DECISION-MAKING IN A MANUFACTURING SYSTEM BASED ON MADM METHODS

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Abstract: *Nowadays, manufacturing systems are much larger with an increasing number of production lines and units. As a result, the decision-making of manufacturing system is a non-trivial problem and requires complex control subsystems. The use of Programmable Logic Controllers (PLCs) allows to program various and non-standard solutions. In the paper the application of Multi-Attribute Decision-Making (MADM) methods to a decision-making related to flow control in a manufacturing system with three production lines is described. For this purpose, the SAW (Simple Additive Method), WASPAS (Weighted Aggregated Sum Product ASsessment) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods are applied and simulated with using manufacturing system model in Matlab Simulink and SimEvents. In methods subjective weights defined by an expert are used. However, in order to move away from subjectivism, Shannon's entropy is used for determining weights of criteria. The used approaches have been compared.*

Keywords: MANUFACTURING SYSTEM, DECISION-MAKING, MADM METHOD, SAW METHOD, WASPAS METHOD, TOPSIS METHOD, FLEXIBLE MANUFACTURING SYSTEM, ENTROPY, SIMULATION

1. Introduction

Manufacturing system is a set of elements related to manufacturing processes. It consists of deliberately designed and organised material, energetic and information systems used for production of defined products to fulfil the needs of consumers [1]. As a result of manufacturing activity new use values appear. From technical and organisation perspective, the manufacturing process is adjustment and transformation of work into a product made with the use of the means of work (machines) with or without the participation of human workforce. Those factors are tightly connected and a change of one results in change of another element [1], which, subsequently, may cause a change in use values. From this perspective, information and decision-making processes are important elements in the manufacturing process. Their aim is to submit complete information to systems and later making decisions based on the choice of an optimal decision variant with an assumed decision criterion which is advantageous for the manufacturing system.

Decision-making processes may be considered in relation to manufacturing process management but not only. Decision-making process may be also considered as a control process in basic and supportive processes – technological operations in simple machine systems, transport operations, and storage operations, etc. Decision criterion which is advantageous for one subsystem may be disadvantageous for another subsystem or for superior control process. Hence, in this article multi-criteria approach to decision-making in production process was considered. A single decision-making process may than consist of criteria adjusted for a single subsystem but it may also consider general criteria adjusted do the management process. They may be simple criteria (e.g. machine activity, processing time on a machine) or complex criteria, which are a result of calculations based on information from different systems or being system/ subsystem productivity indicators.

Decision-making in multi-criteria approach is the aim of Multi-Criteria Decision-Making (MCDM) methods. In case of a finite number of alternatives (variants) Multi-Attribute Decision-Making (MADM) methods can be used. MADM methods determine procedures of processing information concerning alternative assessment in controlling in relations to a set of criteria. It is performed in order to establish a ranking of solutions and best choice. Within the above approach, a wide range of methods can be distinguished [2-6]. In the article three MADM methods are presented and compared while used to decision-making of particular subsystem in automated manufacturing system. This subsystem relates to controlling a trolley and particularly to define trolley's destination. Due to their popularity and minimization of needed expert knowledge the following methods have been chosen: SAW (Simple Additive Method) [7], WASPAS (Weighted Aggregated Sum Product ASsessment) [8] and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [6]. The above methods use weights in order to place preference of criteria during the choice of optimal alternative. As it was shown in [9] determination of criteria weights is a key task in decision-making process. In order to move away from subjectivism, in the article, apart from subjective weights Shannon's entropy [10] was used to determine criteria weights.

The remainder of the paper is organized as follows. In section 2 calculation procedure for SAW, WASPAS and TOPSIS methods is presented. Moreover, steps for establishing criteria weights with reference to Shannon's entropy are described. Section 3 refers to problems of decision-making in manufacturing system. The object of research and its simulative model are described as well as the structure of decision-making process are presented. Simulation results and discussion concerning the comparison of used methods can be found in section 4. Section 5 summarises the research done.

2. Chosen MADM methods

MADM methods relate to making preferential decisions concerning choice, assessment or ranking of decision alternatives in relation to chosen decision criteria. Assessments (values) of each alternative in relations to criteria are most often presented in the form of decision (evaluation) matrix $X = (x_{mn})_{MxN}$ (Table 1). In Table 1 x_{mn} is the evaluation of mth ($m = 1, \dots, M$) alternative in relations to nth ($n = 1, \dots, N$) criterion, however w_n is the weight of nth criterion. Criteria weights, following the requirement $\sum_{n=1}^{N} w_n = 1$, may be determined subjectively or using objective method (e.g. Shannon's entropy).

Table 1: *Structure of decision matrix*

	Criterion 1	Criterion 2	…	Criterion N
Alternative 1	x_{11}	x_{12}	⋯	x_{1N}
Alternative 2	x_{21}	x_{22}	⋯	x_{2N}
…	…	…	x_{mn}	…
Alternative M	x_{M1}	x_{M2}	⋯	x_{MN}
Weights	w_1	w_2	…	w_N

Subsequent steps of calculation procedure of final alternatives' ranking depend on the method used.

SAW method

The SAW method was used for the first time in [7] as a method for solving the portfolio selection problem. The main procedures to find the scores of the alternatives using SAW can be as follows.

1. Determine the normalized decision matrix $R = (r_{mn})_{MxN}$ in the following way:

$$r_{mn} = \begin{cases} \frac{x_{mn}}{\max_n x_{mn}} & if \quad n \in C_{ben} \\ 1 - \frac{x_{mn}}{\max_n x_{mn}} & if \quad n \in C_{cost} \end{cases}, \quad (1)$$

where C_{ben} is the set of benefit criteria, C_{cost} is the set of cost criteria. For benefit criterion the highest value of alternative evaluation is preferred whereas for cost criterion – contrary – the lowest value.

2. Calculate the weighted normalized decision matrix $V = (v_{mn})_{MxN}$ using the weights values (w_n, n = 1,…,N) as follows:

$$v_{mn} = w_n \cdot r_{mn}. \quad (2)$$

3. Aggregate the total relative importance of mth alternative as follows:

$$Q_m = \sum_{n=1}^{N} v_{mn}. \quad (3)$$

WASPAS method

WASPAS method was presented in [8] as an approach combining Weighted Sum and Weighted Product Models (WSM and WPM). Zavadskas et al. suggested that accuracy of WASPAS method is more advantageous than using only WPM or WSM. Stages of WASPAS method are presented below.

1. Determine the weighted sum model (WSM): aggregate the total relative importance of mth alternative in the following form:

$$Q_m^{(1)} = \sum_{n=1}^{N} w_n \cdot r_{mn}, \quad (4)$$

where r_{mn} is calculate using the formula (1).

2. Determine the weighted product model (WPM): aggregate the total relative importance of mth alternative as follows:

$$Q_m^{(2)} = \prod_{n=1}^{N} (v_{mn})^{w_n}. \quad (5)$$

3. Calculate the total importance of mth alternative in the following form [8,11]:

$$Q_m = \lambda \cdot Q_m^{(1)} + (1-\lambda) \cdot Q_m^{(2)}, \ \lambda \in [0,1], \quad (6)$$

where

$$\lambda = \frac{\sum_{m=1}^{M} Q_m^{(2)}}{\sum_{m=1}^{M} Q_m^{(1)} + \sum_{m=1}^{M} Q_m^{(2)}}. \quad (7)$$

TOPSIS method

TOPSIS method, proposed by Hwang and Yoon [6], is one of the most popular methods. It consists in comparison of weighted reference solutions: the positive ideal solution and the negative ideal solution. The total importance of alternatives is calculated by measuring simultaneously their distances from the positive ideal solution and the negative ideal solution. The steps of TOPSIS are as follows.

1. Calculate the weighted normalized decision matrix $V = (v_{mn})_{MxN}$ using the formula (2).

2. Determine the positive ideal solution S^+:

$$S^+ = (v_1^+, v_2^+, \dots, v_N^+) = \{(\max_m v_{mn} \mid n \in C_{ben}), (\min_m v_{mn} \mid n \in C_{cost})\}, \quad (9)$$

where C_{ben} is the set of benefit criteria, C_{cost} is the set of cost criteria.

3. Determine the negative ideal solution S^-:

$$S^- = (v_1^-, v_2^-, \dots, v_N^-) = \{(min_m v_{mn} \mid n \in C_{ben}), (\max_m v_{mn} \mid n \in C_{cost})\}. \quad (10)$$

4. Calculate the distances of each alternative from the positive ideal solution S^+ (d_m^+) and from the negative ideal solution S^- (d_m^-):

$$d_m^+ = \sqrt{\sum_{n=1}^{N} (v_{mn} - v_n^+)^2} \text{ and } d_m^- = \sqrt{\sum_{n=1}^{N} (v_{mn} - v_n^-)^2}. \quad (11)$$

5. Determine the relative closeness of mth alternative to the ideal solutions $S^+$and S^- in the following way:

$$Q_m = \frac{d_m^-}{d_m^+ + d_m^-}. \quad (12)$$

The last stage of these methods is the ranking of the alternatives according to their calculated value Q_m. The best alternative is the alternative with the largest value Q_m.

Determination of criteria weights with the use of Shannon entropy

From the perspective of information and decision-making processes in manufacturing systems as well as any other decision-making process, assessment criteria may have different meanings, hence criteria weights are not equal. Determining proper weights is the main and at the same time difficult stage in decision-making process. In literature, there can be found a division into two groups of methods of weights determining: subjective and objective methods. In case of large amount of data and automated objects the use of subjective methods is difficult or undesirable. In this case the use of subjective methods such as: entropy method, multiple objective programming [12], etc can be considered.

In the article, in order to determine the importance of criteria the concept of Shannon's entropy [10] was used. It plays an important role in information theory and is used for determining general uncertainty measures [13]. Original procedure of calculating weights on the basis of Shannon's entropy is as follows.

1. Calculate the normalized decision matrix $P = (p_{mn})_{MxN}$, where:

$$p_{mn} = \frac{x_{mn}}{\sum_{m=1}^{M} x_{mn}}. \quad (13)$$

2. Determine the entropy h_n $(n = 1, \dots, N)$ as follows:

$$h_n = -h_0 \sum_{m=1}^{M} p_{mn} \cdot ln(p_{mn}), \quad (14)$$

where h_0 as the entropy constant is equal to

$$h_0 = 1/(\ln M). \quad (15)$$

3. Determine the objective weights w_n $(n = 1, \dots, N)$ based on the Shannon's entropy concept:

$$w_n = \frac{1-h_n}{\sum_{n=1}^{N}(1-h_n)}. \quad (13)$$

3. Problem of decision-making in the flow of manufacturing system

The problem of decision-making in production process may be considered on different hierarchy levels. First level consists of machines: programmable controllers, controllers for CNC machines, robots, means of transport, etc. It is the operative control. Second level consists of decision-making in work cell and production line. These are: inspections and statistical process control, materials handling, part sequencing etc. Third level concerns factory floor, that is management process: materials management, maintenance management, quality management etc. Higher levels of decision-making consist of planning strategic controlling processes on the plant and distribution level.

In this article the issue of decision-making on the first level of hierarchy is considered. It concerns the control of the flow of work pieces in PVC (Poly(Vinyl Chloride)) windows manufacturing system with the use of a transport trolley. The details of the problem are presented below.

Problem formulation

The manufacturing system contains three concurrent and independent welding and cleaning lines (WCLs) and three assembly and treating lines (ATLs). The trolley, located between WCLs and ATLs, transports work pieces from one of the production lines

(WCLs) to the appropriate ATL. The problem in question consists in the development of a flow control algorithm for the trolley, which specifies the trolley's destination (the appropriate ATL) [9].

Structure of decision-making process

Flow control algorithm may be considered in the form of structure of decision-making process, where three ATLs (ATL1-ATL3), which are trolley's destination, are alternatives in MADM methods. Criteria for decision-making process are shown in Fig.1.

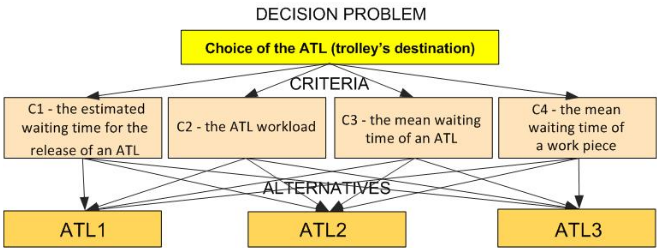

Fig. 1 *The structure of decision problem for trolley in the manufacturing system (cf. [14])*

Simulation model

To verify methods' efficiency a model of analysed manufacturing system has been created with the use of Matlab Simulink with SimEvents (see Fig. 2). Model consists of the following: workstations (units) within WCLs i ATLs (U1-U3), supporting buffers before ATLs, trolley and a trolley's controller. In order to make comparative analysis, the controller bases subsequently on three methods: SAW, WASPAS and TOPSIS. Controller at the input uses signals (information) coming from buffers and units U1-U3 and generates output concerning the destination of a work piece in the trolley (appropriate ATL). Signals from units are saved during the whole simulation and on its basis complex, average parameters are calculated. They are used as criteria in control process.

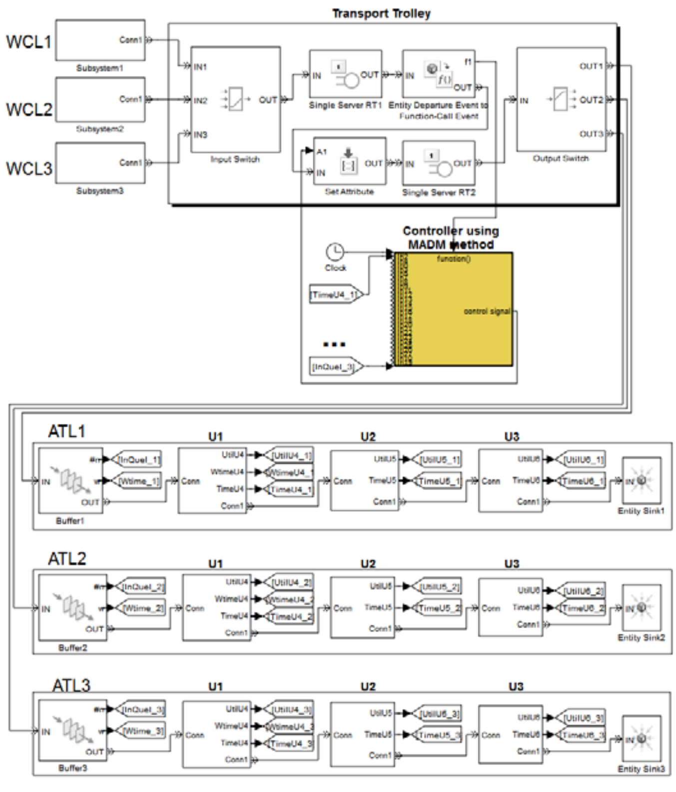

Fig. 2 *Model of manufacturing system in the Matlab Simulink (cf. [9])*

4. Results and discussion

MADM method with subjective weights of criteria

In the simulation, the parameters are calculated according to criteria C1-C4. These parameters can be used at the same time as criteria for the evaluation of the MADM method. The results of the simulation depend on the values of weight vector $w = \{w_n, n = 1, \ldots, n\}$ for production line evaluation criteria. In this paper we present three different subjective weight vectors: $w = \{0.1, 0.4, 0.4, 0.1\}$, which indicates that balancing the workloads of a production line is more important than minimizing the waiting time on a production line; $w = \{0.25, 0.25, 0.25, 0.25\}$, which indicates that all the criteria are equivalent; $w = \{0.4, 0.1, 0.1, 0.4\}$, which indicates that balancing the workloads of a production line is less important than minimizing the waiting time on a production line.

Figure 3 present the results of the simulation using the three weight vectors, on the example of the SAW method. In the simulation we calculate both the workloads of the ATLs and the standard deviation of the workloads, taking into account all three ATLs. Fig. 3 shows that higher weights for criterion C2 (the ATL workload) and criterion C3 (the arithmetic mean waiting time of an ATL) result, in fact, in a better balancing of ATL workloads, but they also increase the mean waiting times of a work piece in the buffer just before the ATLs. Therefore, the application of MADM methods together with criteria weights allows for the individual adjustment of the control. The importance of the criteria can differ depending on the investor.

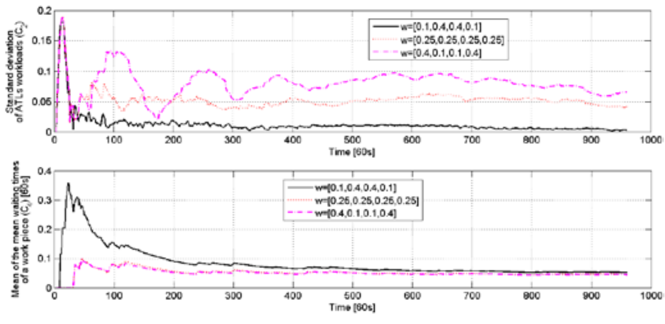

Fig. 3 *The comparison of SAW method with the various vectors of subjective weights*

The SAW, WASPAS and TOPSIS methods have been compared also with other dispatching rule, such as a simple method in which the first non-blocked ATL is used. In the analysis, $w = \{0.1, 0.4, 0.4, 0.1\}$ is used as the vector of criteria weights. Fig. 4 shows a comparison of the parameter values which are the aggregations of ATL parameters.

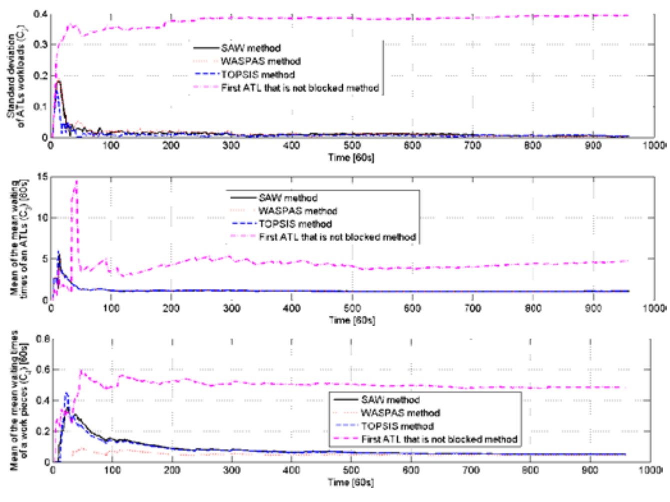

Fig. 4 *The comparison of MADM methods and a method in which the first non-blocked ATL is used*

Simulations using these methods indicate that the best production parameters are those obtained with WASPAS. In this method, the standard deviations of the line workloads are similar to those in the other MADM methods, but the means of mean waiting times of a work piece in ATLs are the lowest. One can also consider the application of TOPSIS; its results are comparable with those of WASPAS for some criteria weights. In this case of flow control, one should not apply the rule of using the first non-blocked ATL.

MADM method with weights based on Shannon entropy

In order to move away from subjective decisions in automated system, analysis considers using also weights basing on Shannon's entropy. Fig.5 presents the comparison of SAW, WASPAS and TOPSIS methods, which use the objective weight vector. On the basis of diagrams it can be stated that due to the mean waiting times of a work piece in the buffer just before the ATLs, SAW and WASPAS methods are more effective, especially at the beginning of manufacturing system operation. From the perspective of two subsequent criteria (the standard deviation of the workloads, the arithmetic mean waiting time of an ATL), it is difficult to say about visible advantage of any of the methods.

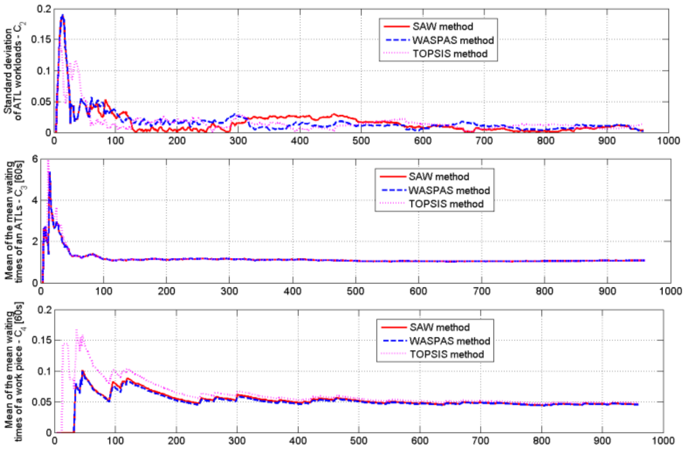

Fig. 5 *The comparison of MADM methods with weights based on Shannon entropy*

Analysed average parameters for manufacturing system (analyses results) for methods with weights based on Shannon entropy are better that in the case of using methods with subjective weights. In a particular case of preference of any of the criteria the value of this parameter (criterion) is advantageous for manufacturing system, however, the remaining parameters are less advantageous. In case of equality of criteria ($w = \{0.25, 0.25, 0.25, 0.25\}$), all analysed parameters are on average level whereas for objective weights the values of analysed parameters are comparable or more advantageous than in case of subjective equivalent criteria.

5. Conclusion

The case study shows that the older MADM methods (SAW, TOPSIS), as well as the new WASPAS method can be used with success as decision-making methods for a transport trolley. The methods presented here are not computationally complex, hence they can be readily used in PLC programming. The application of the multi-criteria approach allows to take into account criteria for machines (units) and all manufacturing system simultaneously. It is more flexible approach, because a change of production parameters has no large effects in lowering the effectiveness of control.

Additionally, the use of subjective criteria weights allows for simple adjustment of control to the investor's requirements. It is advantageous in case of particular preference of any of the criteria. However, in case of lack of particular preference of any of the criteria it is more advantageous to use objective weights basing on Shannon entropy.

The analyzed methods have been compared. The WASPAS method turns out to be the best in the analyzed case: the flow of the manufacturing system is optimal for the presented criteria. The results obtained are close to those of the round robin method but WASPAS can be effectively used in diversified production, which requires adapting to changing conditions and production requirements.

References

1. Brzeziński M. Organization of production in the enterprise [in Polish], Warszawa, Difin, 2013.
2. Mardani, A., E.K. Zavadskas, Z. Khalifah, N. Zakuan, A. Jusoh, K.M. Nor, M. Khoshnoudi, A review of multi-criteria decision-making applications to solve energy management problems: Two decades from 1995 to 2015 - Renewable and Sustainable Energy Reviews, 71, 2017, pp. 216-256, DOI: 10.1016/j.rser.2016.12.053.
3. Kahraman C., S.C. Onar, B. Oztaysi, Fuzzy Multicriteria Decision-Making: A Literature Review - International Journal of Computational Intelligence Systems, Vol. 8 , Iss. 4, 2015, 637-666.
4. Mardani A., A. Jusoh, K. MD Nor, Z. Khalifah, N. Zakwan, A. Valipour, Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014 - Economic Research-Ekonomska Istraživanja, 28:1, 2015, pp. 516-571, DOI: 10.1080/1331677X.2015.1075139.
5. Zavadskas E. K., Z. Turskis, S. Kildienė, State of art surveys of overviews on MCDM/MADM methods - Technological and Economic Development of Economy, Vol. 20 , Iss. 1, 2014, pp. 165-179, http://dx.doi.org/10.3846/20294913.2014.892037.
6. Hwang, C.L., K. Yoon, Multiple Attribute Decision Making Methods and Applications: A State-of-the-Art Survey, New York, Springer-Verlag, 1981.
7. Churchman, C.W., R.L. Ackoff, An approximate measure of value - Journal of Operations Research, Society of America 2 (1), 1954, pp. 172-180.
8. Zavadskas, E., Z. Turskis, J. Antucheviciene, A. Zakarevicius, Optimization of weighted aggregated sum product assessment, Elektronika ir elektrotechnika, 122, 2012, pp. 3–6.
9. Rudnik K., Transport trolley control in a manufacturing system using simulation with the FSAW, FWASPAS and FTOPSIS methods, in: Intelligent Systems in Production Engineering and Maintenance – ISPEM 2017, No. 42, Proceedings of the First International Conference on Intelligent Systems in Production Engineering and Maintenance ISPEM 2017, (Eds.) Burduk A., Mazurkiewicz D., Springer, 2018, DOI:10.1007/978-3-319-64465-3_42 (in press).
10. Shannon C.E., A mathematical theory of communication - Bell Syst. Tech. J., 27, 1948, pp. 379-423.
11. Turskis, Z., E.K. Zavadskas, J. Antucheviciene, N. Kosareva, A hybrid model based on fuzzy AHP and fuzzy WASPAS for construction site selection - International Journal of Computers, Communications and Control, 10 (6), 2015, pp. 873-888.
12. Choo E.U., W.C. Wedley, Optimal criterion weights in repetitive multicriteria decision-making - J. Oper. Res. Soc., 36, 1985, pp. 983-992.
13. Lotfi F.H., R. Fallahnejad, Imprecise Shannon's entropy and multi attribute decision making - Entropy, 12, 2010, pp. 53-62, DOI: 10.3390/e12010053.
14. Rudnik, K., D. Kacprzak, Fuzzy TOPSIS method with ordered fuzzy numbers for flow control in a manufacturing system - Applied Soft Computing, 52, 2017, pp. 1020-1041, http://dx.doi.org/10.1016/j.asoc.2016.09.027.