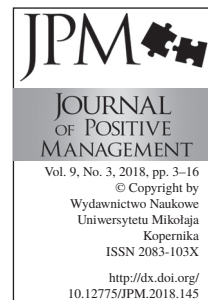


MULTICRITERIA OPTIMISATION METHODS IN LOGISTICS ON THE EXAMPLE OF WAREHOUSE LOCATION

Leszek Reszka

University of Gdansk, Gdansk, Poland

e-mail: leszek.reszka@ug.gda.pl



Abstract

Purpose: The purpose of the paper is to present the warehouse location as one of the key decision problems in logistics, a critical analysis of the centre of gravity method (commonly known and widely used) and to propose the more advanced methods to support the decision process in this area described in the contemporary publications on operational research, such as: AHP (Analytic Hierarchy Process), Simos' method and entropy method.

Methodology: The above purpose was realised by analysing the literature both from the logistics area, especially from one of its areas of activity which is warehousing and from operational research on the use of methods to support the warehouse location decision-making processes was made.

Findings: The article outlines the warehouse location as one of the key decision problems in the area of logistics. It presents centre of gravity approach described in the literature of logistics and shows its advantages and disadvantages. Furthermore, because the warehouse location is multicriteria decision problem, the more advanced methods from the area of operational research were suggested, such as: AHP (Analytic Hierarchy Process), Simos' method and entropy method.

Implications: The methods proposed in the article allow to take many criteria into consideration in the warehouse location process and also make it more objective.

Keywords: logistics, optimisation, warehouse location, multicriteria decision-making process

Paper type: Literature review

1. Introduction

Warehousing is undoubtedly one of the main areas of logistics operation in a company or a group of companies – the supply chain. The need to maintain inventories is a direct result of the logistics task of providing the resources required to realize the basic processes in an organization (Chaberek, 2002). In the production process there is often a relatively significant variation in the supply of resources that are used. That is the reason that their acquisition in periods of increased supply – and usually lower prices – allows for a smooth realization of the production process. The similar situation may also be related to the demand for specific products and its intensification in certain periods of the year, when

it would be impossible to maintain production at such a high level, then stocks could act as a sort of stabilizer, which allows to satisfy the increased demand. Warehousing has also an unquestionable impact on costs in a supply chain, as it reduces the frequency of deliveries and, as a consequence, makes advantages of scale in transport operations possible to gain. Additionally, it allows to receive a price discount from a supplier for whom such a situation can also be profitable. Moreover, inventories are undoubtedly important in the marketing of the company, especially in the area of customer service, as the availability of products and the short lead time seem to be one of the key competitive advantages of the company (Kisperska-Moroń and Krzyżaniak, 2009).

Hence, the proximity of retail outlets, demand centres, or sources of supply has been considered as one of the crucial criteria for warehouse location. However, it should be stated here that this is not the only criterion for their location.

2. Warehouse location as a decision problem

Looking at the warehouse-related issues more widely, it can be seen that they relate not only to their location, but also to a number of other problems associated with placement of warehousing process in the processes supporting operations of a company. Decisions can range from the most general to the more detailed ones.

One of the most strategic decisions about warehouses is the form of their ownership. On the one hand, owning the warehouse increases the independence of the business from external companies and gives the possibility of practically full control over customer service, but on the other hand, it involves the high costs of the warehouse building and its functioning (Jones, 2006).

An alternative decision in this regard may be logistics outsourcing, which in this case is implemented through renting storage space from an external service provider or even, increasingly used in electronic commerce, the so-called *dropshipping*, where the store accepts the order and its supplier executes it (Viswanadham, 2002).

Another, equally important issue regarding warehousing is the appropriate location of the so called *decoupling point* in the supply chain, which is defined as a point in the supply chain where the main stock is maintained and it also divides the flow of material into the area of independent demand and dependent one (Mason-Jones and Towill, 2002). This issue also relates to the number of warehouses in the supply chain and their type. On the one hand, placing the decoupling point near a manufacturer (upstream of the supply chain) gives the opportunity to consolidate inventory even in one central warehouse. On the other hand, moving the decoupling point closer to a customer (downstream of the supply chain) leads to an increase in the number of warehouses which act as regional ones (Bozarth and Handfield, 2016). The disadvantage of such a location

of decoupling point is that it increases the cost of maintaining inventory, however, it also saves the lead time (Țarțavulea et al., 2011).

Another, more specific decision related to the functioning of the warehouse is a selection of its technological system, i.e. the placement of reception and release zones (through, angular or bagging) and its storage facilities' technical equipment (such as racks, hangers, etc.), transport equipment (such as forklifts, cranes, conveyors, etc.), auxiliary equipment both for handling stored goods (such as ramps, platforms, pallets, containers, scales etc.) and for maintaining warehouses (such as thermometers, fire extinguishers, alarms etc.). An essential component of the warehouse equipment is also the appropriate IT system (WMS) (Kisperska-Moroń and Krzyżaniak, 2009).

Nevertheless, it should be noted here that one of the most significant and most frequently described decision problems in the literature of the subject is the optimal warehouse location which is defined according to *English Oxford Living Dictionary* as “a particular place or position” (*English Oxford Living Dictionary*), which suggests that it is treated as a certain feature of the object, in addition to its other features such as its surface, height, colour, etc. Nonetheless, when analysing the application of the term in logistics or spatial management literature – both English (Ozsen et al., 2008) and Polish (Marczuk, 2005) – *location* is also considered as the process of locating an object at a certain point in space. In such a sense the term *location* will also be used in this article. The feature of a facility location decision – here: warehouse location decision – is what causes far-reaching, long-term and irreversible effects, which in the future will be the background for subsequent decisions in this regard (Marczuk, 2005). These factors necessitate to make every effort to achieve the optimal location decision, i.e. to the maximum possible extent to maximize the benefits for future users of the new warehouse.

3. Methods of location decision-making process' support

In view of the above, the problem of optimal warehouse location is relatively widely reported in the literature of the subject. The most frequently described method of warehouse location is the so-called *centre of gravity approach* in which the coordinates of the warehouse (X, Y) are calculated from the formulas (1) and (2).

$$X = \frac{\sum_{i=1}^m W_i X_i + \sum_{j=1}^n W_j X_j}{\sum_{i=1}^m W_i + \sum_{j=1}^n W_j} \quad (1)$$

$$Y = \frac{\sum_{i=1}^m W_i Y_i + \sum_{j=1}^n W_j Y_j}{\sum_{i=1}^m W_i + \sum_{j=1}^n W_j} \quad (2)$$

where:

(X_i, Y_i) – coordinates of position of i -th supplier,

(X_j, Y_j) – coordinates of position of j -th receiver,

W_i – weight for i -th supplier,

W_j – weight for j -th receiver (customer).

The weights for suppliers or receivers are understood here as volumes of resources transported from the suppliers to the warehouse or from the warehouse to the receivers. In some publications they are also supplemented by the unit cost of transportation on individual routes for example in \$ per tkm.

This method, relatively computationally simple, can be regarded as a useful tool for the approximated location of a warehouse, serving as a guide for the decision maker. However, according to the author, taking into account only the size and cost of transportation processes is insufficient to treat the results obtained as the only possible location for the logistics facility. On the contrary, the problem of optimal location is a multi-criteria decision problem and factors related to existing and potential material flows are just one of the criteria categories that should be considered. In addition, according to the author, a broad spectrum of criteria should be considered that can be grouped into categories such as infrastructure, labour characteristics, legal factors and also environmental considerations, as shown in Table 1.

Table 1. Categories and corresponding criteria for warehouse location

Source: own elaboration based on: Kolińska, 2014; Yang and Lee, 1997; MacCarthy and Atthirawong, 2003; Cheng et al., 2005; Singh et al., 2018; Sopha et al., 2018.

Categories	Criteria
Existing and potential material flows	<ul style="list-style-type: none"> • proximity to demand, size of market that can be served/potential customer expenditure, population trends and nature and variance of demand, • location and quality of suppliers, alternative suppliers, competition for suppliers, nature of supply process (reliability of the system) and speed and responsiveness of suppliers • availability and quality of raw materials/resources • responsiveness and delivery time to markets • proximity to parent company • location of competitors • trucking, rail and air freight service • transportation costs

Categories	Criteria
Infrastructure	<ul style="list-style-type: none"> • availability and costs of land and buildings • availability of space for future expansion • existence of modes of transportation (airports, railroads, roads and sea ports, piers) • quality and reliability of modes of transportation • telecommunication systems • quality and reliability of utilities (e.g. water supply, waste treatment, power supply, etc.)
Labour characteristics	<ul style="list-style-type: none"> • availability of labour force • skill levels, productivity and motivation of labour force • unemployment rate • prevailing wage rates • labour unions, attitudes towards work and labour turnover
Legal factors	<ul style="list-style-type: none"> • requirements for setting up local corporations • regulations concerning joint ventures and mergers and regulations on transfer of earnings out of country rate • taxes, custom duties, tariffs • law system; bureaucracy • insurance and compensation laws • environmental regulations and industrial relations laws
Environmental considerations	<ul style="list-style-type: none"> • noise and air pollution around the site • climate • proximity to support services (e.g., fire, police, medical services and so on) • schools, churches, hospitals, recreational opportunities (for staff and children), education system, crime rate and standard of living • financial incentives • government and political stability • country's debt • interest rates/exchange controls and GDP/GNP growth, income per capita • currency, inflation • community attitudes towards business and industry and co-operation with established local industry • different norms and customs, culture, language and customer characteristics

Table 1.
continued

Taking into consideration the multiplicity and variety of criteria presented in the table, in the decision making process there should be used a method which enables to compare the available decision options using these criteria. It is difficult to imagine a situation in which one of the location variants would be characterized by the best performance of each criterion. On the contrary, the criteria are usually concurrent (Anholcer, 2009). As a result of this, the problem of warehouse location seems to be embedded in the broad spectrum of multi-

criteria decision problems in logistics and becomes similar in the methodological and procedural layer to the problem of supplier's evaluation and choice. These similarities may be a prerequisite for searching in the decision-making location process for methods that are used or recommended in the process of supplier's evaluation and choice. One from such methods is undoubtedly developed by Saaty (1987) the Analytic Hierarchy Process (AHP) in which pairs of available location variants are being compared pairwise under the considered criteria. During this comparison the figures corresponding to the descriptive assessment are used in accordance with Table 2.

Table 2.
Rating scale of
location variants in
the AHP method

Source: Trzaskalik,
2008; Reszka, 2014;
Ghorbanzadeh et al.,
2019; Zhou et al.,
2018.

Location variant A with variant B taking into consideration a given location criterion is:	Intensity of importance on an absolute scale
equal	1
equal to moderately preferred	2
moderately preferred	3
moderately to strongly preferred	4
strongly preferred	5
strongly to very strongly preferred	6
very strongly preferred	7
very strongly to extremely preferred	8
extremely preferred	9

On the basis of the resulting *matrices of pairwise comparisons the partial rankings' matrix* and *vector of criteria importance' ranking* are made. The final step in the AHP procedure is to calculate the *final ranking* as the product of the *partial rankings' matrix* and *vector of criteria importance' ranking*.

To illustrate the application of the AHP method, a simple hypothetical situation of choosing one of the three potential warehouse locations (location A, B and C) will be presented. The criteria taken into consideration will be: proximity to demand, quality of infrastructure, availability of labour force, tax rate, government and political stability. Information about possible location variants, with the qualitative description of the considered criteria, can be found in Table 3.

Table 3.
Presentation of
possible location
variants

Source: fictious data.

	location A	location B	location C
proximity to demand	high	low	medium
quality of infrastructure	medium	bad	good
availability of labour force	medium	high	medium
tax rate	15%	20%	10%
government and political stability	stable	stable	not stable

First step in the AHP procedure, as it was mentioned above, is to create the pairwise comparison matrices for decision variants and criteria (Table 4 and Table 5).

	proximity to demand			quality of infrastructure			availability of labour force			tax rate			government and political stability		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
A	1	7	5	1	5	1/5	1	1/5	1	1	5	1/5	1	1	6
B	1/7	1	5	1/5	1	1/5	5	1	5	1/5	1	1/8	1	1	6
C	1/5	1/5	1	5	5	1	1	1/5	1	5	8	1	1/6	1/6	1

Table 4.
Comparison matrices for decision variants

Source: own elaboration based on data from the Table 3.

	proximity to demand	quality of infrastructure	availability of labour force	tax rate	government and political stability
proximity to demand	1	1/3	1/5	1/3	1/3
quality of infrastructure	3	1	3	1/3	1/3
availability of labour force	5	1/3	1	1/3	1/3
tax rate	3	3	3	1	1/2
government and political stability	3	3	3	2	1

Table 5.
Comparison matrix for criteria

Source: own elaboration based on data from the Table 3.

Based on the matrices the so called the partial rankings' matrices are created (both for location variants – Table 6 and for criteria – Table 7).

	proximity to demand	quality of infrastructure	availability of labour force	tax rate	government and political stability
A	0.33	0.45	0.27	0.23	0.35
B	0.27	0.29	0.37	0.31	0.33
C	0.40	0.25	0.36	0.46	0.31

Table 6. Partial rankings' of location variants

Source: own elaboration based on data from the Table 3.

proximity to demand	0.07
quality of infrastructure	0.17
availability of labour force	0.14
tax rate	0.27
government and political stability	0.36

Table 7. Rankings of criteria importance

Source: own elaboration based on data from the Table 3.

a visualization and intuitive understanding of the decision problem solving. According to the method, participants in the study arrange the location criteria from the least to the most important one using the first type of cards, which include names of criteria and, optionally, other additional information about them. Such a set of cards for the example presented above is shown in the Figure 1.

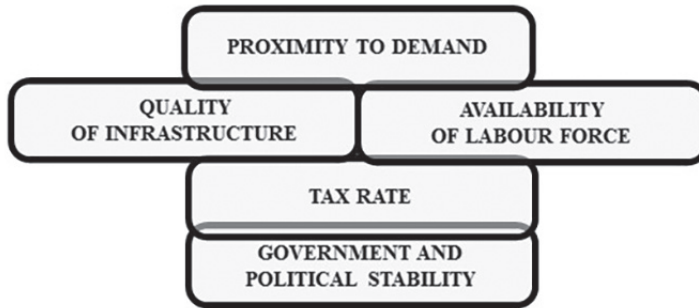


Figure 1.
Visualization of significance hierarchy of location evaluation criteria

Source: own elaboration based on data from the Table 3.

The cards of second type, i.e. empty cards, are used to differentiate the distance between the importance of the criteria (Figure 2 for the described example).

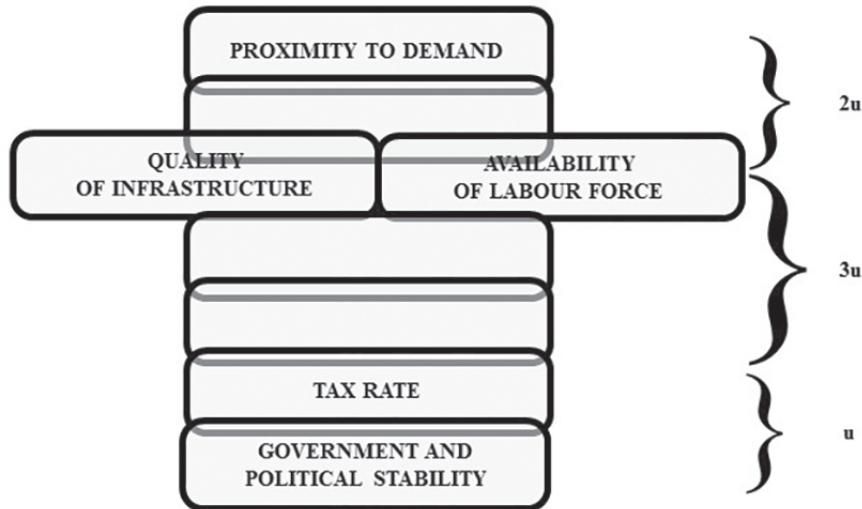


Figure 2.
Determining the distance between the importance of individual criteria for location variants evaluation

Source: own elaboration based on data from the Table 3.

The results of this study are presented in a tabular form using the constant “*u*” as the unit to measure the differentiation of the criteria’s importance. Further, the so called *average (non – normalized) weights* are determined, which in last step are subjected to a normalization process which results in *relative (normalized) weights*. The calculations are presented in table 8. (Górecka, 2009; Figueira and Roy, 2002; Kobryń, 2014; Reszka, 2017; Asihoglu and Memluk, 2017).

Leszek Reszka

Position in the rank	Set of cards	Quantity of cards	Numbers of cards	Non-normalized weights	Normalized weights	Total
1	proximity to demand	1	1	1	0.04	0.04
2	blank	1	2	X	X	X
3	quality of infrastructure, availability of labour force	2	3.4	(3+4)/2=3.5	0.15	0.30
4	blank	1	5	X	X	X
4	blank	1	6	X	X	X
6	tax rate	1	7	7	0.30	0.30
7	government and political stability	1	8	8	0.35	0.35
Sum	X	8	X	X	X	1.00

Table 8. Determination of weights to the criteria according to the Simos' procedure

Source: own elaboration based on data from the Table 3.

After the weights determination procedure, the overall assessments for individual location variants can be calculated as sum of the products of the weights and the quantitative assessments of the criteria (Table 9).

Table 9. Quantitative assessments of possible location variants

Source: own elaboration based on data from the Table 3.

	Location A	Location B	Location C
proximity to demand	5	1	3
quality of infrastructure	3	1	4
availability of labour force	3	5	3
tax rate	3	1	5
government and political stability	4	4	2

In this way, the location A would be selected (getting overall assessment equal to 3.43). The next place would be taken by location C, with a slightly lower score (3.41). Location B, similarly to the AHP procedure, would be the worst (2.65).

A different approach to assigning weights to individual location criteria characterizes the next proposed in this article *the entropy method*, which is also called *the objective weights method* (Deng et al., 2000). In this method the importance of each criterion is determined by the degree of discrepancy among their assessments in particular location variants.

After identification which of the criteria are stimulant (where a higher assessment is related to a higher value of a feature) and which are destimulants (where there is an opposite situation) the decision matrix is created (M).

$$M = \begin{bmatrix} 5 & 3 & 3 & 3 & 4 \\ 1 & 1 & 5 & 1 & 4 \\ 3 & 4 & 3 & 5 & 2 \end{bmatrix}$$

It is then subjected to a normalization process so that the sums of its individual columns corresponding to the sum of the criteria assessments (in the case of the stimulant) or respectively the sum of the reciprocal of the assessments (in the case of the destimulants) give the result equal to one.

$$N = \begin{bmatrix} 0.56 & 0.38 & 0.27 & 0.33 & 0.40 \\ 0.11 & 0.13 & 0.45 & 0.11 & 0.40 \\ 0.33 & 0.50 & 30.27 & 0.56 & 0.20 \end{bmatrix}$$

The decision information contained within the normalized matrix obtained (N) is measured for each criterion by the entropy E_j calculated from the formula (3).

$$E_j = -K \sum_{i=1}^m n_{i,j} \ln n_{i,j} \quad (3)$$

where:

$K = 1/\ln m$ – a constant guaranteeing that ,
 $n_{i,j}$ – elements of the normalized decision matrix.

The entropy vector, calculated according the formula (3), for the described example is:

$$E = [0.58 \quad 0.61 \quad 0.66 \quad 0.58 \quad 0.66].$$

Subsequently, the degree of discrepancy among the location criteria assessments in particular location variants is calculated as the complement of the elements of the entropy vector obtained to one:

$$D = [0.42 \quad 0.39 \quad 0.34 \quad 0.42 \quad 0.34].$$

Since the sum of elements of the resulting vector does not equal one they are also subjected to a normalization process, which is the last step of the described procedure (Kobryń, 2014, p. 47–50):

$$W = [0.22 \quad 0.21 \quad 0.18 \quad 0.22 \quad 0.18].$$

Similarly to the Simos' method, after the weights determination procedure, the overall assessments for individual location variants can be calculated as sum of the products of the weights and the quantitative assessments of the criteria (see Table 9). Again the location A would be selected (getting overall assessment equal to 0.392). The next place would be taken also by location C, with a slightly lower score (0.382). Location B, similarly to the AHP and Simos' procedure, would be the worst (0.227).

4. Conclusions

The methods presented in this article which might be used to assist location decision-making process may support it in a significant manner. The warehouse location is an example of a multi-criteria decision problem in logistics and because of that an assignment of weights seems to be an essential step to maximal

objectification of this process. That is in the author's opinion, possible by using the wide range of methods available in the literature of operational research. Thus the decisions made are optimal taking into consideration not only existing and potential material flows but also a number of other more or less important criteria.

References

- Anholcer, M. (2009), *Badania operacyjne*, Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu, Poznań.
- Asihoglu, F., Memluk, Y.D. (2017), "Determining and Mapping Eco-Cultural Subregions Using GIS and Simos Procedure", *Journal of the Indian Society of Remote Sensing*, Vol. 45 No. 3, pp. 553–567.
- Bozarth, C., Handfield, R.B. (2016), *Introduction to Operations and Supply Chain Management*, Pearson Education Limited, London.
- Chaberek, M. (2002), *Makro- i mikroekonomiczne aspekty wsparcia logistycznego*, Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk.
- Cheng, E.W.L., Li, H., Yu, L. (2005), "The Analytic Network Process (ANP) Approach to Location Selection: a Shopping Mall Illustration", *Construction Innovation*, Vol. 5 No. 2, pp. 1471–1475.
- Deng H., Yeh, Ch-H., Willis, R.J. (2000), "Inter-Company Comparison Using Modified TOPSIS with Objective Weights", *Computers & Operations Research*, Vol. 27 No. 10, pp. 963–973.
- Emec, S., Akkaya, G. (2018), "Stochastic AHP and fuzzy VIKOR approach for warehouse location selection problem", *Journal of Enterprise Information Management*, Vol. 31 No. 6, pp. 950–962.
- English Oxford Living Dictionary*, available at: <https://en.oxforddictionaries.com/definition/location> (accessed 28 February 2018).
- Figueira, J., Roy, B. (2002), "Determining the Weights of Criteria in the ELECTRE Type Methods with a Revised Simos' Procedure", *European Journal of Operational Research*, No. 139, pp. 318–319.
- Gawlik, R. (2016), "Stratyfikacja próby badawczej i dobór ekspertów na przykładzie modelu decyzyjnego opartego na metodzie AHP", *Studia i materiały. Miscellanea Oeconomicae*, Vol. 3 No. 20, pp. 193–200.
- Ghorbanzadeh, O., Moslem, S., Blaschke, T., Duleba, S. (2019), "Sustainable Urban Transport Planning Considering Different Stakeholder Groups by an Interval-AHP Decision Support Model", *Sustainability*, Vol. 11 No. 1, pp. 1–18.
- Górecka, D. (2009), *Wielokryterialne wspomaganie wyboru projektów europejskich*, Wydawnictwo TNOiK „Dom Organizatora”, Toruń.
- Jones, J.V. (2006), *Integrated Logistics Support Handbook*, McGraw-Hill, New York.
- Kisperska-Moroń, D., Krzyżaniak, S. (Eds.) (2009), *Logistyka*, Biblioteka Logistyka, Poznań.
- Kobryń, A. (2014), *Wielokryterialne wspomaganie decyzji w gospodarowaniu przestrzenią*, Difin, Warszawa.
- Kolińska, K. (2014), „Rynek powierzchni magazynowych w Polsce – analiza trendów”, *Gospodarka Materiałowa i Logistyka*, No. 3, pp. 21–25.

- MacCarthy, B.L., Atthirawong, W. (2003), "Factors affecting location decisions in international operations – a Delphi study", *International Journal of Operations & Production Management*, Vol. 23 No. 7, pp. 794–818.
- Marczuk, A. (2005), "Sieciowa metoda lokalizacji obiektów jako czynnik ograniczający koszty transportu w rolnictwie", *Inżynieria rolnicza*, No. 7, pp. 161–168.
- Mason-Jones, R., Towill D.R. (1999), "Using the information decoupling point to improve supply chain performance", *The International Journal of Logistics Management*, Vol. 10 No. 2, pp. 13–16.
- Ozsen, L., Coullard, C.R., Daskin, M.S. (2008), "Capacitated warehouse location model with risk pooling", *Naval Research Logistics*, Vol. 55 No. 4, p. 295–312.
- Prusak, A., Stefanów P. (2014), *AHP – analityczny proces hierarchiczny. Budowa i analiza modeli decyzyjnych krok po kroku*, Wydawnictwo C.H. Beck, Warszawa.
- Reszka, L. (2014), „Możliwości wykorzystania metody AHP do rozwiązywania wielokryterialnych problemów optymalizacyjnych w logistyce”, in: Chaberek, M., Reszka, L. (Eds.), *Modelowanie procesów i systemów logistycznych, Zeszyty Naukowe Uniwersytetu Gdańskiego. Ekonomika Transportu i Logistyka*, No. 51, Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk, pp. 251–259.
- Reszka, L. (2017), "The Applicability of the Simos' Method to Determination of Weights in Optimal Multicriteria Decision Making In Logistics", in: Chaberek, M., Reszka, L. (Eds.), *Modelling of Logistics Processes and Systems, Research Journal of the University of Gdańsk Transport Economics and Logistics*, Vol. 66, Gdańsk University Press, Gdańsk 2017, pp. 81–88.
- Saaty, R.W. (1987), "The Analytic Hierarchy Process – What It Is and How It Is Used", *Mathematical Modelling*, Vol. 9 No. 3–5, pp. 161–176.
- Simos, J. (1990), "Evaluer l'impact sur l'environnement: Une approche originale par l'analyse multicritere et la negociation", *Presses Polytechniques et Universitaires Romandes*, Lausanne.
- Singh, R.K., Chaudhary, N., Saxena, N. (2018), "Selection of warehouse location for a global supply chain: A case study", *Iimb Management Review*, Vol. 30 No. 4, pp. 343–356.
- 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*, Vol. 11 No. 3, pp. 542–568.
- Stoltmann, A. (2015), "Porównanie projektów budowy farm wiatrowych z wykorzystaniem metody AHP", *Zeszyty Naukowe Wydziału Elektrotechniki i Automatyki Politechniki Gdańskiej*, No. 46. Gdańsk, pp. 88–92.
- Szterlik, P. (2016), "Lokalizacja magazynu centralnego z zastosowaniem metod wielokryterialnych", *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, No. 446, pp. 237–249.
- Țarțavulea, R.I.M., Belu, G., Dieaconescu V.C. (2011), "Spatial Modeling in Logistics Decision-Making Processes. Identifying the Optimal Location for a Single Central Warehouse", in: Dodescu, A., Pop, N.A. (Eds.), *Conference proceedings, European Integration – New Challenges 7th edition*, May 27–28 2011.

- Trzaskalik, T. (2008), *Wprowadzenie do badań operacyjnych z komputerem*, Polskie Wydawnictwo Ekonomiczne, Warszawa.
- Viswanadham, N. (2002), „Optimal Retail Order Fulfilment Strategies”, *The 4th Asian Control Conference Proceedings*, Singapore.
- Yang, J., Lee, H. (1997), “An AHP Decision Model for Facility Location Selection”, *Facilities*, Vol. 15 No. 9/10, pp. 241–254.
- Zhou, X., Hu, Y., Deng, Y. (2018), “A Dematel-based Completion Method for Incomplete Pairwise Comparison Matrix in AHP”, *Annals Of Operations Research*, Vol. 271 No. 2, pp. 1044–1066.