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Material handling equipment selection problem: decision making in the domain of logistics systems

Abstract:
The selection procedure is not sufficiently structured, depends on broad areas of knowledge, and requires the use of efficient and effective tools for decision-making. In this study, an integrated approach which employs the fuzzy analytic hierarchy process (F-AHP) and the modified preference ranking organization method for enrichment evaluations (MODIPROM) together is proposed for the optimal selection of material handling equipment. The proposed method is extended with the possibility of taking into account the linguistic expressions of the importance and value of alternative criteria as well as reduction of the number of criteria at the operational and acceptable level.

Keywords: multi-criteria decision making, fuzzy AHP, MODIPROM, criteria, rank

Introduction

As a process, material handling incorporates a wide range of equipment and systems that support logistics and make the logistics system work. Overall, in solving material movement problems, especially the material handling equipment selection as elements of the supply chain there is no ideal solution, i.e. certain questions must be answered before a process of conceptual solving of the transportation and storage system. The application of modern methods for planning the storage system is practically implemented through three main phases: definition of relevant alternatives, evaluation and selection of alternatives, and dynamic analysis of the selected alternative. Generally, while considering any selection problem in the domain of logistics and logistics systems there is a great number of technically feasible alternatives, and the task of designer is to choose from the set of possible solutions the one that best meets the technical and economic conditions defined by the terms of reference. While solving any problem, we can adopt various numbers and kinds of criteria depending on the corresponding decisions and information available. Also, a unique set of criteria of the considered problem is not usually available to a decision maker. A combination of methods for reducing the number of independent criteria, methods for determining the relative importance of the criteria and modified methods for ranking of alternatives leads to making optimal decisions on these problems regardless of the nature of the parameters that describe it. The specificity of the presented approach is the possibility of taking into account the linguistic expressions of the importance and value of criteria.

Proposed integrated approach

The integrated approach (FAMOD) [4] is a combination and expansion of some formulated models for determining relative weights and ranking alternatives of the considered problem and also for a sensitivity analysis of the final order of alternatives due to changes in criteria relative weights. The proposed algorithm of integrated approach, with all the above elements, is shown in Fig. 1. For numerical illustration, the optimal solution of a three-wheel electric forklift in a warehouse should have low costs, larger load capacity, travel speed and lifting height, high safety and ergonomics as well as a smaller width and turning radius. The presented method for decision-making is carried out in several stages already mentioned, for multiple criteria scenario (in this case divided into the group of technical characteristics and costs (Fig.3)), and with the possibility of taking into account the linguistic expressions of the importance of criteria. For numerical illustration, in the first phase an initial set of alternatives is reduced from 25 to 7 alternatives of forklifts that satisfy the required parameters in advance. Their initial values are collected from a database created from appropriate catalogues.

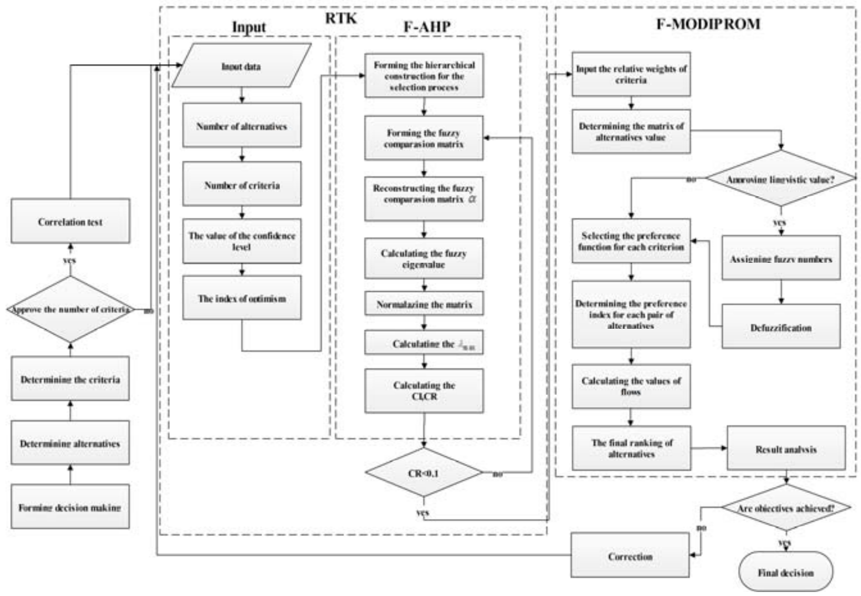

Fig.1 The integrated approach - FAMOD

The final order of alternative solutions depends on the applied technique of multi-criteria decision-making and, especially, on the procedure of defining the evaluation criteria, transformation (normalization) of criteria and determination of their relative importance. Subjective decisions are crucial in the process of determining the relative weight of criteria, and there is a tendency in literature to express the subjective opinion on the weights of criteria through pairwise comparing of criteria [2, 5, 6, 7]. However, the classical technique makes the process of comparison too complicated for collecting the assessment of decision-makers, so fuzzy logic, i.e. the fuzzy analytic hierarchy process technique (F-AHP) [4] is used in order to eliminate this shortcoming in the comparison at all hierarchical levels of the problem. The application of the described methodology of determining the relative weights was performed using the software tool developed for this purpose (Fig. 2). The procedure of this approach can be presented through the determination of relative strength of two elements at the same level of hierarchy by using triangular fuzzy numbers $(\tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9})$ and the determination of fuzzy eigenvalues which represent the solution of the system:

$$\tilde{A}\tilde{x} = \tilde{\lambda}\tilde{x} \tag{1}$$

$\tilde{A}$ is - *n x n* fuzzy matrix which contains fuzzy numbers $\tilde{a}_{ij}$, $\tilde{x}$ is a *n x 1* fuzzy eigenvector containing the fuzzy numbers $\tilde{x}_i$. Interval arithmetic is used for all operations:

$$\begin{aligned} &\forall \alpha \in [0,1] \\ &\tilde{A}\alpha = [l\alpha, u\alpha] = [(m-l)\alpha + l, u-(u-m)\alpha] \end{aligned} \tag{2}$$

$$\begin{aligned} a_{i1l}^{\alpha}x_{il}^{\alpha} + \cdots + a_{inl}^{\alpha}x_{nl}^{\alpha} &= \lambda x_{il}^{\alpha} \\ a_{i1u}^{\alpha}x_{iu}^{\alpha} + \cdots + a_{inu}^{\alpha}x_{nu}^{\alpha} &= \lambda x_{iu}^{\alpha} \end{aligned}$$

$$\tilde{a}_{ij}^{\alpha} = \left[a_{i1l}^{\alpha}, a_{i1u}^{\alpha}\right], \tilde{x}_i^{\alpha} = \left[x_{il}^{\alpha}, x_{iu}^{\alpha}\right], \tilde{\lambda}^{\alpha} = \left[\lambda_l^{\alpha}, \lambda_u^{\alpha}\right] \text{ for } 0 < \alpha \le 1 \text{ и } i=1,2,\ldots,n,\ j=1,2,\ldots,n. \tag{3}$$

where: *l*-lower limit and *u*-upper limit of the fuzzy number (*l, m, u*) [1].

Besides, the developed tool enables decision-makers to use different values of the confidence level and index of optimism as input in the interval [0, 1] and show their influence on the final results. The program automatically generates the α-cuts matrix (Table 1), performs normalization of the matrix from the previous step and determines the fuzzy eigenvalues (Table 2), i.e. the relative weights of criteria (Fig. 2) and the consistency ratio. The application of the decision-making combined approach, after defining the set of independent criteria and determining their relative weight, in the next phase includes the possibility of taking into account the linguistic expressions of the importance and value of alternative criteria.

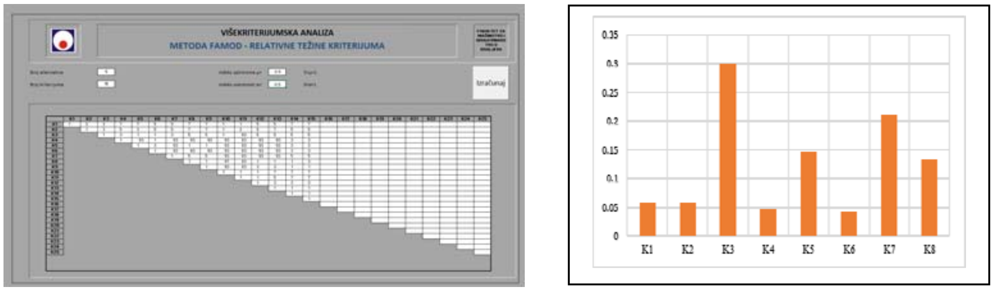

Fig.2 The RTK program user interface and the final result of criteria relative weights - FAMOD

Table 1. α-cut matrix for the observed problem

Criterion	K1	K2	K3	K4	K5	K6	K7	K8
K1	1	1.25	0.144345	3	0.354167	1.25	0.204167	0.354167
K2	0.875	1	0.144345	3	0.354167	1.25	0.354167	0.354167
K3	7	7	1	5	3	5	1.25	3
K4	0.354167	0.354167	0.204167	1	0.204167	3	0.204167	0.354167
K5	3	3	0.354167	5	1	5	0.354167	1.25
K6	0.875	0.875	0.204167	0.354167	0.204167	1	0.354167	0.354167
K7	5	3	0.875	5	3	3	1	1.25
K8	3	3	0.354167	3	0.875	3	0.875	1

Table 2. The fuzzy eigenvalues for the observed problem

Criterion	K1	K2	K3	K4	K5	K6	K7	K8
K1	0.047	0.064	0.044	0.118	0.039	0.056	0.044	0.045
K2	0.041	0.051	0.044	0.118	0.039	0.056	0.077	0.045
K3	0.332	0.359	0.305	0.197	0.334	0.222	0.272	0.379
K4	0.017	0.018	0.062	0.039	0.023	0.133	0.044	0.045
K5	0.142	0.154	0.108	0.197	0.111	0.222	0.077	0.158
K6	0.041	0.045	0.062	0.014	0.023	0.044	0.077	0.045
K7	0.237	0.154	0.267	0.197	0.334	0.133	0.218	0.158
K8	0.142	0.154	0.108	0.118	0.097	0.133	0.190	0.126

The criteria used for the selection of optimal solutions are given in Fig. 3 (costs: fixed and variable, load capacity, travel speed, lifting height, turning radius, width, and safety and ergonomics).

Alternatives	Fixed costs euro/h	Variable costs euro/h	Load capacity (kg)	Travel speed (km/h)	Turning radius (mm)	Width (mm)	Lifting height (mm)	Safety and ergonomics
A1	medium (0,475)	medium (0,5)	1500	16	2070	1000	3320	very good (0,717)
A2	medium (0,475)	medium (0,5)	1600	16	2070	1000	3320	excellent (0,916)
A3	medium (0,475)	medium (0,5)	1800	16	2070	1000	3390	excellent (0,916)
A4	medium (0,475)	medium (0,7)	1500	12	2055	800	3310	good (0,543)
A5	medium (0,475)	high (0,7)	1600	14.5	2110	1070	3300	very good (0,717)
A6	medium (0,475)	high (0,7)	1800	16	2110	1070	3300	good (0,543)
A7	medium (0,475)	high (0,7)	1500	12	1980	1000	3320	good (0,543)

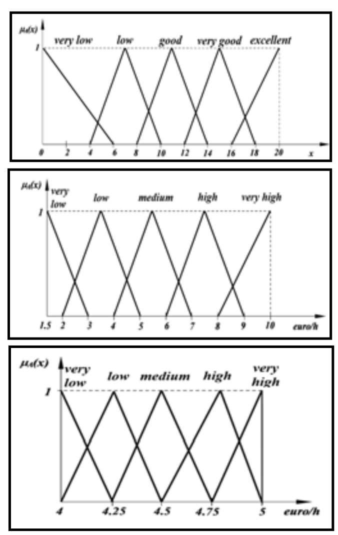

Fig. 3 The matrix of alternative values and fuzzy membership function

The criteria fixed and variable costs as well as safety and ergonomics are defined as linguistic terms, while the others are defined as numerical values. The solution would be the use of fuzzy algorithms or converting linguistic terms and fuzzy numbers into real (in the case of linguistic terms, we first convert them into fuzzy numbers and then into real numbers), which would enable the use of some classic methods of optimization. The next step should be conversion of fuzzy numbers into real – defuzzification phase, so the result of this phase is a decision matrix, which contains only crisp data. Three triangular fuzzy numbers are defined with the corresponding intensity of importance (Fig. 3). With conversion scales it is easy to convert linguistic terms into a fuzzy number. The defuzzification method (Centre of Gravity) was performed using the software tool developed for this purpose (Fig. 4). In the next stage, the predefined alternatives are evaluated on the basis of the adopted criteria and their relative weights (MODIPROM) [3]. Also, the proposed procedure is based on the improvement of the family of methods for multi-criteria ranking (PROMETHEE) through a change of the existing generalized criteria and introduction of the new ones, i.e. the generalized criterion in which the sum of squares of deviations of experimental points from the theoretical curve is the least chosen on the basis of the method of the least squares.

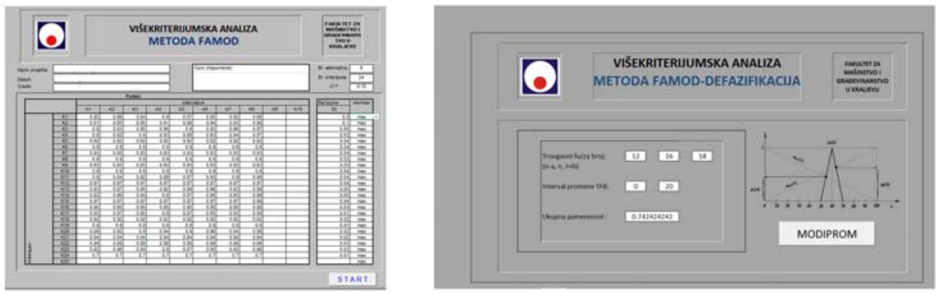

Fig. 4 The FAMOD user interface - Matrix of alternative values and fuzzy membership function

Table 3. Input data for multi-criteria analysis

Criteria	Alternatives							ω_j	max/ min
	A_1	A_2	A_3	A_4	A_5	A_6	A_7		
K_1	0,475	0,475	0,475	0,475	0,475	0,475	0,475	0.145	min
K_2	0,5	0,5	0,5	0,7	0,7	0,7	0,7	0.142	min
K_3	1500	1600	1800	1500	1600	1800	1500	0.032	max
K_4	16	16	16	12	14,5	16	12	0.019	max
K_5	2070	3070	2070	2055	2110	2110	1980	0.032	min
K_6	1000	1000	1000	800	1070	1070	1000	0.048	min
K_7	3320	3320	3390	3310	3300	3300	3320	0.047	max
K_8	0,717	0,717	0,916	0,543	0,717	0,543	0,543	0.018	max

Table 4. The values of index of preference

		The values of index of preferences P(a,b) relative to alternatives							
		A1	A2	A3	A4	A5	A6	A7	Output flow
Examined alternatives	A1	0	0	0	0.1568931	0.18686	0.207601	0.1192212	0.67058
	A2	0.1368125	0	0	0.3062681	0.258047	0.291351	0.2685962	1.26108
	A3	0.48885803	0.3239205	0	0.6327498	0.519485	0.393414	0.6206417	2.97907
	A4	0.04918231	0.0491823	0.0491823	0	0.160956	0.160956	0.033	0.50246
	A5	0.065625	0	0	0.1677033	0	0.029313	0.1677033	0.43034
	A6	0.253125	0.159375	0	0.3430337	0.167946	0	0.3430337	1.26651
	A7	0.12129108	0.1212911	0.1212911	0.1438806	0.261149	0.261149	0	1.03005
	Input flow	1.11489392	0.6537689	0.1704734	1.7505285	1.554443	1.343783	1.5521961	

After defining the criteria given for each alternative and the corresponding transformation of the criterion type min. into the type max. (Fig. 4), the values of the index of preference in accordance with each criterion are given in Tables 3 and 4. The comparative analysis of the results of ranking alternative proper equipment and the proposed procedure for the observed case lead to the conclusion that the conceptual solution (alternative 3 A3) exceeds all limits and represents the best solution. In order to confirm the results obtained by the combined approach and prove its applicability and practicality, the considered problem is analyzed using standard methods of multi-criteria analysis (TOPSIS method). Changes in the order (A3>A2>A5>A1>A6>A7>A4) once again highlight the importance of determining the relative phases of weight in the process of multi-criteria analysis. This study points out that solving the problem of decision-making firstly requires definition of the criteria system and then determination of their relative importance before final ranking of the considered multi-criteria problem alternatives.

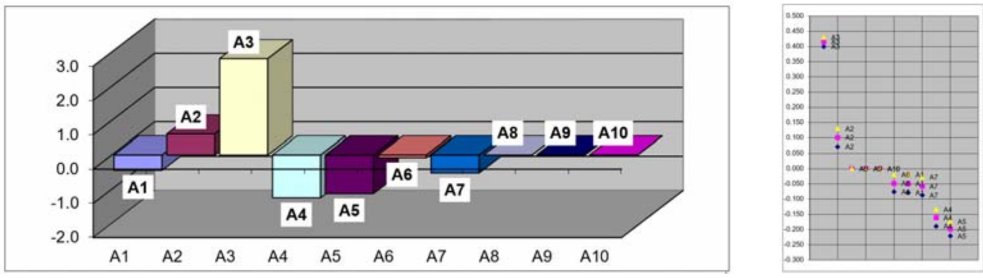

Fig. 5 Final ranking of alternatives

The specificity of the presented approach is the possibility for obtaining a set of independent criteria or reduction of their number to the operational and acceptable level for determining the relative weight. In order to analyze statistical significances of differences between the initial and the reduced numbers of criteria the program tool that uses a special type of correlation test - Spearman’s rank correlation test, is developed. With such a tool developed, it is possible to compare the results of ranking the reduced and the initial sets of criteria for a given level of significance, and also compare the outputs of ranking obtained using a different multiple criteria analysis approach.

Conclusion

The proposed approach is a combination and expansion of certain models formulated so far. In this approach, there is a tendency to edit and possibly standardize multi-criteria methods, where the major premise is that it is easier to express a subjective opinion on relative weights of the criteria by comparing the criteria pairwise rather than all at once. The specificity of the approach is the function of preference, change in the existing generalized criteria and the introduction of new ones, automated procedure for the selection of generalized criteria and analysis of the influence of changes in relative weights on the final order of the alternatives. The proposed method is extended with the possibility of taking into account the linguistic expressions of the importance and value of alternative criteria as well as reduction of the number of criteria at the operational and acceptable level. Such an approach would result in the formation of a comprehensive tool for solving a wide range of real and practical problems.

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