Ondrej STOPKA[*], **Mária STOPKOVÁ, Vladimír ĽUPTÁK**
Institute of Technology and Business in České Budějovice,
Faculty of Technology, Department of Transport and Logistics
Okružní 517/10, 370 01 České Budějovice, Czech Republic
Srećko KRILE
University of Dubrovnik
Put branitelja Dubrovnika 29, 20 000 Dubrovnik, Croatia
Corresponding author. E-mail: stopka@mail.vstecb.cz

APPLICATION OF THE CHOSEN MULTI-CRITERIA DECISION-MAKING METHODS TO IDENTIFY THE AUTONOMOUS TRAIN SYSTEM SUPPLIER

Summary. This paper addresses an application of the specific methods of multi-criteria decision analysis to specify the appropriate supplier of an autonomous train in a certain production–distribution company. This company identifies three potential suppliers dealing with the development and purchase of autonomous train systems. In terms of the multi-criteria decision analysis, the WSA method, the Scoring method and the TOPSIS method were used to define a suitable compromise solution. To apply each method, individual suppliers were sorted depending on the appropriateness for the examined company based on relevance with all the identified criteria and their weights. The evaluation criteria include procurement cost, time of the whole autonomous train system project implementation, references from plants where such a technology has already been introduced, service department availability and battery charge time. Thereafter, the outcomes obtained using individual methods were compared to each other and the compromise supplier of the autonomous train system to be implemented in the selected company was determined.

1. INTRODUCTION

This paper focuses on technological development having a significant impact on individual manufacturing logistics sectors and is actively involved in reducing costs, increasing productivity and optimizing processes within logistics chain. Autonomous transport vehicles represent a very innovative solution and up-to-date topic with a great potential for daily utilization for routine and cycle operations. The inclusion of this subject in strategic government documents, for example Intelligence Specialization Strategy (RIS3), confirms the aforementioned statements. Autonomous transport vehicles considerably contribute to the transport efficiency in the internal logistics chain through its safety and reliability. These aspects are very important in the competitive environment on the market with some objectives, i.e. to meet customer needs faster, to get more appropriate and cheaper product [1].

The case study presented in this paper aims to design a convenient system for its implementation and operation within the selected automotive company, namely, by operating the autonomous logistics trains. The company has decided to adopt a trend of progressive technology especially due to the deficiency of qualified staff, which is currently a major issue for most of its plants and operated devices.

The current situation on the labor market is very complicated and employees are not interested in the specific kind of professional work [1].

The objective of this manuscript is also to prove that by establishing autonomous technologies, the company does not want to take the jobs of employees, but they want to fill the gap in a labor market with respect to their own needs and offer. These days, individual companies want to offer them the opportunity to perform activities that are not physically demanding while increasing efficiency. On the other hand, a low unemployment rate creates scope for salary growth. As a result, manufacturers make efforts to invest in autonomous technologies with the vision of investment return within a short term. In regard to well-functioning companies, aforementioned aspects represent key prerequisites for competitors to effectively compete on the market.

2. LITERATURE REVIEW

Multi-criteria decision analysis issues are discussed in detail in case studies addressing the independent component analysis to address decision-making concerns [2] and a comparative analysis based on the technique for order of preference by similarity to an ideal solution (*hereinafter as the TOPSIS*) for sustainable selection of the supplier for a fundraising strategy [3]. The scientific scope of this manuscript is demonstrated by real data from internal sources of a private company [1]. On the basis of the International Journal of Occupational Safety and Ergonomics and the main findings of the article dealing with the performance and safety optimization, a manuscript section referring to the weighted sum approach (*hereinafter as the WSA*) was elaborated [4]. An example of group decision-making that affects a sustainable approach in terms of supplier specification using the advanced TOPSIS method under an interval-valued Pythagorean fuzzy environment is discussed by the authors Yu et al. (2019) [5].

This article is also based on the publications that describe the utilization of automated identification and RFID systems in European logistics companies [6, 7], as well as manuscripts dealing with an implementation of the analytic hierarchy process (*hereinafter as the AHP*) tool when choosing the proper suppliers, which is discussed in the literature [8, 9]. The model application of the Clarke–Wright economics algorithm to address vehicle routing problems in supply logistics is the subject of other research studies [10, 11].

This paper is conceived in the form of combining multiple methodological guidelines focusing on the identification of suitable locations for enterprises using the AHP, the WSA and the TOPSIS apparatuses [12, 13], as well as allocation of investments into logistics risk of a public–private partnership using the fuzzy TOPSIS method [14]. In the literature [15], Rashidi and Cullinane (2019) present a comparative analysis of the findings by application of two techniques for supplier selection, in particular, the TOPSIS and the DEA (data envelopment analysis), wherein they are implemented for identifying the most preferred suppliers.

Last but not the least, for the purpose of this manuscript, it is important to analyze costs related to repairs of vehicles in the transport enterprise, which is dealt with in the articles [16, 17]. Research in the field of modeling supplier evaluations from the perspective of a real company is addressed in detail in a case study [18], where the authors suggest a model in order to increase the maximum supply chain management efficiency, which enables better reaction to newly created situations, and thus may satisfy the needs of a logistics company.

3. DECRIPTION OF THE EXAMINED AUTOMOTIVE COMPANY

The selected company primarily focuses on the development, manufacture and distribution logistics of seats, exhaust systems, interiors and decorative parts of vehicles. The objective of the proposal consists of ensuring the internal logistics flows within the warehouse department using a suitable autonomous train system.

These days, the industrial plant goes through transformation with the aim to optimize the logistics flows. As mentioned above, the plant is focused on the production as well as the distribution of modern exhaust systems for internal combustion engines. The main production program involves manifold flanges, three-way catalysts and SCR (Selective Catalytic Reduction) system production. The established manufacturing technologies include robotic welding, sheet metal rolling, monolithic sheathing and tube bending.

The company uses multiple well-known manufacturing systems, wherein emphasis is placed on cost reduction, while maintaining and enhancing the quality of products. These systems are based on slimness (slim production), high efficiency and a high degree of standardization. The prime goal is to achieve competitive market capability in terms of low price, high quality and compliance with the required delivery time to the customer in the desired quantity as well as the proper location [1, 19].

4. APPLICATION OF THE MULTI-CRITERIA DECISION-MAKING METHODS – A CASE STUDY

As mentioned above, in terms of innovative potential handling equipment in the future, the plant (as a part of the investigated company) takes into consideration implementation of the autonomous logistics train system, which represents the very proposal and the application part of this manuscript per se.

The solution of an autonomous train is based on standard AGV (automated guided vehicle) warehouse trucks and advanced system software solutions for such a vehicle control. The development of such a system and commissioning the proposal will be the responsibility of the particular supplier, and will be provided in a turnkey form based on a fixed price offer. The project proposal assumes that the overall costs will include the design, installation and implementation of the system solution, specifically [20]:
- project management,
- analysis and concept of the design,
- customer workshops and simulations,
- specifications and detailed design,
- installation,
- vehicles in service,
- tuning layout,
- system configuration and communication infrastructure setup,
- safety and risk analysis,
- trial operation and performance tuning,
- customer user training and so on.

Individual works will be carried out partly onsite and partly on the supplier's premises or at other sites.

As the main suppliers being considered, several manufacturers involved in the development and production of such a technology were chosen. They all belong to global suppliers of warehouse and distribution transport-logistics equipment and handling devices [21]. The specifications and parameters of individual scenarios (evaluated variants) are as follows [1]:
- *Variant 1* – This includes the JGH 1000 autonomous logistics train set, including the JGH towing autonomous truck and three big trolleys, for cyclical material distribution within a specified object. This system appropriate especially for light industry and assembly-logistics premises. The towing truck technicalities include the following: maximum towing capacity – 4,800 kg; maximum forward speed – 2.3 m/s; beam height – 2,440 mm; height safety sensor – 105 mm; turning radius – 1,627 mm; and clear height – 48 mm.

- *Variant 2* – This includes the TAE 500 autonomous logistics train set, consisting of a TAE 500 towing vehicle and four manufacture-adapted trolleys, allowing the system to operate without a driver of a towing vehicle for cyclically recurring material flows. This solution increases productivity, ergonomics and safety, and reduces repair and operation costs. The towing vehicle parameters include the following: maximum towing capacity – 5,000 kg; maximum forward speed – 2.2 m/s; beam height – 2,350 mm; height safety sensor – 107 mm; turning radius – 1,636 mm; and clear height – 49 mm.
- *Variant 3* – This includes the LD-A7 autonomous logistics train set, consisting of an LD-A7 towing cart and four customizable pulled trolleys. This scenario is advantageous due to its operating speed and light weight. The towing cart specifications are as follows: maximum towing capacity – 4,750 kg; maximum forward speed – 2.5 m/s; beam height – 2,300 mm; height safety sensor – 102 mm; turning radius – 1,600 mm; and clear height – 47 mm.

The type model of the autonomous logistics train set being evaluated is illustrated in the following Fig. 1.

Fig. 1. Depiction of the type model of an autonomous logistics train set. Source: Authors, according to [1]

For the purpose of this case study, five relevant criteria, taken into account when applying the specific multi-criteria decision analysis methods, were identified in relation to key financial and operational indicators. These were chosen in particular based on consultation with the management of the examined company as well as experts in the addressed field of research. Hence, the main criteria for the decision-making process are as follows [1]:

- C_1 – procurement costs (hereinafter referred to as price) [€],
- C_2 – time of the whole autonomous train system project implementation (hereinafter referred to as time) [months],
- C_3 – references from plants in which this technology is already being used (hereinafter referred to as references) [*1 implies excellent, 2 implies fine and 3 implies good*],
- C_4 – service department availability (i.e. waiting time for technical staff to come to provide service operations on the specific autonomous train system, hereinafter referred to as availability) [hours] and
- C_5 – battery charging time (hereinafter referred to as battery) [min].

The specific values assigned to each evaluated variant by each criterion are summarized in Table 1 based on an analysis of individual suppliers and information obtained from other plants (workplaces) of the selected company [1].

Table 1

Values assigned to each variant by each criterion

	Price [€]	Time [months]	References [-]	Availability [hours]	Battery [min]
Variant 1 – V₁	285,460	12	fine	8	30
Variant 2 – V₂	296,370	9	excellent	4	25
Variant 3 – V₃	274,275	14	fine	10	30
Nature	MIN	MIN	MAX	MIN	MIN

Source: Authors, according to [1].

4.1. Determination of the weights of criteria by the Fuller triangle method

First of all, it is imperative to determine the individual weights of each defined criterion, so that the multi-criteria decision-making methods may be applied subsequently.

The Fuller triangle method is one of the techniques to evaluate criteria relevance as well. The Fuller triangle is comprised of two lines, in which each a criteria pair occurs just once [4]. For each pair, the number of that criterion, which is considered to be more important by the decision-maker, is indicated (marked) somehow. To determine the normalized weight of the C_j criterion quantification, equation 1 (see below) is applied.

The criterion considered more important than another criterion is marked from the perspective of all pairs. The next step of this technique lies in adding up criteria marked as more important, which will be calculated in the individual lines and finally divided depending on their total number (sum of marked criteria).

Therefore, for each criterion, the number of times the criterion is marked as preferred rather than another criterion is to be calculated. To determine the weight of criteria, each criterion is divided by the amount of all the comparisons.

Furthermore, each criterion preference has to be increased by 1. Thereafter, a criterion with a preference of zero will have the value of 1.

Individual criteria are to be entered in the table as shown below (see Table 2 – general procedure of the Fuller triangle method of specifying the value of weights for individual criterion; values of 1-5, where 1 – excellent and 5 - insufficient).

Table 2

Fuller triangle compilation –
general procedure

1	1	1	……	1
	2	3	……	n
	2	2	……	2
		3	……	n
………				…
		n-2		n-2
		n-1		n
				n-1
				n

Source: [4].

Table 3 compares each pair of criteria depending on the importance. Emphasis is placed on the procurement costs, time of the whole project implementation, references by other users, the service department availability and the charging time of the batteries.

Table 3 also summarizes all the weights of criteria quantified by equation 1, and thus compilation of the Fuller triangle [22]. Individual input preferences among each criteria pair were assigned by several experts dealing with the examined subject, and, thereafter, the means of all input values were obtained.

$$w_j = \frac{v_j}{\sum_{k=1}^{n} V_k}; j = 1,2,....,n, \quad [\text{-}] \tag{1}$$

where w_j denotes the share of the sum of criterion preferences (v_j) divided by the total number of all preferences (v_k), i.e., the normalized weight of individual criteria C_j with the weight of v_j.

Table 3

Values of weights for individual criteria – compilation of the Fuller triangle method

Fuller´s triangle	Criteria	Number of preferences (v_j)	$v_j + 1$	Weight	w_j
C_1 C_1 C_1 C_1 C_2 C_3 C_4 C_5	C_1	4	5	**5/15**	**0.33**
C_2 C_2 C_2 C_3 C_4 C_5	C_2	0	1	**1/15**	**0.06**
C_3 C_3 C_4 C_5	C_3	1	2	**2/15**	**0.13**
C_4	C_4	3	4	**4/15**	**0.26**
C_5	C_5	2	3	**3/15**	**0.2**
Total	-	**10**	**15**	**1**	1

Source: Authors.

As already mentioned, given the fact that the C_2 criterion has no preference, so far, it is impossible to quantify its weight. For this reason, v_j+1 is added to each criterion preference. Thus, criterion C_2 reaches a preference of 0.06 [18].

4.2. Calculation by the Weighted Sum Approach (WSA)

In terms of the WSA technique, the maximization criterion is preferred; thus, all the minimization criteria need to be converted into the maximization criteria.

Hence, in our case study, all the minimization criteria (listed in Table 1) need to be converted into the maximization criteria for the first.

Minimization criteria include price, time, service department availability time and battery charging time. The references are given in the nature of maximization, and therefore the relevant values are assigned as follows: *3 denotes excellent, 2 denotes fine, 1 denotes good* [5, 8, 9].

For example, from the price 285,460 for V_1, a maximization value is converted based on equation 2 [13]:

$$y_{ijmax} = h_{jmin} - y_{ijmin} \tag{2}$$

where y_{ijmax} is the determined value of the *i-th* variant by the *j-th* criterion in the terms of maximization; h_{jmin} represents the highest value of the *j-th* criterion in the terms of minimization; and y_{ijmin} is the value of the *i-th* variant by *j-th* criterion in the terms of minimization.

This entire conversion, even with the new criteria values, is carried out in Table 4.

Table 4

Input criteria matrix and its values for subsequent calculations

	C_1	C_2	C_3	C_4	C_5
V_1	10,910	2	2	2	0
V_2	0	5	3	6	5
V_3	22,095	0	1	0	0
w_j	0.33	0.06	0.13	0.26	0.20
Nature	MAX	MAX	MAX	MAX	MAX

Source: Authors.

The next step of the WSA method lies in determining the best marginal values, i.e. the ideal H variant, as follows {22,095; 5; 3; 6; 5}, and the worst marginal values, i.e. the basal D variant, are respectively {0; 0; 1; 0; 0}. Subsequently, the matrix for each variant is built up, and then the partial (sub-utility) utility function is calculated. The partial benefit of the value y_{ij} criterion is calculated by equation 3 [11]:

$$u_{ij} = \frac{y_{ij} - d_j}{h_j - d_j}; \; i = 1,2, \ldots, m; j = 1,2, \ldots, n, \quad [-] \tag{3}$$

where u_{ij} is the partial benefit (utility function) of the value y_{ij}; y_{ij} denotes the determined value of the *i-th* variant by the *j-th* criterion; d_j is the worst value of the *j-th* criterion (basal variant); and h_j is the best (highest) value of the *j-th* criterion.

An overview of partial benefits for all the variants is presented in Table 5.

Table 5

Criteria matrix by the WSA method – partial utility function for all the variants u_{ij}

	C_1	C_2	C_3	C_4	C_5
V_1	0.4938	0.40	0.50	0.3333	1.73
V_2	0	1.00	1	1	2.00
V_3	1.00	0.00	0.00	0	1.00
w_j	0.33	0.06	0.13	0.26	0.20

Source: Authors.

The final step of the WSA method is to calculate the aggregate utility function (benefit) for each variant $u(V_i)$. Hence, the partial benefits for all the variants must be multiplied by the given normalized criterion weight (w_j), according to equation 4 (see Table 6 – normalized criteria matrix) [13]:

$$u(V_i) = \sum_{j=1}^{n} w_j u_{ij} ; \; i = 1,2, \ldots, m; j = 1,2, \ldots, n, \quad [-] \tag{4}$$

Table 6

Normalized criteria matrix by the WSA method

	C_1	C_2	C_3	C_4	C_5
V_1	0.163	0.024	0.065	0.087	0.346
V_2	0.000	0.060	0.130	0.260	0.400
V_3	0.330	0.000	0.000	0.000	0.200

Source: Authors.

Finally, the aggregate utility function for each variant is quantified, and thereby, the order of individual variants (suppliers) is determined (see Table 7). Since the function is in the terms of maximization, the variant with the biggest benefit (quantified value) is considered to be the compromise (the most appropriate) variant.

Table 7

Variants' ranking by the WSA method

	Benefit	Order of variants
V_1	0.685	2.
V_2	0.850	**1.**
V_3	0.530	3.

Source: Authors.

Based on the application of the WSA method, variant no. 2 represents the best possible offer.

4.3. Calculation applying the Scoring method

First of all, it is necessary to specify the sequence of the criteria values. The highest preference has the value of *0* and the worst preference has the value of *3*. For example, in terms of the criterion C_1

(procurement costs), the supplier V_2 is the most preferred one, considering the fact that the procurement costs for the V_2 are the lowest ones compared to all the suppliers. On the contrary, the V_3 variant is the least preferred supplier, since the procurement costs for the V_3 are the highest ones compared to all the suppliers. So, as far as the criterion C_1 is concerned, the supplier V_2 has assigned the value of 1 and the supplier V_3 has assigned the value of 3. As for the criterion C_5 (battery charging time), the supplier V_1 has assigned the value of 0, due to the fact that this supplier does not offer an autonomous train equipped with a battery [14, 23]. If the values are the same, the same position within the ranking will be assigned. Individual assigned values are listed in Table 8.

Table 8

Criteria matrix and its values for calculation by the Scoring method

	C_1	C_2	C_3	C_4	C_5
V_1	2	2	2	2	0
V_2	1	3	3	3	1
V_3	3	1	1	1	0
w_j	0.33	0.06	0.13	0.26	0.20

Source: Authors.

Subsequently, the values of individual variants by each criterion are multiplied by the weight of the relevant criterion (see Table 9).

Table 9

Normalized criteria matrix by the Scoring method

	C_1	C_2	C_3	C_4	C_5
V_1	0.660	0.120	0.260	0.520	0.000
V_2	0.330	0.180	0.390	0.780	0.200
V_3	0.990	0.060	0.130	0.260	0.000

Source: Authors.

Finally, after filling in individual values into the criteria matrix for each variant, the suppliers' ranking may be defined (see Table 10).

Table 10

Variants' ranking by the Scoring method

	Total value	Variants ranking
V_1	1.56	2.
V_2	1.88	**1.**
V_3	1.44	3.

Source: Authors.

Using the Scoring method, supplier no. 2 is considered to be the best possible scenario.

4.4. Calculation applying the TOPSIS method

The technique for Order Preference by Similarity to Ideal Solution is well known as TOPSIS method. This technique is one of the MCDM methods where the variants' evaluation is carried out through comparison with the ideal variant. To explain the deviation from alternatives, various units are utilized. The fundamental of the TOPSIS method lies in standard Euclidean metrics.

As for the TOPSIS technique, where the maximization is preferred as well, and thereby all the minimization criteria must be converted into the maximization criteria [11, 13].

Hence, the first step of the TOPSIS method comes from the values listed in Table 4 (values already converted to maximization criteria) while maintaining the same weights determined by the Fuller triangle. The next step is to compile the criteria matrix $R = (r_{ij})$ (see Table 11).

This matrix R is compiled according to equation 5 [14]:

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}} \; ; i = 1,2, \dots, m; j = 1,2, \dots, n, \quad [\text{-}] \tag{5}$$

Table 11

Criteria matrix R by the TOPSIS method

	K_1	K_2	K_3	K_4	K_5
V_1	0.44	0.37	0.53	0.32	0.00
V_2	0.00	0.93	0.27	0.95	1.00
V_3	0.90	0.00	0.80	0.00	0.00
w_j	0.33	0.07	0.13	0.27	0.20

Source: Authors.

As for the next step, the normalized criteria matrix $Z = (z_{ij})$ needs to be compiled by multiplying the normalized variant's value by each criterion and the normalized weight of the relevant criterion (equation 6), from which the ideal variant H and the basal variant D can be specified thereafter (see Table 12) [15].

$$z_{ij} = w_j r_{ij}, \quad [\text{-}] \tag{6}$$

where w_j is the relevant normalized criterion weight and r_{ij} denotes the normalized value of the particular variant by each criterion.

Table 12

Normalized criteria matrix Z by the TOPSIS method

	K_1	K_2	K_3	K_4	K_5
V_1	0.15	0.02	0.07	0.08	0.00
V_2	0.00	0.06	0.04	0.25	0.20
V_3	0.30	0.00	0.11	0.00	0.00
D	0.00	0.00	0.04	0.00	0.00
H	0.30	0.06	0.11	0.25	0.20

Source: Authors.

The next step is to quantify the deviation of each Z matrix value from the ideal d_i^+ variant (see equation 7) [6, 16, 17].

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(z_{ij} - h_j)^2} \; ; i = 1,2, \dots, m; j = 1,2, \dots, n, \quad [\text{-}] \tag{7}$$

Analogously, the deviation of each Z matrix value from the basal variant d_i^- needs to be determined (see equation 8) [6, 16].

$$d_i^- = \sqrt{\sum_{j=1}^{n}(z_{ij} - d_j)^2} \; ; i = 1,2, \dots, m; j = 1,2, \dots, n, \quad [\text{-}] \tag{8}$$

All variants are then sorted depending on the values of the relative indicator c_i and the variants' ranking can be specified (see Table 13). This indicator is calculated as follows (see equation 9) [6, 16, 17]:

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-} \; ; i = 1,2, \dots, m, \quad [\text{-}] \tag{9}$$

The relative indicator values for all the variants as well as the variants' ranking are clearly presented in Table 13.

Final evaluation of variants by the TOPSIS method

	d_i+	d_i-	c_i	Variants ranking
V_1	0.308	0.174	0.360	3.
V_2	0.308	0.326	0.510	**1.**
V_3	0.326	0.308	0.490	2.

Source: Authors.

Even based on the TOPSIS method, from the results in Table 13, supplier no. 2 represents the best possible, i.e. compromise, variant.

5. FINAL RESULTS AND DISCUSSION

The final comparison of individual multi-criteria decision-making methods is carried out in Table 14. In our comparison, applied methods denote the identified criteria and the methods' rankings represent the critical values. The final outcome (the most appropriate supplier) is set based on the lowest value obtained by the sum of all the variants' ranking values.

Final variants' ranking and the determination of the best supplier

	WSA method	Scoring method	TOPSIS method	$\sum$	Final variants ranking
V_1	2.	2.	3.	7	2.
V_2	1.	1.	1.	3	**1.**
V_3	3.	3.	2.	8	3.

Source: Authors.

Thus, following the elaborated literature review (see Chapter 2) as well as previous calculations and values obtained (see Chapter 4 and 5), based on the evaluation of individual scenarios by using the specific multi-criteria decision analysis methods, supplier no. 2 is recommended to be the most appropriate variant in terms of operating the autonomous train in the examined company [24].

Based on the existing criteria set, scenario V_2 achieved the best possible results for all three methods, especially due to the fact that it demonstrated a strong relationship with high-weight-value criteria C_4 (service department availability in hours, **0.26**) as well as C_5 (battery charging time in min, **0.2**), where it clearly obtained the highest values for all methods. Certainly, the recommended supplier could differ depending on the type and scale of criteria determined and, of course, the mathematical methods applied in individual stages of evaluation of variants.

The implementation of the suggested solution may also offer other options for the future possible development of autonomous technology in the examined manufacturing facility. A potential benefit could be to introduce autonomous pallet carts for carrying finished products from production lines and distributing empty packaging to individual lines. With this solution, additional savings regarding an absence of a prospective construction design or adjustment could be achieved, since carts are operated on the same platform as those already working in the manual mode. The expected savings may also be achieved to decrease the number of warehouse workers [25, 26].

Another phase may involve the implementation of an autonomous cart for pallet distributions with input material to the particular zone. This could help toward time savings and increasing warehouse productivity during handling with input parts that are subsequently taken off by logistics trains. Here, the demand for one autonomous cart arises. The main benefit of this solution may be considered as a saving of one operator per shift (3 warehouse operators in total) [27, 28].

The advantage of this system lies in the fact that autonomous technology can be gradually complemented for multiple logistics operations to different workplaces and departments [29].

Nevertheless, all the above-formulated recommended aspects were not the objective of our case study.

6. CONCLUSION

Logistics in the automotive industry is a very dynamic field and currently represents an important challenge for the industrial sector economy. Customer satisfaction is regarded to be a key factor for the logistics chain success and, thus, in this industrial sector, the continuous development of modern innovative and progressive trends, as well as gaining of new knowledge into practice have been taking place. Modern development trends have a great perspective and future in the wake of the 4th industrial revolution (Industry 4.0), which, according to a study by the Department of Commerce and Industry, will transform a production from stand-alone automated units into fully automated and continuously optimized manufacturing environments.

New global networks, based on the interconnection of individual devices into cyber-physical systems, will emerge. These systems will be interconnected in order to be able to autonomously exchange and control each other. Responsible staff has to pay attention to the opportunities and risks of the Industry 4.0 and to be able to ensure the conditions for their integration into the systems and logistics operation. These changes will have tremendous economic and social transformation impacts on society.

The aim of this case study was to compare several different methods to specify the most appropriate supplier of autonomous train systems for their operation in the selected company. To this end, three multi-criteria decision-making methods were applied. The values of importance of five determined criteria were specified applying the Fuller triangle method, by which the weights of each criterion were calculated.

Following the outcomes achieved, it can be concluded that using the WSA method, the Scoring method as well as the TOPSIS method, supplier no. 2 is considered the most appropriate variant based on the predefined criteria. On the basis of the investigated subject, it also can be stated that no similar publication has been published as yet using the same exact mathematical methods, criteria set or formulation of the problem objective of this manuscript.

Acknowledgement

References

1. *Company Faurecia.* 2019. Available at: https://www.faurecia.com/en
2. Pelegrina, G.D. & Duarte, L.T. & Romano, J.M.T. Application of independent component analysis and TOPSIS to deal with dependent criteria in multicriteria decision problems. *Expert Systems with Applications*. 2019. Vol. 122. P. 262-280.
3. Yu, B. Cai, M. & Li, Q. A λ-rough set model and its applications with TOPSIS method to decision making. *Knowledge-Based Systems*. 2019. Vol. 165. P. 420-431.
4. Agarski, B. & Hadzistevic, M. & Budak, I. & et al. Comparison of approaches to weighting of multiple criteria for selecting equipment to optimize performance and safety. *International Journal of Occupational Safety and Ergonomics*. Vol. 25. No. 2. P. 228-240.
5. Yu, C. & Shao, Y. & Wang, K. & Zhang, L. A group decision making sustainable supplier selection approach using extended TOPSIS under interval-valued Pythagorean fuzzy environment. *Expert Systems with Applications*. 2019. Vol. 121. P. 1-17.

6. Šeba, J. & Hruška, R. & Švadlenka, L. Analysis of automatic identification and data capture systems use in logistics. *Logi - Scientific Journal on Transport and Logistics*. 2016. Vol. 7. No. 1. P. 124-135. ISSN 1804-3216.

7. Bach, M.P. & Zoroja, J. & Loupis, M. RFID usage in European enterprises and its relation to competitiveness: Cluster analysis approach. *International Journal of Engineering Business Management*. 2016. Vol. 8. P. 1-11.

8. Plakhin, A. & Kampf, R. & Ogorodnikova, E. & et al. Localization strategies of the Czech companies on the basis of industrial-logistics parks in the Sverdlovsk region. *MATEC Web of Conferences*. 2017. Vol. 134.

9. Hruška, R. & Průša, P. & Babić, D. The use of AHP method for selection of supplier. *Transport*. 2014. Vol. 29. No. 2. P. 195-203.

10. Jeřábek, K. & Majercak, P. & Kliestik, T. & et al. Application of Clark and Wright´s savings algorithm model to solve routing problem in supply logistics. *Nase More*. 2016. Vol. 63. No. 3. P. 115-119.

11. Houska, M. Reply to the paper 'Multi-criteria analysis of economic activity for European Union member states and candidate countries: TOPSIS and WSA applications' by S. E. Dincer. *European Journal of Social Sciences*. 2012. Vol. 30. No. 2. P. 290-295.

12. Adetunji, O. & Bischoff, J. & Willy, C.J. Managing system obsolescence via multicriteria decision making. *Systems Engineering*. 2018. Vol. 21. No. 4. P. 307-321.

13. Dockalikova, I. & Klozikova, J. MCDM Methods in Practice: Localization Suitable Places for Company by the Utilization of AHP and WSA, TOPSIS Method. In: *Proceedings of the Conference on European Management Leadership and Governance*. MilitaryAcademy, Lisbon, Portugal. 2015. P. 543-552.

14. Kauf, S. & Tłuczak, A. Allocation of logistic risk-investment in public-private-partnership - Use of fuzzy TOPSIS method. In: *MATEC Web of Conferences*. 2018.

15. Rashidi, K. & Cullinane, K. A comparison of fuzzy DEA and fuzzy TOPSIS in sustainable supplier selection: Implications for sourcing strategy. *Expert Systems with Applications*. 2019. Vol. 121. P. 266-281.

16. Droździel, P. & Komsta, H. & Krzywonos, L. An analysis of costs of vehicle repairs in a transportation company. Part I. *Transport Problems*. 2012. Vol. 7. No. 3. P. 67-75.

17. Ližbetinová, L. & Kampf, R. & Ližbetin, J. Requirements of a transport system user. *Communications: scientific letters of the University of Žilina*. 2012. Vol. 14. No. 4. P. 106-108. ISSN 1335-4205.

18. Ližbetin, J. & Černá, L. & Ľoch, M. Model evaluation of suppliers in terms of real company for selected criteria. *Nase More*. 2015. Vol. 62. P. 147-152.

19. Kampf, R. & Lorincová, S. & Hitka, M. & Caha, Z. The application of ABC analysis to inventories in the automatic industry utilizing the cost saving effect. *Nase More*. 2016. Vol. 63. P. 120-125.

20. He, C. & Mao, J. AGV optimal path planning based on improved ant colony algorithm. *MATEC Web Conference*. 2018. Vol. 232. Art. no. 03052. DOI: 10.1051/matecconf/201823203052.

21. Fedorko, G. & Molnar, V. & Vasil, M. & Hanzl. J. Application of the Tecnomatix Plant Simulation Program to Modelling the Handling of Ocean Containers using the AGV System. *Nase More*. 2018. Vol. 65. No. 4. P. 230-236. DOI: 10.17818/NM/2018/4SI.12.

22. Hilmani, A. & Maizate, A. & Hassouni, L. Multi-criteria analysis and advanced comparative study of self-organization protocols in wireless sensor network. *Journal of Engineering and Applied Sciences*. 2018. Vol. 13. No. 13. P. 5168-5180.

23. Sun, Y., Su, T. & Tu, Z. Faster R-CNN based autonomous navigation for vehicles in warehouse. In: *IEEE/ASME International Conference on Advanced Intelligent Mechatronics. AIM*. Munich, Germany, 3-7 July 2017. P. 1639-1644. DOI: 10.1109/AIM.2017.8014253.

24. Lubikowski, K. & Radkowski, S. The project of shoulder of the suspension system for autonomous platform. *The Archives of Automotive Engineering – Archiwum Motoryzacji*. 2017. Vol. 751. No. 1. P. 85-92. DOI: 10.14669/AM.VOL75.ART5.

25. Ding, B. & Qu, X. & Song, W. A new collaboration distribution network base on third party logistics alliance. *Advanced Materials Research*. 2012. Vol. 403-408. P. 2772-2775. DOI: 10.4028/www.scientific.net/AMR.403-408.2772.
26. Georgiou, D. & Mohammed, E.S. & Rozakis, S. Multi-criteria decision making on the energy supply configuration of autonomous desalination units. *Renewable Energy*. 2015. Vol. 75. P. 459-467. DOI: 10.1016/j.renene.2014.09.036.
27. Kampf, R. & Hlatka, M. & Savin, G. Proposal for optimizing specific distribution routes by means of the specific method of operational analysis. *Communications - Scientific Letters of the University of Zilina*. 2017. Vol. 19. No. 2. P. 133-138.
28. Albus, J. & Bostelman, R. & Madhavan, R. & Scott, H. & Barbera, T. & Szabo, S. & Hong, T. & Chang, T. & Shackleford, W. & Shneier, M. & Balakirsky, S. & Schlenoff, C. & Huang, H.M. & Proctor, F. Intelligent control of mobility systems. *Studies in Computational Intelligence*. 2008. Vol. 132. P. 237-274. DOI: 10.1007/978-3-540-79257-4_13.
29. Wang, S. & Li, Z. Exploring the mechanism of crashes with automated vehicles using statistical modeling approaches. *PLoS ONE*. 2019. Vol. 14. No. 3. Article number e0214550. DOI: 10.1371/journal.pone.0214550.