ARCHIVES OF TRANSPORT
Volume 64, Issue 4, 2022

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.5604/01.3001.0016.1049*

MODELING THE DESIGNS IN TERMS OF LOGISTICS SERVICE CENTER PLACEMENT: A CASE STUDY

Ondrej STOPKA[1], Paweł DROŹDZIEL[2], Vladimír ĽUPTÁK[3]

[1, 3] Department of Transport and Logistics, Faculty of Technology, Institute of Technology and Business in České Budějovice, České Budějovice, Czech Republic

[2] Department of Sustainable Transport and Powertrains, Faculty of Mechanical Engineering, Lublin University of Technology, Lublin, Poland

Abstract:

Suggesting the proper location for logistics facility can be considered as a decision making problem, wherein the final solution/decision is affected by multiple external or even internal circumstances. In order to address the decision making issues, various multi-criteria decision making (MCDM) techniques may be implemented; and hence, they can be applied even when making a decision about an adequate logistics service center (LSC) placement in an examined territory (i.e., national logistics network of the selected territory), which is an aim of this manuscript. Following the statements above, as for the individual instruments of MCDM to be implemented in terms of the crucial objective of this research, the definite decision making process will be carried out by applying the Analytic Hierarchy Process (AHP) followed by the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), on the basis of criteria weights defined by the Saaty pairwise comparison method. The methods used appear to be ideal instruments towards decision making on the most suitable location which is represented by the region in our case. Subsequently, these will be ordered from the most preferred to least one by using a preference ranking. As a result of the application of AHP and TOPSIS approaches, based on the conducted calculations in regard to decision making on identifying the proper LSC location out of eight selected regions, one specific region will be defined as the most suitable (so-called compromise) scenario. Individual tools allow for reducing the number of assigned criteria that are taken into account in searching process for individual solutions. In order to objectify the entire decision making procedure, ten topic-involved experts having practical experience with a subject of logistics object allocation will be asked to participate in the process. Preferences differ from one decision maker (expert) to another; hence, the outcome depends on who is making decisions and what their goals and preferences are.

Keywords: *multi-criteria decision making, logistics service center, facility location, AHP, TOPSIS*

To cite this article:

Stopka, O., Droździel, P., Ľupták, V., (2022). Modeling the designs in terms of logistics service center placement: a case study. Archives of Transport, 64(4), 59-71. DOI: https://doi.org/10.5604/01.3001.0016.1049

Contact:
1) stopka@mail.vstecb.cz [https://orcid.org/0000-0002-0932-4381] – corresponding author; 2) p.drozdziel@pollub.pl [https://orcid.org/0000-0003-2187-1633], 3) luptak@mail.vstecb.cz [https://orcid.org/0000-0001-7550-5714]

1. Introduction

The selection of some logistics facility (for instance, such as warehouse, distribution center, logistics hub or logistics service center; LSC) locations can be considered either from a macro-view or a micro-view aspect. In particular, the macro-view aspect deals with the geographic location of LSC across the area in order to achieve better ensuring business resource and better business offers (i.e., increased service levels and / or cost reductions). The micro-view aspect deals with the factors that are critical in term of choosing a particular location within large geographic areas (Molnar et al., 2018).

In regard to the selection of some hub location from a macro-view scale, according to one of the most well-known American experts focusing on macro-view aspect of hub location with respect to economic capacity deployment Edgar M. Hoover, three basic types of location strategies can be distinguished (Makarov et al., 2017):

- market-oriented strategy;
- production-oriented strategies;
- central placement strategy.

In order to standardize, define and select methods of evaluation for multi-criteria evaluation of variants which support MCDM process, it is necessary to know the following matters: what is to be decided; what goals are to be met (what objectives are to be achieved and under what conditions); aspects of what is to be decided (what aspects the decision making process must adhere) and the time line for the outcome of the decision making process. The general procedure for the multi-criteria analysis, i.e., evaluation of variants, involves six follow-up steps (Díaz-Madroñero et al., 2017):

(1) identifying a set of variants;
(2) establishing a set of criteria;
(3) determining the weights of criteria;
(4) determining the criterion examples;
(5) partial evaluation of variants;
(6) selecting the most suitable variant.

To deal with the aforementioned, this study presents the research related to implementation of selected MCDM methods towards finding the most suitable region in a chosen logistics market to place the logistics service center within a national range. In other words, the crucial aim of the paper is to answer the question of where to locate the LSC out of eight considered regions in the context of national logistics network in the given territory.

As for the research problems addressed in the study, as well as its value added, these lie in particular in an endeavor towards designing a theoretical guideline for compiling a logistics service center allocation model at a national scale using specific multi-criteria analysis methods. The suggested model encompasses four main elements, namely defying a set of variants, establishing a set of criteria, determining the weights of criteria, and above all the very determination of the most suitable variant (Čarný et al., 2020). As far as a partial contribution of the paper goes, it summarizes a wide array of literature sources regarding the logistics facility allocation problem when using multi-criteria decision analysis (see Section 2). Furthermore, as for utilization of partial outcomes of the research (as its value added), these may be applied to:

- support decision making processes in terms of locating and allocating various logistics facilities in different territories;
- further decision making processes in the field of establishing an integrated functional network of various logistics facilities in different territories;
- support decision making processes in the context of implementing innovative information systems and technologies within logistics processes (Orynycz and Tucki, 2020);
- pedagogical activities; i.e., providing knowledge on the up-to-date state of logistics facilities, various location-allocation models and methods of multi-criteria analysis;
- and last but not least, needs of state government or regional government, logistics service providers, developers, decision makers and experts in the given fields of research, and other entities that can use the acquired knowledge for their needs.

Following the above, it can be stated that no analogous scientific paper on discussing the similar topic when applying the identical MCDM methods along with the same set of criteria has been published yet. And just suitable and effective combination of such instruments and their implementation in the specific area of logistics is where the novelty, innovative solution and value added of this work lies; it fills the gap in the literature dealing with the location-allocation tasks of logistics service centers at a national scale.

The remainder of this paper is organized as follows. Section 2 presents an in-depth literature review comprising pertinent sources. The data and methods used are described in Section 3. Section 4, as the most important part of the research conducted, the results obtained along with a relating discussion are formulated. And ultimately, Section 5 concludes this work and outlooks some recommendations for future research.

2. Literature review

There are a number of publications on LSC placement or logistics network design which have been addressed in numerous literature sources. They can be classified into different major categories depending on the modeling technology classical location-allocation theory models, and freight network spatial models when mostly using Operations Research methods (above all various methods of multi-criteria decision analysis). In regard to classical location-allocations models, there is a tendency in searching for the optimal solution of one or two of inter-hub links to amass large flows, while the others have relatively little flow moving across them. In this context, the author O'Kelly (1987) formulates the hub-location problem as a quadratic integer programming model, whereas Alumur et al. (2012) examine a multimodal hub-location problem from a network design point of view, considering together shipping cost as well as travel time, and designed a mixed stochastic programming approach regarding this issue.
On the other hand, in the paper (Sender and Clausen, 2011), a LSC network location model of wagon-load traffic in Germany railway logistics is discussed, which deals with determining the appropriate hub location and its size when taking into account cost aspect as well as the network system efficiency. The research study (Tang et al., 2013) presents an optimization model for a location planning problem of logistics parks with variable capacity, wherein the aim is to identify the optimal locations and allocate customers to logistics parks using a hybrid heuristic algorithm.
As far as the Technique for Order Preference by Similarity to the Ideal Solution is concerned, for instance, a comparative analysis based on the TOPSIS method in regard to determine a sustainable supplier for fundraising strategy is dealt with in the study (Yu et al., 2019a). Whereas by Kheika (2022), the TOPSIS is used as a basic tool to deal with generalized hesitant fuzzy numbers and their implementation in addressing general multi-attribute decision making processes. The case study aimed at the allocation of regional mountain railway track by using the twice-improved TOPSIS method is from a group of authors (Li et al., 2022), which is directly related to the presented study of logistics facility placement under specific (national) conditions.
Another application study is elaborated by (Sánchez-Lozano et al., 2022), wherein they similarly implement the optimal location problem to the selection of offshore wind sites to install wind power plants, which confirms the correct approach of our study and the adequate use of the methods. Specifically, they are focused on comparative analysis among fuzzy versions of MCDM approaches, including GIS technologies, when combining a classical AHP technique with two distance-based methods (namely, TOPSIS and VIKOR). The AHP method for assigning weights to the criteria, the TOPSIS approach for addressing the decision making matrix and the 2-fold linguistic model for processing qualitative information are introduced in the scientific work by Silva et al. (2022). On the other hand, Yu et al. (2019b) deal with a scenario of a group decision-making process that affects a sustainable approach in terms of appropriate supplier specification using the extended TOPSIS method under interval-valued Pythagorean fuzzy environment.
In the literature (Rashidi and Cullinane, 2019), a report of a comparative analysis of findings by using two supplier specification approaches, namely TOPSIS and DEA techniques, implemented to identify the most preferred suppliers. The article by Adetunji et al. (2018) is compiled for the purpose of combining multiple opted MCDM methods, specifically the TOPSIS and Monte Carlo simulations, wherein adding to the proposed methodology by incorporating an expert judgment criterion, in an effort to eliminate the risk of obsolescence in logistics. Whereas Kauf and Tłuczak (2018) use the fuzzy TOPSIS method for allocating investments associated with the logistics risk of public-private partnerships (PPP) in order to identify the best contractor for a certain logistics project under PPP approach. When compiling this paper, the research conducted by Zhang and Dai (2022) also entailed an important inspiration, which, by implementing decision-theoretic rough fuzzy sets, and designing an innovative TOPSIS approach in the field of logistics, analyzes

the connection between the classification of considered scenarios and the complete loss of scenarios. Simultaneously, it assesses the ranking rules when the scenarios are included in the same decision making domain compared to the ranking rules when the scenarios are included in distinct decision making domains. In addition, the authors execute several simulations in order to evaluate the ranking function attributes of the classic TOPSIS instrument in comparison with the upgraded (suggested) one.

As for the use of MCDM in relation to determining the appropriate location of various logistics facilities, a number of research and case studies have been published. For example, in (Awasthi et al., 2011) (Sopha et al., 2018), a framework of fuzzy multi-criteria decision making approach is proposed and its application to evaluate and select the appropriate location for urban distribution center under uncertainty in certain regions is demonstrated. And, Tadić et al. deal with the selection of efficient inland intermodal terminal types applying a novel approach for defining the types of inland terminals and a hybrid model for evaluating their efficiency (Tadić et al., 2019). The proposed model combines the fuzzy evaluation based on distance from average solution method (referred to as EDAS) and the assurance region data envelopment analysis (referred to as AR DEA) non-parametric method.

The authors of the literature source (Li et al., 2017) design a novel methodological apparatus for the location of industrial wastewater discharge applying Weighted Sum Approach (WSA), Analytic Hierarchy Process method and Saaty pairwise comparison method. And, for example, the other authors in (Dey et al., 2016) (Mangalan et al., 2016) (Özcan et al., 2011) compare different MCDM methodologies capable of handling subjective and objective factors for the evaluation and selection of warehouse locations. In these studies, several MCDM techniques, e.g., Technique for Order Preference by Similarity to the Ideal Solution, Simple Additive Weight (referred to as SAW), Multi-Objective Optimization on the basis of Ratio Analysis (referred to as MOORA) and others, are applied and compared with each other in order to offer advantages and disadvantages of these methods (methodologies).

For example, the literatures (Jablonský, 2007) (Zavadskas and Turskis, 2011) (Zopounidis and Pardalos, 2010) contain an overview of existing methods used for addressing MCDM in analogous concerns. However, some of them do not take into consideration the weight of each criterion and, therefore are not appropriate for this research work because, in the group of criteria affecting the final LSC location, considerable differences in terms of significance of criteria occur.

3. Data and methods

The general procedure of multi-criteria evaluation of variants as an integral part of a MCDM process assumes that at least two possible variants (considered scenarios) as solutions for the issue exist (Hamurcu and Eren, 2018). For the manuscript, it was decided that the process of multi-criteria evaluation of variants ought to be reduced only to include four crucial steps: defying a set of variants, establishing a set of criteria, determining the weights of criteria, and selecting the most suitable variant.

3.1. Defying a set of variants

As for the first step, it is necessary to identify a set of variants from which the definite solution is to be selected. To this end, individual regions located in the selected territory, wherein the LSC of national importance should potentially be placed, are specified as a set of following variants: Region A; Region B; Region C; Region D; Region E; Region F; Region G and Region H.

In order to obtain more precise outcomes, it would be reasonable to take into consideration the division at district level; however, in such a case, it would be very hard to retrieve the particular data necessary to fill in the criteria matrix, as most of the relevant data is not publicly accessible at a district level. On the other side, each region has only one larger city (county seat) in which implementation of particular logistics solutions can be considered in the future.

3.2. Establishing a set of criteria

The second step of the MCDM procedure consists in establishing a set of criteria which affect the whole process of decision making. After specifying goals of the available experiences and knowledge analysis relevant to this research work, desired set of criteria was needed to be specified. In regard to decision making on logistics facility allocation, in order to provide as high objectivity as possible, ten decision makers acting as experts, whose area of expertise is in particular logistics, were questioned to choose them. As an output of this partial decision making process, ten criteria primarily from socio-economic and transport areas potentially related to logistics approaches were defined. For clarity, all the criteria are summarized in the overview bellow:

- Criterion 1 – GDP (stands for gross domestic product per capita) [purchasing power standards - referred to as PPS];
- Criterion 2 – GDPGR (stands for average GDP growth over 5 years) [-];
- Criterion 3 – FDI (stands for value of foreign direct investment) [€ thousands];
- Criterion 4 – TGR (stands for amount of transported goods by road transport via public roads) [thousands of tons];
- Criterion 5 – LEs (stands for the number of large enterprises; i.e. > 250 employees) [pcs];
- Criterion 6 – SMEs (stands for the number of small and medium sized enterprises; i.e. < 250 employees) [pcs];
- Criterion 7 – PS (stands for region population size) [pcs];
- Criterion 8 – AGW (stands for average gross monthly wage) [€];
- Criterion 9 – RN (stands for road network density, including motorways, expressways and I. class roads) [km];
- Criterion 10 – AGTC (stands for regional connections to network of railway lines included in the European Agreement on Important International Combined Transport Lines and Related Installations) [pcs].

Table 1 shows the specific values of criteria related to individual variants (regions in the selected territory) over the year 2021.

3.3. Methods Applied

As mentioned, the final decision making process will be executed by applying the AHP, followed by the TOPSIS, based on the weights specified by the Saaty pairwise comparison method.

Saaty method is a technique of quantitative pairwise comparison of individual criteria. Generally, for the evaluation of paired comparison of criteria, a 9-point scale is utilized. For more detailed evaluation of criteria pairs, it is possible to use intermediate values as well (2, 4, 6, 8) (Saaty et al., 1983): 1 - equal criteria *i* and *j*; 3 - slightly preferred criterion *i* above *j*; 5 - strongly preferred criterion *i* above *j*; 7 - very strongly preferred criterion *i* above *j*; 9 - absolutely preferred criterion *i* above *j*.

The most commonly method to calculate the weights v_i is referred to as normalized geometric mean of a row in the Saaty matrix. The Saaty method can be used not only to determine the preferences between criteria, but also among variants by analyzing the original assignment, which is called as an AHP method. The entire Saaty method procedure is summarized, e.g., in (Hruška et al., 2014).

To calculate the geometric mean of each row of the matrix *S*, equation 1 is used (Awasthi et al., 2011):

$$g_i = \sqrt[k]{\prod_{j=1}^{k} s_{ij}}, \dots i,j = 1,2,\dots,k, \tag{1}$$

where: g_i is geometric mean; s_{ij} denotes elements of the Saaty matrix; $\prod$ is the product of values of the Saaty matrix elements.

The normalized geometric mean is calculated for each criterion using the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria. This step is carried out by the following equation (see Eq. 2) (Hruška et al., 2014).:

$$w_i = \frac{g_i}{\sum_{i=1}^{k} g_i}, \dots i,j = 1,2,\dots,k, \tag{2}$$

where: w_i is normalized geometric mean; $\sum$ denotes the sum of geometric means' values.

Table 1. Assignment of criteria and their values to individual scenarios

	Criterion:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Variant:	A	16,862	1.03	928,254	3,882	47	12,773	649,788	980	768.36	0
	B	53,779	1.02	27,291,407	8,138	172	48,124	650,838	1,449	240.51	3
	C	19,009	1.08	2,628,408	6,170	59	14,837	799,217	1,039	384.04	2
	D	19,992	1.03	1,634,817	2,967	58	15,621	678,692	1,021	555.80	2
	E	13,682	1.04	523,007	4,461	56	12,992	823,826	996	752.72	2
	F	18,947	1.01	1,794,988	7,091	72	10,214	587,364	1,020	404.22	2
	G	24,829	1.01	3,229,763	5,766	59	13,978	562,372	1,186	360.48	3
	H	20,509	1.04	2,913,839	6,497	69	16,336	691,023	1,015	673.39	3

So, decision makers compare each pair of criteria and determine the values of preferences between each other. Subjective assessment of the investigators is partially eliminated by normalization of the geometric mean. AHP method, first suggested by Saaty (Saaty et al., 1983) almost four decades ago, is one of the widely used MCDM tools. AHP can effectively handle both qualitative and quantitative data to decompose the problem hierarchically wherein the problem is thoroughly broken down. In regard to the hierarchical level, sub-elements of the problem are listed to the sub-objectives in relation with the overall objective (Saaty, 1990).
General AHP procedure is composed of four main phases, see, for instance, in (Kalčevová, 2008). This is a method of decomposition of a complex unstructured situation into simpler components, and thereby creating a hierarchical system for a problem. At each level of the hierarchical structure, the Saaty method of quantitative pairwise comparison (as described above) is used. Using subjective ratings of pairwise comparison, this method then assigns quantitative characteristics to each element indicating their importance. Subsequently, synthesis of these evaluations determines the component with the highest priority which the decision maker focuses on in order to obtain a solution to the decision making problem (Baric and Zeljko, 2021). This method does not require the exact values of individual criteria assigned to each variant to determine the overall variants' ranking. Its goal is to select the variant that results in the greatest value of the objective function. This is considered a compensatory optimization approach (Saaty et al., 1983).
TOPSIS tool is one of the MCDM methods where the variants' evaluation is carried out through comparison with ideal variant. To refer the deviation from options, various units are utilized. The fundamental of the TOPSIS method lies in standard Euclidean metrics. As far as the TOPSIS technique is concerned, the maximization nature is preferred, and hence all the minimization criteria must be converted into the maximization nature (Dockalikova and Klozikova, 2015). The next step is to compile the criteria matrix $R= (r_{ij})$ according to the equation 3:

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}} \text{; i} = 1,2, \dots, m; j = 1,2, \dots, n, \text{ [-]} \quad (3)$$

where: y_{ij} is the determined value of i-th variant by j-th criterion.
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 (see Eq. 4), from which the ideal variant H and basal variant D can be specified thereafter (Pelegrina et al., 2019).

$$z_{ij} = w_j r_{ij}, \text{ [-]} \quad (4)$$

where: w_j is relevant normalized criterion weight; r_{ij} denotes the normalized value of the given variant by each criterion.
The next step is to calculate the deviation d_i^+ of each Z matrix value from the ideal variant (see Eq. 5):

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - h_j\right)^2} \text{; i} = 1,2, \dots, m; \text{ [-]} \quad (5)$$
$$j = 1,2, \dots, n$$

where: h_j is the best (highest) value of the *j-th* criterion, i.e., ideal variant.
Analogously, the deviation d_i^- of each Z matrix value from the basal variant needs to be determined (see Eq. 6):

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - d_j\right)^2} \text{; i} = 1,2, \dots, m; \text{ [-]} \quad (6)$$
$$j = 1,2, \dots, n$$

where: d_j is the worst value of the *j-th* criterion, i.e., basal variant.
All the variants are then sorted depending on the values of the relative indicator c_i and the variants' ranking can be specified. This indicator is calculated by the equation 7 (Ejem et al., 2021):

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-} \text{; i} = 1,2, \dots, m, \text{ [-]} \quad (7)$$

4. Results and discussion

The ensuing sections (namely, 4.1-4.3) encompass the suggested decision making approach methodology of the decision making in relation to the logistics facility allocation.

4.1. Determining the weights of criteria

As far as this work is concerned, individual weights of criteria are about to be specified by the Saaty pairwise comparison method. The first step of this approach is to define the relationship among each pair of criteria, wherein the preference level is calculated within a range of 1-9. This is specified as follows:

a) and again, to ensure the greatest possible objectivity in terms of designing the LSC location methodology, ten decision makers (experts in the given field of research) were asked to assign preferences among individual criteria pairs;
b) for each cell of the initial Saaty matrix, a sum of the sub-matrices of all the experts was calculated and then the arithmetic mean was obtained. In order to keep to the technique procedure, individual values were rounded down to the nearest whole number.

The following Table 2 presents the resulting Saaty matrix after individual evaluation by experts.

Then, cell values of the Saaty matrix are used for further calculations. Individual values obtained for each criterion during intermediate calculations (product of cell values in each row; geometric mean for each line of the Saaty matrix – see Eq. 1) and the final values of the normalized geometric mean of weights (see Eq. 2) for each criterion are listed in Table 3.

From Table 3, apparently, the highest priority is assigned to factors associated with a transport infrastructure as well as transport characteristics of a given region. Those are represented by the road network density in km and the number of AGTC railway lines passing through a given region, as well as the amount of goods transported by road transport.

4.2. Selecting the most suitable variant using the AHP method

According to the general AHP procedure (Saaty, 2008), a comparison of individual options among each other by each defined criterion is to be performed. And again, ten experts were asked to specify preferences among individual variant pairs by each criterion. Each of ten experts assigned a level of significance for each pair of variants by the corresponding criterion. Consequently, for each evaluation part, a product of all the sub-matrices by all the experts was established; and then, the arithmetic mean can be calculated.

Table 2. Resulting Saaty matrix after experts' evaluation

Criterion	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	1.00	1.00	2.00	0.33	2.00	1.00	0.50	0.50	0.25	0.33
2.	1.00	1.00	2.00	0.33	2.00	1.00	0.50	0.50	0.33	0.25
3.	0.50	0.50	1.00	0.17	1.00	0.33	0.25	0.25	0.17	0.20
4.	3.00	3.00	6.00	1.00	5.00	3.00	2.00	2.00	0.50	1.00
5.	0.50	0.50	1.00	0.20	1.00	0.50	0.25	0.25	0.13	0.20
6.	1.00	1.00	3.00	0.33	2.00	1.00	0.50	0.50	0.25	0.33
7.	2.00	2.00	4.00	0.50	4.00	2.00	1.00	1.00	0.50	0.50
8.	2.00	2.00	4.00	0.50	4.00	2.00	1.00	1.00	0.50	1.00
9.	4.00	3.00	6.00	2.00	8.00	4.00	2.00	2.00	1.00	2.00
10.	3.00	4.00	5.00	1.00	5.00	3.00	2.00	1.00	0.50	1.00

Table 3. Resulting values obtained by applying the Saaty method

	Criterion	Product of cell values	Geometric mean	Priority vector
1.	**GDP**	0.0272250	0.6974	0.0558
2.	**GDPGR**	0.0272250	0.6974	0.0558
3.	**FDI**	0.0000298	0.3527	0.0282
4.	**TGR**	1620.0000	2.0939	0.1675
5.	**LEs**	0.0000406	0.3638	0.0291
6.	**SMEs**	0.0408375	0.7263	0.0581
7.	**PS**	16.000000	1.3195	0.1055
8.	**AGW**	32.000000	1.4142	0.1131
9.	**RN**	36864.000	2.8619	0.2290
10.	**AGTC**	900.00000	1.9744	0.1579
			$\sum = 12.501370$	$\sum = 1.00000$

Due to considerable extent of the entire following procedure and limited length of the paper, only first two sample comparisons of variants by 2 criteria namely, gross domestic product per capita (GDP) and average GDP growth over 5 years out of 10 determined criteria are presented in the following tables (Table 4 and 5), where b_i denotes geometric mean of values in each line of each comparison matrix and c_i indicates normalized geometric mean (i.e., resulting weights) for individual variants in each matrix.

In total, ten criteria were identified and, for each one, its weight was defined. This weight must be subdivided among the variants. Weights criteria and also weights of variants by each criterion were calculated. In order to determine the overall order of evaluated regions, sum of values of each variant by individual criteria multiplied by the corresponding normalized geometric mean (i.e., priority vector) was counted. Then, variants were listed in descending order, thereby the final variants ranking was determined (see Table 6).

Table 4. The comparison matrix of variants by gross domestic product per capita

GDP	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	b_i	c_i
A	1.00	0.25	0.50	0.50	2.00	0.50	0.50	0.50	0.59	0.06
B	4.00	1.00	3.00	3.00	5.00	3.00	2.00	3.00	2.75	0.30
C	2.00	0.33	1.00	1.00	2.00	1.00	0.50	1.00	0.95	0.10
D	2.00	0.33	1.00	1.00	2.00	1.00	0.50	1.00	0.95	0.10
E	0.50	0.20	0.50	0.50	1.00	0.50	0.33	0.50	0.46	0.05
F	2.00	0.33	1.00	1.00	2.00	1.00	0.50	0.50	0.87	0.10
G	2.00	0.50	2.00	2.00	2.00	2.00	1.00	2.00	1.54	0.17
H	2.00	0.33	1.00	1.00	2.00	2.00	0.50	1.00	1.04	0.11

Table 5. The comparison matrix of variants by average GDP growth over 5 years

GDPGR	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	b_i	c_i
A	1.00	1.00	0.33	1.00	1.00	2.00	2.00	1.00	1.04	0.12
B	1.00	1.00	0.33	1.00	0.50	1.00	1.00	0.50	0.73	0.08
C	3.00	3.00	1.00	3.00	2.00	4.00	4.00	2.00	2.54	0.28
D	1.00	1.00	0.33	1.00	1.00	2.00	2.00	1.00	1.04	0.12
E	1.00	2.00	0.50	1.00	1.00	2.00	2.00	1.00	1.19	0.13
F	0.50	1.00	0.25	0.50	0.50	1.00	1.00	0.50	0.59	0.07
G	0.50	1.00	0.25	0.50	0.50	1.00	1.00	0.50	0.59	0.07
H	1.00	2.00	0.50	1.00	1.00	2.00	2.00	1.00	1.19	0.13

Table 6. Resulting weights and final order of variants by the AHP method

Criterion		**Partial evaluation of variants**							
No.	**Priority vector**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1	0.0558	0.06	0.30	0.10	0.10	0.05	0.10	0.17	0.11
2	0.0558	0.12	0.08	0.28	0.12	0.13	0.07	0.07	0.13
3	0.0282	0.04	0.51	0.08	0.06	0.03	0.07	0.10	0.10
4	0.1675	0.08	0.16	0.14	0.07	0.11	0.14	0.14	0.14
5	0.0291	0.06	0.30	0.11	0.11	0.11	0.11	0.11	0.11
6	0.0581	0.07	0.38	0.10	0.11	0.07	0.06	0.08	0.13
7	0.1055	0.10	0.10	0.18	0.10	0.18	0.09	0.09	0.14
8	0.1131	0.21	0.02	0.14	0.14	0.16	0.14	0.05	0.15
9	0.229	0.22	0.04	0.07	0.13	0.22	0.07	0.07	0.18
10	0.1579	0.03	0.19	0.10	0.10	0.10	0.10	0.19	0.19
Resulting values		0.12	0.15	0.12	0.11	0.14	0.10	0.11	0.15
Variants' ranking by the AHP method		4.	**1.**	4.	6.	3.	8.	6.	**1.**

Following the carried-out calculations, it can be stated that the AHP method can be used as one of options in the matter of decision making on the most suitable location of LSC in the selected territory out of eight potential regions

In the light of aforementioned, ten performance criteria were taken into account while decision making. Ultimately, having considered the prior mentioned outcomes of calculations of the overall order of variants, the region H seems to be the ideal place in this context, along with the region B

4.3. Selecting the most suitable variant using the TOPSIS method

In the theory of the MCDM, we usually operate with a general number of criteria *c* and a general number of variants *v*. The value assigned to the *j-th* criterion by variant *i* is designated as y_{ij} and referred to as criterion value. One of the sub-steps of the MCDM is to list these values into a matrix which is called an input (or original) criteria matrix. Its lines are formed by individual variants and its columns correspond to individual criteria containing relevant values. A criteria matrix in our case is identical to Table 1.

Inasmuch as by implementing the TOPSIS approach, the variants' evaluation is carried out through their comparison with ideal variant, the maximization nature is preferred; and hence, all the minimization criteria must to be converted into the maximization nature on the basis of Eq. 8 (Díaz-Madroñero et al., 2017).

$$y_{ijmax} = h_{jmin} - y_{ijmin} \tag{8}$$

where: y_{ijmax} is the determined value of *i-th* variant by *j-th* criterion with a maximization nature; h_{jmin} represents the highest value of the *j-th* criterion with a minimization nature; y_{ijmin} denotes the value of *i-th* variant by *j-th* criterion with a minimization nature.

Thus, a modified criteria matrix looks as presented in the Table 7.

The next partial step is to build up a criteria matrix $R = (r_{ij})$ according to Eq. 3 (see the following Table 8). Sample:

$$r_{i1} = \frac{y_{i1}}{\sqrt{\sum_{i=1}^{m}(16862)^2 + (53779)^2 + \cdots + (20509)^2}} \tag{9}$$

As far as the next partial step goes (see Eq. 4), the normalized criteria matrix $Z = (z_{ij})$ needs to be compiled via multiplying the normalized variant values by each criterion with a priority vector (normalized weights of individual relevant criteria), from which the ideal variant H_j and basal variant D_j can be specified then (see the following Table 9).

According to the specified TOPSIS method procedure, next steps are to calculate the deviation of individual *Z* matrix values from the ideal variant d_i^+ (see Eq. 5), the deviation of individual *Z* matrix values from the basal variant d_i^- (see Eq. 6) and the relative indicator c_i (see Eq. 7) in order to sort all the variants in a descending order. Sample:

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(z_{1j} - h_1\right)^2} = \sqrt{\sum_{j=1}^{n}(0.0127 - 0.0404)^2 + \cdots + (0 - 0.0722)^2} \tag{10}$$

For all the variants, values of all these indicators as well as the final variants' ranking are clearly overviewed in the following Table 10.

Identically to the previous method, following the above-specified calculations undergone in terms of decision making on identifying the proper LSC location out of eight selected regions, when applying TOPSIS technique method, region H was laid down as the most suitable scenario. Besides, region E seems to be the second most appropriate option.

Table 7. Assignment of criteria and their modified values to individual scenarios

	Criterion:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Variant:	**A**	16,862	1.03	928,254	3,882	47	12,773	649,788	469	768.36	0
	B	53,779	1.02	27,291,407	8,138	172	48,124	650,838	0	240.51	3
	C	19,009	1.08	2,628,408	6,170	59	14,837	799,217	410	384.04	2
	D	19,992	1.03	1,634,817	2,967	58	15,621	678,692	428	555.80	2
	E	13,682	1.04	523,007	4,461	56	12,992	823,826	453	752.72	2
	F	18,947	1.01	1,794,988	7,091	72	10,214	587,364	429	404.22	2
	G	24,829	1.01	3,229,763	5,766	59	13,978	562,372	263	360.48	3
	H	20,509	1.04	2,913,839	6,497	69	16,336	691,023	434	673.39	3

Table 8. Criteria matrix R obtained by the TOPSIS method

Variant \ Criterion	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
A	0.2269	0.3535	0.0333	0.2346	0.2000	0.2106	0.3350	0.4250	0.4941	0
B	0.7238	0.3501	0.9786	0.4918	0.7321	0.7935	0.3355	0	0.1547	0.4573
C	0.2558	0.3707	0.0943	0.3729	0.2511	0.2446	0.4120	0.3715	0.2470	0.3049
D	0.2691	0.3535	0.0586	0.1793	0.2468	0.2576	0.3499	0.3878	0.3574	0.3049
E	0.1841	0.3569	0.0188	0.2696	0.2383	0.2142	0.4247	0.4105	0.4841	0.3049
F	0.2550	0.3466	0.0644	0.4285	0.3064	0.1684	0.3028	0.3887	0.2599	0.3049
G	0.3342	0.3466	0.1158	0.3485	0.2511	0.2305	0.2899	0.2383	0.2318	0.4573
H	0.2760	0.3569	0.1045	0.3926	0.2937	0.2693	0.3562	0.3932	0.4330	0.4573
Priority vector	0.0558	0.0558	0.0282	0.1675	0.0291	0.0581	0.1055	0.1131	0.2290	0.1579

Table 9. Normalized criteria matrix *Z* obtained by the TOPSIS method

Variant \ Criterion	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
A	0.0127	0.0197	0.0009	0.0393	0.0058	0.0122	0.0353	0.0481	0.1131	0
B	0.0404	0.0195	0.0276	0.0824	0.0213	0.0461	0.0354	0	0.0354	0.0722
C	0.0143	0.0207	0.0027	0.0625	0.0073	0.0142	0.0435	0.0420	0.0566	0.0481
D	0.0150	0.0197	0.0017	0.0300	0.0072	0.0150	0.0369	0.0439	0.0818	0.0481
E	0.0103	0.0199	0.0005	0.0452	0.0069	0.0124	0.0448	0.0464	0.1109	0.0481
F	0.0142	0.0193	0.0018	0.0718	0.0089	0.0098	0.0319	0.0440	0.0595	0.0481
G	0.0186	0.0193	0.0033	0.0584	0.0073	0.0134	0.0306	0.0270	0.0531	0.0722
H	0.0154	0.0199	0.0029	0.0658	0.0085	0.0156	0.0376	0.0445	0.0992	0.0722
H_j	0.0404	0.0207	0.0276	0.0824	0.0213	0.0461	0.0448	0.0481	0.1131	0.0722
D_j	0.0103	0.0193	0.0005	0.0300	0.0058	0.0098	0.0306	0	0.0354	0

Table 10. Final evaluation of variants using the TOPSIS method

Variant \ Indicator	d_i^+	d_i^-	c_i	**Variants' ranking by the TOPSIS method**
A	0.1002	0.1042	0.5098	4.
B	0.0919	0.1057	0.5349	3.
C	0.0820	0.0761	0.4813	8.
D	0.0829	0.0805	0.4927	7.
E	0.0704	0.1030	0.5940	2.
F	0.0811	0.0813	0.5006	5.
G	0.0846	0.0846	0.5000	6.
H	0.0535	0.1125	0.6777	**1.**

5. Conclusions

Concluding, the presented approach makes it possible to integrate logistic cells connected via processes of different nature (production, distribution, financial, or informational). The necessary condition for using the described approach is the presence of optional variants of technological processes, this belonging to the field of process engineering. The presented guideline can assist managers and engineers to design flows of various kinds of technological, distribution, and transportation processes in any chain-like structure.

One may employ the methodology presented in this paper as supplementation of methods/tools packets for improving manufacture and/or distribution processes (for example, according to the Lean production/Lean distribution concepts). Another possible use of the presented approach may include an obtained value of the integration loss index as an additional criterion for a multi-criteria evaluation for selecting the preferred variant of a technological process for every pair of neighboring links of a supply chain.

Main difficulties in applying the proposed multi-criteria tools for selecting a preferred logistics facility option may be described twofold. On the one hand, the quality of the transformation of the needs of individual logistic cells into a membership function is essential. On the other hand, it is necessary to define the probability densities for the process and, simultaneously, preserve its parameters as reliably as possible. Thus, the robustness and the reliability of the presented methodology is a derivative of the robustness of the employed approaches for evaluating the membership functions and probability densities, this being a common feature of methods based on fuzzy logic. Also, the results may be disturbed by irrational/irresponsible setting the weights in the multi-criteria techniques for selecting a preferred variant. Therefore, further works are needed to increase the applicability of the proposed methodology considering the difficulties mentioned above.

References

[1] Adetunji O., Bischoff J., Willy C.J., (2018). Managing system obsolescence via multicriteria decision making. Systems Engineering, 21(4), 307–321. DOI: 10.1002/sys.21436.
[2] Alumur S.A., Kara B.Y., Karasan O.E., (2012) Multimodal hub location and hub network design. Omega, 40(6), 927–939.
[3] Awasthi A., Chauhan S.S., Goyal S.K., (2011) A multi-criteria decision making approach for location planning for urban distribution centers under uncertainty. Mathematical and Computer Modelling, 53(1-2), 98–109. DOI: 10.1016/j.mcm.2010.07.023.
[4] Baric D., Zeljko L., (2021) Multi-Criteria Decision-Making on Road Transport Vehicles by the AHP Method. The Archives of Automotive Engineering – Archiwum Motoryzacji, 94(4), 17–26. DOI: 10.14669/AM.VOL94.ART2.
[5] Čarný Š., Šperka A., Zitrický V., (2020) Multicriteria Evaluation of Railway Transport Using Evaluation Method. LOGI – Scientific Journal on Transport and Logistics, 11(2), 88–99. DOI: 10.2478/logi-2020-0018.
[6] Dey B., Bairagi B., Sarkar B., Sanyal S.K., (2016) Warehouse location selection by fuzzy multi-criteria decision making methodologies based on subjective and objective criteria. International Journal of Management Science and Engineering Management, 11(4) 262–278. DOI: 10.1080/17509653.2015.1086964.
[7] Díaz-Madroñero M., Mula J., Peidro D., (2017) A mathematical programming model for integrating production and procurement transport decisions. Applied Mathematical Modelling, 52, 527–543. DOI: 10.1016/j.apm.2017.08.009.
[8] Dockalikova I., Klozikova J., (2015) MCDM Methods in Practice: Localization Suitable Places for Company by the Utilization of AHP and WSA, TOPSIS Method. Proceedings of the Conference on European Management Leadership and Governance, Lisbon, Portugal, 543–552.
[9] Ejem E.A., Uka C.M., Dike D.N., Ikeogu C.C., Igboanusi C.C., Chukwu O.E., (2021) Evaluation and Selection of Nigerian Third-Party Logistics Service Providers Using Multi-Criteria Decision Models. LOGI – Scientific Journal on Transport and Logistics, 12(1), 135–146. DOI: 10.2478/logi-2021-0013.
[10] Hamurcu M., Eren T., (2018) An application of multicriteria decision-making for the evaluation of alternative monorail routes. Mathematics, 7(1), 16. DOI: 10.3390/math7010016.
[11] Hilmani A., Maizate A., Hassouni L., (2018). Multi-criteria analysis and advanced comparative study of self-organization protocols in wireless sensor network. Journal of Engineering and Applied Sciences, 13(13), 5168–5180.
[12] Hruška R., Průša P., Babić D., (2014) The use of AHP method for selection of supplier. Transport, 29(2), 195–203. DOI: 10.3846/16484142.2014.930928.
[13] Jablonský J., (2007) Operační výzkum: kvantitativní modely pro ekonomické rozhodování, ed. 3, Prague: Professional Publishing, Czech Republic, 323 p. ISBN 978-80-86946-44-3 (in Czech).
[14] Kalčevová J., (2008) Multikriteriální analýza, Study materials, Available at: http://jana.kalcev.cz/vyuka/kestazeni/EKO422-Kriterialni-Matice.pdf., (Accessed 20th July 2019) (in Czech).
[15] Kauf S., Tłuczak A., (2018). Allocation of logistic risk-investment in public-private-partnership - use of fuzzy TOPSIS method. Paper presented at the MATEC Web of Conferences, 184. DOI: 10.1051/matecconf/ 201818404025.

[16] Keikha A., (2022). Generalized hesitant fuzzy numbers and their application in solving MADM problems based on TOPSIS method. Soft Computing, 26(10), 4673–4683. DOI: 10.1007/s00500-022-06995-z.

[17] Li Y., Lin C., Wang Y., Gao X., Xie T., Hai R., Wang X., Zhang X., (2017) Multicriteria evaluation method for site selection of industrial wastewater discharge in coastal regions. Journal of Cleaner Production, 161, 1143–1152. DOI: 10.1016/j.jclepro.2017.05. 030.

[18] Li Y., Jiang P., Fan M., Fan H., Wu W., Yang C., (2022). Optimal selection of mountain railway location design based on twice-improved TOPSIS method. Xinan Jiaotong Daxue Xuebao/Journal of Southwest Jiaotong University, 57(2), 253–260. DOI: 10.3969/j.issn.0258-2724.20200056.

[19] Makarov E.I., Nikolaeva Y.R., Shubina E.A., Golikova G.V., (2017) Impact of risks on stable and safe functioning of transport and logistics cluster of the transit region., (Book Chapter), Contributions to Economics, Issue 9783319552569, 321–326. DOI: 10.1007/978-3-319-55257-6_42.

[20] Mangalan A.V., Kuriakose S., Mohamed H., Ray A., (2016) Optimal location of warehouse using weighted MOORA approach. International Conference on Electrical, Electronics, and Optimization Techniques, ICEEOT 2016, Tamilnadu, India, 3-5 March 2016, Article no. 7754764, 662–665. DOI: 10.1109/ICEEOT .2016.7754764.

[21] Molnar V., Fedorko G., Honus S., Girovska, L., Ližbetin J., (2018) Selection and allocation of a warehouse linked to reloading terminal and seaport. Nase More, 65(4), 169–173. DOI: 10.17818/NM/2018/4SI.1.

[22] O'Kelly M.E., (1987) A Quadratic Integer Program for the Location of Interacting Hub Facilities. European Journal of Operational Research, 32, 393–404.

[23] Orynycz O., Tucki K., (2020) Technology management leading to a smart system solution assuring a decrease of energy consumption in recreational facilities. Energies, 13(13). DOI: 10.3390/en13133425.

[24] Özcan T., Elebi N., Esnaf A., (2011) Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem. Expert Systems with Applications, 38(8), 9773–9779. DOI: 10.1016/j.eswa.2011.02.022.

[25] Pelegrina G.D., Duarte L.T., Romano J.M.T., (2019) Application of independent component analysis and TOPSIS to deal with dependent criteria in multicriteria decision problems. Expert Systems with Applications, 122, 262–280.

[26] Rashidi K., Cullinane K., (2019). A comparison of fuzzy DEA and fuzzy TOPSIS in sustainable supplier selection: Implications for sourcing strategy. Expert Systems with Applications, 121, 266–281. DOI: 10.1016/j.eswa. 2018.12.025.

[27] Saaty T.L., (1990) Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, RWS Publications, Pittsburgh, Pennsylvania, USA, 292.

[28] Saaty T.L., (2008) Decision Making with the Analytic Hierarchy Process, International Journal of Services Sciences, 1(1), 83–98. DOI: 10.1504/IJSSci.2008.0175.

[29] Saaty T.L., Vargas L.G., Wendell R.E., (1983) Assessing Attribute Weights by Rations. Omega – International Journal of Management Science, 2(1), 9–13.

[30] Sánchez-Lozano J.M., Ramos-Escudero A., Gil-García I.C., García-Cascales M.S., Molina-García A., (2022). A GIS-based offshore wind site selection model using fuzzy multi-criteria decision-making with application to the case of the Gulf of Maine. Expert Systems with Applications, 210. DOI: 10.1016/j.eswa.2022. 118371.

[31] Sender J., Clausen U., (2011) A new hub location model for network design of wagonload traffic. Procedia – Social and Behavioral Sciences, 20, 90–99. DOI: 10.1016/j.sbspro. 2011.08.014.

[32] Silva R.R.D., Santos G.D., Setti D., (2022). A multi-criteria approach for urban mobility project selection in medium-sized cities. Sustainable Cities and Society, 86. DOI: 10.1016/j.scs.2022.104096.

[33] Sopha B.M., Asih A.M.S., Nursitasari P.D., (2018) Location planning of urban distribution center under uncertainty: A case study of Yogyakarta special region province, Indonesia.

Journal of Industrial Engineering and Management, 11(3), 542–568. DOI: 10.3926/jiem. 2581.
[34] Tadić S., Krstić M., Brnjac N., (2019) Selection of efficient types of inland intermodal terminals. Journal of Transport Geography, 78, 170–180. DOI: 10.1016/j.jtrangeo. 2019.06. 004.
[35] Tang J., Tang L., Wang X., (2013) Solution method for the location planning problem of logistics park with variable capacity. Computers and Operations Research, 40(1), 406–417.
[36] Yu B., Cai M., Li Q., (2019a) A λ-rough set model and its applications with TOPSIS method to decision making. Knowledge-Based Systems, 165, 420–431.
[37] Yu C., Shao Y., Wang K., Zhang L., (2019b). A group decision making sustainable supplier selection approach using extended TOPSIS under interval-valued Pythagorean fuzzy environment. Expert Systems with Applications, 123. DOI: 10.1016/j.eswa.2019.01.053.
[38] Zavadskas E.K., Turskis Z., (2011) Multiple Criteria Decision Making (MCDM) Methods in Economics: An Overview. Technological and Economic Development of Economy, 17(2), 397–427. DOI: 10.3846/20294913.2011. 593291.
[39] Zhang K., Dai J., (2022). A novel TOPSIS method with decision-theoretic rough fuzzy sets. Information Sciences, 608, 1221-1244. DOI: 10.1016/j.ins.2022.07.009.
[40] Zopounidis C., Pardalos P.M., (2010) Handbook of Multicriteria Analysis: Applied Optimization, 103, Springer-Verlag Berlin/Heidelberg. DOI: 10.1007/978-3-540-92828-7_2.