14th International Scientific Conference "Business and Management 2024"
May 16–17, 2024, Vilnius, Lithuania

NEW TRENDS IN CONTEMPORARY ECONOMICS, BUSINESS AND MANAGEMENT

ISSN 2029-4441 / eISSN 2029-929X
eISBN 978-609-476-363-2
Article Number: bm.2024.1239
https://doi.org/10.3846/bm.2024.1239

MULTI-CRITERIA ALGORITHM DEVELOPMENT FOR SUSTAINABLE TRANSPORTATION IN A RAPIDLY CHANGING ENVIRONMENT

Aleksei IURASOV [1], Olga IURASOVA [2*], Larisa IVASHKO [3]

[1,2]Faculty of Business Management, Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania
[3]Faculty of Economics and Law, Odesa I. I. Mechnikov National University, Frantsuzskiy Boulevard 24/26, 65058, Odesa, Ukraine

Received 15 January 2024; accepted 9 March 2024

Abstract. This study aims to develop an algorithm to optimize road transport delivery costs, with a focus on warehouse selection and delivery planning. The main objectives are to reduce delivery costs and ensure supplier reliability. The study is confined to Ukraine's southern regions. The algorithm, based on the Pareto front in a two-criteria transport problem, when applied, its selects two additional warehouses from five reserves, finds the best delivery plan, and reduces the total delivery route length, thereby cutting transportation costs. The study concludes by highlighting the algorithm's potential to enhance transportation efficiency and reliability in Ukraine.

Keywords: Multi-criteria decision making, logistics process management, supply chain optimization, sustainable transportation, transportation algorithm development.

JEL Classification: M00, L91.

1. Introduction

Under the influence of the current situation in Ukraine, the problem of reducing risks and increasing the reliability of transportation has become especially relevant. In Ukraine, logistics is formed to a large extent in conditions of the transport environment ambiguity and instability, requiring the formation of new methods of management. In such a situation, companies form supply chains based not only on the transportation cost and time, but also on the route reliability (Grechan, et al., 2022; Kotenko et al., 2022).

The Odessa region, like the whole of Ukraine, is currently characterized by rapidly changing environmental conditions. Further development of the logistics concept, among other requirements, implies prompt changes in supply routes due to changes in transportation risks. This ensures the sustainability of the logistics system. At the same time, delivery of the goods to the recipient at the minimum cost is also of paramount importance.

Currently, large companies have few warehouses in different part of the city, as well as medium and small enterprises, are interested in solving the routing problem to reduce transport costs during the mass transportation of raw materials or finished products. Solving the routing problem is still especially relevant for intracity transportation. Now, there is a lack of well-proven techniques for effectively solving the routing problem.

Currently existing methods and software products created on their basis, as a rule, solve specific problems – finding the shortest route.

The purpose of the article is to develop a methodology for efficiently distributing goods within a retail network by leveraging intermediate warehouses. The key criteria considered in this method are transportation costs, safety, and reliable supply. The goal is to enhance the overall efficiency and effectiveness of the distribution process.

This necessitates the development of fairly simple and practically implementable algorithms for optimizing the logistics performance of road transport with minimal risks and low cost.

2. Literature review

Despite the complexity and multifaceted nature of constructing, managing, and optimizing a flexible logistics system for a business, there are still unresolved

* Corresponding author. E-mail: *olga.iurasova@vilniustech.lt*

issues that necessitate further research and development.

The first approach is to consider the case of a single target transportation problem that supposes inequality constraints in addition to equality constants in the model (Charnes & Cooper, 1954; Hitchcock, 1941; Koopmans, 1951). Such a model has various applications but allows to solve only one problem at a time, such as cost reduction, profit augmentation, ensuring the secure goods transit, or decreasing delivery duration. Currently, little attention has been given to this model in the scientific papers due to the accuracy required for solving the problem. However, the primary objective of this approach is to maximize overall cargo capacity and minimize the overall transport costs (Azad et al., 2017; Liu et al., 2024; Rekha, et al., 2014; Sharma et al., 2015).

A single objective transportation problem, which is still relevant today (and the common optimization problems class), is the traveling salesman problem (TSP). The essence of the problem comes down to finding the optimal, that is, the shortest, path that passes through certain points once. For instance, such a problem is usually used for getting the most profitable route, which is to transport cargo around certain cities and return to the starting point. An indicator of the profitability of a route will be the minimum travel time, the minimum transport cost or, in the simplest case, the minimum of travel distance. (Guan et al., 2012; Kalantari et al., 1985; Laporte, 1992; Phu-Ang, 2021; Vieira et al., 2003).

The next approach relates to the multicriteria transportation problem with specified parameters, which is a generalization of the basic classical transportation problem (Ambroziak, et al., 2018). Generally, the classical transportation problem considers only two criteria, such as sources and destinations and transportation cost, as the main aim. However, the task is called a multicriteria transportation problem when more than two criteria are considered. The multicriteria transportation problem provides a practical solution to many distribution-related problems (Al-Haidous et al., 2022).

The third approach is the most complex and takes into account the uncertainties of transportation problems. It is a multicriteria transportation problem with unspecified parameters.

A fundamentally different approach to solving the problem is based on fuzzy logic. Kumar proposed an intuitive fuzzy zero-point method to find the optimal solution. One of the main advantages of this approach is that the resulting solution is every time optimal and doesn't require the allocation of (m+n-1) records. (Kumar, 2020).

For solving the same problem, another group of authors (Kumar et al., 2019) presented a new computational process for solving the fuzzy Pythagorean transport problem. The authors proposed a method for solving the transport problem in a fuzzy Pythagorean environment, which includes two subalgorithms. The first subalgorithm represents a method for determining a starting baseline result for a transportation problem, and the second subalgorithm is an existing method for calculating the optimal transportation cost. The effectiveness of this model is proven by several experiments presented in the article.

Other authors proposed a solution to the trapezoidal fuzzy transport problem type 1 and type 2 by converting it into a clear problem that is easily accessible and applicable to existing methods for solving transportation problems. Once a clear shape is obtained from a fuzzy one, it is solved by the northwest corner method to obtain an initial solution (Bisht & Srivastava, 2020).

The following concept applies to Hesitation fuzzy expectation of fuzzy and intuitionistic fuzzy numbers and presents the concept of fuzzy fractional transport problem and the solution based on iterative method using the score and accuracy functions (Bharati, 2019).

Another research using the iterative method presented a new method for solving a distribution problem in a fuzzy formulation, consisting of two steps. In the first step, the authors formulated the solving problem as a classical, completely fuzzy transport problem. They proposed a new simple numerical solution method that uses approximation of fuzzy values and probabilistic approach to the comparison of intervals. The method allows for a direct fuzzy extension of the simplex method. It is important to note that the results are fuzzy values. In the second stage, the results achieved earlier in the first stage (fuzzy profit) are used as natural constraints on the parameters of the multi-objective problem. The approach suggested by the author to solve the allocation problem uses criteria of fuzzy logic based on total profits and the contract violation risks (Kaczmarek et al., 2019).

However, Ebrahimnejad contradicts all previously discussed works and proves that after selecting a ranking function, the fuzzy transportation problem is converted into a clear one, which is easily solved by standard supply chain algorithms. It turns out that you can find the same optimal solution without solving any fuzzy transport problem (Ebrahimnejad, 2014).

Such criteria are poorly applicable to the modern conditions of Ukraine, where the primary task is the reliability of transportation and the importance of the cargo.

3. Problem

The transportation problem in Ukraine has recently become a significant issue due to the need to minimize transport costs and increase the reliability of supplies. The risk associated with transportation has become a crucial factor to consider, not only for inter-regional deliveries but also for intra-city movements. Therefore, the development of the algorithm to solve this multi-criteria transport problem is critical important.

This algorithm has to optimise two main criteria:

- Minimising the delivery cost. It means to find the most cost-effective routes and modes of transport, considering factors (such as fuel costs, road tolls) and maintenance costs.

– Maximising the delivery reliability: It means that goods are delivered on time and in good condition. This may require consideration of wartime conditions, with several critical factors, including the safety of human lives and the conservation of critical material resources.

The problem is that these two objectives can often contradict each other. For example, the most cost-effective route may not be the most reliable. As a result, the algorithm needs to detect a balance between the two objectives, while taking an acceptable level of risk into consideration.

This problem can be approached using various methods from operations research, such as multi-objective optimization. The algorithm would need to be able to handle many variables and constraints, and to adapt rapidly to changing conditions and requirements. It would also need to be robust and reliable, to ensure that it can provide useful solutions under a wide range of circumstances.

The creation of such an algorithm is a complex but vital task for improving the efficiency and reliability of transportation in Ukraine. It has the potential to make a significant contribution to the country's economy and the well-being of its people.

The e-commerce store "Nadezhda" specializes in the sale of consumer goods, operating with its own storage facility. Approximately half of all sales are attributed to seasonal goods, while the other half consists of Fast-Moving Consumer Goods.

Sales predictions are made based on the owner's data from the previous season and official Ukrainian statistics (Statista, n.d.). The owner finalizes contracts with regular customers, decides on the purchase of seasonal goods stock, and locates storage for peak load periods.

The proprietor of the e-commerce store "Nadezhda" prefer to prepare for the season ahead of time. This is because prices for goods during the off-season are significantly lower than during the season. Supply chain uncertainties can cause disruptions in online stores. Hence, it is crucial to prepare for the season: anticipate demand, establish stocks, secure storage capacity (warehouses), initiate a marketing campaign, and attract additional resources to address logistical issues promptly.

The online store has seven consistent purchasers for this product, with known order volumes (refer to Table 1).

"Nadezhda" operates one storage with a capacity of 12 thousand units of goods. However, the store's current storage cannot fully satisfy the demand for goods from these purchasers, encouraging this business to plan storehouse expansion. Overall consumer demand is currently stood at last year's 24 000 units. This commercial firm is in negotiations to rent two additional storages, each with capacities of 7 and 7.4 thousand units of goods, respectively.

As a result, five suitable reserve storages with needed capacity, and conditions of concerning its appearance, quality, or working order, and reasonable rent was determined. Out of the five storages located in various city districts, two need to be selected based on transportation reliability and costs. Any two of these, along with the existing storage, will provide the needed goods storage volume for customers. The distances from the own storage and reserve storages to each customer are added in Table 2.

All long-term clients are willing to collaborate with the "Nadezhda" company and purchase a certain amount of goods. The proprietor of the e-commerce business is tasked with identifying which two reserve warehouses, out of the five available, should be leased to minimize transportation costs for customer deliveries.

Therefore, to address the logistics management issue – reducing the delivery cost from storage to buyer, considering the safety of human lives and the conservation of critical material resources in wartime – the owner of the "Nadezhda" online store should employ a linear programming optimization problem known as transportation problem.

Table 1. Demand for goods, units

Demand for goods, units						
Purchaser 1	Purchaser 2	Purchaser 3	Purchaser 4	Purchaser 5	Purchaser 6	Purchaser 7
2400	2880	2040	6000	3600	5280	1800

Table 2. Distance from storages to customers, km

Storages	Customers						
	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7
Own storage	116.6	172.7	66	272.8	202.4	196.9	391.6
Storage 1	114.4	88	79.2	183.7	242	194.7	377.3
Storage 2	168.3	341	218.9	304.7	128.7	84.7	116.6
Storage 3	89.1	259.6	93.5	311.3	85.8	119.9	303.6
Storage 4	160.6	34.1	133.1	150.7	292.6	233.2	403.7
Storage 5	250.8	259.6	281.6	125.4	337.7	236.5	267.3

4. Methodology

The transport problem involves finding an optimal plan for transporting products while minimizing transportation costs. When additional conditions of the problem are added, it becomes multicriteria. The goal of the research is to describe a method for solving a transport problem with an additional objective function. Problem formulation: consider a multicriteria transport problem with two objective functions. The following are used as such: minimizing transportation costs and maximizing the degree of transportation reliability specified by experts. Known:

X_i – warehouses with capacity x_i, $i = (1, \ldots, n)$; Y_j consumption points with demand quantity y_j, $j = (1, \ldots, m)$; z_{ij} – transport costs for product unit from warehouse X_i to consumption point Y_j, $z_{ij} \geq 0, i = \overline{1,n}, \quad j = \overline{1,m}$; r_{ij} – transportation degree reliability from warehouse X_i to consumption point Y_j; v_{ij} – quantity of products transported from point to point.

Exact quantity of products that need to be transport from warehouse *Xi* to consumption point Y_j is unknown, but this quantity is limited by the warehouse capacity.

Authors transform this multi-criteria transport problem in the form of multi-criteria linear programming, and find its solution based on the work (Abdelati et al., 2023).

It is required to find extreme values of indicators of the cost of transportation and the degree of its reliability.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} z_{ij}a_{ij} \rightarrow \min, \tag{1}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} r_{ij}a_{ij} \rightarrow \max, \tag{2}$$

where limits for indicators are:

$$\begin{cases} \sum_{j=1}^{m} v_{ij} = x_i \ ; & (3) \\ \sum_{i=1}^{n} v_{ij} = y_j; & (4) \\ v_{ij} \geq 0, & (5) \end{cases}$$

where $i = (1, \ldots, n)$, $j = (1, \ldots, m)$.

With such restrictive conditions, the volume of products available in wholesale warehouses must match the volume of products required at points of consumption. This corresponds to a closed transport model. Open transport models have conditions of the following:

$$\begin{cases} \sum_{j=1}^{m} v_{ij} \leq x_i; \\ \sum_{i=1}^{n} v_{ij} \geq y_j; \\ v_{ij} \geq 0, \end{cases} \tag{6}$$

or

$$\begin{cases} \sum_{j=1}^{m} v_{ij} \geq x_i; \\ \sum_{i=1}^{n} v_{ij} \leq y_j; \\ v_{ij} \geq 0, \end{cases} \tag{7}$$

where $i = (1, \ldots, n)$, $j = (1, \ldots, m)$.

These restrictions are valid in two cases:

- when untransported products may remain at werehouses;
- when there are not enough products to provide demand consumption.

Open transport models can be changed to a closed model. The changing is based on adding of an effective point of consumption or an effective retail warehouse. We denote the set of vectors v satisfying conditions (3)–(5) by V.

For our case, where we have to minimize the common transport costs (Z) and maximize the transportation reliability, the authors propose to use an algorithm based on finding the optimal solution using the Pareto front.

To form an algorithm our case solving, we introduced the notations:

$$G = \sum_{i=1}^{n}\sum_{j=1}^{m} z_{ij}a_{ij} \rightarrow \min; \tag{8}$$

$$H = \sum_{i=1}^{n}\sum_{j=1}^{m} r_{ij}a_{ij} \rightarrow \max. \tag{9}$$

With the restrictions (3)–(5).

1. Let's bring the criteria to one form by transforming the criterion G (Schulze, 1998).

2. Next algorithm step is to bring all criteria to one form by transforming the criteria G (Strang, 1988).

Add a Sumption, there is no a^* at which the conditions are met.

$$\tilde{G}\left(a^*\right) \geq \tilde{G}\left(a\right),\ H\left(a^*\right) \geq H\left(a\right),\ \forall a \in A. \tag{10}$$

This corresponds to the Pareto efficiency condition and allows the solution of our case to be represented as a Pareto front of optimal solutions $Q \subseteq A.$ Solutions from the Pareto front are equivalent, since a solution from the Pareto front of optimal solutions cannot be improved in one of the objective functions without worsening it in another (Mornati, 2013; Geerolf, 2017).

$$a^* \in Q \Leftrightarrow (\forall a \in A; \tag{11}$$

$$a \neq a^*) \neg \left(\left(G^{\beta}\left(a\right) \geq G\left(a^*\right)\right) \times \left(\exists_{\beta} G^{\beta}\left(a\right) > G^{\beta}\left(a^*\right)\right), \tag{12}$$

where $\beta = \overline{1,l}$; l – number of objective functions for the task.

To obtain the Pareto front in a two-criteria transport problem, we will use the multi-criteria Simplex method (Nourie & Güder, 1994).

This method is based on the following:

1. S is the set of optimal vertices of the polyhedron A.
2. D – combination of Pareto vertices (face of the polyhedron A). The Pareto front is their union.
3. The algebraic method eliminates majorization: If $a^* \in A$:

$$a^* \in Q \Leftrightarrow \delta = 0\ ; \tag{13}$$

$$a^* \in A \setminus Q \Leftrightarrow \delta > 0, \tag{14}$$

where δ – is the case solution

$$\delta = \max \sum_{i=1}^{l} d_i . \tag{15}$$

In our case l = 2, so $f = d1 + d1$->max.

Algorithm of the multicriteria Simplex method:

1. Formation of an empty set of Pareto values.
2. Finding the first Pareto value.
3. Checking for optimality of all points adjacent to V in accordance with the program without majorization.
4. The points that turned out to be Pareto optimal are included in the set C, and the points adjacent to them are also checked for optimality.

Pareto front creation based on the vertices of Pareto front. It can be represented in the criterial space G(Q) where N indicator is the number of Pareto points. This Pareto points included in the set S. (Rao & Lakshmi, 2021).

When choosing a single solution, the entire Pareto front is considered. The entire point characteristic V reflects the configuration of the Pareto front. The algorithm for determining the optimal point is as follows:

1. First obtaining a convex combination of all points from the set of parallel vertices S with equal weights.
2. Obtaining the desired point V from the Pareto set as an optimal combination of V.

The result of problem solving is the optimal characteristics of V in the solution of the case.

5. Main results

The proposed multi-criteria distribution algorithm in a rapidly changing environment allows us to optimize the process of making logistics decisions and achieve uninterrupted transportation with minimal costs and maximum reliability. The result of the calculation of the approach described above is the selection of additional warehouses for the e-commerce company from which products will be delivered with minimal risks during transportation.

According to the algorithm, many possible solutions are found to find the optimal solution. The entire point characteristic of all possible solutions is reflected in the Pareto front configuration (Figure 1).

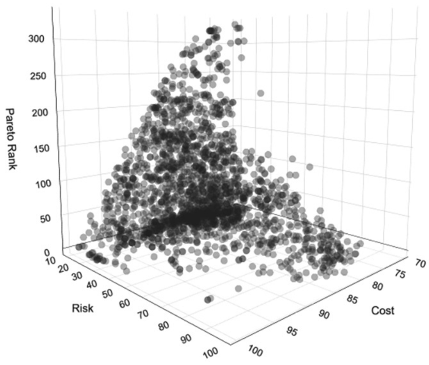

Figure 1. Function surface of Pareto front

When choosing a single solution, the entire Pareto front is considered. So, the task is to select two additional warehouses from five reserve ones with the possibility of forming several supply chain options with maximum reliability. The solution to the case under consideration is the choice of the second and fourth warehouses.

The solution to the problem of selecting 2 storage is represented on Figure 2.

Hence, the authors scrutinize the outcomes of the applied model of adaptive transition for logistics management in a rapidly changing environment (Figure 2), and strive to offer the e-commerce business "Nadezhda" suggestions the algorithm for sustainable transportation in wartime.

To ensure that the reliability of delivery of goods from three warehouses to seven customers is high and sustainable, it is necessary to rent the 2nd and 4th storages from 5 options. The minimum transport route in this case amounts to a little bit more than 3 thousand km. Also, there is the highest number of possible routes in this combination of storage. The optimal product distribution with entered reliability of environment could be: from company's own storage 2,4 thousand of product units should be delivered to Purchaser 1, the volume of 2040 units – to Purchaser 3, the volume of 1880 units – to Purchaser 4, and the 3280 product units to Purchaser 5; And the optimal product distribution from the 4th storage: the biggest volume of delivery (more than 5.2 thousand units) transfer to buyer 6, the 320 product units should be delivered to Purchaser 5, 1800 units – to client 7.

	A	B	C	D	E	F	G	H	I	J	K	L
2		Distance between warehouse and customer, km										
3			Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Fictitious Customer		
4	Own warehouse		116,6	172,7	66	272,8	202,4	196,9	391,6	0		
5	Warehouse 1		114,4	88	79,2	183,7	242	194,7	377,3	0		
6	Warehouse 2		168,3	341	218,9	304,7	128,7	84,7	116,6	0		
7	Warehouse 3		89,1	259,6	93,5	311,3	85,8	119,9	303,6	0		
8	Warehouse 4		160,6	34,1	133,1	150,7	292,6	233,2	403,7	0		
9	Warehouse 5		250,8	259,6	281,6	125,4	337,7	236,5	267,3	0		
10												
11		Delivery plan to customers from warehouses, units										
12		Choose/ Not choose	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Fictitious Customer	Actual capacity	Planned capacity
13	Own warehouse	1	2400	0	2040	1880	3280	0	0	2400	0	12000
14	Warehouse 1	0	0	0	0	0	0	0	0	0	0	7000
15	Warehouse 2	1	0	0	0	0	320	5280	1800	0	0	7400
16	Warehouse 3	0	0	0	0	0	0	0	0	0	0	7000
17	Warehouse 4	1	0	2880	0	4120	0	0	0	0	0	7000
18	Warehouse 5	0	0	0	0	0	0	0	0	0	0	7000
19	Actual order		0	0	0	0	0	0	0	0		OF
20	Planned order		2400	2880	2040	6000	3600	5280	1800	2400	26400	3008588

Figure 2. Storage selection and planning the optimal product delivery volume from X_i storage to Y_j purchaser

When resolving the issue through step-by-step searching for 2 storages out of 5 reserve ones, authors will be able to evaluate the worst and best variants, and ensuring that in any scenario the optimal plans align with the meaning of the value functions. The optimal values of the functions (1) and (2) are equal. At the same time, the best delivery plans according to product volume to customers are the same.

In the least favourable scenario of selecting warehouses (1st and 5th), the total distance for product delivery would amount to 3,708,188 km, while in the most favourable scenario (2nd and 4th storages), it would be 3,008,588 km. An examination of the function values indicates the total distance in the least favourable scenario exceeds that of the most favourable case by 691,600 km.

By employing a mathematical model to resolve the reliability problem adaptive changing decision-making process in logistics, managers can make the optimal choice, identify the best transportation plan, and minimize the total distance of the delivery route, and therefore the transporting time, and minimize risks and costs to meet the customer needs.

6. Conclusions

The research highlights the importance of dynamic transportation optimization in enhancing supply chain efficiency in urban logistics, especially in developing economies like Ukraine. Authors developed an algorithm to optimize logistics performance in road transport, focusing on a two objective transportation problem with inequality constraints. The proposed model enabled simultaneous selection of warehouses and optimal delivery plans for an online store, considering the transport costs, needs of seven customers and the availability of reserve warehouses.

The method, based on the Pareto front in a two-criteria transport problem, aimed to minimize the total length of delivery routes in logistics management. The practical application of the algorithm led to the optimal selection of 2 extra storages from 5 reserve ones, the determination of the best delivery plan, and the reduction of the total distance of the transportation path.

The results showed that the total distance of product delivery from three warehouses to seven purchases was minimized. This was achieved by choosing the 2nd and 4th warehouses from five reserve warehouses and distributing the product delivery in a specific manner.

The study also compared the best and worst options for choosing warehouses and found that the total distance of the product transportation in the worst option exceeded by 23%.the total distance of the product delivery route in the best option.

The model chooses the best delivery route from many available options. The route that the model chooses may involve intermediate storage facilities (warehouses). The mathematical model application for problem solving of sustainable adaptive conversion in logistics decision making led to significant improvements in logistics processes. Future research will focus on refining these models and exploring their applicability in other contexts. It is recommended that logistics companies in developing economies adopt dynamic transportation optimization to optimize their supply chain operations and remain competitive in the rapidly changing business environment.

References

Abdelati, M. H., Abd-El-Tawwab, A. M., Ellimony, E. E. M. & Rabie, M. (2023). Solving a multi-objective solid transportation problem: A comparative study of alternative methods for decision-making. *Journal of Engineering and Applied Science*, *70*(82). https://doi.org/10.1186/s44147-023-00247-z

Al-Haidous S., Govindan R., Elomri A., & Al-Ansari T. (2022). An optimization approach to increasing sustainability and enhancing resilience against environmental constraints in LNG supply chains: A Qatar case study. *Energy Reports*, *8*, 9742-9756. https://doi.org/10.1016/j.egyr.2022.07.120

Ambroziak, T., Malesa, A., & Kostrzewski, M. (2018). Analysis of multicriteria transportation problem connected to minimization of means of transport number applied in a selected example. *WUT Journal of Transportation Engineering*, *123*, 5–20. https://doi.org/10.5604/01.3001.0013.7349

Azad, S. M., Hossain, M. B., Rahman, M. M. (2017). An algorithmic approach to solve transportation problems with the average total opportunity cost method. *International Journal of Scientific and Research Publications*, *7*(2), 266–270. https://www.ijsrp.org/research-paper-0217/ijsrp-p6240.pdf

Bharati, S. K. (2019). Detailed study of uncertainty and hesitation in transportation problem. *Life Cycle Reliability and Safety Engineering*, *8*, 357–364. https://doi.org/10.1007/s41872-019-00095-y

Bisht, D. C. S., & Srivastava, P. K. (2020). Trisectional fuzzy trapezoidal approach to optimize interval data based transportation problem. *Journal of King Saud University – Science*, *32*(1), 195–199. https://doi.org/10.1016/j.jksus.2018.04.013

Charnes, A., & Cooper, W.W. (1954). The stepping stone method of explaining linear programming calculations in transportation problems. *Management Science*, *1*(1), 49–69. https://doi.org/10.1287/mnsc.1.1.49 https://doi.org/10.1287/mnsc.1.1.49

Ebrahimnejad, A. (2014). A simplified new approach for solving fuzzy transportation problems with generalized trapezoidal fuzzy numbers. *Applied Soft Computing*, 19, 171–176. https://doi.org/10.1016/j.asoc.2014.01.041

Geerolf, F. (2017). A theory of Pareto distributions (Working Paper). https://fgeerolf.com/pareto.pdf

Grechan, A., Bezuglyi, A., Parfentieva, O., Kompanets, K., Groza, A., & Kara, I. (2022). Implementation of sustainable development goals on the example of the transport and logistics sector. *Financial and Credit Activity Problems of Theory and Practice*, *4*(45), 191–201. https://doi.org/10.55643/fcaptp.4.45.2022.3802

Guan, L, Zhang, B., & Huang, D. (2012). An improved self-organizing algorithm for solving the traveling salesman problem [J]. *Journal of Shanghai Second Polytechnic University*, *29*(1), 48–52.

Hitchcock, F. L. (1941). The distribution of a product from several sources to numerous localities. *Journal of Mathematics and Physics*, *20*(1–4), 224–230. https://doi.org/10.1002/sapm1941201224

Kaczmarek, K., Dymova, L., & Sevastjanov, P. (2019). A two phase method for solving the distribution problem in a fuzzy setting. *Entropy*, *21*(12), Article 1214. https://doi.org/10.3390/e21121214

Kalantari, B., Hill, A.V., & Arora, S., R. (1985). An algorithm for the traveling salesman problem with pickup and delivery customers. *European Journal of Operational Research*, *22*(3), 377–386. https://doi.org/10.1016/0377-2217(85)90257-7

Koopmans, T. C. (1951). An analysis of production as an efficient combination of activities. In T. C. Koopmans (Ed.), *Activity analysis of production and allocation, cowles commission for research in economics* (Monograph No. 13, pp. 33–97). Wiley. https://cowles.yale.edu/sites/default/files/2022-09/m13-all.pdf

Kotenko, S., Mashkantseva, S., Ganzhurenko, I., Vasylyuk, M., Lavrushchenko, Y., & Kucher, I. (2022). The economic crisis as a factor in changing the structure of multimodal transportation routes. *Financial and Credit Activity Problems of Theory and Practice*, *6*(41), 277–284. https://doi.org/10.18371/fcaptp.v6i41.251454

Kumar, P. S. (2020). Intuitionistic fuzzy zero point method for solving type-2 intuitionistic fuzzy transportation problem. *International Journal of Operational Research*, *37*(3), 418–451. https://doi.org/10.1504/IJOR.2020.105446

Kumar, R., Edalatpanah, S. A., Jha, S., & Singh, R. (2019). A Pythagorean fuzzy approach to the transportation problem. *Complex & Intelligent Systems*, *5*, 255–263. https://doi.org/10.1007/s40747-019-0108-1

Laporte, G. (1992). The traveling salesman problem: An overview of exact and approximate algorithms. *European Journal of Operational Research*, *59*(2), 231–247. https://doi.org/10.1016/0377-2217(92)90138-Y

Liu, M., Wang D., & Si, S. (2024). Solving algorithm design for the cost minimization reliability optimization model driven by a novel cost-based importance measure. *Reliability Engineering & System Safety*, *244*, Article 109907. https://doi.org/10.1016/j.ress.2023.109907

Mornati, F. (2013). Pareto optimality in the work of Pareto. *Revue Européenne des Sciences Sociales*, 51(2), 65–82. https://doi.org/10.4000/ress.2517

Nourie, F. J., & Güder, F. (1994). A restricted-entry method for a transportation problem with piecewise-linear concave costs. *Computers & Operations Research*, *21*(7), 723–733. https://doi.org/10.1016/0305-0548(94)90002-7

Phu-Ang, A. (2021). An improve artificial immune algorithm for solving the travelling salesman problem. In *Proceedings of the 2021 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering* (pp. 261–264). Cha-am, Thailand. IEEE. https://doi.org/10.1109/ECTIDAMTNCON51128.2021.9425773

Rao, R. V., & Lakshmi, R. J., (2021). Ranking of Pareto-optimal solutions and selecting the best solution in multi- and many-objective optimization problems using R-method. *Soft Computing Letters*, *3*, Article 100015. https://doi.org/10.1016/j.socl.2021.100015

Rekha, S., Srividhya, B., Vidya, S. (2014). Transportation cost minimization: Max min penalty approach. *IOSR Journal of Mathematics*, *10*(2), 6–8. https://doi.org/10.9790/5728-10210608

Schulze, M. (1998). *Linear programming for optimization*. Perceptive Scientific Instruments.

Sharma, A., Verma, V., Kaur, P., & Dahiya, K. (2015). An iterative algorithm for two level hierarchical time minimization transportation problem, *European Journal of Operational Research*, *246*(3), 700–707. https://doi.org/10.1016/j.ejor.2015.03.034

Statista. (n.d.). *Ecommerce – Ukraine* [Chart]. https://www.statista.com/outlook/emo/ecommerce/ukraine

Strang, G. (1988). *Linear algebra and its applications* (3rd ed.). Harcourt Brace Jovanovich.

Vieira, F. C., Neto A. D. D., & Costa J. A. F. (2003). An efficient approach to the travelling salesman problem using self-organizing maps. *International Journal of Neural Systems*, *13*(2), 59–66. https://doi.org/10.1142/S0129065703001443