THE PAPER IN ENGLISH

UDC 658.286.2-52:658.78 https://doi.org/10.18503/2222-9396-2019-9-1-4-20

A MULTI-CRITERIA MODEL FOR EVALUATION AND SELECTION OF AGV'S IN A WAREHOUSE

Stojčić Mirko[1], Stević Željko[1], Nikolić Andrej[1], Božičković Zdravko[1]

[1] University of East Sarajevo, Faculty of Transport and Traffic Engineering, Doboj, Bosnia and Herzegovina

Abstract

A set of tools, devices, applications aimed at facilitating the handling of material and products in a warehouse, but also between, for example, a warehouse and a plant, represent Material Handling Equipment. The important type of material handling equipment is automatic guided vehicles (AGV) which play a key role in warehouse automation. The advantages set by AGVs in the warehouse automation process are reducing staff costs and labor costs, increased reliability and productivity, reduced damage of goods, improved security, managing and controlling a complete system, etc. In the paper, a hybrid FUCOM-EDAS model is applied to select an AGV vehicle. The FUCOM method is used to determine weight coefficients, and EDAS to obtain the best solution. The selection is based on nine AGV vehicles and seven criteria. To evaluate the stability of the obtained results and the applied model, the assessment and ranking of alternatives is performed by WASPAS, SAW, MABAC and ARAS methods. Preliminary results show that two alternatives are best, since the same results were obtained by all four methods, with priority given to the alternative A5.

Keywords: AGVs, FUCOM method, EDAS method, Material Handling Equipment, WASPAS, SAW, MABAC, ARAS.

1. Introduction*

Currently, logistics has been constantly facing new challenges and changing faster than in any other period of time. The most obvious change is the increased application of a new technologies, especially information and communication technologies. Its application and role are visible on every step such as electronic identification of packages, satellite tracking of vehicles, automatic guided vehicles, etc. One of the areas affected by new logistics trends is a warehousing subsystem. From the history, warehouses have faced many changes, i.e. various technologies have been implemented in warehouses, depending on when each of them was active. Currently, we are witnessing that warehouses could be fully automated. Many technological processes in a warehouse have been automated, from receiving and dispatch, internal transportation, packaging, commissioning, etc. A set of tools, devices, applications aimed at facilitating the handling of material and products in a warehouse, but also between, for example, a warehouse and a plant, represent Material Handling Equipment. The most general listed equipment consists of four basic categories such as storage and handling equipment, engineered systems, industrial trucks, equipment for bulk material handling [1]. The main aim of applying new technologies for the mentioned purpose is to save in energy and work force, which also significantly reduce the price of the final product [2]. The selection and configuration of equipment for carrying out material handling tasks is very sophisticated since there are numerous limitations, opposing criteria, uncertainty, a wide range of equipment, etc. [3]. There are various methods for selecting optimal equipment, and most of them are based on multi-criteria decision-making along with intelligent solutions such as fuzzy logic [4,5]. In the paper [6], an expert system was developed to select the optimum equipment for delivering the materials within a factory. In [7] combined fuzzy sets, the Analytic Network Process and PROMETHEE method. The AHP method creates a hierarchical structure by forming levels and sublevels [8]. The integration of the AHP method and expert systems was proposed in [9], within the MHESA (Material Handling Equipment Selection Advisor) system. A hybrid method that involves the application of expert systems, fuzzy logic and genetic algorithms was presented in [10].

The important type of material handling equipment is automatic guided vehicles (AGV) which play a key role in warehouse automation. The advantages set by AGVs in the warehouse automation process are reducing staff costs and labor costs, increased reliability and productivity, reduced damage of goods, improved security, managing and controlling a complete system, etc.

The main purpose of this paper is to evaluate and select an appropriate AGV for performing operations in the warehouse system by using a hybrid FUCOM-EDAS model. To the best of our knowledge, there is no studies in the combination of FUCOM-EDAS methods to study the evaluation and selection of AGVs in a warehouse.

The rest of the paper is organized as follows. The first part contains introduction. The second section lies in the detailed review of the methods used in the work, which is the FUCOM method for obtaining weight coefficients and the EDAS method for obtaining the best solution of the set model. In the third section, the types of AGVs are analyzed. The basic functions of these vehicles are also described in detail. In the fourth section, the selection of AGVs is performed based on nine alternatives, i.e. nine automatic guided forklift trucks and seven criteria that are most commonly used in the selection and implementation of these vehicles into a warehouse system. In the fifth section, a sensitivity analysis is performed using WASPAS, SAW, MABAC and ARAS methods. Finally, certain conclusions are given.

2. Methods

By applying multi-criteria decision-making methods, it is possible to select appropriate strategies, rationalize certain logistic and other processes, and make appropriate decisions that have an impact on the operations of companies or their subsystems, as evidenced by the following studies [11–16].

This paper proposes the application of two methods the FUCOM method for obtaining weight coefficients and EDAS method for obtaining the best of potential solutions. Additionally, within the stability evaluation of the obtained results and the applied model, the assessment and ranking of alternatives are performed using WASPAS, SAW, MABAC and ARAS method.

2.1 The FUCOM method

The FUCOM method was developed by Pamučar, Stević and Sremac [17] for determining the weights of criteria. According to the authors, this new method is better than AHP (Analytical Hierarchy Process) and BWM (Best Worst Method).

FUCOM provides a possibility to validate the model by calculating the error size for obtained weight vectors, by determining the degree of consistency. On the other hand, in other models for determining the weights of criteria, the BWM [18] and the AHP [19] model, redundancy in pairwise comparison appears which makes them less susceptible to errors in judgment, while the methodological procedure of FUCOM eliminates that problem.

We aim to present the procedure for obtaining weight coefficients of criteria by applying FUCOM.

Step 1. In this step, the criteria from the predefined set of the evaluation criteria $C = \{C_1, C_2, ..., C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} . \quad (1)$$

Step 2. In this step, a comparison of the ranked criteria is carried out and the comparative priority ($\varphi_{k/(k+1)}$, k=1,2 …, n, where k represents the rank of the criteria) of the evaluation criteria is determined

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, ..., \varphi_{k/(k+1)}\right). \quad (2)$$

Step 3. In this step, the final values of the weight coefficients of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the following two conditions:

a) The ratio of the weight coefficients is equal to the comparative priority among the observed criteria $\varphi_{k/(k+1)}$ defined in Step 2, i.e. the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} ; \quad (3)$$

b) In addition to Condition (3), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.

Since $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\varphi_{(k+1)/(k+2)} = w_{(k+1)}/w_{(k+2)}$,

$\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained.

Thus, another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} . \quad (4)$$

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned} & \min \chi, \\ & s.t. \\ & \left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| = \chi, \ \forall j, \\ & \left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| = \chi, \ \forall j, \\ & \sum_{j=1}^{n} w_j = 1, \ \forall j, \\ & w_j \geq 0, \ \forall j. \end{aligned} \quad (5)$$

By solving the model (5), we obtain the final values of evaluation criteria $(w_1, w_2, ..., w_n)^T$ and the degree of consistency (χ) of the results obtained.

2.1 The EDAS method

The EDAS method was developed by [20] for the multi-criteria classification of inventories. The steps of this method are presented below:

Step 1. Select the most important criteria that describe alternatives.

Step 2. Form an initial decision-making matrix as shown:

$$X = \left[x_{ij}\right]_{nm} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ x_{31} & x_{32} & \cdots & x_{3m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}, \quad (6)$$

where x_{ij} denotes the values of the i^{th} alternative according to the j[th] criterion.

Step 3. Determine the average solution according to all the criteria as shown:

$$AV = \left[AV_j\right]_{1m}, \quad (7)$$

where

$$AV_j = \frac{\sum_{i=1}^{i=n} X_{ij}}{n}. \tag{8}$$

Step 4. Calculate the positive distance from average (*PDA*) and negative distance from average (*NDA*) matrices depending on the type of criteria (benefit or cost) according to the following expressions:

$$PDA = \left[PDA_{ij} \right]_{nm}, \tag{9}$$

$$NDA = \left[NDA_{ij} \right]_{nm}. \tag{10}$$

If the criterion is of beneficial type,

$$PDA_{ij} = \frac{\max\left(0, \left(X_{ij} - AV_j\right)\right)}{AV_j}, \tag{11}$$

$$NDA_{ij} = \frac{\max\left(0, \left(AV_j - X_{ij}\right)\right)}{AV_j}, \tag{12}$$

and if it is a cost criterion,

$$PDA_{ij} = \frac{\max\left(0, \left(AV_j - X_{ij}\right)\right)}{AV_j}, \tag{13}$$

$$NDA_{ij} = \frac{\max\left(0, \left(X_{ij} - AV_j\right)\right)}{AV_j}, \tag{14}$$

where PDA_{ij} and NDA_{ij} denote the positive and negative distance of the i^{th} alternative from the average solution in accordance to the j criterion, respectively.

Step 5. Determine the weighted sum of *PDA* and *NDA* for all alternatives as follows:

$$SP_i = \sum_{j=1}^{j=m} w_j PDA_{ij}, \tag{15}$$

$$SN_i = \sum_{j=1}^{j=m} w_j NDA_{ij}, \tag{16}$$

where w_j is the weight of j^{th} criterion.

Step 6. Normalization of *SP* and *SN* values for all alternatives according to the following expressions:

$$NSP_i = \frac{SP_i}{\max_i (SP_i)}, \tag{17}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i (SN_i)}. \tag{18}$$

Step 7. The appraisal score (*AS*) for all alternatives according to the following expression:

$$AS_i = \frac{1}{2}\left(NSP_i + NSN_i\right), \tag{19}$$

where $0 \le AS_i \le 1$.

Step 8: Rank alternatives according to decreasing values of appraisal score (*AS*). The alternative with the highest *AS* is the best choice among the potential alternatives.

3. AGVs

Automatic guided vehicles are defined as self-power vehicles, with their own energy source and handling devices, intended for the transportation of materials. Another definition of automatic guided (managed) vehicles, also known as AGVs, says that these are unmanned ground transportation vehicles that are computer controlled, most electrically powered with batteries. It is important to highlight that these vehicles are without drivers, i.e. they can function without operators, with a special emphasis on the fact that the costs reduced by worker's salary in non-automated processes are up to about 75% of the cost. The beginning of the use of automatic guided vehicles is linked to the achievement of the American company Barrett Vehicle Systems, which in 1954 for the first time managed to automate a single towing vehicle with mechanical guidance, in a way that a wire was placed above a vehicle. Then, development and further automation moved to Germany, and since 1963, the first companies were Jungheinrich and Wagner. Since 1970, automatic guided vehicles (AGVs) have been involved in material flow processes and in hospitals [21].

The AGV system consists of a vehicle, a control system, and additional necessary equipment. Modern ground vehicles are controlled by microprocessors built into them, and most of them are monitored by a control system that optimizes their work. It generates and distributes orders for transportation, monitors vehicles with their loads and serves as a traffic light for movement through a warehouse based on priorities [22].

3.1 The types of AGVs

The systems of automatic guided vehicles are very interesting and useful since they offer a high degree of flexibility and automation in material transportation. In contrast to many other material transportation systems, AGV systems rarely require a specific construction to support the transportation of materials and goods. With the development of AGVs and the application of automation and a high degree of flexibility, today we distinguish many types of vehicles in terms of the weight of load they can transport. Load capacity varies from less than 1 kg to up to 100 t. We distinguish several types of AGVs:

- towing vehicles;
- unit load vehicles;
- pallet trucks;
- forklift trucks;
- special-purpose vehicles.

Towing vehicles were the first type of those vehicles and have been used today. They are the oldest and most popular type of AGVs. They can pull several trailers/wagons and have a capacity ranging from four to 25 tons. They are usually applied to the transportation of loads to/from a warehouse (receiving and dispatch zone), and since it refers to large quantities of material, they are mostly used for loading and unloading the vehicles of external transportation.

Unit load AGV with a loading space is also a type of vehicle that is used for the transportation of goods loaded onto a platform on the vehicle and their transfer. These vehicles are also referred to as vehicles of unit loads (pallets, boxes, individual pieces) and most often they also have automatic load transfer (using a lifting deck, chain, band or roller conveyor). They are used for transportation at shorter distances with high flow rates, and due to the ability to automatically connect to conveyors, workstations, devices and AS/RS systems, they are often integrated into an automated manufacturing or warehousing system.

Automatic guided pallet trucks are designed for the transportation of palletized materials, loading from the ground and unloading onto the ground, where pallets are lifted several centimeters from the ground, thus eliminating the need for fixed places for the deposition of load units. Loading of such vehicles can be in two ways: with automatic loading (necessity of correct positioning for loading) and with manual loading (need for operator's handling the vehicle when loading).

Automatic guided forklift trucks are the newest type of AGVs. In their appearance and function, they are similar to the classic versions of forklifts. In addition to transportation, the ability to transfer palletized material not only at ground level but also at higher levels makes them suitable and justified for application into the systems where full automation and greater flexibility in connecting with other subsystems are required. The latest trend of automatic guided forklift trucks enables automated delivery, application in warehousing, loading and unloading of goods into/out of the warehouse, and also enables load transfer into vehicles of external transportation (trucks, etc.) without manual control. Special-purpose automatic guided vehicles are vehicles for carrying heavy loads up to 65 tons of irregular shape.

3.2 Main functions of AGVs

In order for the systems of automatic guided vehicles to function in a warehouse where they are installed and to carry out their tasks without difficulty, it is essential that they have the ability to accomplish several basic functions, such as:

- guidance;
- routing;
- traffic management;
- load transfer;
- system management.

The guidance of AGVs can be divided into two basic categories, i.e. two basic principles. The first category is based on the principle of fixed paths. The second category is based on the principle of free paths. The principles of guidance that belong to fixed-path guidance are mechanical guidance, inductive guidance, and optical guidance, while laser guidance is applied for free guidance.

AGVs must have a system for determining the path of movement, for example, throughout a warehouse where it has to perform several tasks. This problem is solved with several different methods. Routing the vehicle is the selection of the route of movement in terms of choosing an optimal route towards a particular destination. There are two methods of routing automatic guided vehicles: a frequency selection method and a selection method with a switch.

Traffic management is the ability of a system or vehicle to avoid collisions while maximizing the flow of vehicles and materials. There are three types of traffic management: zone control, sensor control, and combinatorial control.

Load transfer includes the method of loading and unloading, which can be simple or integrated within other subsystems. There are various methods of load transfer, some of which are a manual method, a method of automatic connection and separation, a method of load transfer by rolling, belt or chain conveyor and a lifting and lowering method.

Management implies the methods of controlling the system used for its operation. It can be divided into two areas: vehicle-dispatch methods and system-monitoring methods.

4. The selection of AGVs

For the selection of AGVs, two methods was used, the FUCOM method for determining weight coefficients and the EDAS method for obtaining the best solution. The selection was based on nine AGVs and seven criteria.

4.1 Forming a multi-criteria model

It has been considered an example in which a purchaser of AGV evaluates the considered alternatives using the following seven criteria: C1 – dimensions, C2 – minimum lift height, C3 – price, C4 – capacity of AGVs, C5 – battery capacity of AGVs, C6 – maximum lift height and C7 – speed of AGVs. **Tab. 1** provides an overview of the alternatives that represent the types of forklift trucks and values of criteria for each of them.

Table 1

Initial decision-making matrix

Alternatives		Criteria						
		C1, mm	C2, mm	C3, $	C4, kg	C5, Ah	C6, mm	C7, km/h
A1	AGV OKDD16	1480x896x825	85	90000	1600	240	3000	5
A2	AGV OKDD16-III	1480x896x825	85	90000	1600	240	4500	5
A3	AGV OKDD20	1480x896x825	85	90000	2000	260	2500	5
A4	EFORK CDD10-25	2120x850x1830	80	75000	1000	210	2050	5.8
A5	OKAVGV OK-FDuX-JX-II	1480x896x825	85	90000	2500	240	2050	5
A6	AMA MLF1500AGV	1975x796x3493	100	65000	1500	240	3900	5.8
A7	EFORK YF-JG01 1098	2500x1100x2500	80	110000	2000	210	3000	5.8
A8	HICTRL HAS16	2125x1160x2450	80	85000	1600	240	3000	3
A9	HICTRL HAR18	2455x2630x2100	80	85000	1800	315	3000	3

4.2 Determining criteria weights using the FUCOM method

It has been considered an example in which a purchaser of AGV evaluates the considered alternatives using the following seven criteria: C1 – dimensions (min), C2 – minimum lift height (min), C3 – price (min), C4 – capacity of AGVs (max), C5 – battery capacity of AGVs (max), C6 – maximum lift height (max) and C7 – speed of AGVs (max). The first three criteria belong to cost criteria, while the other four belong to benefit criteria.

Step 1. In step, the decision-makers perform the ranking of the criteria based on the consensus: C4 = C7 > C1 > C3 > C6 > C5> C2.

Step 2. In this step, the decision-makers perform a pairwise comparison between the ranked criteria from Step 1. The comparison is made with respect to the first-ranked C4 criterion. The comparison is based on the scale [1,9]. Thus, the priorities of criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in Step 1 are obtained (**Tab. 2**).

Table 2

Priorities of criteria

Priority	Criteria						
	C4	C7	C1	C3	C6	C5	C2
$\varpi_{C_{j(k)}}$	1	1	1.5	1.9	2.6	2.9	3.1

Based on the obtained priorities of the criteria, the comparative priorities of the criteria are calculated $\varphi_{c4/c7}$ = 1/1 = 1, $\varphi_{c7/c1}$ = 1.5/1 = 1.5, $\varphi_{c1/c3}$ = 1.9/1.5 = 1.27, $\varphi_{c3/c6}$ = 2.6/1.9 = 1.37, $\varphi_{c6/c5}$ = 2.9/2.6 = 1.11, $\varphi_{c5/c2}$ = 3.1/2.9 = 1.07.

Step 3. The final values of the weight coefficients should meet the following two conditions:

a) The final values of the weight coefficients should meet Condition (3), i.e. that $w_4/w_7 = 1$, $w_7/w_1 = 1.5$, $w_1/w_3 = 1.27$, $w_3/w_6 = 1.37$, $w_6/w_5 = 1.11$, $w_5/w_2 = 1.07$.

b) In addition to Condition (2), the final values of the weight coefficients should meet the condition of mathematical transitivity, i.e. that: $w_4/w_1 = 1{\cdot}1.5 = 1.5$, $w_7/w_3 = 1.5{\cdot}1.27 = 1.91$, $w_1/w_6 = 1.27{\cdot}1.37 = 1.74$, $w_3/w_5 = 1.37{\cdot}1.11 = 1.52$, $w_6/w_2 = 1.11{\cdot}1.07 = 1.19$.

By applying Expression (5), the final model for determining the weight coefficients can be defined as:

$$\min \chi,$$

$$\begin{cases} \left|\frac{w_4}{w_7}-1\right| = \chi,\ \left|\frac{w_7}{w_1}-1.5\right| = \chi,\ \left|\frac{w_1}{w_3}-1.27\right| = \chi, \\ \left|\frac{w_3}{w_6}-1.37\right| = \chi, \left|\frac{w_6}{w_5}-1.11\right| = \chi,\ \left|\frac{w_5}{w_2}-1.07\right| = \chi, \\ \left|\frac{w_4}{w_1}-1.5\right| = \chi, \left|\frac{w_7}{w_3}-1.91\right| = \chi,\ \left|\frac{w_1}{w_6}-1.74\right| = \chi, \\ \left|\frac{w_3}{w_5}-1.52\right| = \chi \left|\frac{w_6}{w_2}-1.19\right| = \chi, \\ \sum_{j=1}^{7} w_j = 1,\ w_j \geq 0, \forall j. \end{cases}$$

By solving this model, the final values of the weight coefficients are w_1 = 0.157, w_2 = 0.076, w_3 = 0.124, w_4 = 0.236, w_5 = 0.081, w_6 = 0.091, w_7 = 0.236 and the DFC (Deviation from Full Consistency) of the results are χ = 0.0013 or 0.13%. The obtained DFC shows the total objectivity of obtained results, which allows the application of the FUCOM method.

By applying the FUCOM method, the criteria weights are obtained. The results show that the most important criteria for solving this problem are the fourth and seventh criterion with a value of 0.236. After that is the first criterion with a value of 0.157. These are followed by the third criterion with a value of 0.124, the sixth criterion with a value of 0.091, the fifth criterion with a value of 0.081 and by the second criterion with a value of 0.076.

4.3 Evaluation and ranking of alternatives by applying the EDAS method

By applying the EDAS method, the best solution to the problem is determined, which is explained in detail below.

Step 1. Select the most important criteria that describe alternatives.

The most important criteria are C1 – dimensions, C2 – minimum lift height, C3 – price, C4 – vehicle capacity, C5 – vehicle battery capacity, C6 – maximum lift height, C7 – vehicle speed.

Step 2. Construct the initial decision-making matrix according to expression (6). **Tab. 3** provides the form of the initial decision-making matrix.

Step 3. Determine the average solution according to all criteria based on expression (7, 8). **Tab. 4** shows the average solutions.

Step 4. Calculate the positive distance from average (*PDA*) and the negative distance from average (*NDA*) matrices in terms of the type of criteria (benefit or cost) according to expressions (9-14). The results are given in **Tab. 5** and **Tab. 6**.

Step 5. Determine the weighted sum of *PDA* and *NDA* for all alternatives according to expressions (15) and (16). The weighted *PDA* and *NDA* matrices are given in **Tab. 7** and **Tab. 8.**

Step 6. Normalization of *SP* and *SN* values for all alternatives according to expressions (17) and (18).

The values obtained for NSP_i are: 0.535; 0.728; 0.721; 0.396; 1.000; 0.464; 0.393; 0.028; 0.174.

The values obtained for NSN_i are: 0.896; 0.902; 0.914; 0.495; 0.856; 0.553; 0.176; 0.284; 0.000.

Step 7. Calculate the appraisal score (*AS*) for all alternatives according to expression (19). The values obtained for the appraisal score (*AS*) are: A1 = 0.716; A2 = 0.815; A3 = 0.817; A4 = 0.446; A5 = 0.928; A6 = 0.499; A7 = 0.284; A8 = 0.156; A9 = 0.097.

Step 8. Rank the alternatives according to the decreasing values of appraisal score (*AS*). The alternative with the highest *AS* is the best choice among the potential alternatives: A5 → A3 → A2 → A1 → A6 → A4 → A7 → A8 → A9. Considering the values obtained for the appraisal score, a ranking according to decreasing values has been performed and the above expression has been obtained. The alternative A5 appears as the best solution, i.e. AGV OKAVGV OK-FDuX-JX-II.

Table 3

The form of the initial decision-making matrix

Criteria	Alternatives									Goal
	A1	A2	A3	A4	A5	A6	A7	A8	A9	
C1	1	1	1	3	1	5	7	5	7	MIN
C2	85	85	85	80	85	100	80	80	80	MIN
C3	90000	90000	90000	75000	90000	65000	110000	85000	85000	MIN
C4	1600	1600	2000	1000	2500	1500	2000	1600	1800	MAX
C5	240	240	260	210	240	240	210	240	315	MAX
C6	3000	4500	2500	2500	2050	3900	3000	3000	3000	MAX
C7	5	5	5	5.8	5	5.8	5.8	3	3	MAX

Table 4

The average solutions according to all criteria

Criteria	Alternatives									Цель	AV_j	W_j
	A1	A2	A3	A4	A5	A6	A7	A8	A9			
C1	1	1	1	3	1	5	7	5	7	MIN	3.44	0.157
C2	85	85	85	80	85	100	80	80	80	MIN	84.44	0.076
C3	90000	90000	90000	75000	90000	65000	110000	85000	85000	MIN	86666.67	0.124
C4	1600	1600	2000	1000	2500	1500	2000	1600	1800	MAX	1733.33	0.236
C5	240	240	260	210	240	240	210	240	315	MAX	243.89	0.081
C6	3000	4500	2500	2500	2050	3900	3000	3000	3000	MAX	3050.00	0.091
C7	5	5	5	5.8	5	5.8	5.8	3	3	MAX	4.82	0.236

Table 5

Positive distances of the i^{th} alternative from the average solution

Criteria	Alternatives									W_j
	A1	A2	A3	A4	A5	A6	A7	A8	A9	
C1	0.710	0.710	0.710	0.129	0.710	0.000	0.000	0.000	0.000	0.157
C2	0.000	0.000	0.000	0.053	0.000	0.000	0.053	0.053	0.053	0.076
C3	0.000	0.000	0.000	0.135	0.000	0.250	0.000	0.019	0.019	0.124
C4	0.000	0.000	0.154	0.000	0.442	0.000	0.154	0.000	0.038	0.236
C5	0.000	0.000	0.066	0.000	0.000	0.000	0.000	0.000	0.292	0.081
C6	0.000	0.475	0.000	0.000	0.000	0.279	0.000	0.000	0.000	0.091
C7	0.037	0.037	0.037	0.203	0.037	0.203	0.203	0.000	0.000	0.236

Table 6

Negative distances of the i^{th} alternative from the average solution

Criteria	Alternatives									W_j
	A1	A2	A3	A4	A5	A6	A7	A8	A9	
C1	0.000	0000	0.000	0.000	0.000	0.452	1.032	0.452	1.032	0.157
C2	0.007	0.007	0.007	0.000	0.007	0.184	0.000	0.000	0.000	0.076
C3	0.038	0.038	0.038	0.000	0.038	0.000	0.269	0.000	0.000	0.124
C4	0.077	0.077	0.000	0.423	0.000	0.135	0.000	0.077	0.000	0.236
C5	0.016	0.016	0.000	0.139	0.016	0.016	0.139	0.016	0.000	0.081
C6	0.016	0.000	0.180	0.180	0.328	0.000	0.016	0.016	0.016	0.091
C7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.378	0.378	0.236

Table 7

The weighted *PDA* matrices

Criteria	Alternatives									$\max_i(SP_i)$
	A1	A2	A3	A4	A5	A6	A7	A8	A9	
C1	0.111	0.111	0.111	0.020	0.111	0.000	0.000	0.000	0.000	
C2	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.004	0.004	
C3	0.000	0.000	0.000	0.017	0.000	0.031	0.000	0.002	0.002	
C4	0.000	0.000	0.036	0.000	0.104	0.000	0.036	0.000	0.009	
C5	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.024	
C6	0.000	0.043	0.000	0.000	0.000	0.025	0.000	0.000	0.000	
C7	0.009	0.009	0.009	0.048	0.009	0.048	0.048	0.000	0.000	
SP_i	0.120	0.163	0.162	0.089	0.225	0.104	0.088	0.006	0.039	0.225

Table 8

The weighted *NDA* matrices

Criteria	Alternatives									$max_i(SN_i)$
	A1	A2	A3	A4	A5	A6	A7	A8	A9	
C1	0.000	0.000	0.000	0.000	0.000	0.071	0.162	0.071	0.162	
C2	0.001	0.001	0.001	0.000	0.001	0.014	0.000	0.000	0.000	
C3	0.005	0.005	0.005	0.000	0.005	0.000	0.033	0.000	0.000	
C4	0.018	0.018	0.000	0.100	0.000	0.032	0.000	0.018	0.000	
C5	0.001	0.001	0.000	0.011	0.001	0.001	0.011	0.001	0.000	
C6	0.001	0.000	0.016	0.016	0.030	0.000	0.001	0.001	0.001	
C7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.089	0.089	
SN_i	0.026	0.025	0.022	0.128	0.036	0.118	0.208	0.181	0.253	0.253

5. A sensitivity analysis

The application of the analysis in multi-criteria decision-making can provide a new perspective on the area of interest. In the field of multi-criteria decision-making, the best alternative should be determined within a set of available ones. In such decision-making, a set of evaluation criteria is used. The criteria are associated with significance, i.e. weights. Intuitively, a higher weight implies the greater significance of a criterion. A sensitivity analysis provides a new perspective to a decision-making issue, introducing criterion criticality. Regarding criticality, we can imply the impact of a change in the significance or value of the criteria on the result of decision-making. Therefore, it is possible for the criteria of little significance to be critical in a certain situation, i.e. to be decisive in a decision-making process. Thus, a sensitivity analysis can provide us a view of the situations that we have not noticed before. It can further result in an analysis that is much more efficient and finally in the implementation of a better final solution. In this paper, four methods for a sensitivity analysis are applied: WASPAS [23], SAW [24], MABAC [25] and ARAS [26], and the ranking of alternatives according to the same methods is given in **Tab. 9**.

Table 9

Ranking the alternatives by applying different methods

Alternatives	Methods for a sensitivity analysis							
	WASPAS		SAW		MABAC		ARAS	
	Grade	Rank	Grade	Rank	Grade	Rank	Grade	Rank
A1	0.789	**4**	0.795	**4**	0.078	**4**	0.796	**4**
A2	0.819	**3**	0.825	**3**	0.134	**3**	0.829	**3**
A3	0.823	**2**	0.828	**2**	0.138	**2**	0.830	**2**
A4	0.641	**7**	0.671	**7**	0.017	**6**	0.639	**7**
A5	0.851	**1**	0.861	**1**	0.184	**1**	0.864	**1**
A6	0.694	**5**	0.734	**5**	0.070	**5**	0.702	**5**
A7	0.661	**6**	0.711	**6**	-0.008	**7**	0.677	**6**
A8	0.572	**9**	0.598	**9**	-0.162	**9**	0.576	**9**
A9	0.585	**8**	0.627	**8**	-0.125	**8**	0.603	**8**

Figure 1 shows the positions in the ranking of individual alternatives for each of the four methods used in the sensitivity analysis. As it can be seen in **Fig. 1**, the best-ranked alternative is A5 and then A3. In **Tab. 9**, it can be seen that these two alternatives are identified as the best ones, since they obtain identical results by all four methods, with an advantage being given to alternative A5. By the calculation, other alternatives have lower values and are less ranked than the two above mentioned, as can be seen in the figure. Position 3 is occupied by alternative A2 according to all methods. At position 4, alternative A1 according to all methods. Position 5 is taken by alternatives A6. Position 6 is occupied by alternatives A7 according to WASPAS, SAW and ARAS methods, and A4 according to MABAC method. At position 7, alternatives A4 according to WASPAS, SAW and ARAS and A7 are ranked according to the MABAC method. Position 8 is taken by alternative A9 to all methods. The last position 9 is taken by alternative A8.

6. Conclusion

Warehousing as a subsystem of logistics is the link in a chain that offers numerous optimization options. This is particularly prominent in our region since the application of modern technologies is not present as it is the case in western countries. In the paper, an emphasis is put on warehouse automation throughout the selection of an optimum automatic guided vehicle - AGV. As a component of material handling equipment, AGV is a solution that can greatly improve the operation process in the warehouse itself, and therefore in the entire supply chain. Their use can save energy, so that a lower price of a final product can be expected if they are used in manufacturing plants.

The methods of multi-criteria decision-making are applied daily in the real world, and thus in warehouse systems. The most significant contribution of the paper is reflected in the application of FUCOM-EDAS hybrid model. In this paper, the FUCOM method has demonstrated its exceptional capabilities in determining the weight coefficients of criteria where the objectivity and consistency of the obtained results could be seen.

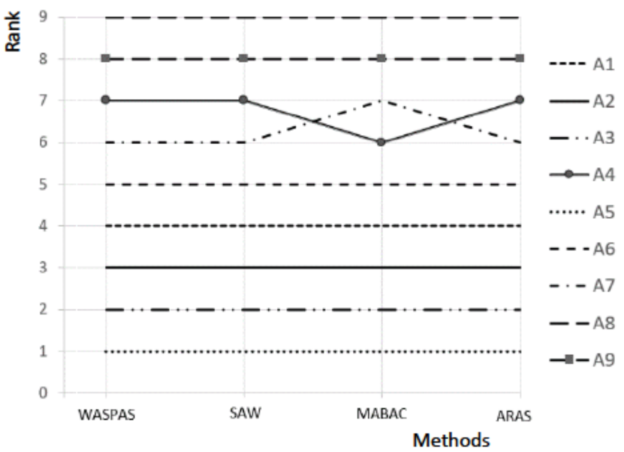

Fig. 1. The results of sensitivity analysis

The ranking of the alternatives was performed according to the EDAS method and the best solution was selected, i.e. the best automatic guided vehicle - a forklift truck. At the end of the paper, a comparison of different multi-criteria decision-making methods was made for a specific example of the selection of automatic guided vehicles throughout a sensitivity analysis.

References

1. Fanisam M.BN., Dewa B., Ayush M., Yogesh M., Harshal M. Material handling equipment // International Journal of Recent Scientific Research. 2018, vol. 9, no. 2, pp. 24083–24085.
2. Kay M. G. Material Handling Equipment. Available at: https://people.engr.ncsu.edu/kay/Material_Handling_Equipment.pdf.
3. Park Y.-B. ICMESE: Intelligent consultant system for material handling equipment selection and evaluation // Journal of Manufacturing Systems. 1996, vol. 15, no. 5, pp. 325–333. doi: 10.1016/0278-6125(96)84195-1.
4. Onut S., Kara S. S., Mert S. Selecting the suitable material handling equipment in the presence of vagueness // The International Journal of Advanced Manufacturing Technology. 2009, vol. 44, 7-8, pp. 818–828. doi: 10.1007/s00170-008-1897-3.
5. Kulak O. A decision support system for fuzzy multi-attribute selection of material handling equipments // Expert Systems with Applications. 2005, vol. 29, no. 2, pp. 310–319. doi: 10.1016/j.eswa.2005.04.004.
6. Fisher E. L., Farber J. B., Kay M. G. Mathes: An expert system for material handling equipment selection // Engineering Costs and Production Economics. 1988, vol. 14, no. 4, pp. 297–310. doi: 10.1016/0167-188X(88)90034-1.
7. Tuzkaya G., Gülsün B., Kahraman C., Özgen D. An integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem and an application // Expert Systems with Applications. 2010, vol. 37, no. 4, pp. 2853–2863. doi: 10.1016/j.eswa.2009.09.004.
8. Chakraborty S., Banik D. Design of a material handling equipment selection model using analytic hierarchy process // The International Journal of Advanced Manufacturing Technology. 2006, vol. 28, 11-12, pp. 1237–1245. doi: 10.1007/s00170-004-2467-y.
9. Chan F.T.S. Design of material handling equipment selection system: an integration of expert system with analytic hierarchy process approach // Integrated Manufacturing Systems. 2002, vol. 13, no. 1, pp. 58–68. doi: 10.1108/09576060210411512.
10. Mirhosseyni S. H. L., Webb P. A Hybrid Fuzzy Knowledge-Based Expert System and Genetic Algorithm for efficient selection and assignment of Material Handling Equipment // Expert Systems with Applications. 2009, vol. 36, no. 9, pp. 11875–11887. doi: 10.1016/j.eswa.2009.04.014.
11. Stević Ž., Pamučar D., Vasiljević M., Stojić G., Korica S. Novel Integrated Multi-Criteria Model for Supplier Selection: Case Study Construction Company // Symmetry. 2017, vol. 9, no. 11, p. 279. doi: 10.3390/sym9110279.
12. Vasiljevic M., Fazlollahtabar H., Stević Ž., Vesković S. A rough multicriteria approach for evaluation of the supplier criteria in automotive industry // Decision Making: Applications in Management and Engineering. 2018, vol. 1, no. 1, pp. 82–96. doi: 10.31181/dmame180182v.
13. Zavadskas E. K., Stević Ž., TANACKOV I., PRENTKOVSKIS O. A Novel Multicriteria Approach – Rough Step-Wise Weight Assessment Ratio Analysis Method (R-SWARA) and Its Application in Logistics // Studies in Informatics and Control. 2018, vol. 27, no. 1. doi: 10.24846/v27i1y201810.
14. Radović D., Stević Ž., Pamučar D., Zavadskas E., Badi I., Antuchevičiene J., Turskis Z. Measuring Performance in Transportation Companies in Developing Countries: A Novel Rough ARAS Model // Symmetry. 2018, vol. 10, no. 10, p. 434. doi: 10.3390/sym10100434.
15. Nunić Z. Evaluation and selection of the PVC carpentry manufacturer using the FUCOM-MABAC model // Operational Research in Engineering Sciences: Theory and Applications. 2019, vol. 1, no. 1, pp. 13–28. doi: 10.31181/oresta19012010113n.
16. Stanujkić D., Karabašević D. An extension of the WASPAS method for decision-making problems with intuitionistic fuzzy numbers: a case of website evaluation // Operational Research in Engineering Sciences: Theory and Applications. 2019, vol. 1, no. 1, pp. 29–39. doi: 10.31181/oresta19012010129s.
17. Pamučar D., Stević Ž., Sremac S. A New Model for Determining Weight Coefficients of Criteria in MCDM Models: Full Consistency Method (FUCOM) // Symmetry. 2018, vol. 10, no. 9, p. 393. doi: 10.3390/sym10090393.
18. Rezaei J. Best-worst multi-criteria decision-making method // Omega. 2015, vol. 53, pp. 49–57. doi: 10.1016/j.omega.2014.11.009.
19. Saaty T. L. The analytic hierarchy process: planning, priority setting, resource allocation. New York, London: McGraw-Hill International Book Co. 1980.
20. Keshavarz Ghorabaee M., Zavadskas E. K., Olfat L. Multi-Criteria Inventory Classification Using a New Method of Evaluation Based on Distance from Average Solution (EDAS) // Informatica. 2015, vol. 26, no. 3, pp. 435–451. doi: 10.15388/Informatica.2015.57.
21. Galović J. Sustavi automatski vođenih vozila: Završni Rad [Automatic Guided Vehicles: Undergraduate thesis]. Zagreb: University of Zagreb. 2015. 80 p.
22. Gudelj A., Krčum M., Coric M. Modelling and multiobjective optimization for automated guided vehicles at container terminals // 35th Conference on Transportation Systems with International Participation Automation in transportation. 2015, Zagreb: KoREMA.
23. Zavadskas E. K., Turskis Z., Antucheviciene J. Optimization of Weighted Aggregated Sum Product Assessment // Electronics and Electrical Engineering. 2012, vol. 122, no. 6. doi: 10.5755/J01.EEE.122.6.1810.
24. MacCrimmon K.R. Decision making among multiple-attribute alternatives: a survey and consolidated approach. Santa Monica, California: The RAND Corporation. 1968. 63 p.
25. Pamučar D., Ćirović G. The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC) // Expert Systems with Applications. 2015, vol. 42, no. 6, pp. 3016–3028. doi: 10.1016/j.eswa.2014.11.057.
26. Zavadskas E. K., Turskis Z. A new additive ratio assessment (ARAS) method in multicriteria decision-making // Technological and Economic Development of Economy. 2010, vol. 16, no. 2, pp. 159–172. doi: 10.3846/tede.2010.10.

Received 19/12/2018

Stojčić M., Stević Ž., Nikolić A., Božičković Z. A multi-criteria model for evaluation and selection of AGV's in a warehouse // Modern Problems of Russian Transport Complex. 2019, vol.9, no.1, pp. 4-20