MULTI-ATTRIBUTE GROUP DECISION MAKING CONSIDERING DIFFERENCE IN EXPERTS KNOWLEDGE: AN EXCEL APPLICATION

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ABSTRACT

The investigated problem deals with selection of business intelligence software represented as multi-attribute group decision making problem. A group of experts with different experience and knowledge is involved to evaluate the features of the software and make the selection. The major challenge is to aggregate different points of view of experts to determine the optimal choice from given set of software alternatives. For the goal, a modification of simple additive weighting method is proposed. In contrast to classical simple additive weighting approach the new utility function takes into account also importance of experts' points of view. The described approach is implemented in MS Excel environment for real problem of business-intelligence software selection. Three different levels of knowledge and experience of group members are considered. The numerical results show that optimal choice is influenced by importance of experts' evaluations expressed by corresponding weighted coefficients. This proves the effectiveness of proposed approach for group decision making in real life applications.

KEYWORDS: *different importance of experts' opinions, modified simple additive weighting method, MS Excel application, multi-attribute group decision making.*

1. INTRODUCTION

Today using of digital technologies can be recognized as a driving force for innovation in all human being activities including the area of business intelligence. The new business challenges require using of digital technology as business intelligence tools to optimize and improve productivity, quality of products and customer service. In this respect, the selection of most appropriate business intelligence software (BIS) is an important issue. BIS software is capable to process and analyze corporate data and to produce different reports to support the business processes management. This kind of software involves variety of metrics to measure and compare business indicators able to show strengths and weaknesses.

The investigated problem concerns selection of BIS from several potential BIS according to the set of evaluation criteria. This selection is realized via multi-attribute group decision making (MAGDM) process by a group of experts. The major challenge is to get optimal alternative by aggregation of different point of view of all experts toward evaluation criteria together with differences in experts' knowledge and experience. The differences in experts' importance evaluations are considered by introducing of weighted coefficients for each of experts.

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2. LITERATURE REVIEW

The intense competition among business corporations makes the selection of proper BIS significant for business success (Sureeyatanapas et al., 2018). The problem of this selection is complex as large number of criteria needs to be evaluated toward given set of possible alternatives. Alternatives' ranking algorithm based on multicriteria optimization is proposed for quantitative reasonable decision making (Mustakerov & Borissova, 2013). Other approach suitable for quantitative and qualitative selection problem is realized by integrating of traditional decision support system with the advances of expert system (Borissova & Mustakerov, 2012). To be more objective the selection process, a group of experts with different competency should be involved (Korsemov et al., 2018). The strategies of decision making can be divided on compensatory or no compensatory strategies (Keeney & Raiffa, 1993). The compensatory strategy in decision making rely on set of suitable attributes to the decision, assigning weights to express attribute importance and calculation overall score for each alternative leading to rational decisions. The methods based on no compensatory decisions simplify the decision process by using of some kind of heuristics (Lee & Anderson, 2009). Representative examples of compensatory strategy in decision making are the mathematical methods based on multi-attribute utility theory (Dyer, 2005). The major effort in multi-attribute decision making (MADM) methods is put on the construction of utility function to estimate alternatives in accordance to the performance criteria (Mulliner et al., 2016). In cases, where more than one decision-maker is involved, this utility function needs to be modified to consider a group of decision experts, i.e. to use group decision making (GDM) methods. All of these considerations transform the BIS selection problem to multi-attribute group decision making problem. Many applications for decision problems with multiple criteria are realized using popular and well known spreadsheets software (Perzina & Ramik, 2014; Jablonsky, 2014; Borissova, 2008).

3. MULTI-ATTRIBUTE GROUP DECISION MAKING CONSIDERING DIFFERENCE IN KNOWLEDGE OF EXPERTS

The challenge in MAGDM is to consider the group members expertise and importance of their evaluations. In the article, the most commonly used and well known Simple Additive Weighting (SAW) method is modified to take into account this issue.

3.1. Simple Additive Weighting

The SAW is the oldest and well known method for multiple attribute decision making (Hwang & Yoon, 1981). The technique of SAW consists in assigning to each alternative a sum of values of the evaluation criteria and weighted coefficients for relative importance of particular criterion. For the goal, the weighted average for each alternative is multiplied by weighted coefficient of each criterion with the assessment of the alternative against this criterion. The overall estimates for each of the alternatives A_i is calculated as (Triantaphyllou, 2000):

$$A_i^* = \max \sum_{j=1}^{N} w_j a_{ij}, \quad \text{for } i = 1,2,\ldots,\text{M} \tag{1}$$

where w_j are weights for relative importance of evaluation criteria with restriction $\sum_{j=1}^{N} w_j = 1$, N is number of evaluation criteria, M is number of alternatives, a_{ij} is the evaluation of performance of i-th alterative toward j-th criterion.

In the case of maximization of the relation (1), the best alternative would be the one that has a maximum value for evaluation under all criteria. It is assumed that the data for assessing alternatives toward criteria are expressed in uniform dimensions. Otherwise, the normalization should be done and the relation (1) is transformed as follows:

$$A_i^* = \max \sum_{j=1}^{N} w_j \left(a_{ij}\right)_{norm}, \quad \text{for } i = 1,....,\text{M} \qquad (2)$$

The normalized value $(a_{ij})_{norm}$ can be determined in two ways depending on whether maximization or minimization of usefulness in an attribute is considered (Geldermann & Schobel, 2011). For maximization of criteria the normalization is:

$$(a_{ij})_{norm} = \frac{a_{ij}}{a_{ij}^{\max}} \quad \text{or} \quad (a_{ij})_{norm} = \frac{a_{ij}^{\max} - a_{ij}}{a_{ij}^{\max} - a_{ij}^{\min}} \qquad (3)$$

and for minimization of criteria it is:

$$(a_{ij})_{norm} = \frac{a_{ij}^{\min}}{a_{ij}} \quad \text{or} \quad (a_{ij})_{norm} = \frac{a_{ij} - a_{ij}^{\min}}{a_{ij}^{\max} - a_{ij}^{\min}} \qquad (4)$$

Due the well structured problem described above it can be represented by *decision matrix* (Rao, 2013):

Table 1. Decision matrix

Alternatives	**Criteria & weights**			
	C_1 (w_1)	**C_2 (w_2)**	**…..**	**C_n (w_n)**
A_1	a_{11}	a_{12}		a_{1n}
A_2	a_{21}	a_{22}		a_{2n}
A_3	a_{31}	a_{32}		a_{3n}
….	…	…		…
A_m	a_{m1}	a_{m2}		a_{mn}

Source: adapted from Rao (2013), p. 4

In this decision matrix *m* is given number of alternatives, *n* is number of evaluation criteria (attributes), w_n is the weighted coefficient for *n-th* criterion, a_{mn} is the evaluation score for *m-th* alternative toward *n-th* criterion.

3.2. Modified Simple Additive Weighting (MSAW)

In contrast to widely accepted applications of SAW, the MSAW considers the existence of different significance of experts' points of view due their differences in knowledge and experience. This is taken into account by introducing of weighed coefficients for each expert. The proposed MSAW is as follows:

$$A^* = \max \sum_{k=1}^{K} \lambda^k \sum_{i=1}^{M} \sum_{j=1}^{N} \left(w_j (a_{ij})_{norm}\right)^k \qquad (5)$$

$$\sum_{j=1}^{N} w_j = 1 \quad (6)$$

$$\sum_{k=1}^{K} \lambda^k = 1 \quad (7)$$

where λ^k express the weighted coefficients for expertise of the group members, K is number of experts (k = 1,…,K), i is index of alternatives (i = 1,…, M), j is index of evaluation criteria (j = 1,…,N), w_j is the coefficient for relative importance of *j-th* criterion, $\sum_{j=1}^{N}(w_j a_{ij})^k$ represents the performance of alternatives from the *k-th* expert' point of view.
The corresponding MSAW decision matrix is shown in Table 2.

Table 2. MSAW decision matrix

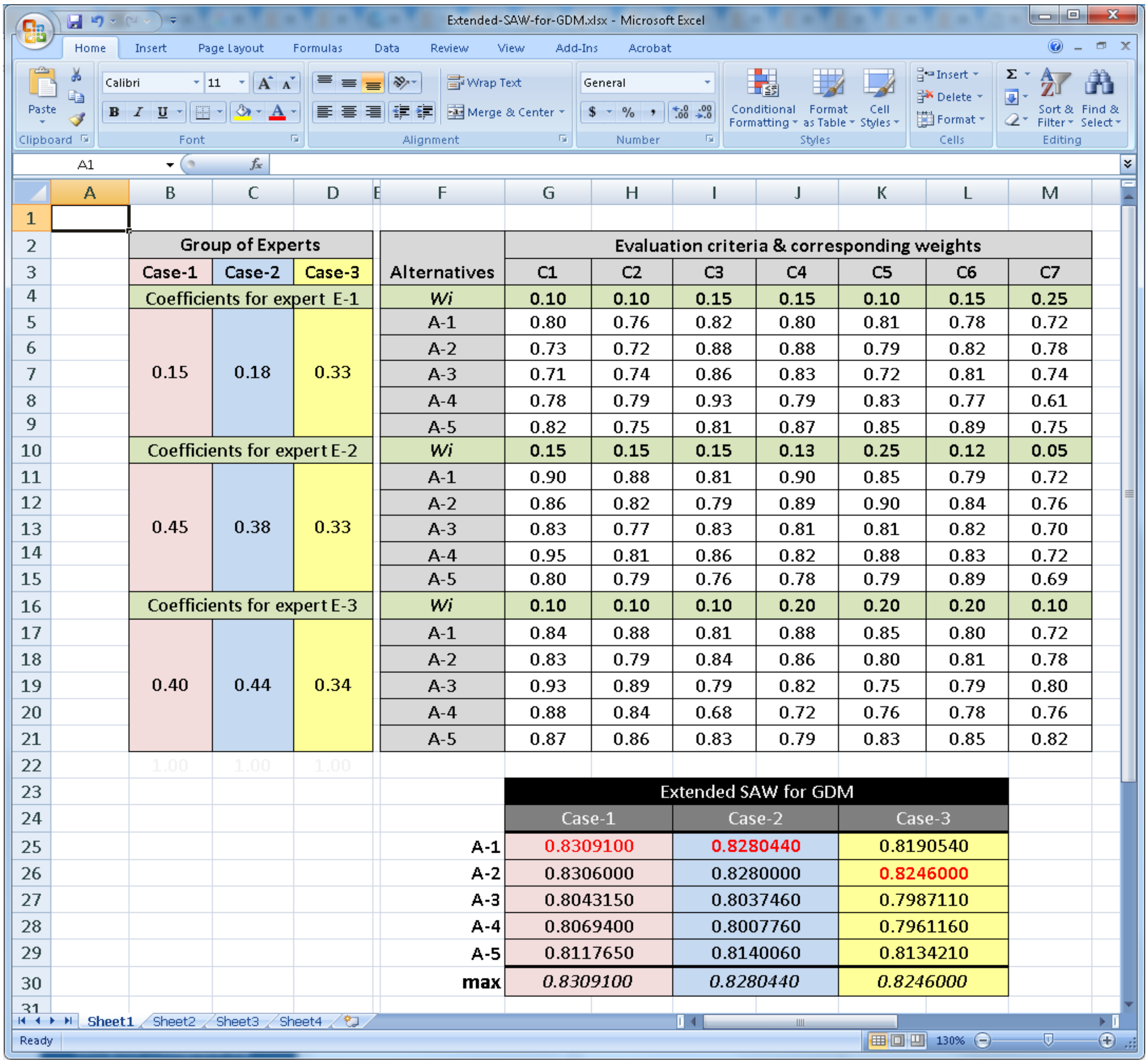
Experts & Weighted coefficients for their expertise	**Alternatives**	**Evaluation criteria & corresponding weights**			
		C_1	**C_2**	**…..**	**C_n**
E^1 **(λ^1)**		w_1^1	w_2^1		w_n^1
	A_1	$a_{1.1}^1$			$a_{1.n}^1$
	A_2	$a_{2,1}^1$			$a_{2.n}^1$
	….				
	A_m	$a_{m,1}^1$			$a_{m.n}^1$
…	….	…	…	…	…
E^k **(λ^k)**		w_1^k	w_2^k		w_n^k
	A_1	$a_{1.1}^k$			$a_{1.n}^k$
	A_2	$a_{2,1}^k$			$a_{2.n}^k$
	….				
	A_m	$a_{m,1}^k$			$a_{m.n}^k$

Source: made by authors

In MSAW decision matrix m is the number of alternatives, n is number of evaluation criteria, w_n^k is the weighted coefficient for *n-th* criterion defined by *k-th* expert, $a_{m.n}^k$ is the evaluation score for *m-th* alternative toward *n-th* criterion according to the opinion of *k-th* expert.
Using the formulation (5) – (7) allows to determine the optimal alternative taking into account not only alternatives evaluations ($a_{m.n}^k$) in accordance to the criteria and their relative importance (w_n^k) but also considering the weighted coefficients for expertise of the group members (λ^k). The used weighted coefficients for expertise of the group members' λ^k could be determined by high level managers or by other authorised person.

4. MS EXCEL APPLICATION

The proposed modified simple additive weighting for optimal choice is implemented as MS Excel tool. The described group decision making model (5) – (7) is used for determination of the optimal choice of BIS using real data. The corresponding Excel table is shown in Fig. 1.



Group of Experts				Evaluation criteria & corresponding weights						
Case-1	Case-2	Case-3	Alternatives	C1	C2	C3	C4	C5	C6	C7
Coefficients for expert E-1			Wi	0.10	0.10	0.15	0.15	0.10	0.15	0.25
0.15	0.18	0.33	A-1	0.80	0.76	0.82	0.80	0.81	0.78	0.72
			A-2	0.73	0.72	0.88	0.88	0.79	0.82	0.78
			A-3	0.71	0.74	0.86	0.83	0.72	0.81	0.74
			A-4	0.78	0.79	0.93	0.79	0.83	0.77	0.61
			A-5	0.82	0.75	0.81	0.87	0.85	0.89	0.75
Coefficients for expert E-2			Wi	0.15	0.15	0.15	0.13	0.25	0.12	0.05
0.45	0.38	0.33	A-1	0.90	0.88	0.81	0.90	0.85	0.79	0.72
			A-2	0.86	0.82	0.79	0.89	0.90	0.84	0.76
			A-3	0.83	0.77	0.83	0.81	0.81	0.82	0.70
			A-4	0.95	0.81	0.86	0.82	0.88	0.83	0.72
			A-5	0.80	0.79	0.76	0.78	0.79	0.89	0.69
Coefficients for expert E-3			Wi	0.10	0.10	0.10	0.20	0.20	0.20	0.10
0.40	0.44	0.34	A-1	0.84	0.88	0.81	0.88	0.85	0.80	0.72
			A-2	0.83	0.79	0.84	0.86	0.80	0.81	0.78
			A-3	0.93	0.89	0.79	0.82	0.75	0.79	0.80
			A-4	0.88	0.84	0.68	0.72	0.76	0.78	0.76
			A-5	0.87	0.86	0.83	0.79	0.83	0.85	0.82
1.00	1.00	1.00								

	Extended SAW for GDM		
	Case-1	Case-2	Case-3
A-1	0.8309100	0.8280440	0.8190540
A-2	0.8306000	0.8280000	0.8246000
A-3	0.8043150	0.8037460	0.7987110
A-4	0.8069400	0.8007760	0.7961160
A-5	0.8117650	0.8140060	0.8134210
max	*0.8309100*	*0.8280440*	*0.8246000*

Figure 1. Choice of BIS by group decision making via MSAW in MS Excel environment
Source: made by authors

The experts should evaluate the BIS alternatives by scores within values between 0 and 1, i.e. they are uniform and no normalization is needed. The higher value of estimation scores means better performance of alternative toward criteria, i.e. $a_{ij} = 1$ is used for the best performance and $a_{ij} = 0$ is used for the worst. The determination of the optimal alternative for BIS by MSAW and GDM is based on the following input data:

- Five BIS are considered as five possible alternatives: A-1 (*Tableau*), A-2 (*Quik View*), A-3 (*SAP Business Objects*), A-4 (*IBM Cognos Analytics*) and A-5 (*SQL Server*).
- These BIS are to be evaluated toward the following criteria: 1) deployment, 2) training, 3) support, 4) business-intelligence software features, 5) ease of use, 6) recommendations by other users, 7) price. The deployment criterion is focused on features as cloud, SaaS

(software as a service), Web, installations on Mac, Windows, mobile installations on Android Native, iOS Native. The criterion for training concerns organized activity related with instructions to improve the user's performance as documentation, webinars, live online and in person, while the criterion for support is focused on online support and support over business hours. BIS features are parameters: ad hoc analysis, ad hoc query, ad hoc reports, benchmarking, budgeting and forecasting, dashboard, data analysis, data visualization, key performance indicators, OLAP (online analytical processing), performance metrics, predictive analytics, profitability analysis, strategic planning, trend or problem indicators. Criterion for ease of use is expressed by hours needed to train before starting to use the product. The experience of other users of product is another criterion including information about satisfaction of customers, their complaints and recommendations, etc. The criterion about the price and different payment options (payment on delivery, payment in advance, deferred payment or decreasing of price per certain numbers of licenses and so on) is always worth to consider.

- The evaluation of these 5 BIS alternatives accordingly to the given 7 criteria are done by group of 3 experts. The group is composed of experts with different competency area: financial consultant (E-1), IT specialist (E-2), and final user of the product (E-3).

These input data are entered in cells G4:M21 (Fig. 1). The expert E-1 enters the coefficients for relative importance of each criterion in cells G4:M4. His evaluation scores of alternatives toward to criteria are entered in cells G5:M9. Expert E-2 enters his coefficients and evaluations in cells G10:M15 and expert E-3 fills up these data in cells G16:M21. Three different sets of weighting coefficients are used to simulate three different scenarios for various expertises of group members. These weighted coefficients express the difference in experts' knowledge and relation to the problem and are entered by high level managers in the cells B5:B9, B11:B15 and B17:B21 for Case-1, for Case-2 – in cells C5:C9, C11:C15 and C17:C21 and for Case-3 the corresponding cells are D5:D9, D11:D15 and D17:D21. The overall performance of alternative A-1 for Case-1, considering all data for it (weighted coefficients for evaluation criteria and evaluation scores of all 3 experts together with coefficients for expertise of experts') is calculated by mean of the formula in cell G25:

=B5*(G5*G4+H5*H4+I5*I4+J5*J4+K5*K4+L5*L4+M5*M4) +
B11*(G11*G10+H11*H10+I11*I10+J11*J10+K11*K10+L11*L10+M11*M10) +
B17*(G17*G16+H17*H16+I17*I16+J17*J16+K17*K16+L17*L16+M17*M16) (8)

The performance scores of alternative A-2 is calculated similarly as A-1 by using of the formula entered in cell G26:

=B5*(G6*G4+H6*H4+I6*I4+J6*J4+K6*K4+L6*L4+M6*M4) +
B11*(G12*G10+H12*H10+I12*I10+J12*J10+K12*K10+L12*L10+M12*M10) +
B17*(G18*G16+H18*H16+I18*I16+J18*J16+K18*K16+L18*L16+M18*M16) (9)

The overall scores of other alternatives are calculated as follows:

- for alternative A-3 in cell G27:

=B5*(G7*G4+H7*H4+I7*I4+J7*J4+K7*K4+L7*L4+M7*M4) +
B11*(G13*G10+H13*H10+I13*I10+J13*J10+K13*K10+L13*L10+M13*M10) +
B17*(G19*G16+H19*H16+I19*I16+J19*J16+K19*K16+L19*L16+M19*M16) (10)

- for alternative A-4 in cell G28:

=B5*(G8*G4+H8*H4+I8*I4+J8*J4+K8*K4+L8*L4+M8*M4) +
B11*(G14*G10+H14*H10+I14*I10+J14*J10+K14*K10+L14*L10+M14*M10) +
B17*(G20*G16+H20*H16+I20*I16+J20*J16+K20*K16+L20*L16+M20*M16) (11)

- for alternative A-5 in cell G29:

=B5*(G9*G4+H9*H4+I9*I4+J9*J4+K9*K4+L9*L4+M9*M4) +
B11*(G15*G10+H15*H10+I15*I10+J15*J10+K15*K10+L15*L10+M15*M10) +
B17*(G21*G16+H21*H16+I21*I16+J21*J16+K21*K16+L21*L16+M21*M16) (12)

In the same way the rest two cases (Case-2 and Case-3) are entered in the corresponding cells to obtain the alternatives performance (Fig. 1).
The best alternative performance in Case-1 is calculated in cell G30 as:

=MAX(G25:G29) (13)

For the rest 2 cases, the best alternative performance is calculated in the same way in cells I-30 and K30. The introduced weighted coefficients for the knowledge and experience of each of experts can be different according the specific problem which adds flexibility of the proposed modeling approach.

5. RESULTS AND DISSCUSION

The results by using the described approach implemented as MS Excel tool, considering 3 different cases of weighted coefficients for representation of the experts' importance are shown in Table 3.

Table 3. Results of application of MSAW for GDM

Case	Weighted coefficients for experts' importance			The most preferable alternative
	E-1	E-2	E-3	
Case-1	0.15	0.45	0.40	A-1
Case-2	0.18	0.38	0.44	A-1
Case-3	0.33	0.33	0.34	A-2

Source: made by authors

The solution results are illustrated graphically in Fig. 2 to visualize the performance of alternatives by using the proposed MSAW.
In Case-1, where the most important are the evaluations of expert E-2, followed by E-3 and E-1 the solution determines as optimal alternative A-1, closely followed by A-2 (Fig.2). In Case-2 where the most important are the evaluations of expert E-3, followed by E-2 and E-1 the optimal alternative is also alternative A-1 followed by A-2 (Fig.2). Case-3 expresses experts' points of view as equal importance and the corresponding optimal solution is the alternative A-2 (Fig. 2).
Using of weighted coefficients for the experts' evaluations importance allows determining optimal solution taking into account the differences in qualification and experience of expert to the investigated problem. The numerical results prove the effectiveness of proposed approach for group decision making and could be used for different real life problems.

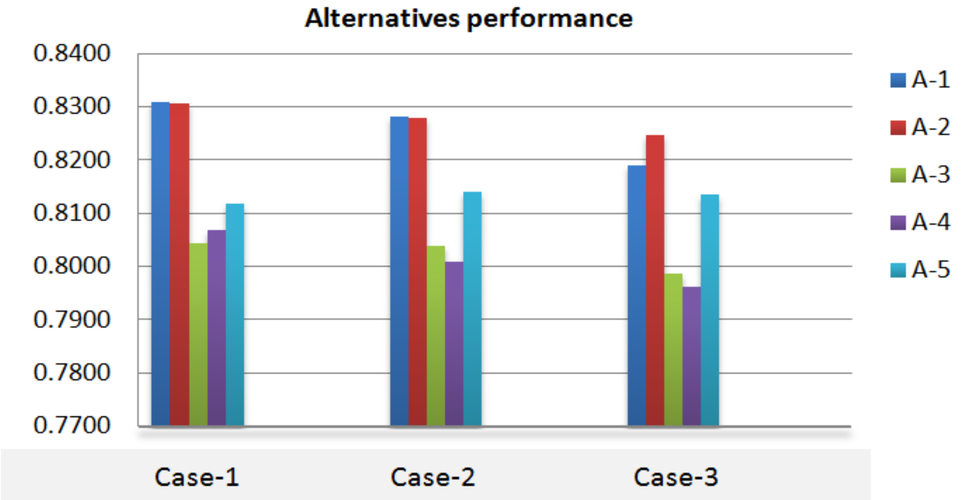


Figure 2. Graphical illustration of alternatives performance by MSAW for GDM
Source: made by authors

In contrast to the classic MADM methods, the proposed modification of classical SAW includes new utility function and adds additional restriction concerning weighted coefficients for the group members' expertise. This provides flexibility that better reflects the real life scenarios for GDM than classical SAW.
The described structure of MS Excel spreadsheet can be modified to meet the requirements of other problems for choice by group decision making considering experts' importance. The increasing number of columns will correspond to more evaluation criteria, while additional rows will reflect in increasing of the number of alternatives and group members.

6. CONCLUSIONS

In the article is proposed modified simple additive weighting approach. The distinguish feature of this modification is introducing of weighted coefficients expressing the differences of group members evaluations' importance. For the goal, a new formulation of utility function is proposed and additional restriction for experts' weighted coefficients is included. This feature is essential to get more grounded and reasonable determination of the best alternative by group decision making techniques for many real life applications. The users of the described Excel tool should structure the data for other type of problems following five basic components: 1) evaluation criteria, 2) coefficients for criteria importance, 3) set of alternatives, 4) group of experts and 5) weighted coefficients for group' members expertise. By the described framework of MS Excel spreadsheet, all of these input data will determine the optimal alternative while considering different experts' points of view.
Future developments of the proposed approach are related to the use of other methods based on the multi-attribute utility theory, in terms of the possibilities to apply different levels of knowledge and experience of experts in the group decision making process.

REFERENCES

Borissova, D. (2008). Optimal scheduling for dependent details processing using MS Excel Solver. *Cybernetics and Information Technologies*, Vol. 8(2), 102–111.

Borissova, D., Mustakerov, I. (2012). An integrated framework of designing a decision support system for engineering predictive maintenance. *International Journal Information Technologies & Knowledge*, *6*(4), 366–376.

Dyer, J., S. (2005). *Maut – Multiattribute Utility Theory. In: Multiple Criteria Decision Analysis: State of the Art Surveys*. International Series in Operations Research & Management Science, doi: https://doi.org/10.1007/0-387-23081-5_7.

Geldermann, J., & Schobel, A. (2011). On the similarities of some multi-criteria decision analysis methods. *Journal of Multi-Criteria Decision Analysis*, *18*, 219–230.

Hwang, C., L., Yoon, K. (1981). *Multiple attribute decision making: Methods and applications: a state-of-the-art survey*. Lecture Notes in Economics and Mathematical Systems, Springer-Verlag.

Jablonsky, J. (2014). MS Excel based software support tools for decision problems with multiple criteria. *Procedia Economics and Finance*, *12*, 251–258.

Keeney, R., L., Raiffa, H. (1993). *Decisions with Multiple Objectives: Preferences and Value Trade-offs*. Wiley, New York, 569 pages.

Korsemov, D., Borissova, D., Mustakerov, I. (2018). Combinatorial optimization model for group decision-making. *Cybernetics and Information Technologies*, *18*(2), 65–73.

Lee, L., Anderson, R. (2009). A comparison of compensatory and non-compensatory decision making strategies in IT project portfolio management. *International Research Workshop on IT Project Management 2009*. Retrieved from http://aisel.aisnet.org/irwitpm2009/9.

Mulliner, E., Malys, N., Maliene, V. (2016). Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. *Omega*, *59*, 146–156.

Mustakerov, I., Borissova, D. (2013). A combinatorial optimization ranking algorithm for reasonable decision making. *Comptes rendus de l'Academie bulgare des Sciences*, *66*(1), 101–110.

Perzina, R., Ramik, J. (2014). Microsoft Excel as a tool for solving multicriteria decision problems. *Procedia Computer Science,* 35, 1455–1463.

Rao, R., V. (2013). *Decision making in the manufacturing environment using graph theory and fuzzy multiple attribute decision making methods*. Springer Series in Advanced Manufacturing. DOI: 10.1007/978-1-4471-4375-8_1, Springer-Verlag, London.

Sureeyatanapas, P., Sriwattananusart, K., Niyamosoth, Th., Sessomboon, W., Arunyanart, S. (2018). Supplier selection towards uncertain and unavailable information: An extension of TOPSIS method. *Operations Research Perspectives*, *5*, 69–79.

Triantaphyllou, E. (2000). Multi-criteria decision making methods. In: *Multi-criteria Decision Making Methods: A Comparative Study*. *Applied Optimization*, *44*, 320 pages https://doi.org/10.1007/978-1-4757-3157-6_2.