ARCHIVES OF TRANSPORT
Volume 63, Issue 3, 2022

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.5604/01.3001.0015.9929*

MODEL OF OPERATIONAL PLANNING OF FREIGHT TRANSPORTATION BY TRAM AS PART OF A GREEN LOGISTICS SYSTEM

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Abstract:

The introduction of environmentally friendly technologies is becoming increasingly necessary to combat global warming and air pollution in cities. The concept of eco-logistics is seen as an effective approach to the management of materials and related flows in order to reduce environmental and economic damage to the environment. The sustainable development of green supply chains is based on the use of environmentally friendly types of vehicles, reduction of energy and other resources consumption, optimization of transport and technological processes in delivery systems. As part of the development of green supply chain, it is proposed to transport goods by freight trams, which eliminates the need for heavy trucks in the city, improves traffic conditions and reduces the environmental impact of transport. The research was conducted for the city of Poznan. The distribution system of the city of Poznan operates in conditions of stochastic demand for deliveries from clients and the risk of lack of sufficient supplies in distribution centers. To take into account the specificity of the distribution system of cargo delivery in conditions of uncertainty and risk, a simulation model of the organization of the material flows within the transport system of the city of Poznan has been proposed. The result of simulation is the optimal assignment of clients to the distribution centers, as well as the value of total mileage with the load, which is a random variable. It is assumed that the random variable is distributed according to the normal distribution law. The results were calculated and compared for two variants, i.e. for constant demand and sufficient quantity of cargo in distribution centers, and for variable demand and uncertainty conditions, e.g. insufficient cargo quantity in distribution centers. The purpose of the paper is to develop a simulation model for planning supplies of small consignments of goods by trams implementing green logistics concept with variable demand for transportation. After a short introduction of the problem, the literature review related to the concept of green logistics and requirements of transport and distribution system are presented in section 2. In section 3, the research problem and research methodology are described. Section 4 provides the results of assignment of clients to distribution centers. The paper ends with concluding remarks.

Keywords: *freight tram, green logistics, stochastic demand, simulation model*

To cite this article:

Shramenko, N., Merkisz-Guranowska, A., Kiciński, M., Shramenko, V., (2022). Model of operational planning of freight transportation by tram as part of a green logistics system. Archives of Transport, 63(3), 113-122. DOI: https://doi.org/10.5604/01.3001.0015.9929

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1. Introduction

Among the main trends in the development of modern logistics, scientists (Husaková, 2014; Johnson et al., 1999; McKinnon et al., 203; Aktas et al., 2018) highlight the growing public attention to the problems of environmental impact of transport. Companies pay more attention to the environment (Hurzhiy and Belikova, 2016), due to such trends as: raising awareness and self-awareness of consumers, the growing threat of regional and global environmental problems (i.e. climate change, pollution, noise), political regulation of environmental issues.

The application of the concept of sustainable development, is a reaction of the world community to existing threats and involves the harmonious coexistence of nature and society, and which requires consideration of environmental and social factors in all spheres of human life (Andrzejczyk and Rajczakowska, 2020; Epicoco and Falagario, 2022; Beamon, 1999). The new concept of logistics called environmental logistics (green logistics or eco-logistics) which in the concept of implementing sustainable development into freight transport is seen as an effective approach to managing material and related flows to reduce environmental damage to the environment (Ping, 2009; Rakhmangulov et al., 2017).

The main directions that allow to create conditions for the formation of a green logistics system based on the sustainable development of the green supply chain are: the use of environmentally friendly types of vehicles, reduction of energy consumption, reduction of the use of materials and resources of various kinds, optimization of transport and technological processes in delivery systems.

2. Literature review

The concept of green logistics can be defined as organizational activities aimed at addressing environmental issues in supply chains in order to reduce the impact of negative factors on the environment in the process of promoting material flows from suppliers to end users and achieve stable balance between environmental, economic and social objectives of the logistics system (Ping, 2009; Chukurna et al., 2019; Korniyko and Valiavskaya, 2019). The global development of the concept of green logistics is facilitated by four main factors - the company itself, customer attitude, political and social order (Karpova and Pilipovich, 2016).

Urban activities, including urban mobility and city logistics, play an essential role in climate change mitigation (Tarkowski, 2021). According to this, it is necessary to introduce a comprehensive policy and measures for sustainable urban transport, taking into account research and development. Transport and logistics operators are considering alternative ways to deliver goods to urban areas using electric vehicles, cargo bikes, inland vessels and rail transport (De Langhe et al., 2019) or are implementing new urban delivery modes i.e. urban consolidation centers that reduce the need for freight vehicles to deliver goods to urban areas (Savchenko et al., 2022).

Decision-making process regarding green logistics is influenced by the level of development of transport infrastructure, the volume of cargo transported, organizational measures, and a feasibility study. The EU countries are actively experimenting with the development of electric modes of transport. Thus, environmentally friendly water trams with electric motors were introduced in the port of Copenhagen (Baird Maritime, 2020). In some European countries (for example, Germany, Switzerland, Austria, the Netherlands, Poland), interest in an environmentally friendly and effective freight tram is being revived (Behiri et al. 2018; De Langhe et al.,2019; Pietrzak and Pietrzak, 2021; Pietrzak et al., 2021). Specialists and scientists pay work on new approaches when deciding on the development of regional transport systems (Jacyna et al., 2018; Vojtov et al., 2019; Bosov and Khalipova, 2017). Considering fuel and energy deficit, special attention should be given to the promotion of resource-saving technologies in the organization of transport and distribution system (Shramenko et al. 2020) and its branches (Jacyna et al., 2015).

The formation of the transport and distribution system requires comprehensive control over the transportation process using modern communication and information technologies (Alekseev, 2018; Semenov et al., 2019; Shramenko and Shramenko, 2020). For the purpose of the structure of the distribution network, the simulation model can be developed (Bowersox and Closs, 1996).

To obtain an optimal freight plan, scientists propose to use a decision support system for rational organization of freight flows in transport networks based on open transport problems with unbalanced supply and demand of goods, which offers the user a better

transportation plan based on the results of four methods (fictitious node method, difference method, coefficient method, simplex method) (Prokudin et al., 2022). The criterion is the total cost of delivery.
Challenges such as technical development, environmental requirements, competition, market relations require new standards of organization of transport services, taking into account the interests of both providers of transport services (carriers) and their clients, and society as a whole. It is necessary to solve logistical problems: to optimize the transport process, finding internal reserves and reducing overall costs and in the same time to create conditions for meeting the requirements of clients. Moreover, it is necessary to consider the interests of society in the organization of environmentally friendly transportation. And also the specificity of each system that has its own unique conditions, which reflect the nature of its functioning.

3. Research problem and methodology

The subject of the research is the process of transportation of small consignments by trams in urban area with variable demand in conditions of risk.
In the distribution network in cities there are facilities that accumulate freight like distribution centers, logistics terminals, manufacturers' warehouses, wholesalers with centralized deliveries of goods. Then the flow of goods is distributed through the channels to small recipients of shipments (shops) that need small batches of cargo. These recipients (clients) are characterized by variable demand with unevenness by day of the week. As part of the development of the concept of eco-logistics, it is proposed to transport goods by freight trams which eliminates the need for heavy trucks in the city, improves traffic conditions and reduces the environmental impact of transport.
The planned deliveries must satisfy the requirements of both the client in terms of supply and the carrier in terms of minimum mileage during transport services.
The purpose of the study is to develop a simulation model for planning supplies of small consignments of goods by trams implementing green logistics concept with variable demand for transportation. Probability theory and methods of mathematical statistics were used to assess the technical and operational indicators of freight transportation process. Development of simulation model and software is based on the use of geographic information systems, methods of linear programming and information processing.
The research was conducted for the city of Poznan that is a medium-sized city with 550,000 inhabitants. The city has an extensive tram network, and the trams do not operate at night except for one line. Hence, the existing tram network can be used to organize the delivery of goods at night in order to not interfere with the movement of passenger trams. Providing freight delivery services by trams requires the organization of dedicated distribution centers. The location of 6 potential distribution centers in different part of the city is presented in figure 1 (V1 to V6). Distribution centers are located near the main access roads on the outskirts of the city center. All distribution centers provide supplies of identical products. In the city of Poznan, a significant number of potential clients are concentrated in 9 large locations which are large shopping centers and local markets that are also presented in the figure 1 (AM 1 to AM3 for local markets and S1 to S6 for shopping centers). There are also three existing tram depots (T1 to T3).
The city tram-network provides access tracks for the delivery of goods from distribution centers to clients. From public tram tracks, access tracks branch off and enter the area of the respective clients, where loading and unloading platforms are built for freight trams. This does not apply for markets as the tram tracks run along the border of all considered markets.
Based on the existing network of tram tracks and geolocation of the facilities of the cargo supply process (distribution centers, clients and tram depots), the corresponding matrix of the shortest distances was obtained.
The vast majority of clients are characterized by variable demand. Transported cargo are small batches of clothes, cosmetics, household care products, vegetables and fruits, toys and other consumer goods. The freight must be compatible (not contraindicated for transportation together), packed (mostly in boxes or crates) and placed directly on pallets or in wire mesh basket pallets. Loading and unloading can be mechanized or manual.
Transportation is carried out by three-section freight trams, an example of which is shown in figure 2. Nominal capacity of the main section of the tram is 10 tons and freight section is 15 tons which allows to carry up to 40 tons of freight. Structurally freight

tram is a modified passenger tram, where the passenger compartment is replaced with the cargo platform for transporting pallets.

An important aspect is the selection of criteria for efficient delivery of goods. This choice depends on the specific conditions of transportation and the problem to be solved. The economic efficiency of the transport process is assessed by single or integrated (Muzylyov et al., 2020), natural and economic measures, as well as indicators of non-transport effect (Kiciński et al., 2019a; Kiciński et al., 2019b; Shramenko and Shramenko, 2018). Single efficiency criteria are applied if the compared transport options differ on one, separate indicator. Technological parameters of the transport process are often used as single or partial indicators of efficiency.

Therefore, as a criterion of efficiency in optimizing the process of transportation of goods by trams from distribution centers to clients, the total mileage with cargo for the working shift of trams was chosen L_{carg}:

$$L_{carg} = \sum_{j=1}^{n} \sum_{b=1}^{s} l_{bj} \rightarrow \min \qquad (1)$$

where: l_{bj} – the length of the cargo departure of the b-th route for the j-th client, km; n – number of customers, units; s – number of routes, units.

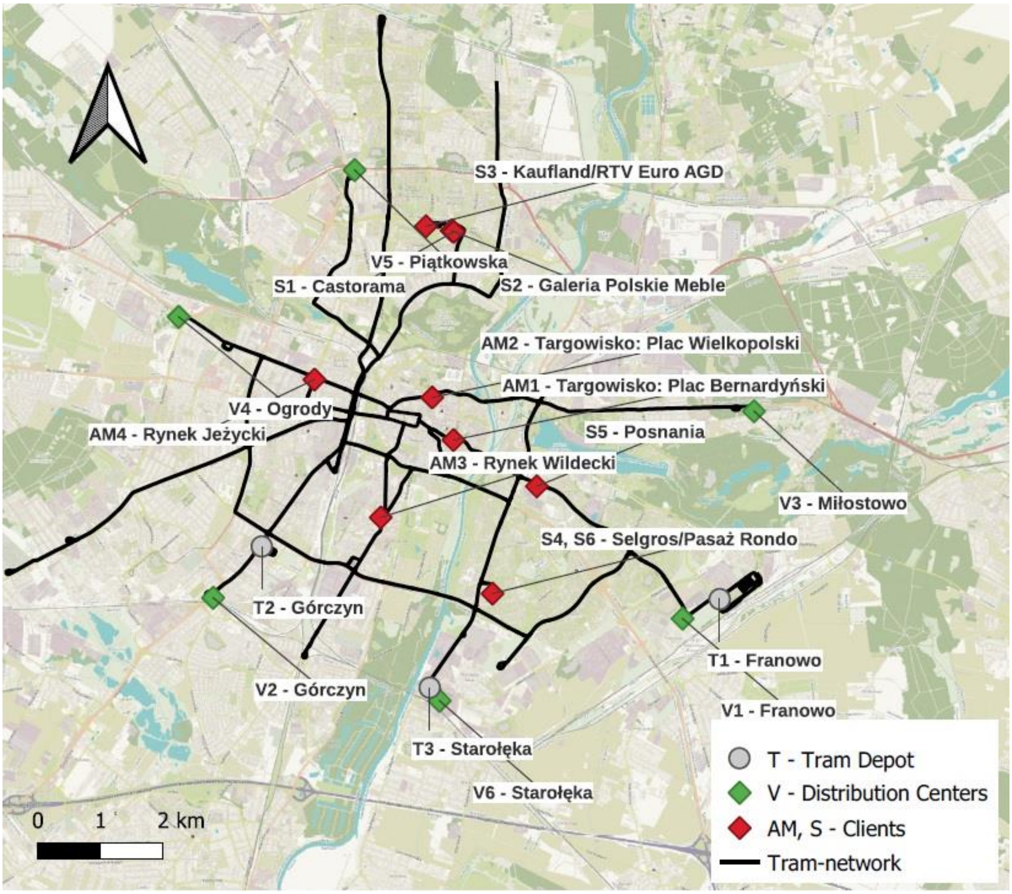

Fig. 1. Scheme of dislocation of entities in the process of cargo transportation by trams in Poznań

Fig. 2. Example of a three-section tram for urban freight (Hinčica, 2022)

In the first stage, in order to obtain a basic solution for comparing the simulation results, the problem of optimal assignment of customers to distribution centers was solved for constant demand (distribution centers have a sufficient number of products ordered by clients and the demand for products is satisfied). In this case, the optimal shuttle routes are selected on the basis of the shortest distance matrix with the criterion of minimizing the mileage with load.

However, the difficulty of implementing a logistics approach is that transport is a "living" system that operates in conditions of uncertainty and risk. Uncertainty is characterized by the stochastic demand for goods from clients, which requires the operational planning of freight transportation.

In addition to demand uncertainty, the risk may arise from the following factors:

– shortage of products in certain distribution centers,
– technical and technological failures in the operation of distribution centers,
– road works or other traffic disruptions on sections of the tram network in the city.

The presence of at least one of these events leads to the inability to deliver products to a particular distribution center and fully satisfy its demand. Therefore, the risk for the i-th distribution center can be assessed as follows:

$$Y_i = 1 - (1- P_i(Q))\ (1- P_i(B))\ (1- P_i(S)), \tag{2}$$

where: $P_i\ (Q)$ – the probability of shortage of stock in the i-th distribution center; $P_i\ (B)$ – the probability of technical and technological failures in the i-th distribution center; $P_i\ (S)$ – the probability of road works on sections of the street and road network of the city, going to the i-th distribution center.

In order to take into account the specificity of the distribution system of freight delivery in conditions of uncertainty and risk, a simulation model of the organization of material flows within the transport system of the city of Poznan has been developed.

The simulation model is based on solving an open transport problem with an unbalanced volume of deliveries and orders of goods. The model assumes stochastic demand for products from clients, and also takes into account the risk of shortages in certain distribution centers (or the inability to supply products from the distribution center for different reasons). The transport problem is a linear programming problem for which the simplex method is used.

The following assumptions were made to solve the problem:

– demand for products is a random variable that is distributed according to the normal law,
– taking the risk into account means a variation of 20% from the base values,
– only routes with load are considered in the optimization criterion (return routes/empty runs are not taken into account),
– transportation of goods involves the use of shuttle routes from distribution centers to clients.
– Limitations to the model are the following:

$$\sum_{i=1}^{m} Q_{dc\ i} \geq \sum_{j=1}^{n} Q_{c\ j}; \tag{3}$$

$$q_f \leq q_t, \tag{4}$$

where: $Q_{dc\ i}$ – the actual availability of cargo in the i-th distribution center, t; $Q_{c\ j}$ – volume of cargo order j client, t; q_f – actual shipment, t; q_t – nominal load capacity of the tram, t.

4. Results

The simulation model is implemented in the form of a software, an example of the interface of which is shown in figure 3.

Software has been developed using Python programming language for simulating the process of optimal assignment of suppliers to consumers under conditions of stochastic demand for products and the risk of product availability in distribution centers. For the optimal assignment of suppliers to consumers, an algorithm for solving an open-type transport problem

based on the simplex method was implemented. Stochastic demand for client j was generated using the normal distribution $N(\bar{Q}_j, \sigma)$, where $\bar{Q}_j$ is the average demand for goods for client j over the analyzed period, σ is the standard deviation, which in this study is assumed to be 20. The value of the available quantity of goods in the distribution centers was generated with the specified probability of deviation from the required quantity that ranged from 1% to 20%.
The input data is a list and characteristics of the facilities in the tram freight system. For clients it is geolocation and demand for supplies, for freight terminals their geolocation and volume of available goods, for tram depots their geolocation and number of rolling stock.
First a calculation was made for a constant demand. For the optimal assignment of clients to distribution centers under the conditions of constant demand, the total distance with load is 158.2 km. Distribution center V3 is not assigned to any client (Tab.1). Distribution center V4 will supply 294 tonnes of goods to clients AM2, AM4, S1 and S3. Distribution center V1 will supply 474 tonnes to client S5 and additionally 2 tonnes to AM1. Distribution center V6 will provide 294 tonnes of supply to clients S4 and S6 who are located next to each other and V5 will provide 117 tonnes to S2. The smallest load (4 tonnes) will be delivered by V2 to the client AM3.

For stochastic demand and under conditions of risk it is difficult to identify single optimal solution. For every change in value (demand, supply, exclusion of routes), the optimal assignment will be different. Using the developed software, 800 simulation experiments were conducted, which resulted in optimal plans for assigning clients to distribution centers in conditions of uncertainty and risk, as well as the value of total mileage with L_{carg} cargo in the supply of these goods. table 2 shows the average values of the obtained results.
Depending on the results of the simulation, distribution centers were assigned to supply the goods to specific clients. table 3 shows in how many simulations a given client was assigned to a specific distribution center. Based on statistical data, a histogram of the distribution of the random variable L_{carg} is constructed (figure 4).Hypotheses about the distribution laws of the random variable L_{carg} are tested. The following distribution laws were used for comparison: betta distribution, normal distribution, gamma distribution, lognormal distribution, χ^2 - distribution. It is determined that the random variable is distributed according to the normal distribution law with the parameters: mathematical expectation μ = 201.1 km, standard deviation σ = 19.99 km:

$$f(x) = \frac{1}{19.99\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-201.1}{19.99}\right)^2} \quad (5)$$

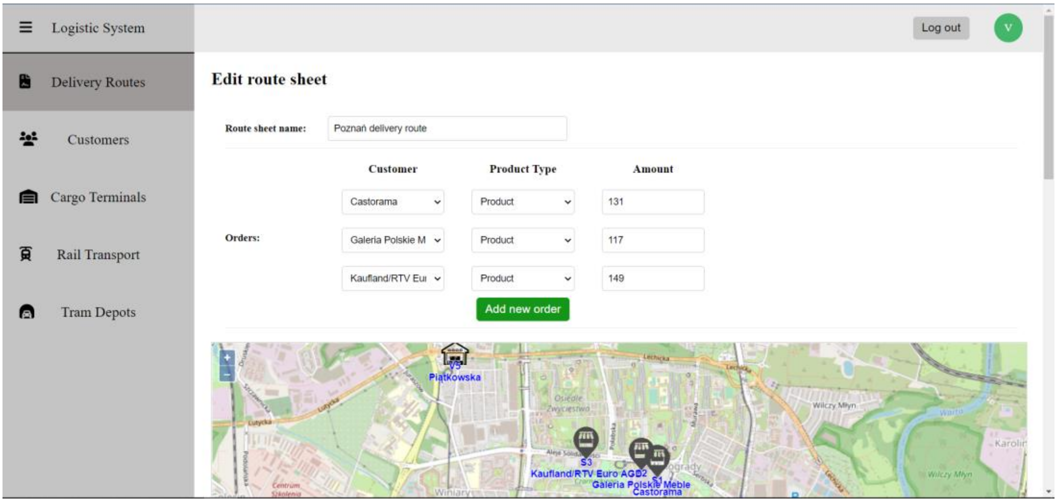

Fig. 3. Software interface for simulation model of operational planning of transport and distribution system of cargo supply in the city of Poznań

Table 1. Optimal assignment of clients to distribution centers for constant demand (assigned load in tonnes)

Clients \ Distribution center	V1	V2	V3	V4	V5	V6
AM1	2	0	0	0	0	0
AM2	0	0	0	4	0	0
AM3	0	4	0	0	0	0
AM4	0	0	0	10	0	0
S1	0	0	0	131	0	0
S2	0	0	0	0	117	0
S3	0	0	0	149	0	0
S5	474	0	0	0	0	0
S4&S6	0	0	0	0	0	384
Total load [t]	476	4	0	294	117	384

Table 2. Average values of load for assigning clients to distribution centers for stochastic demand and including risk (in tonnes)

Clients \ Distribution center	V1	V2	V3	V4	V5	V6
AM1	0.4	0.2	0.7	0.5	0.0	0.2
AM2	0.0	0.6	2.2	1.1	0.2	0.0
AM3	0.3	0.8	1.3	0.8	0.0	0.8
AM4	0.0	0.2	0.9	8.8	0.2	0.0
S1	0.0	10.8	28.9	78.5	14.4	0.0
S2	0.0	15.2	42.3	18.2	41.2	0.0
S3	4.6	18.9	78.9	28.5	21.8	0.0
S5	149.0	1.5	95.7	0.0	0.0	24.3
S4&S6	24.4	31.5	120.1	0.0	0.0	186.5

Table 3. The percentage of assignment of a given client to a specific distribution center (in %)

Clients \ Distribution center	V1	V2	V3	V4	V5	V6
AM1	19	10	33	26	2	11
AM2	0	15	54	27	4	0
AM3	7	21	33	19	1	19
AM4	0	2	9	88	2	0
S1	0	9	29	75	15	0
S2	0	14	50	28	65	0
S3	2	15	54	25	18	0
S5	86	1	64	0	0	16
S4&S6	12	12	49	0	0	88

The simulation results are summarized in table 4. The value of the parameter of total mileage with cargo L_{carg} in stochastic demand and risk slightly increases compared to stationary demand and the availability of sufficient cargo in distribution centers, which should be taken into account when determining the cost of transportation.

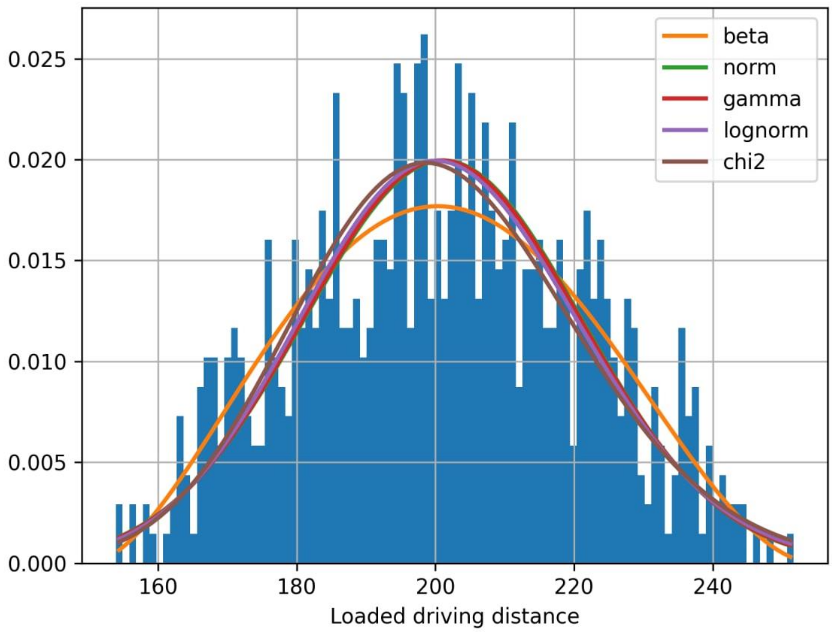

Fig. 4. Histogram of the distribution of the random variable "total mileage with cargo"

Table 4. The value of the total mileage with the load

Modeling conditions	Total mileage with load, L_{carg}
Stationary demand and availability of sufficient freight in distribution centers	L_{carg} takes the minimum possible value – 158.2 km
Stochastic demand and the risk of not having enough freight in distribution centers	L_{carg} is a random variable that is distributed according to the normal law: mathematical expectation μ = 201.1 km, standard deviation σ = 19.99 km

5. Conclusions

The introduction of environmental principles, energy-efficient technologies of urban freight transport or using non fossil fuelled vehicles determines the sustainable development of green supply chains.

The developed simulation model allows for optimal assignment of clients to distribution centers in order to quickly plan urban freight transportation by trams under conditions of uncertainty and risk.

The research was conducted for the city of Poznan. As a result of simulation, the optimal plans for assigning customers to distribution centers in conditions of uncertainty and risk, as well as the value of the total mileage with the load, which is a random variable were proposed. It is determined that the random variable is distributed according to the normal distribution law with the parameters: mathematical expectation – 201.1 km, standard deviation – 19.99 km. Therefore, when determining the cost of transportation, it is necessary to take into account the presence of conditions of uncertainty and risk.

The use of the developed software facilitates the adoption of rational management decisions when planning deliveries of freight to selected clients with stochastic demand under conditions of risk.

The downside of the proposed model is that empty runs are not taken into account and the number of transports carried out by one tram is neither considered. Further research should include those aspects and focus on the formation of optimal routes for the delivery of goods by trams from distribution centers to clients.

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