI	q_1	0.3	0.40	0.120	12.0	8	96.00	9	108.00	12.00
	q_2		0.40	0.120	12.0	8	96.00	8	96.00	0.00
	q_3		0.20	0.060	6.0	8	48.00	8	48.00	0.00
			1.00	0.300	30.0		240.00		252.00	12.00
QII	q_4	0.28	0.10	0.028	2.8	8	22.40	8	22.40	0.00
	q_5		0.17	0.048	4.8	9	42.84	9	42.84	0.00
	q_6		0.20	0.056	5.6	7	39.20	8	44.80	5.60
	q_7		0.20	0.056	5.6	8	44.80	9	50.40	5.60
	q_8		0.15	0.042	4.2	7	29.40	9	37.80	8.40
	q_9		0.18	0.050	5.0	8	40.32	9	45.36	5.04
			1.00	0.280	28.0		218.96		243.60	24.64
QIII	q_{10}	0.3	0.20	0.060	6.0	8	48.00	9	54.00	6.00
	q_{11}		0.20	0.060	6.0	8	48.00	8	48.00	0.00
	q_{12}		0.17	0.051	5.1	8	40.80	9	45.90	5.10
	q_{13}		0.18	0.054	5.4	8	43.20	9	48.60	5.40
	q_{14}		0.13	0.039	3.9	8	31.20	8	31.20	0.00
	q_{15}		0.12	0.036	3.6	7	25.20	8	28.80	3.60
			1.00	0.300	30.0		236.40		256.50	20.10
QIV	q_{16}	0.12	0.25	0.030	3.0	7	21.00	9	27.00	6.00
	q_{17}		0.20	0.024	2.4	8	19.20	8	19.20	0.00
	q_{18}		0.30	0.036	3.6	8	28.80	8	28.80	0.00
	q_{19}		0.25	0.030	3.0	7	21.00	9	27.00	6.00
		Σqi=	1.00	0.120	12.0		90.00		102.00	12.00
			Σ*Gi*=	**1**	**100**		**785.36**		**854.10**	

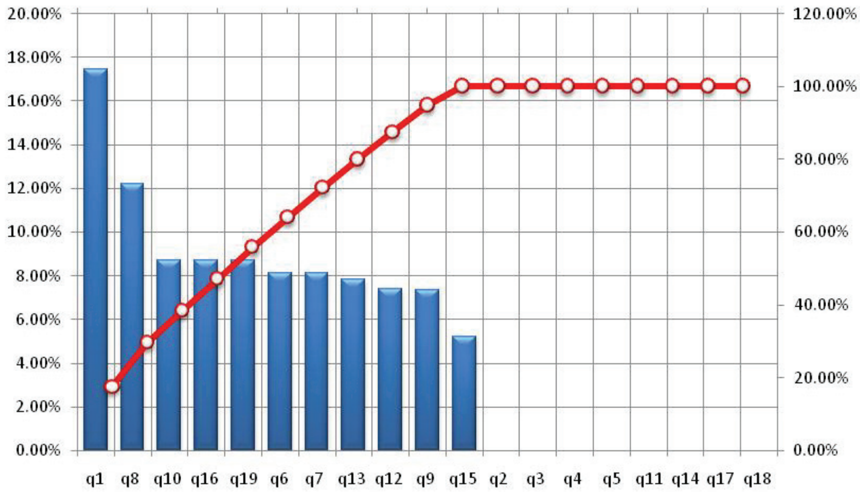


Fig. 13 Sequence of attributes ranked by the value of deviation from the leader

Conclusion

The milling tool systems for processing road and rail infrastructure facilities are very complex products. Their complexity is related to the number of components as well as their adequate layout. In the phase when the development of a new product is completed, it is necessary to evaluate the product by comparing its attributes (characteristics) to those of other products from the same field in order to select the product characteristics which still do not fulfill the satisfactory quality level and which should be improved for the purpose of obtaining a world class product.

It should be taken into account that for the application of the multi-attribute decision-making method it is necessary to have a team composed of experts who are quite familiar with that field and products on the market, as well as those who have good knowledge of the method which is applied in order to eliminate subjectivity and obtain as objective results as possible.

References

1. Čupić M.,1987, *Uvod u teoriju odlučivanja*, Naučna knjiga, Beograd.
2. Grupa autora, 1995, *Sistem kvaliteta, Unapređenje – metode i tehnike*, Fakultet tehničkih nauka, Novi Sad.
3. Nikolić, I., Borović, S., 1996, *Višekriterijumska optimizacija - metode, primena u logistici, softver*, Centar vojnih škola Vojske Jugoslavije, Beograd.
4. Radojičić, M., Žižović, M., 1998, *Primena metoda višekriterijumske analize u poslovnom odlučivanju*, Tehnički fakultet, Čačak.
5. Kolarević M., 2004, *Brzi razvoj proizvoda*, Zadužbina Andrejević, Beograd.
6. Ilić, N., Petrović, A., Babić, A., Pljakić M., 2010, *Modelling of milling tools in the procession of road and railway infrastructure facilities*, Opatija, Proceedings, pp. 971-975, ISBN 978-953-6272-37-2
7. Ilić, N., Petrović, A., Babić, A., Pljakić, M., 2010, *Modelovanje montažne strukture sistema glodačkih diskova u CAD/CAA okruženju*, 36. Jupiter konferencija, Beograd, Zbornik radova, str. 3.47-3.52, ISBN 978-86-7083-696-9
8. Tomić, V., Marinković, Z., 2011, Janošević, D., *Promethee Method Implementation With Multi-Criteria Decision,* Facta Universitatis, Series Mechanical Engineering, Vol. 9, No 2, pp. 193-202.

PRIMENA VIŠEKRITERIJUMSKOG ODLUČIVANJA ZA POREĐENJE OSOBINA GLODAČKIH DISKOVA ZA OBRADU INFRASTRUKTURNIH PROFILA

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U okviru projekta tehološkog razvoja "Integrisani razvoj procesa simultanog projektovanja specifičnih proizvoda za varijantnu obradu infrastrukturnih profila" razvijene su familije glodačkih diskova za obradu infrastrukturnih profila. U radu je pomoću Metoda jednostavnih aditivnih težina utvrđen položaj proizvoda na tržištu u trenutku poređenja koji može da posluži kao podloga za utvrđivanje mogućnosti poboljšanja kvaliteta ovog proizvoda.

Ključne reči: *glodački diskovi, metod jednostavnih aditivnih težina, poboljšanje kvaliteta proizvoda*