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Decision Making in Machine Tool Selection: An Integrated Approach with SWARA and COPRAS-G Methods

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Machine tools are one of the important parts of manufacturing process that could help company to achieving high competitiveness in the marketplace. In addition, the quality of their outputs depends on their machines and therefore every company should select the best machine by itself. Also, a choice of appropriate machine tool is very significant for a manufacturing company as it helps to reach high productivity and efficiency. Furthermore, market offers variety kind of machines with different brands. Besides, there are many criteria with respect to numerous alternatives that should be considered as part of proper machine tool selection, such as cost, operative flexibility, safety, etc.

Consequently selection of machine tool can be regarded as a multiple-attribute decision making (MADM) problem. Generally, MADM methods deal with the process of selection of an alternative among number of different alternatives in the presence of usually conflict objectives and criteria. In this study two MADM methods, step-wise weight assessment ratio analysis (SWARA) and complex proportional assessment of alternatives with grey relations (COPRAS-G), were applied for machine tool evaluation and selection.

This model is a hybrid model which integrates two MADM methods for improving the quality and accuracy of the selection. Literature survey was used to identify the most attractive criteria which influence the selection of a machine tool. Eight criteria for evaluation process include cost, operative flexibility, maintainability and service ability, size and physical, compatibility, safety, precision and productivity. More precisely, the first part of the proposed methodology, i.e. SWARA is useful for determining the importance of each criterion and calculating weight of each criterion, while the second part with COPRAS-G is useful for evaluating alternatives more precisely than usual crisp COPRAS and for ranking machine tool alternatives from the best to the worst ones. In evaluation process decision maker has to assess criteria which are not accurate. Grey relation analysis allows incorporating the vague and imprecise information in to the decision model. For illustration of the proposed methodology, a case study was explained in a manufacturing company in Karaj, Iran. This model can help managers to evaluate and select the best machine tool alternative based on own company strategies, resources, policies, etc. for their organization.

Keywords: *Machine tool selection problem; Multi-attribute decision making; step-wise weight assessment ratio analysis (SWARA); Complex PRoportional ASsessment with Grey relations (COPRAS-G)*

Introduction

Today every company uses their machines for producing goods or providing services for own customers. One of the starting points of many companies for achieving high competitiveness in market appropriate is a selection of machine tools (Yurdakul, 2004). Clearly, the quality of their outputs depends on their machines and therefore every company should select the best machine by itself. Besides, there are many machine producers in the market and they offer a wide range of choices for selecting machine alternatives. Also, a decision maker (manager or engineer) should consider many factors, such as productivity, cost, safety, reliability, etc. for appropriate machine selection. Furthermore, selecting a suitable machine tool can improve productivity, efficiency, effectively, quality, safety and profit. Machine tools are one of the important kinds of machines that are used in manufacturing process. Also, according to Onut *et al.,* (2008) decision making about this issue is very sophisticated and time consuming because of many feasible machine tools for selection and conflicting objectives. For these reasons, we considered machine tool selection process as a multiple attribute decision making (MADM) problem. Operation research/Management science has many sub-disciplines and MADM is one of them. Also, MADM is one of the two main categories of multi criteria decision making (MCDM). The other category of MCDM is multi objective decision making

(MODM). In many decision-making problems, decision maker (DM) should deal with selecting an alternative among existing alternatives. Also, for making a decision by DM, alternatives should be compared and evaluated (Zavadskas *et al.,* 2009).

Some of the most famous MADM tools include analytic hierarchy process (AHP) (Saaty, 1980), analytic network process (ANP) (Saaty & Vargas, 2001), technique for order preference by similarity to ideal solution (TOPSIS) (Hwang, Yoon, 1981), Elimination and Choice Translating Reality (ELECTRE) (Roy, 1968), MUSA (Grigoroudis & Siskos, 2002), VI sekriterijumska optimizacija i Kompromisno Resenje (VIKOR) (Opricovic, 1998), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Brans *et al.,* 1984), Simple Additive Weighting (SAW) (Churchman & Ackoff, 1954, Multi-Objective Optimization on basis of Ratio Analysis (MOORA) (Brauers & Zavadskas, 2006;), Complex Proportional ASsessment (COPRAS) (Zavadskas & Kaklauskas, 1996), Complex PRoportional ASsessment with Grey relations (COPRAS-G) (Zavadskas *et al.,* 2009), Additive Ratio Assessment (ARAS) (Zavadskas & Turskis, 2010), Step-wise Weight Assessment Ratio Analysis (SWARA) (Kersuliene *et al*., 2010), Factor Relationship (FARE) (Ginevicius, 2011), Weighted Aggregated Sum Product Assessment (WASPAS) (Zavadskas *et al.,* 2012).

The aim of this paper is proposing combined SWARA and COPRAS-G tools for evaluation and choosing of a machine tool. Weight of criteria is calculated by SWARA and the COPRAS grey is used to select a machine tool alternative. There are some reasons for selection of this study. In the literature, there were some papers about assessing the machine tool alternatives and selection. But among these studies a few of them have been used MADM methods for selection with consideration of human judgments, grey relations, finite, infinite and multi- criteria.

Besides, there is no evidence in the literature that any of them were prepared with the aim of the selection of the machine tool using the SWARA and COPRAS-G. Furthermore, there are hardly any studies that deal with machine tool selection in Iran and this study hopes to fill these gaps.

The remainder of this paper is organized as follows. Section 2 is summarized literature review of the most related studies. In Section 3 the proposed methodology is described. In this section, proposed SWARA – COPRAS-G integrated approach for selection of the machine tool is described and phases of the proposed approach and steps are presented in detail. How the proposed approach is used on a real world case study is explained in section "Case study". The results of the case study are presented in section 5. Finally, section 6 concludes the paper.

Literature review

Over the past decades with rapid increase in the complexity of economical decisions, highlighting the importance of developing and implementing sophisticated and efficient quantitative analysis techniques for supporting and aiding economical decision-making has increased (Zavadskas & Turskis, 2011). Besides, the business world has changed and this situation becomes more competitive and unforeseen so emphasizing on the importance of effective decision making is critical (Wallenius *et al.,* 2008). Therefore, decision making become more and more sophisticated, time consuming with high risk and decision maker or makers should consider many factors for decision making.

According to aforementioned reasons, machines are one of the important parts of manufacturing companies to maintain ability to compete in the market. Usually, every process of making products should include machines so machines would influence on the companies outputs. Nowadays, many research projects are defining as improving productivity, quality, life cycle, etc. Besides, market offers variety of machines with different brands. Therefore, it is critical for every company to select appropriate machine for itself. Some general criteria such as axis movement, table size, power, spindle speed, axis speed, tool number, machine size and machine cost, work piece size, work piece material, work piece size, work piece complexity, material removal rate, finish tolerances, process type, etc. are often used for evaluating qualitative and quantitative criteria (Kalpakjian & Schmid, 2001; Maleki, 1991; Sun, 2002).

In the literature models for machine selection problems are proposed by researchers. Table 1 depicts the machine tool selection techniques, approaches and systems including analytic hierarchy process (AHP), analytic network process (ANP), technique for order preference by similarity to ideal solution (TOPSIS), elimination and choice translating reality (ELECTRE), preference ranking organization method for enrichment evaluations (PROMETHEE), DELPHI, multi-criteria weighted average (MCWA), decision support systems (DSS), rule-based techniques, Expert systems, goal programming (GP), simulation techniques, linear programming, integer programming, genetic algorithm (GA), Web-based manufacturing environments, Computer-aided tool selection (CATS), Computer-aided process planning (CAPP) systems, generative process planning (GENPLAN) systems, Ant colony optimization (ACO). In addition, fuzzy logic has been used in many studies for selection of machine tool because usually evaluations are vague and imprecise and nature of fuzzy logic is suitable for these evaluations. Some of these techniques include fuzzy multiple-attribute decision-making (FMADM), fuzzy analytic hierarchy process (FAHP), Fuzzy analytic network process (FANP), Fuzzy TOPSIS. Furthermore, Vasilash (1997) developed a computer program called "machine tool selector" which reaches a feasible set of machine tools by searching the data base and deleting in appropriate ones.

Proposed Methodology

The aim of this paper is use of MADM approaches to assess and choose the best machine tool for a manufacturing company. There are some reasons for using MADM approaches.

Firstly, MADM methods deal with the process of selecting the best alternative among existing alternatives with respect to many conflicting qualitative and quantitative multiple criteria based on decision maker (DM) judgments.

Table 1

Machine tool selection techniques

Techniques	Authors	Techniques	Authors
MCWA	(Arslan *et al.,* 2004)	Two-stages ranking, Fuzzy sets membership functions	(Devedzic & Pap, 1999)
AHP	(Lin & Yang, 1996)	ACO ,GP, Fuzzy	(Chan & Swarnkar, 2006)
AHP	(Yurdakul, 2004)	AHP, Discrete- event simulation	(Ayag, 2007)
AHP, Rule-based	(Tabucanon *et al.,* 1994)	IP, GA	(Moon *et al.,* 2002)
AHP	(Cimren *et al*., 2007)	GP, Fuzzy	(Mishra *et al.,* 2006)
AHP,VIKOR, Fuzzy	(Ilangkumaran *et al.,* 2012)	Web-based manufacturing environments, CATS, CAPP	(Chung & Peng, 2004)
LP, IP	(Atmani & Lashkari, 1998)	AHP, Fuzzy	(Duran & Aguilo, 2008)
MADM, Fuzzy	(Wang *et al.,* 2000)	AHP,TOPSIS, Fuzzy	(Onut *et al*., 2008)
Program design	(Vasilash, 1997)	ANP, Fuzzy	(Ayag & Ozdemir, 2011)
Optimization, Simulation	(Almutawa *et al.,* 2005)	TOPSIS, Fuzzy	(Yurdakul & Ic, 2009b)
AHP, Fuzzy	(Ayag & Ozdemir, 2006)	Scoring model	(Georgakellos, 2005)
step-by-step methodology	(Gerrald, 1988)	ELECTRE III	(Balaji, 2009)
AHP, Fuzzy PROMETHEE, Fuzzy	(Taha & Rostam, 2011)	GA	(Keung *et al.,* 2001)
AHP,PROMETHEE, Delphi, Fuzzy	(Ozgen *et al.,* 2011)	GP,GA, Fuzzy	(Rai *et al.,* 2002)
AHP, GRA	(Samvedi *et al.,* 2012)	weighted sum model	(Goh *et al.,* 1995)
TOPSIS, FAHP	(Azadeh, 2011)	AHP, PROMETHEE	(Dagdeviren, 2008)
FAHP, FTOPSIS	(Lashgari *et al.,* 2011)	AHP, ANP	(Paramasivam *et al*., 2011)
TOPSIS, Spearman's rank correlation	(Yurdakul & Ic, 2009a)	TOPSIS, AHP, ANP	(Lashgari *et al.,* 2012)

Secondly, determining and evaluating all these factors is a difficult task for decision maker. Besides, it is hard to select the exact number for every criterion and DM's evaluations are subjective and imprecise. Therefore grey relations analysis can be a natural approach for dealing with this kind of issue.

After reaching consensus about needs for purchasing machine tool, alternatives for this decision are defined evaluation procedure. Figure 1 describes the evaluation procedure of this study which consists of three main phases:

Phase I. After constructing decision making team, the most important criteria for machine tool selection was identified. Next, the qualitative and quantitative criteria were defined. The criteria listed in Table 2 are selected based on the literature survey. Finally, the project team constructed the selection criteria and problem structure (see Figure 2).

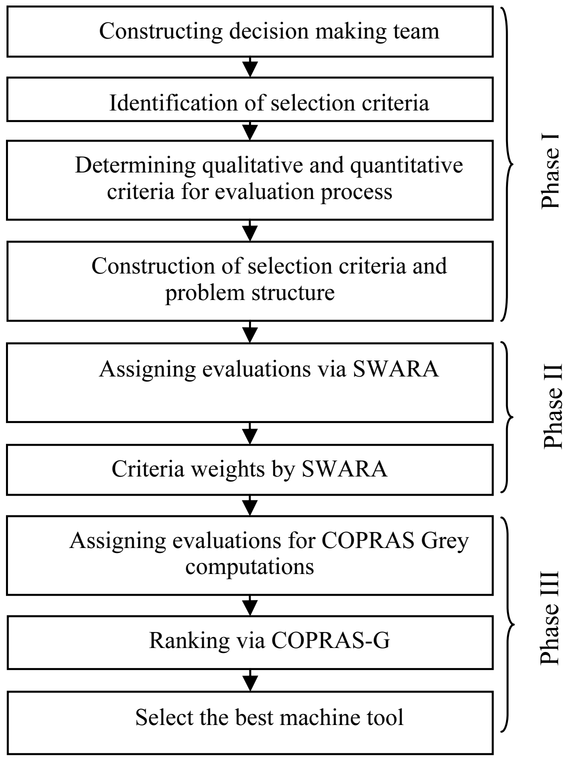

Figure 1. The evaluation procedure

Phase II. Criteria weights were calculated by applying SWARA method and based on experts' evaluations.

Phase III. In this stage, all alternatives were evaluated by project team and COPRAS-G method was applied to achieve the final ranking results.

A step-wise weight assessment ratio analysis (SWARA) method (Kersuliene *et al.,* 2010)

There is a variety of approaches for assessing weights in the literature such as (Zavadskas *et al.,* 2010), e.g. the eigenvector method, SWARA (Kersuliene *et al.,* 2010), expert judgment method (Zavadskas *et al*., 2012), analytic hierarchy process (AHP) (Saaty, 1977, 1980), Entropy method (Susinskas *et al.,* 2011, Kersuliene & Turskis, 2011), FARE (Ginevicius, 2011), etc.

Among these approaches, SWARA method is one of the brand-new ones. The most significant criterion is given rank 1, and the least significant criterion is given rank last. The overall ranks to the group of experts are determined according to the mediocre value of ranks (Kersuliene & Turskis, 2011).

Table 2

Criteria and their descriptions

Evaluation Criteria	Description	Reference
Cost (C1)	The purchasing cost of the machine.	(Yurdakul, 2004; Onut *et al.,* 2008; Arslan *et al.,* 2004)
Operative flexibility (C2)	The possibility of using the machine tool as desired, Number of tools, Rotary table, Number of pallets, Index table, CNC type, U or V axis, Head changer, Spindle power.	(Yurdakul, 2004; Arslan *et al.,* 2004; Ozgen *et al.,* 2011; Balaji, 2009)
Maintainability & serviceability (C3)	The ability to be maintained and serviced, Training, Repair service, Spare parts, Regular maintenance.	(Arslan *et al.,* 2004; Ozgen *et al.,* 2011; Lin & Yang, 1996; Cimren *et al.,* 2007)
Size and Physical (C4)	Machine dimensions, Machine weight, Auxiliary equipment (loading/unloading, material handling, quality).	(Arslan *et al.,* 2004; Ayag & Ozdemir, 2011)
Compatibility (C5)	The ability of using computer and machine together, CNC type, Number of tools, Taper number.	(Onut *et al.,* 2008; Arslan *et al.,* 2004; Ayag & Ozdemir, 2006)
Safety (C6)	The machine tool is safe to use for its intended, Mechanical risk, Work organization, Operator training, Mist collector, Safety door, Fire extinguisher	(Yurdakul & Ic, 2009b; Lin & Yang, 1996; Chung & Peng, 2004)
Precision (C7)	Axis precision, Repeatability, Thermal stability, Static and dynamic rigidity.	(Arslan *et al.,* 2004; Ayag & Ozdemir, 2006);
Productivity (C8)	Speed, power, Cutting feed, Tool change time, Rapid speed, Pallet changer	(Yurdakul, 2004; Onut *et al.,* 2008; Arslan *et al.,* 2004; Ayag & Ozdemir, 2011)

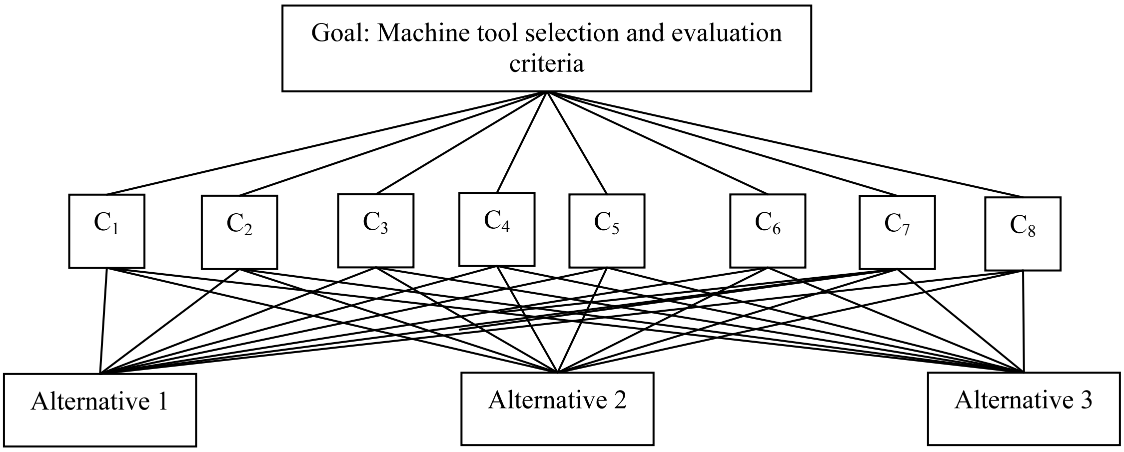

Figure 2. Problem structure, selection criteria and alternatives

The step-wise weight assessment ratio analysis (SWARA) (Kersuliene et al., 2010) methodology is developed in 2010 and applied for the selection of rational dispute resolution method (Kersuliene & Turskis, 2011). The procedure for the criteria weights determination is presented in Figure 3. The ability to estimate experts' opinion about importance ratio of the criteria in the process of their weights determination is the main element of this method (Kersuliene *et al.,* 2010). This method is useful for coordinating and gathering data from experts. SWARA applications are uncomplicated and experts in various fields can contact with general idea of this method easily. All developments of decision making models based on SWARA method up to now are listed below:

- Kersuliene *et al.,* (2010) in selection of rational dispute resolution method.
- Kersuliene and Turskis (2011) for architect selection.
- Hashemkhani Zolfani *et al.,* (2012) in design of products.

The COPRAS-G method

In order to evaluate the overall efficiency of an alternative, it is essential to identify most important criteria, to evaluate alternatives and assess information with respect to these criteria; develop methods for evaluating the criteria to meet the DMs' needs. Decision analysis is concerned with the situation in which a DM has to choose among several alternatives by considering a particular set of, usually conflicting criteria. For this reason Complex proportional assessment (COPRAS) method which was developed by (Zavadskas & Kaklauskas, 1996) can be applied. In real situations, the most of the criteria for evaluating alternatives deal with vague feature, and values of criteria cannot be expressed by exact numbers.

Therefore MADM approaches need to be functioned not only with exact criteria values, but with fuzzy values or with values in some intervals. (Zavadskas *et al*., 2008) presented the main ideas of complex proportional assessment method with grey interval numbers (COPRAS-G) method.

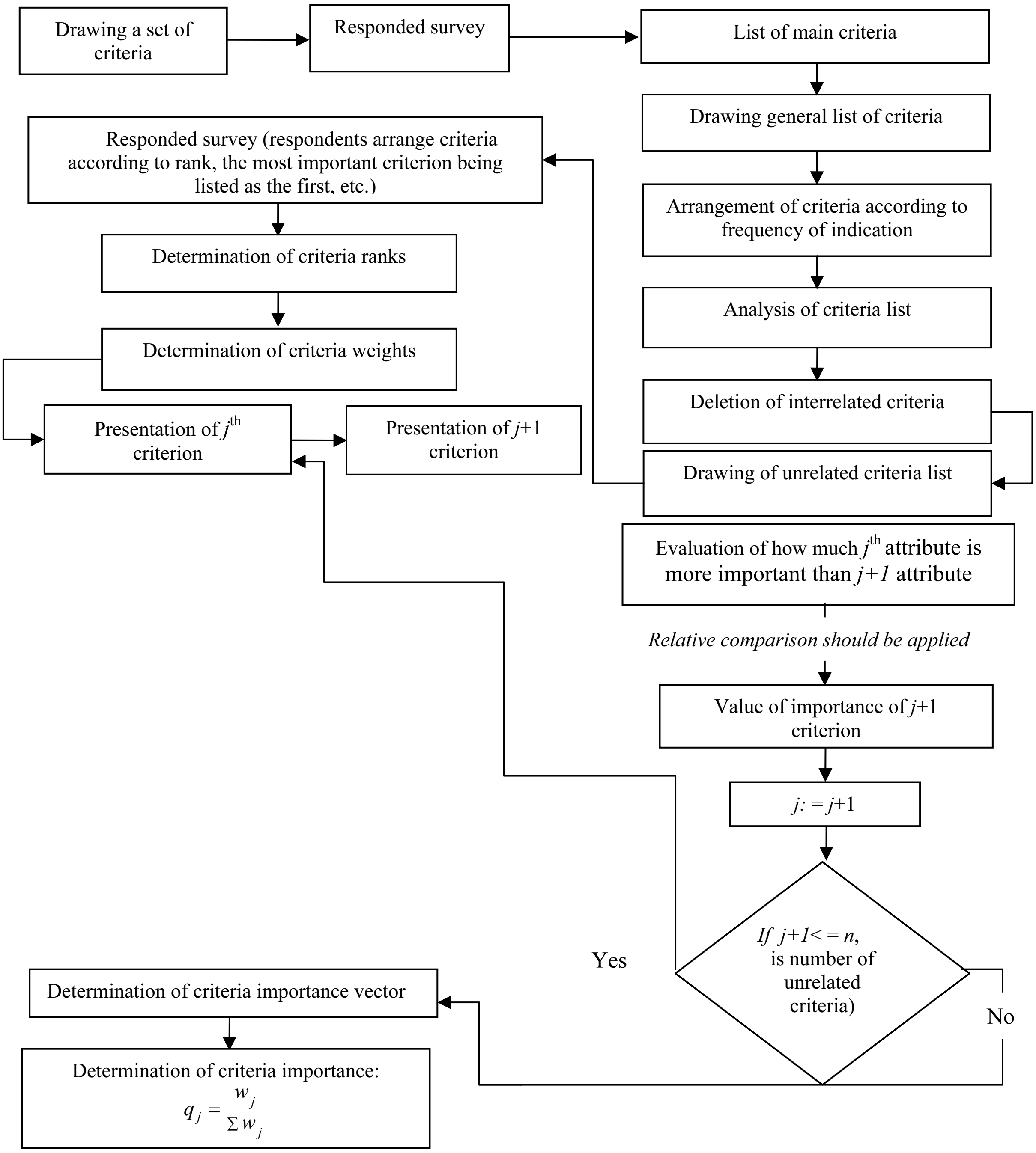

Figure 3. Determining of the criteria weights based on (Kersuliene & Turskis, 2011)

The idea of COPRAS-G method with criterion values expressed in intervals is based on the real conditions of decision making and applications of the Grey systems theory (Deng, 1982). The COPRAS-G method uses a stepwise ranking and evaluating procedure of the alternatives in terms of significance and utility degree (Hashemkhani Zolfani *et al.,* 2012a, b)**.** The recent developments of decision making models based on COPRAS and COPRAS-G method are listed below:

- Hashemkhani Zolfani *et al.,* (2011) in forest roads locating;
- Hashemkhani Zolfan*i et al.,* (2012a) in supplier selection;
- Hashemkhani Zolfani *et al.,* (2012b) in quality control manager selection;
- Aghdaie *et al.,* (2012) in prioritizing projects of municipality;
- Rezaeiniya *et al.,* (2012) in greenhouse locating;
- Bitarafan *et al.,* (2012) in evaluating the construction methods of cold-formed steel structures in reconstructing the areas damaged in natural crises;
- Das *et al.,* (2012) in measure relative performance of institutions.
- Aghdaie *et al.,* (2013) in market segment evaluation and selection;
- Chaterjee *et al.,* (2011) in materials selection.

– Maity *et al.,* (2012) in materials selection.

The procedure of applying the COPRAS-G method consists of the following steps (Zavadskas *et al.* 2009):

1. Selecting the set of the most important criteria, describing the alternatives.
2. Constructing the decision-making matrix $\otimes X$.

Here $\otimes x_{ji}$ is determined $\underline{x}_{ji}$ (the smallest value, the lower limit) and $\overline{x}_{ji}$ (the biggest value, the upper limit).

3. Determining significances of the criteria q_i .
4. Normalizing the decision-making matrix $\otimes X$ is calculated by formula 2.

$$\otimes X=\begin{bmatrix}[\otimes x_{11}] & \dots & \dots & [\otimes x_{1m}]\\ [\otimes x_{21}] & \dots & \dots & [\otimes x_{2m}]\\ \vdots & \dots & \ddots & \vdots\\ [\otimes x_{n1}] & \dots & \dots & [\otimes x_{nm}]\end{bmatrix}=\begin{bmatrix}[\underline{x}_{11};\overline{x}_{11}] & [\underline{x}_{12};\overline{x}_{12}] & \dots & [\underline{x}_{1m};\overline{x}_{1m}]\\ [\underline{x}_{21};\overline{x}_{21}] & [\underline{x}_{22};\overline{x}_{22}] & \dots & [\underline{x}_{2m};\overline{x}_{2m}]\\ \vdots & \vdots & \ddots & \vdots\\ [\underline{x}_{n1};\overline{x}_{n1}] & [\underline{x}_{n2};\overline{x}_{n2}] & \dots & [\underline{x}_{nm};\overline{x}_{nm}]\end{bmatrix};j=\overline{1,n},i=\overline{1,m} \quad (1)$$

$$\underset{\sim}{x}=\frac{\underline{x}_{ji}}{\frac{1}{2}\left(\sum_{j=1}^{n}\underline{x}_{ji}+\sum_{j=1}^{n}\overline{x}_{ji}\right)}=\frac{2\underline{x}_{ji}}{\left(\sum_{j=1}^{n}\underline{x}_{ji}+\sum_{j=1}^{n}\overline{x}_{ji}\right)},\ \tilde{\overline{x}}=\frac{\overline{x}_{ji}}{\frac{1}{2}\left(\sum_{j=1}^{n}\underline{x}_{ji}+\sum_{j=1}^{n}\overline{x}_{ji}\right)}=\frac{2\overline{x}_{ji}}{\sum_{j=1}^{n}(\underline{x}_{ji}+\overline{x}_{ji})};\ j=\overline{1,n};\ i=\overline{1,m} \quad (2)$$

In formula (2) $\underline{x}_{ji}$ – the lower value of the *I* criterion in the alternative *j* of the solution; $\overline{x}_{ji}$ – the upper value of the criterion *i* in the alternative *j* of the solution; *m* – the number of criteria; *n* – the number of the alternatives, compared. Then, the decision-making matrix is normalized and determined according to the formula 3:

$$\otimes\tilde{X}=\begin{bmatrix}[\underset{\sim}{x}_{11};\tilde{\overline{x}}_{11}] & [\underset{\sim}{x}_{12};\tilde{\overline{x}}_{12}] & \cdots & [\underset{\sim}{x}_{1m};\tilde{\overline{x}}_{1m}]\\ [\underset{\sim}{x}_{21};\tilde{\overline{x}}_{21}] & [\underset{\sim}{x}_{22};\tilde{\overline{x}}_{22}] & \cdots & [\underset{\sim}{x}_{2m};\tilde{\overline{x}}_{1m}]\\ \vdots & \vdots & \ddots & \vdots\\ [\underset{\sim}{x}_{n1};\tilde{\overline{x}}_{n1}] & [\underset{\sim}{x}_{n2};\tilde{\overline{x}}_{n2}] & \cdots & [\underset{\sim}{x}_{nm};\tilde{\overline{x}}_{nm}]\end{bmatrix}; \quad (3)$$

5. Calculating the weighted normalized decision matrix $\otimes\hat{X}$. The weighted normalized values $\otimes\hat{x}_{ji}$ are calculated as follows:

$$\otimes\hat{x}_{ji}=\otimes\tilde{x}_{ji}\cdot q_i;\ or\ \hat{\underline{x}}_{ji}=\underset{\sim}{x}_{ji}\cdot q_i\ and\ \hat{\overline{x}}_{ji}=\tilde{\overline{x}}_{ji}\cdot q_i \quad (4)$$

where q_i is the significance of the i-th criterion. Then, the normalized decision-making matrix is:

$$\otimes\hat{X}=\begin{bmatrix}[\otimes\hat{x}_{11}] & [\otimes\hat{x}_{12}] & \cdots & [\otimes\hat{x}_{1m}]\\ [\otimes\hat{x}_{21}] & [\otimes\hat{x}_{22}] & \cdots & [\otimes\hat{x}_{1m}]\\ \vdots & \vdots & \ddots & \vdots\\ [\otimes\hat{x}_{n1}] & [\otimes\hat{x}_{n2}] & \cdots & [\otimes\hat{x}_{nm}]\end{bmatrix}=\begin{bmatrix}[\hat{\underline{x}}_{11};\hat{\overline{x}}_{11}] & [\hat{\underline{x}}_{12};\hat{\overline{x}}_{12}] & \cdots & [\hat{\underline{x}}_{1m};\hat{\overline{x}}_{1m}]\\ [\hat{\underline{x}}_{21};\hat{\overline{x}}_{21}] & [\hat{\underline{x}}_{22};\hat{\overline{x}}_{22}] & \cdots & [\hat{\underline{x}}_{2m};\hat{\overline{x}}_{2m}]\\ \vdots & \vdots & \ddots & \vdots\\ [\hat{\underline{x}}_{n1};\hat{\overline{x}}_{n1}] & [\hat{\underline{x}}_{n2};\hat{\overline{x}}_{n2}] & \cdots & [\hat{\underline{x}}_{nm};\hat{\overline{x}}_{nm}]\end{bmatrix}; \quad (5)$$

6. Calculating the sums P_j of criterion values, whose larger values are more preferable:

$$P_j=\frac{1}{2}\sum_{i=1}^{k}(\hat{\underline{x}}_{ji}+\hat{\overline{x}}_{ji}); \quad (6)$$

7. Calculating the sums R_j of criterion values, whose smaller values are more preferable:

$$R_j=\frac{1}{2}\sum_{i=k+1}^{m}\left(\hat{\underline{x}}_{ji}+\hat{\overline{x}}_{ji}\right);i=\overline{k,m} \quad (7)$$

In formula (7), $(m-k)$ is the number of criteria which must be minimized.

8. Determining the minimal value of R_j as follows:

$$R_{\min}=\min_j R_j,\ \ j=\overline{1,n} \quad (8)$$

9. Calculating the relative significance of each alternative Q_j the expression:

$$Q_j=P_j+\frac{\sum_{j=1}^{n}R_j}{R_j\sum_{j=1}^{n}\frac{1}{R_j}}; \quad (9)$$

10. Determining the optimally criterion by K the formula:

$$K=\max_j Q_j,\ \ i=\overline{1,n}; \quad (10)$$

11. Determining the priority order of the alternatives.

12. Calculating the utility degree of each alternative by the formula:

$$N_j=\frac{Q_j}{Q_{\max}}\times 100\%. \quad (11)$$

Here Q_j and Q_{max} are the significances of the alternatives obtained from Eq (9).

Case Study

A real case study problem has been chosen to show the performance and application of the model. The study was conducted by a well-known company in manufacturing industry. This company is an average sized manufacturing company which has 80 employers and located in Simin Dasht Industrial area, Iran. This company makes some kind of press machines such as hydraulic and pneumatic, and casts of them. Besides, it is a supplier of Zamyad Automobile manufacturing Company. Recently, there has been a regular increase in request for products of this company and company needs to buy a new CNC machine for making new casts. Therefore, manager of the company has decided to buy a new CNC machine. After defining a new project for buying a new CNC, a project team including two industrial engineers, two mechanical engineer and manager of the company was collected (see table 3). The project team identified three potential machines as alternatives for purchase. The alternatives were denoted as A_1, A_2, and A_3, respectively. For receiving general agreement in every step of this project, face to face interviews and Delphi method were used. So, after a lot of discussions, a project team identified criteria for evaluation and they constructed problem structure. Then the project team accepted the criteria list that was explored from the literature study (see table 2). As mentioned before, in this paper SWARA was used for calculating criteria weights.

After determining all selection criteria and machine tool alternatives, SWARA method was used to tackle the ambiguities involved in the process of the linguistic assessment of the data. Like other similar methods (AHP and ANP), SWARA is also based on expert's ideas or thoughts but experts can participate without difficulty in this method. Information about experts is shown in Table 3. Table 4 shows the results of criteria weights. The rank of criteria was shown in the first column and the last column was shown the weight of each criterion.

Table 3

The characteristics of the five decision-making experts

	Gender	Age	Education Level	Experience (years)	Job title	Job responsibility
Decision-making expert1(D1)	Male	55	Bachelor's in management	> 30	Manager of the company (CEO)	In charge of the most important decisions of the company.
Decision-making expert1(D2)	Male	51	Master's in mechanical engineering	> 25	Project manager and supply chain analysis	Managing the engineering team, supply chain, suppliers and new projects.
Decision-making expert1(D3)	Male	50	Bachelor's in mechanical engineering	> 20	Quality control and maintenance manager	Managing repair and maintenance programs, teams. Designing new programs for improving quality and processes.
Decision-making expert1(D4)	Male	49	Bachelor's in industrial engineering	> 15	Production planning and material handling manager	Managing product lines, buying new materials and inventory planning.
Decision-making expert1(D5)	Female	46	Doctor of philosophy's industrial engineering	> 15	Marketing and Sales manager	Responsible for R&D, new products, marketing research and pricing decisions.

Table 4

Final results of SWARA method in weighting criteria

Criterion	Comparative importance of average value S_j	Coefficient $k_j = s_j + 1$	Recalculated weight $w_j = \frac{x_{j-1}}{k_j}$	Weight $q_j = \frac{w_j}{\sum w_j}$
C_1		1	1	0.191
C_2	0.15	1.15	0.869	0.166
C_7	0.16	1.16	0.749	0.143
C_3	0.13	1.13	0.662	0.126
C_4	0.14	1.14	0.580	0.112
C_8	0.13	1.13	0.513	0.099
C_5	0.15	1.15	0.446	0.086
C_6	0.12	1.12	0.398	0.077

Results

After representing the case study, proposed model, selecting the project team, identifying most important criteria for evaluating, representing the decision model and using analytical techniques, the remaining part of the study will focus on the obtained numerical results. The hierarchical structure of decision problem consists of three levels: at the highest level the objective of the problem is situated while in the second level, the criteria are listed. The goal is selecting the most suitable CNC for the company. The criteria are C_1, C_2, C_3, C_4, C_5, C_6, C_7, and C_8(see Table 2). Among all criteria only C_1 is a cost criterion (the minimum amount of this criterion is desirable) and others are benefit criteria. At this stage of the application, the group of experts evaluated each alternative according to each criterion and developed Table 5. The evaluations of these three alternatives according to the previously stated criteria, i.e., evaluation matrix, are displayed in Table 5.

Also, Table 5 indicates initial decision making matrix, with the criterion values described in intervals. For the weight q_i of criteria, we used the weights in Table 4. As mentioned before, the aim of using SWARA is to determine importance weight of criteria that will be employed in COPRAS-G method.

The initial decision making matrix, has been normalized first as discussed in section 3.2. The normalized decision making matrix is presented in Table 6 by using equations (6) to (11) or all the alternatives. Table 6 shows normalized weighted decision making matrix. According to results of Table 7, it shows evaluation of utility degree, **A**$_3$>**A**$_1$>**A**$_2$. **A**$_3$ is defined as the best alternative for this selection that a project team can choose for buying new CNC. Hybrid approach results indicate that **A**$_3$ is the best candidate with the highest degree and is the best machine tool alternative for selection.

Table 5

Initial decision making matrix with the criteria values described in intervals

	$\otimes x_1$	$\otimes x_2$	$\otimes x_3$	$\otimes x_4$	$\otimes x_5$	$\otimes x_6$	$\otimes x_7$	$\otimes x_8$
opt	Min	Max	Max	Max	Max	Max	Max	Max
q_i	0.191	0.166	0.126	0.112	0.086	0.077	0.143	0.099
Alternatives	$\underline{x}_1, \overline{x}_1$	$\underline{x}_2, \overline{x}_2$	$\underline{x}_3, \overline{x}_3$	$\underline{x}_4, \overline{x}_4$	$\underline{x}_5, \overline{x}_5$	$\underline{x}_6, \overline{x}_6$	$\underline{x}_7, \overline{x}_7$	$\underline{x}_8, \overline{x}_8$
A$_1$	60 70	50 60	80 90	70 80	60 70	60 70	80 90	80 90
A$_2$	70 80	50 60	60 70	60 70	50 60	70 80	80 90	70 80
A$_3$	60 70	70 80	60 70	60 70	60 70	60 70	90 95	70 80

Table 6

Normalized weighted decision making matrix

	$\otimes\hat{x}_1$	$\otimes\hat{x}_2$	$\otimes\hat{x}_3$	$\otimes\hat{x}_4$	$\otimes\hat{x}_5$	$\otimes\hat{x}_6$	$\otimes\hat{x}_7$	$\otimes\hat{x}_8$
Opt.	Min	Max	Max	Max	Max	Max	Max	Max
Alternatives	$\underline{x}_1, \overline{x}_1$	$\underline{x}_2, \overline{x}_2$	$\underline{x}_3, \overline{x}_3$	$\underline{x}_4, \overline{x}_4$	$\underline{x}_5, \overline{x}_5$	$\underline{x}_6, \overline{x}_6$	$\underline{x}_7, \overline{x}_7$	$\underline{x}_8, \overline{x}_8$
A$_1$	0.055 0.065	0.044 0.054	0.046 0.052	0.038 0.043	0.027 0.032	0.022 0.026	0.043 0.049	0.033 0.037
A$_2$	0.065 0.074	0.044 0.054	0.035 0.041	0.032 0.038	0.023 0.027	0.026 0.030	0.043 0.049	0.029 0.033
A$_3$	0.055 0.065	0.062 0.071	0.035 0.041	0.032 0.038	0.027 0.032	0.022 0.026	0.049 0.051	0.029 0.033

Table 7

Evaluation of utility degree

Alternatives	P_j	R_j	Q_j	N_j	Rank
A$_1$	0.273	0.060	0.339	99.7%	2
A$_2$	0.252	0.0695	0.309	90.8%	3
A$_3$	0.274	0.060	0.340	100%	1

Conclusions and Discussions

Today machines are used for producing many goods in every company and they can be considered as an asset of a company. Machines can influence quality of the products so it is important to select the most appropriate machine for every company. Besides, the cost of buying a new machine is expensive so this decision should be considered as a critical decision for every organization. Therefore the evaluation and selection of new machine is a crucial managerial or political activity for every company. It helps a company to choose its own machine tool so lead to companies effectively satisfying customers' needs and wants.

In this paper, a hybrid MADM methodology with three phases based on integrating two MADM methods for selecting the most suitable machine tool was proposed. According to the results of this study, DMs faced with critical factors that were found to influence an organization's decisions about selecting a new machine tool. Based on this research, it was shown that DMs have a great impact on decisions in an organization so their decisions could influence the final outcomes. Specifically, this study provides valuable view which DMs should selected as a decision making team.

Though DMs' judgments, education and expertise play important roles in the success or failure of manufacturing decisions, sometimes their evaluations or judgments are vague and imprecise. These inaccuracies can cause difficulties in the process of decision making. Another meaningful contribution to this study is the proposed COPRAS-G, an effective mathematical model which uses grey relation analysis for dealing with vagueness. Although, the most important criteria and problem structure was constructed based on literature study, some of selected criteria and evaluations were qualitative. So for dealing uncertainty and improving lack of precision in evaluating criteria and machine tool alternatives, grey numbers were used. In COPRAS-G method, the score option can provide better insight to the DM by taking into account both the differences and similarities of the alternatives according to the best and the worse alternatives. The grey numbers enabled DM to get better results in the overall importance of criteria and real alternatives.

In addition, SWARA method was used as a decision making tool for extracting weights of criteria which COPRAS-G needed. Therefore, COPRAS-G used SWARA result weights as input weights. Therefore, another significant contribution to this study is the proposed SWARA –COPRAS-G integrated approach.

In general, the findings of this study have contributed towards providing important and advanced knowledge by various criteria and a simple, efficient method with which managers of a company or decision makers can increase their ability to choose an appropriate machine tool in their efforts to develop the firms' outputs' qualities. As a result of the study, we found that the proposed approach is practical for ranking machine tool alternatives with respect to multiple conflicting criteria.

This integration was proposed as an analytical model for dealing with uncertainly and imprecise information in conflict management situations. Therefore further research can apply this method as an adaptable approach to other situations. Also, further research could focus on using other multi-attribute decision making (MADM) approaches including ARAS, VIKOR, ANP, and PROMETHEE, etc. and compare with the results of this paper.

The study results show that decision criteria significantly influence the choice of machine tool selection. However in this paper the most important criteria were selected based on the in-depth literature survey; another study can be designing a new structure with other criteria, sub-criteria and assessing alternatives with a new structure.

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Sprendimo priėmimas pasirenkant mechanines stakles: jungtinis SWARA ir COPRAS-G metodas

Santrauka

Šiais laikais beveik visos kompanijos, gamindamos gaminius naudoja savo stakles. Staklių kokybė gali daryti įtaką gaminių kokybei, todėl kiekvienai kompanijai svarbu pasirinkti pačias tinkamiausias stakles. Naujos staklės yra brangios, todėl siekį įsigyti stakles, reikėtų laikyti svarbiu kiekvienos organizacijos sprendimu. Naujų staklių įvertinimas ir pasirinkimas yra svarbi kiekvienos kompanijos valdymo arba politikos dalis. Mechaninės staklės yra viena iš svarbiausių gamybos proceso dalių, kuri gali padėti kompanijai pasiekti aukštą konkurencingumą rinkoje. Be to, kompanijos rezultatų kokybė priklauso nuo staklių ir todėl kiekviena kompanija turėtų pati pasirinkti joms tinkamiausias ir geriausias stakles. Tam tikrų staklių pasirinkimas yra labai reikšmingas gamybos kompanijai, nes tai padeda pasiekti aukštą našumą ir efektyvumą jų veikloje. Rinka siūlo daugybę skirtingų rūšių staklių. Tinkama staklių pasirinkimo dalimi reikėtų laikyti staklių kainą, saugumą, gamybinį lankstumą. Tai pagrindiniai kriterijai, į kuriuos reiktų atkreipti dėmesį renkantis stakles. Tinkamas staklių pasirinkimas ir įsigyjimas leidžia kompanijai efektyviau tenkinti vartotojų poreikius ir norus.

Taigi staklių pasirinkimą galima laikyti viena iš sprendimų priėmimo pagal daugelį savybių (MADM - *multiple-attribute decision making*) problema. Dažniausiai, naudojant MADM metodus, susiduriama su daugybės skirtingų alternatyvų pasirinkimo procesu, kuris atsiranda esant konfliktui tarp tikslų ir kriterijų. Šio *darbo tikslas* yra pasiūlyti jungtinę *tinkamų žingsnių svorio* įvertinimo santykio analizę (SWARA - *step-wise weight assessment ratio analysis*) ir sudėtinį proporcingą alternatyvų įvertinimą *grey* santykiu (COPRAS-G - *complex proportional assessment of alternatives with grey relations*), kuris skirtas įvertinti ir pasirinkti stakles.

Šiame tyrime, pasirenkant ir įvertinant stakles, buvo panaudoti du MADM metodai, SWARA ir COPRAS-G. Norint nustatyti patraukliausius kriterijus, kurie daro įtaką pasirenkant stakles, buvo išsamiai išanalizuota teorinė literatūra. Išskirti aštuoni įvertinimo proceso kriterijai. Tai kaina, gamybinis lankstumas, eksploatavimo ir aptarnavimo galimybė, dydis ir fiziniai kriterijai: suderinamumas, saugumas, tikslumas ir našumas. Pasiūlytos metodikos pirmoji dalis, t. y. SWARA, yra naudinga nustatant kiekvieno kriterijaus svarbą ir apskaičiuojant kiekvieno kriterijaus svorį, o antroji dalis COPRAS-G, yra naudinga įvertinant alternatyvas daug tiksliau, nei įprastiniu glaustu COPRAS metodu ir surikiuojant staklių alternatyvas nuo geriausios iki blogiausios. Asmenų, priimančių sprendimus išsilavinimas yra labai svarbus . Nuo jų dažnai priklauso gamybos sprendimų sėkmė arba nesėkmė. Dažnai priimančių sprendimus asmenų įvertinimai arba sprendimai yra nemotyvuoti ir netikslūs. Tokie netikslumai gali sukelti sunkumų įvertinant ir priimant sprendimus. Įvertinimo metu, spendimų priėmėjas turi įvertinti kriterijų, kuris yra netikslus. *Grey* santykio analizė leidžia įtraukti neaiškią ir netikslią informaciją į sprendimo modelį.

Šis modelis yra hibridinis modelis. Jį sudaro du MADM metodai, skirti pagerinti pasirinkimo kokybę ir tikslumą. Taip pat šį modelį sudaro trys fazės. Fazėje I, sudarius sprendimų priėmimo komandą, buvo nustatyti patys svarbiausi staklių pasirinkimo kriterijai. Toliau buvo nustatyti kokybiniai ir kiekybiniai kriterijai. Kriterijų sąrašas pasirinktas remiantis literatūros apžvalga. Galiausiai, projekto komanda sudarė pasirinkimo kriterijų ir problemos struktūrą. Fazėje II, kriterijų svoriai buvo apskaičiuoti taikant SWARA metodą bei remiantis ekspertų įvertinimais. Fazėje III, projekto komanda įvertino visas alternatyvas ir buvo pritaikytas COPRAS-G metodas, siekiant gauti galutinius rezultatus.

Norint pailiustruoti pasiūlytą metodiką, buvo atliktas tyrimas gamybinėje kompanijoje Karaj mieste, Irane. Kaip alternatyvos buvo trys kompiuterinio skaitmeninio valdymo staklės, kurias projekto komanda parinko įvertinti, ir viena iš jų turėtų būti pasirinkta kaip geriausia alternatyva. *Delphi* metodika buvo panaudota, norint gauti bendrą daugelio šio modelio žingsnių variantą. Penki sprendimų priėmimo ekspertai buvo pasirinkti alternatyvoms įvertinti, prieš tai atsižvelgiant į nustatytus kriterijus. Šis modelis gali padėti vadovams įvertinti ir pasirinkti geriausią staklių alternatyvą, remiantis savo kompanijos strategija, resursais, politika ir t.t.

Šio tyrimo rezultatai leido nustatyti įvairius kriterijus, taip pat paprastą ir efektyvų metodą, kuriuo naudodamiesi kompanijos vadovai arba sprendimų priėmėjai turi galimybę pasirinkti atitinkamas stakles, stengdamiesi plėtoti kompanijų produkcijos kokybę. Tyrimo metu mes supratome, kad pasiūlytas metodas yra praktiškas, nes vertinant ir klasifikuojant staklių alternatyvas, remiamasi daugeliu prieštaringų kriterijų. Šiame darbe svarbiausi kriterijai buvo pasirinkti remiantis išsamia literatūros apžvalga. Kitas tyrimas gali būti apie naujos struktūros kūrimą su kitais kriterijais, *sub*-kriterijais ir įvertinant alternatyvas su nauja struktūra.

Remiantis šio tyrimo rezultatais, sprendimų priėmėjai susidūrė su svarbiais veiksniais, kurie darė įtaką organizacijos sprendimams renkantis naujas stakles. Remiantis šiuo tyrimu buvo parodyta, kad sprendimų priėmėjai turi didelę įtaką organizacijos sprendimams. Jų sprendimai turi įtaką ir galutiniams rezultatams. Tiksliau sakant, šis tyrimas pateikia vertingą nuomonę, kurią sprendimų priėmėjai turėtų pasirinkti kaip sprendimų priėmimo komanda.

Raktažodžiai: *mechaninių staklių pasirinkimo problema; daugiakriteris sprendimų priėmimas; SWARA; COPRAS-G.*

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