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Location selection for logistics centre using PROMETHEE method

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Abstract: Logistics and distribution centres are essential to the supply chains of many manufacturing and logistics companies. Efficiently locating logistic centres involves thorough search for optimal place, prioritizing proximity to suppliers and minimizing costs. Companies' management often solves the location problem of new halls, mostly to minimise the associated costs. Such a problem is solved in the automotive industry as part of the launch of a new international project. The key factor for the decision of where to locate the logistics centre is the location of the suppliers, since material deliveries generate a large part of the project costs. The aim of this study is to define a methodology for the location of the logistics centre, considering several alternative locations and relevant criteria. The location alternatives and criteria are defined in terms of minimising project costs and sustainability elements. The problem is solved using the multi-criteria decision-making approach. First, the AHP method is used to assign weights to the criteria. Then the PROMETHEE method is applied to find a suitable location for the logistics centre and to perform a thorough sensitivity analysis. The sensitivity analysis is focused on the impact of values of weights on the solution. Consequently, the analysis proves the correctness of the selected alternative. Based on the case study, a general methodology for locating a logistics centre is proposed.

1 Introduction

Finding a location for a logistics centre, distribution centre or warehouse is a crucial logistics issue that is being addressed by many companies and researchers around the world in different fields. These objects are considered as value generators in the flow of products that influence the efficiency of the whole supply chain [1]. The choice of their location is one of the strategic logistics decisions. A logistics strategy that reflects industry and market needs leads to higher competitiveness [2]. The choice of location requires systematic decision-making and forecasting, as its establishment involves high investment costs. By making inappropriate decisions, a company can endanger not only its economic situation, but also its environment and stakeholders [3].

Logistics centres have been part of supply chains since the last century. However, there is no standard methodology and criteria for determining the location of a logistics centre [1]. One of the reasons for this is the individuality of needs and input data, which require different approaches. The content of this paper is a case study in the automotive environment, focusing on the proposal of the logistics centre location for a new international project of a major automotive company. The production of a car requires the handling of a large number of parts and components supplied by a wide range of suppliers. This case study is specific in terms of the need to use intermodal transport. When intermodal transport is used, the same unit (container) is transported by 3 modes of transport - water, rail and road. The availability of the intermodal transport network plays an important role in transport efficiency [4]. The importance of the distance of transport hubs from the logistics centre in relation to the reduction of environmental impacts has been demonstrated in a research paper in [5]. Their research was supported by 8000 scientific articles. Several of these articles were analysed in detail. In addition, the proposed location of the logistics centre should meet the conditions of sustainability. Sustainability includes not only environmental criteria, but also economic and social criteria [6].

Considering the risks involved in the construction of the logistics centre and the magnitude of the problem, it was appropriate to solve the location problem scientifically. There are many approaches to solving the location problem in the literature. However, there is missing standardised methodology that could be applied regardless of the specifics and would be less complicated for companies to use in practice. This could be seen as a research gab.

The aim of the paper is to propose a methodology for the location of a logistics centre that works with the structure of the supply chain (location of suppliers in reference to a case study) and other criteria related to minimising logistics costs and supporting the sustainable development of the company. A methodology is proposed to explore relevant factors that represent location constraints. It also proposes an appropriate approach to differentiate their importance.

In order to achieve the objectives given, it was first necessary to consider the distribution of suppliers in the logistics network when designing the methodology. The reason why their placement is so important is that material supply generates the majority of the total project costs. Minimising material supply costs was achieved by using the gravity centre method. However, other relevant criteria also influence the decision-making process. The individual criteria were selected in relation to the pillars of sustainability. Due to the existence of several criteria, the gravity centre method was followed by multi-criteria decision making (MCDM) methods. Criteria weights were calculated using the Analytic Hierarchy Process (AHP) method [7]. The defined alternatives were ranked using the Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE) [8]. The combination of these two MCDM methods has been already applied by [9] and [10].

Section 2 contains the theoretical background of all used methods. In Section 3, the methods are applied in the case study. Section 4 presents the results and provides recommendations.

2 Theoretical background

This section briefly recalls three mathematical methods used in this paper. Namely, the gravity centre method for finding the location, the AHP method (only the part of the method that is necessary to calculate the weights of the criteria) and the PROMETHEE methods for ranking the alternatives. In all three cases, the reasons for the choice of method are also provided.

2.1 Gravity centre method

This simulation method deals with the problem of planning a logistics network in which a transport flow is carried out from an initial location to a final location. The method is based on the minimisation of transport costs, taking into account the distance and volume of goods transported between current facilities. The found gravity centre is considered as the optimal point of the logistics node in the system of objects. The method does not take into account the costs generated by the geographical location of the facility (e.g., land use charges, construction costs, labour costs). Nor does it take into account the future benefits of the facility. This mathematical technique is often used in practice, for example, to find the ideal location for a distribution centre or warehouse [11].

The coordinates of the gravity centre, determining the appropriate location of the device, are calculated according to the formula (1) and (2). The w_i represents the volume of supply or demand in considered location i $(i = 1,2,\dots,n)$, which corresponds to the coordinates d_{ix} and d_{iy} [12].

$$x = \frac{\sum_{i=1}^{n} d_{ix} w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

$$y = \frac{\sum_{i=1}^{n} d_{iy} w_i}{\sum_{i=1}^{n} w_i}. \tag{2}$$

In the literature, transport costs are often included in the centre of gravity model through a transport rate [13]. This method is applied to obtain the values of one of the important criteria in the case study.

2.2 AHP method – deriving the weights

The AHP algorithm can be split into two phases. In the first phase, the weights of criteria w_j are found. In the second phase, the utility of alternatives is calculated. Since the method is used just to derive the weights in this paper, the second phase will not be described here. An interested reader can look at Saaty [14]. The AHP method is based on the hierarchical structure of the problem, and the hierarchical structure of the criteria. Namely, each criterion C_i out of k evaluation criteria are split into g_i sub-criteria C_{ij}. Then, the criteria and each group of sub-criteria are evaluated one by one using the Saaty's matrix. This matrix provides pair-wise preferences s_{ij} using the Saaty's scale (1 = indifference, 2, 3, …, 9 = increasing preferences), for more details [14]. There are more ways how to derive the priorities from the Saaty's scale. The geometric mean method [12] is one of them, see (3):

$$w_i^L = \frac{\left(\prod_{j=1}^{k} s_{ij}\right)^{1/k}}{\sum_{i=1}^{k}\left(\prod_{j=1}^{k} s_{ij}\right)^{1/k}}, \forall i, \tag{3}$$

where s_{ij} stands for the element of the Saaty's matrix.

These priorities are called local weights and denoted as w_j^L (in case of criteria) and w_{ji}^L (in case of sub-criteria of the criterion i). The final (global) weights w_{ji}^G are calculated for each sub-criterion in the group i using (4). In total, $\sum_{i=1}^{k} g_i = K$ global weights are calculated. Since the hierarchical structure is not relevant for the rest of the algorithm, we can consider the problem as an MCDM problem with flat (single level) structure of K criteria.

$$w_{ji}^G = w_{ji}^L w_i, \forall i, j \tag{4}$$

The quality of each matrix should be checked using Consistency Ratio CR, which can be calculated from (5). If $CR < 0.1$, then the quality of the matrix is good enough. Otherwise, the evaluation should be adjusted.

$$CR = \frac{\lambda^{\max} - k}{(k-1)RI} \tag{5}$$

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where $\lambda^{\max}$ is the greatest real-valued eigenvalue of the

Saaty's matrix, k represents the size of the Saaty's matrix and RI is the random index (tabularized value dependent on k, see Saaty [14].

2.3 PROMETHEE method

PROMETHEE ranking method has been introduced by [15] almost 40 years ago. Since that time, its popularity grows for many reasons: (a) it is simple and well traceable; (b) it can handle all data types without the necessity of uncomfortable transformation; (c) it is well supported with available software, providing attractive graphical outputs; (d) it allows performance profiles of alternatives for the analysis, which make understanding of the solved problem easier.

The cornerstone of PROMETHEE ranking is a preference function, which assigns the so-called preference degree $P_i(x_j, x_l) \in [0; 1]$ to each pair of alternatives ($\forall x_j, x_l \in \mho$) with respect to each criterion $i \in \varkappa$, where $\mho$ ($|\mho| = n$) and $\varkappa$ ($|\varkappa| = k$) stands for the set of alternatives and criteria, respectively. The preference degree is assigned based on the difference in values of the compared alternatives in terms of the given criterion. A decision-maker can choose different shape of the preference function with different parameters for each criterion. [15] introduced 6 predefined shapes of the preference functions. By far, when looking at the published applications, see the review article [16], the most widely used shape is the linear one, with the indifference threshold q and preference threshold p (see Figure 1). After comparing all pairs of alternatives with respect to all criteria, the positive and negative flows of the j-th alternative are calculated as follows (6), (7):

$$\phi^+(x_j) = \frac{\sum_{l \neq j} \sum_{i=1}^{k} w_i \, P_i(x_j, x_l)}{n-1}, \tag{6}$$

$$\phi^-(x_j) = \frac{\sum_{l \neq j} \sum_{i=1}^{k} w_i \, P_i(x_l, x_j)}{n-1}, \tag{7}$$

where w_i stands for the weight of the i-th criterion reflecting its relative importance among the criteria.

The positive flow $\phi^+(x_j)$ expresses to what extent the alternative x_j performs on average better than other alternatives. The other way around, the negative flow $\phi^-(x_j)$ says to what extent the alternative x_j performs on average worse than other alternatives. The partial ranking using PROMETHEE reveals the preference of x_j over x_l if $\phi^+(x_j) \geq \phi^+(x_l) \wedge \phi^-(x_j) \leq \phi^-(x_l)$ (excluding the case when both pairs of flows are equal, revealing the equivalence of both alternatives). Otherwise, the pair of alternatives is incomparable using the partial PROMETHEE ranking (too much controversy in their profiles exists). If one requires the complete order on $\mho$, the complete ranking, using the net flows can be used instead (the grater the net flow, the better the alternative is) (8):

$$\phi(x_j) = \phi^+(x_j) - \phi^-(x_j). \tag{8}$$

To explore the modelled system into details, the partial flows can be calculated for each criterion separately (without adding them together), resulting in the structure of the flows and profiles of the given alternatives.

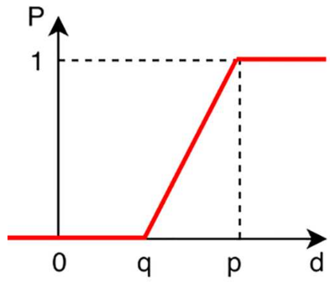

Figure 1 Linear shape of the preference function [16]

3 The case study

The case study focuses on the practical application of the chosen methods to find a suitable location for a logistics centre to be used for a new overseas project of a company operating in the automotive industry. The company manufactures a product consisting of a large number of different parts sourced from 514 suppliers in 26 countries. 96% of the suppliers are located in Europe. Of these, 80% are concentrated in Central Europe. The remaining 4% of suppliers are located outside Europe. The distribution of suppliers is shown in Figure 2.

Figure 2 Location of suppliers

3.1 Application of the gravity centre method

Supplier distribution is a key issue for the company. Material supply is a significant part of project costs. This observation leads to the choice of the gravity centre method, which makes it possible to locate the facilities in a way that minimises transport costs. However, minimising transport costs is only one of several criteria taken into account when searching for a suitable location for a logistics centre. The gravity centre method can be applied by knowing the GPS coordinates of the suppliers and the assumed annual volumes of material (in m^3 /year) that the suppliers will transport to the destination. Initially, the location of the logistics centre was searched only within the Czech Republic. Then the method was extended to the whole world, depending on the location of the suppliers and their future volumes provided to the project. There are several reasons why the gravity centre method was initially applied only within the Czech Republic. Based on the analysis of the input data, it was found that 74.9% of the annual material volumes are delivered by suppliers from the Czech Republic. Logically, it would be convenient to locate the logistics centre in the Czech Republic, especially in order to save transport costs. For these reasons, the company preferred to locate the logistics centre in the country. Another reason is the possibility of using the coordinate system of the Unified Trigonometric Cadastral Network (referred to as S-JTSK) to find the coordinates, which are essential data in the gravity centre method [12]. Its advantage is the display of the mathematical orientation of the coordinate axes. Working with S-JTSK allows more accurate data to be obtained than with manual coordinates, which must then be used to apply the method to global suppliers.

Based on the formula for calculating the gravity centre [12], the resulting GPS coordinates are [1045993.53, 651168.13]. By specifying the coordinates in S-JTSK, it was found that the coordinates correspond to an uninhabited area in Lhota pod Libčany (Královehradecký region).

In order to determine the appropriate location of the logistics centre based on the distribution of global suppliers, their selection is limited to suppliers that provide at least 100 m^3/year, to ensure data quality and relativity. This condition is met by 152 out of 514 suppliers. For the application of the centre of gravity centre method, the map with a coordinate system is used to determine the location of each supplier. The corresponding formula [12] is used to calculate the resulting gravity centre coordinates [143, 106]. The location found is a town - Nymburk in the Czech Republic (Central Bohemia region). This result confirms the suitability of the location of a logistics centre in the Czech Republic. The resulting location of the centre of gravity is only indicative. The centre of gravity method does not take into account whether the location found will be inhabited or uninhabited. It also does not take into account whether there are facilities in the vicinity that meet the requirements. The gravity centre method should not be used as the main decision-making tool. In the real world, the location should be considered from multiple perspectives and criteria. Therefore, in this case study, two methods of multi-criteria decision making were applied together.

3.2 Application of MCDM methods

For the location of the logistics centre, not only variants defined by the gravity centre method are considered. The company selected 4 other locations that would be appropriate for economic, distance or other reasons. This resulted in 6 alternatives that were compared using multi-criteria decision making. The criteria are chosen to meet the needs of the company and the principles of sustainability in relation to the organisation and society. The first step is to select and weight the evaluation criteria. Since it is natural to find a hierarchical structure of the criteria, the AHP method is used for the evaluation. In the second step, the weights obtained are used to rank the alternatives using the PROMETHEE method.

3.2.1 Evaluation criteria and their evaluation using AHP method

The criteria are divided into three groups - distance, economic and infrastructure (see Figure 3). In [17], PROMETHEE II is used for selection of facility location considering 8 criteria. Similarly, among the criteria, the authors used labour force and traffic intensity.

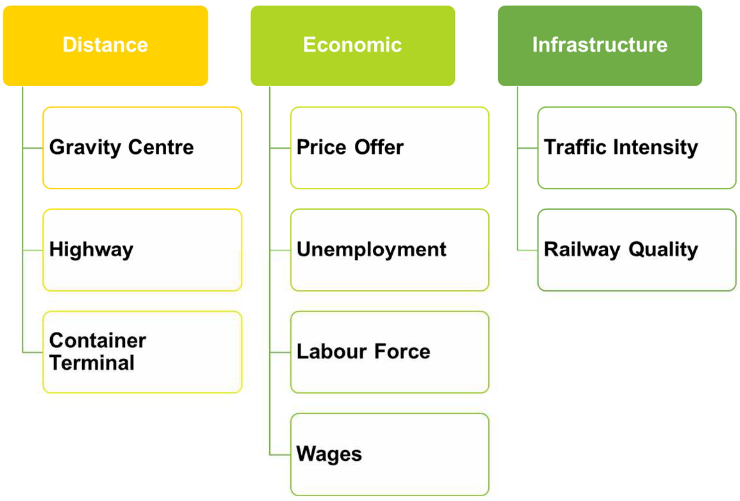

Figure 3 Defined criteria

In addition to the distance from the gravity centre, the distance to the container terminal and the nearest highway entrance were also included in the distance criteria. The distance to the gravity centre is important because it provides a clue, where should be located the facility in order to reduce input costs of the project that are generated by the delivery of materials from suppliers. Moreover, the amount of total logistics costs and emission will be affected by the necessary transport of containers with material from the logistics centre to the chosen container terminal. Therefore, the distance from the gravity centre and the container terminal is directly related to the economic pillar of sustainability by taking into account the minimising transport costs. It is also related to the environmental pillar of sustainability. As a result of minimizing transport costs, the environmental impact of transport will be reduced. The distance to the nearest highway entrances has been included to estimate the quality of the serviceability of the potential logistics centre's accessibility by road, which will be used frequently during the project.

One of the most important criteria are the price offers from potential logistics centre providers, which have a significant impact on the future performance of the company. Price offers are closely related to the economic principle of sustainable development of the company. Similarly, average wages in the location under consideration also have a relevant impact on the future economic situation of the company. The economic criteria also include unemployment and the level of the labour force according to the region to which the location belongs. Unemployment and the level of the labour force are important to the company in relation to the ability of the location to provide sufficient staff. The labour force includes all persons aged 15+ years who fulfil the requirements to be classified as employed or unemployed. The Czech Republic currently faces low unemployment and a shortage of skilled labour [18]. This may represent a risk to the company. In terms of these criteria, it is appropriate to locate the facility in a location with higher unemployment and labour force levels. These criteria can be considered as an instrument to achieve social development in the area where the logistics centre will be located.

The infrastructure in the area is assessed on the basis of traffic intensity and the railway quality. The railway quality represents the coverage of the rail network. Both criteria are also related to the quality of serviceability of the future logistics centre, which will receive large volumes of material deliveries at short intervals. The logistics centre will contribute to an increase in road traffic density, which will have a negative impact on living conditions in the area. Time also plays a role in the delivery of materials to the logistics centre. Delays in deliveries due to traffic density can cause process problems. Therefore, it is advisable to look for areas with lower traffic density from a logistical and environmental point of view. The quality of the rail network is considered aspect due to the potential to use the rail network instead of road transport for materials deliveries from the logistics centre in the future. The use of rail transport would reduce the carbon burden from transport. At the same time, transport costs would be reduced.

The choice of these criteria ensures that the proposed location of the logistics centre links the basic principles of sustainable development. Furthermore, it can ensure efficiency. The criteria form a logical tree structure, which allows to use the AHP method, see Sec. 2.2. First, the local weights, and then the global weights of the criteria have been calculated. The calculation of the weights was based on expert judgement. The results are shown in Table 1.

Table 1 AHP results

Main class	Distance			Economic				Infrastructure	
Local weights	0.540			0.297				0.163	
Criteria	Gravity Centre	Highway	Container Terminal	Price Offer	Unemployment	Labour Force	Wages	Traffic Intensity	Railway Quality
Label	C1	C2	C3	C4	C5	C6	C7	C8	C9
Local weights	0.648	0.122	0.230	0.599	0.104	0.078	0.220	0.800	0.200
Global weights	0.350	0.066	0.124	0.178	0.031	0.023	0.065	0.131	0.033

3.2.2 Evaluation of locations using PROMETHEE method

The PROMETHEE method was used to rank the 6 defined alternatives. These alternatives were compared in the Visual PROMETHEE software. The input data are summarized in Table 2, which also includes the weights obtained by the AHP method. Lhota pod Libčany, determined by applying the gravity centre method, was replaced by the regional city of Hradec Králové, which is 10 km away from the village. The reason was lack of data for some of the criteria. All distances in Table 2 are given in kilometres. The economic criteria - the unemployment rate [%], the level of the labour force [number of people] and the average wages [CZK] are related to the regions to which the area belongs. This information comes from the Czech Statistical Office. The price offer is evaluated with a point estimate in the interval from 1 to 10. The evaluation is carried out by experts from the selected company. In the case of infrastructure, the information on the intensity of local traffic [millions] also refers to the region and comes from data of the Road and Highway Directorate of the Czech Republic (referred to as ŘSD ČR). The railway quality is evaluated subjectively on a point scale from 1 to 10. The Railway Administration portal was used as the basis for the scoring. The railway quality was evaluated according to the number of lines for cargo transport and the existence of a container terminal, including its suitability for foreign dispatch. A negligibility value was determined according to the values obtained. The preferred function was defined as linear for all the criteria (see Figure 1) with the indifference threshold q determined expertly, and the preference threshold p set equal to the variation range of all alternatives (that brings the highest distinguishing power among alternatives).

Table 2 Decision matrix and parameters of preference functions

	Distance			Economic				Infrastructure	
Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9
Hradec Králové	13	10	120	4	3.32	277717	36912	3.656	4
Kvasiny	60	40	46	7	3.32	277717	36912	3.656	2
Pardubice	22	25	153	1	3.08	265515	34823	3.176	6
Paskov	265	3	2.5	3	5.20	591399	35599	6.645	8
Nymburk	0.5	20	53	4	3.37	758515	39716	10.082	3
Mladá Boleslav	40	0.5	50	5	3.37	758515	39716	10.082	5
MIN/MAX	MIN	MIN	MIN	MAX	MAX	MAX	MIN	MIN	MAX
Weight	35.00	6.60	12.40	17.78	3.09	2.30	6.53	13.10	3.30
Preference Fn.	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Indifference threshold	10	2.0	8	0	0.10	50000	500	0.100	0
Preference threshold	264	39	150	6	2.12	500000	4900	6.900	6

4 Results and discussion

This chapter contains the results of the PROMETHEE methodology. The results are examined on the basis of the net flows and the main visual tools of PROMETHEE. The quality of the results is verified through sensitivity analysis. The aim of the discussion and recommendations section is to provide a guide to the methodology including the benefits and barriers of applying the method.

4.1 Results

Using the PROMETHEE method, the alternatives were ranked according to the value of phi (see Table 3). Kvasiny was evaluated as the best alternative. The value of ϕ was based on the difference between positive and negative flows. The positive flow ϕ^+ indicates how much better a given variant is than the others. On the other hand, the negative flow ϕ^- indicates how much worse a given variant is than the others. How strong its weaknesses are.

Table 3 Ranking of alternatives

Rank	Location	ϕ	ϕ^+	ϕ^-
1	Kvasiny	0.1327	0.2630	0.1303
2	Hradec Králové	0.0906	0.2042	0.1136
3	Mladá Boleslav	0.0194	0.1880	0.1686
4	Nymburk	-0.0186	0.1692	0.1879
5	Pardubice	-0.0375	0.1942	0.2317
6	Paskov	-0.1866	0.2127	0.3994

Figure 4 displays the positive flows (advantages) and negative flows (disadvantages) of each option graphically. The positive flows are displayed using bars above the axis. On the other hand, the negative flows are shown below the axis. The greater the area of the bar represents the greater flow (and thus, either greater advantage or disadvantage). As Figure 4 shows, the main strength of Kvasiny is the price offer. However, its major weakness is distance to the highway entrance, which is not considered a significant factor.

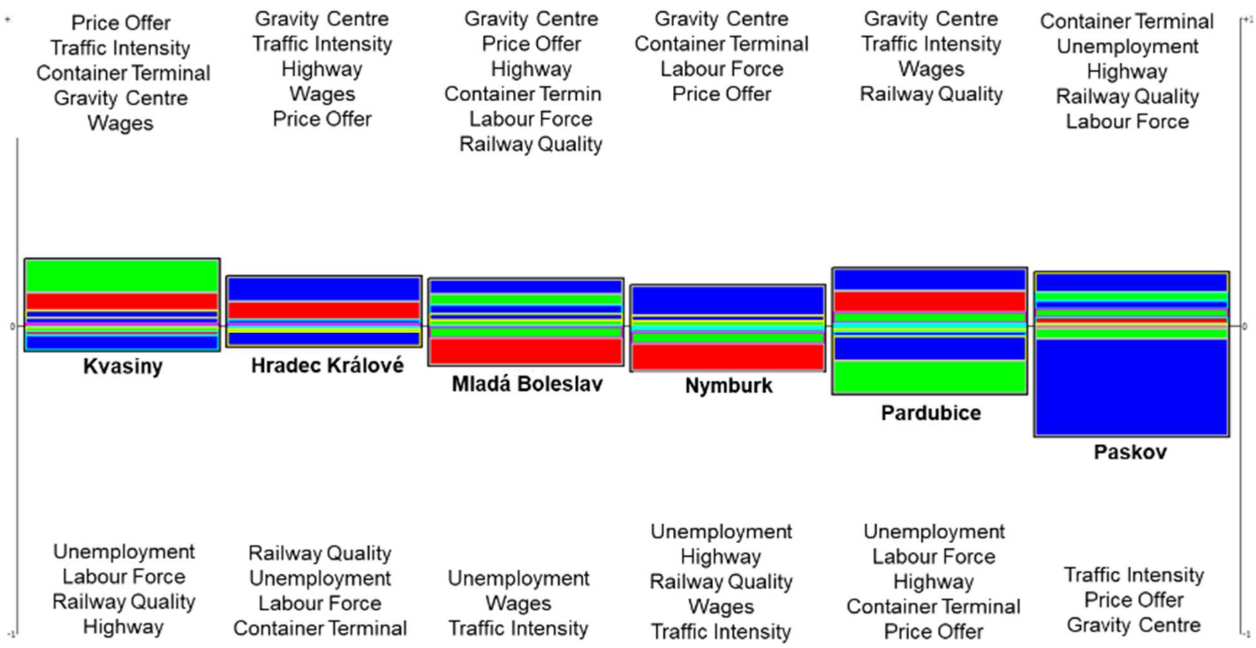

Figure 4 PROMETHEE Rainbow created in Visual PROMETHEE Software

Through Figure 5 it was discovered that there is no connection between Kvasiny and Hradec Králové. These alternatives are not comparable to each other. Kvasiny is the best alternative only in terms of net flows $\phi^+$and ϕ^-.

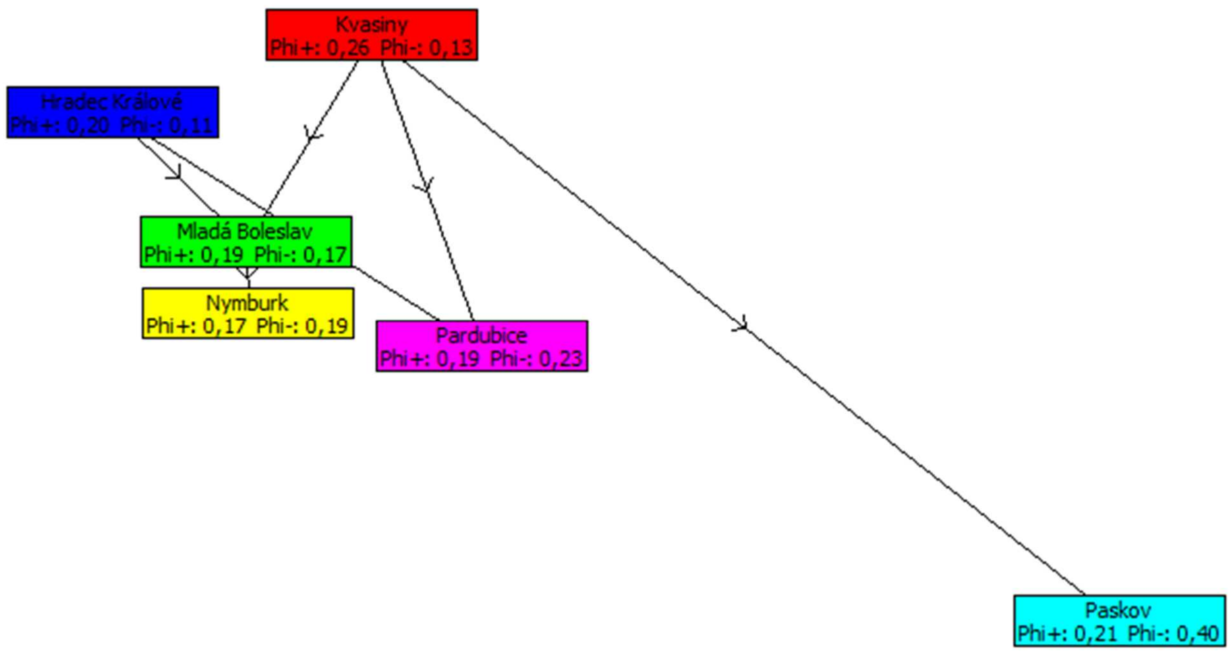

Figure 5 PROMETHEE Network created in Visual PROMETHEE Software

4.2 Sensitivity analysis

The sensitivity analysis is focused on the impact of values of weights on the solution. For this purpose, the tool called "Visual stability intervals" available in Visual PROMETHEE was used. This tool finds an interval for each weight $[LB.RB]$ within which the ranking does not change. Naturally the wider interval, the more stable solution obtained, see Table 4. In the same table, the values by which the current weights would have to be increased/decreased $\uparrow w_i / \downarrow w_i$ are provided together with the swaps of alternatives which would occur the first when exceeding the bounds.

Table 4 Sensitivity analysis of results

	C1	C2	C3	C4	C5	C6	C7	C8	C9
LB	0.248	0	0.103	0.151	0	0.007	0	0.072	0
RB	0.475	0.107	0.224	0.394	0.141	0.081	0.081	0.144	0.063
$\uparrow w_i$	0.125	0.037	0.104	0.214	0.111	0.061	0.011	0.014	0.033
↑swap	HK-KV	HK-KV	PE-PV	PE-PV	PE-PV	HK-MB	PE-NY	PE-NY	PE-NY
$\downarrow w_i$	0.103	-	0.018	0.029	-	0.013	-	0.058	-
↓swap	PE-PV	-	PE-NY	PE-NY	-	PE-NY	-	HK-MB	-

It can be seen that there are 4 criteria, which if they were removed from the model, the final ranking would have persisted (C2 Highway, C5 Unemployment, C7 Wages, C8 Railway quality). A change of the winner happened only in case of two criteria (C1 Gravity centre and C2 Highway). In both cases, Hradec Králové would replace Kvasiny. However, this swap would happen after the change of the weight of Gravity centre by more than 0.1 and such change would mean extreme revolution in preferences. Therefore, the most noteworthy possible change of the winning alternative would happen when the weight of Highway increases at least by 0.037. Nevertheless, the current solution can be considered very stable with respect to changes in weights.

The last analysis explores the role of the weights in general. In other words, how much the ranking changes if all 9 criteria are considered equally important. Surprisingly, complete reshuffle of the final net flows would happen. Namely, the current winner (Kvasiny) would become by far the worst. On the other hand, the current worst solution (Paskov) would become a new best option. This shows how much important is to distinguish different weights for criteria in the solved model.

Based on the results it is apparent that the only two locations which can be considered the best (compromise) ones are Kvasiny and Hradec Králové. Fig. 4 shows that the greatest advantage of Kvasiny is its good performance in price offer. It can be shown that if the price offer of Hradec Králové improves at least to the level of Mladá Boleslav, the net flow of Hradec Králové outperforms the net flow of Kvasiny (and Hradec would become the best option in terms of the partial PROMETHEE ranking. see Sec. 3.2). In case that the price offer of Hradec Králové improves at least to the same level as Kvasiny. Hradec Králové would outperform Kvasiny even in terms of the complete PROMETHEE ranking and the final recommendation would be unambiguous. The other way around if Kvasiny should be evaluated as the best location in terms of complete ranking due to the change in the price offer, then the current Kvasiny price offer would have to be improved to the best possible rating, i.e., 10.

4.3 Methodology and recommendation

The methodology presented in Figure 6 was developed by generalising the case study. The main step of the methodology is to define the objective of the logistics centre. Subsequently, data on the distribution of supply chain subjects are collected. In the case study, these are parts suppliers. Based on the required data about the subjects, the center of gravity method is applied. Through the centre of gravity method, the location that minimizes the transportation cost with respect to the selected subjects is found. This step is followed by defining other considered location alternatives. An essential part of the process is to define all relevant criteria for site selection that will minimise costs and support the company's objectives. The AHP method is used to determine the weights of the criteria. The ranking of alternatives is determined using the PROMETHEE method. The application of this method is followed by a sensitivity analysis to verify the predictive ability of the result. If the result shows to be very sensitive to the change in weights, a revision of the AHP method is required. If the result is judged to be sufficiently stable, the selected site is verified and validated. If there are doubts about the correctness of the result with respect to the specified criteria, the AHP method and the following steps need to be revised again. In the case, the resulting alternative location is considered suitable, real implementation in practice can take place.

The proposed methodology is suitable for those who intend to find a facility location that minimises logistics costs and supports sustainable business development. It is based on methods that can be adapted to different user needs. At the same time, it is versatile enough to be applied to different projects. Moreover, at the same time, it is designed to be easier to implement in the real world of business. This is achieved by combining the gravity centre method with two multi-criteria decision-making methods – AHP and PROMETHEE.

In order to use the centre of gravity method, it is necessary to know the location of the unit in relation to which the facility is located, the amount of material it supplies, its demand or other quantitative indicators. It should be noted that this mathematical and graphical method provides a location that is only indicative. It is important to work with it further. The gravity centre method should be only one of the methods used to decide on the location of the facility. The result is obtained by a weighted arithmetic average, so it is important to be aware of outliers in the form of supplier locations that are more distant than others. For example, if our key suppliers are located overseas, we should use the coordinates of the port to which the material is delivered. This can reduce the number of outliers that distort the result.

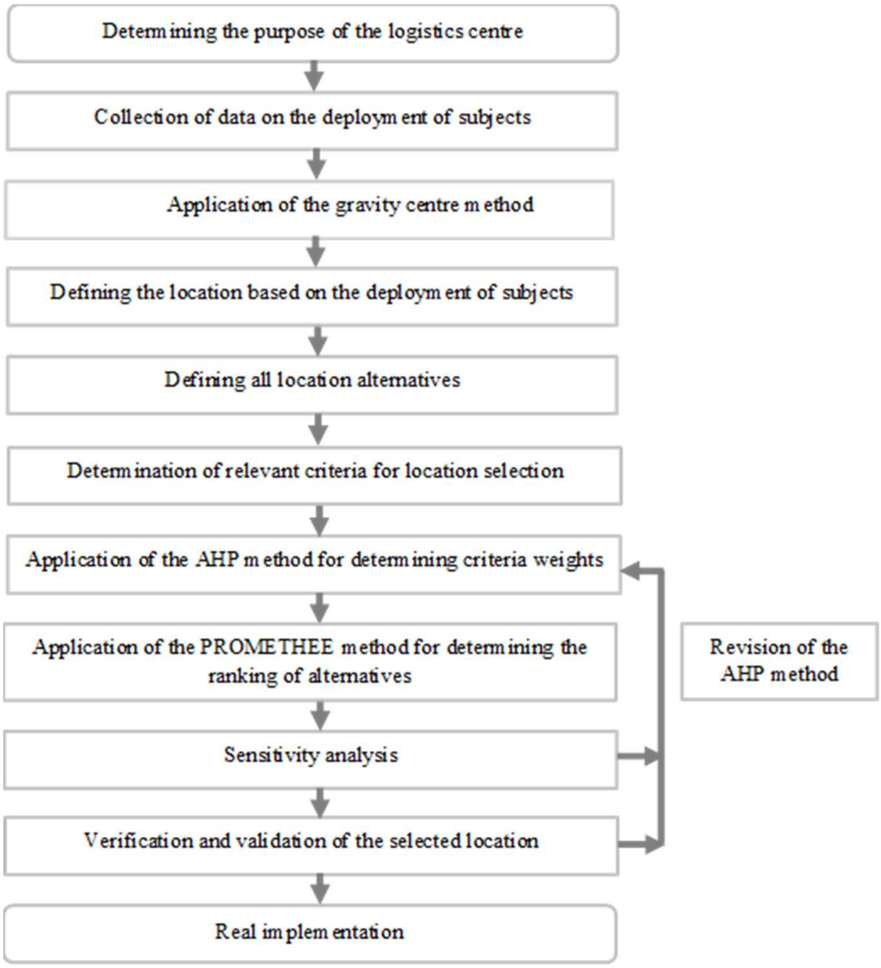

Figure 6 The proposed methodology

A prerequisite for the application of AHP and PROMETHEE methods is the ability to identify the relevant criteria and their weights. The hybrid combination of the AHP and PROMETHEE method provides several advantages for a decision-maker discovered already, e.g., by Taha and Rostam [9]. First, the AHP is invincible for structuring of criteria to the hierarchy that helps to handle more criteria in a single problem and potentially understand the problem better. Second, the PROMETHEE method (supported by free software) brings not only the ranking of the alternatives, but its deeper analysis through the structure of the resulting flows and easy sensitivity analysis too. Third if the ranking of two alternatives is in fact not so clear due to the controversial performance values and their completely different performance profile the PROMETHEE partial ranking reveals this fact and evaluates the given pair of alternatives as mutually incomparable.

Through the defined criteria, the methodology allows for the integration of multiple perspectives that can be used to examine the location of the facility from the perspective of the individual needs of the selected company. At the same time, in this case study, the criteria are designed to ensure that the individual needs of the organisation are consistent with the pillars of sustainability. The selected criteria are not a dogma, but a recommendation. The selection of criteria should be approached according to priorities. In particular, the criteria categorised under distance and infrastructure should always be adapted according to the organisation's material flow structure. The group of criteria could be extended to include. For example, the technological specification (capacity, level of technology, etc.) of the logistics centres in the locations under consideration.

5 Conclusions

This paper dealt with the design of a methodology for finding a suitable location for a logistics centre. The intention was to propose a missing methodology that would complete the research gap in terms of universality and practicality. The methodology was designed with the requirement to be able to work with the material flow structure in order to minimise logistics costs as the logistics centre has a significant impact on its efficiency. The gravity centre method was chosen for this purpose. This method can be applied universally to any supplier or customer structure. The method was followed by multi-criteria decision-making methods - AHP and PROMETHEE, which allow location alternatives to be examined from several perspectives. The chosen methods were practically applied in the case study. The case study focused on the design of a suitable location for a logistics centre for a new overseas project of a company operating in the automotive industry. The logistics centre will be used to consolidate materials from suppliers and then ship the consolidated shipment to the foreign plant. The supplier network was mapped using data analysis. The distribution of the supplier network was considered using the gravity centre method. Due to the intention to locate the centre domestically and the possibility to use S-JTSK to refine the result. the gravity centre method was first applied within the Czech suppliers. Subsequently, data from other global suppliers providing at least 100 m^3/year were used for its application. The resultant was Lhota pod Libčany in the work with Czech suppliers. In the case of applying the method within the world suppliers, the resulting gravity centre was located near Nymburk using manual coordinates. The result of the gravity centre method, combined with data from global suppliers, confirmed the suitability of locating the logistics centre in the Czech Republic. The defined locations became part of the 6 alternatives examined using multi-criteria decision-making methods. The alternatives were evaluated on the basis of 3 groups of criteria.

The criteria were selected taking into account the needs of the organisation and the pillars of sustainability. The weights of each criterion, which form a logical tree structure, were obtained using the AHP method. One of the main objectives of the company's logistics was to minimise transport costs. Transport costs represent a high proportion of the total project costs. For this reason, distance from the centre of gravity was given the highest weight. The second most important criterion was the price offers received from the logistics centre providers. The PROMETHEE method was used to rank the alternatives. According to the value of net flows, Kvasiny was determined to be the most suitable location. Based on the sensitivity analysis, the result was found to be stable with respect to the change of weights. However, if the criteria were equally important, Paskov would be the "winner" and Kvasiny the "loser". The sensitivity analysis showed that the compromise alternative for Kvasiny is Hradec Králové. The results of the PROMETHEE methods show that these alternatives are in fact incomparable.

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