В дослідженні запропоновано новий критерій оцінки ефективності системи перевезень, який базується на врахуванні коливань рівня завантаження рухомого складу по маршрутах однієї системи перевезення. Критерій оцінює рівень приросту доданої вартості товару внаслідок процесу доставки товарів по рітейл мережі за умови мінімізації собівартості транспортування однієї тонни. Розроблено екстремальний план повного факторного експерименту з варіюванням параметрів на трьох рівнях. Встановлено, що попит на перевезення в рітейл мережі великого міста має дискретний характер. Статистичний аналіз обсягів замовлення на перевезення дозволив зробити висновок про можливість опису даної величини біноміальним законом розподілу. Проведено експеримент над полігоном обслуговування клієнтів рітейл мережі в великому місті. На основі сформованих 9 альтернативних систем логістики останньої милі досліджено вплив варіативності попиту на перевезення на формування рівнів завантаження транспортних засобів по маршрутах. Отримані статистичні дані слугували основою для розрахунку розмірів собівартості транспортування однієї тонни вантажу та оцінки розміру надлишкової доданої вартості товарів.

Проведена оцінка рівня варіативності розміру сумарної та середньої доданої вартості товару. Встановлено, що процес транспортування по роздрібній мережі може формувати приріст в сумарній доданій вартості по всій мережі в розмірі 444,5 відсотків (12 маршрутів в системі перевезення) та середнє значення для одного колового маршруту – 37,03 відсотки. Дана оцінка ефективної області функціонування логістики останньої милі, яка гарантується при умові незначного коливання рівня завантаження транспортних засобів. Це відповідає значенню коефіцієнта варіації завантаження рухомого складу в діапазоні від 0 до 10 відсотків. Поряд з цим встановлено, що найбільш чутливим до коливань обсягів замовлення є рухомий склад малої та середньої вантажності

Ключові слова: логістика останньої милі, маршрут перевезення, собівартість транспортування, додана вартість, варіативність

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ASSESSING THE IMPACT OF PARAMETERS FOR THE LAST MILE LOGISTICS SYSTEM ON CREATION OF THE ADDED VALUE OF GOODS

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1. Introduction

Transportation process plays an important role in forming the added value to goods, which necessitates the minimization of the negative impact of this process on the final price of a product. One variant to resolve this issue is to search for a rational mode of transportation or their combination [1, 2], which is an effective measure at the stage of trunk line (long-haul) transportation in the supply chain. Servicing the trunk line (long-haul) transporting flows requires the rational location of terminals with the appropriate handling capabilities [3, 4] and the description of a delivery system taking into consideration a stochastic nature of the progress of a material flow [5]. In this case, it is necessary to take into consideration the variating character of the transportation demand that is typically solved based on applying the aggregated, disaggregated models and considering the data from time series [6, 7]. According to study [8], the level of stochasticity of transportation demand is not the same for various product groups. That in turn predetermines different strategies for forming a supply chain, which becomes especially relevant at the stage of the last mile logistics. Of special importance here are the issues related to the number of logistical connections within the polygon of services, its division into districts for delivery, and determining a universal packaging for transportation [9]. The expected growth level of urban population up to 66 % by 2050 [10] will increase the concentration of goods in urban agglomerations by orders of magnitude. That will, accordingly, increase the number of transportation operations within city limits. Under such conditions, the application of existing strategies for customer service at the stage of the last mile logistics might prove to be problematic in terms of effectiveness of the results to be obtained. Papers [11, 12] have substantiated that delivery at the last mile logistics could create a disproportion in the overall costs of transportation throughout the entire supply chain. This becomes a factor in the high added value of a batch of goods delivered to a retail network. The formed tendency for the urbanization of population has predetermined over recent years the development of relevant measures in the field of the last mile logistics [11–26]. The most common directions to solve the problematic issues include: a low load of the rolling stock [11], problems related to evaluating the effect of reducing the mileage [12] under the "cost-benefit" analysis, prolonged empty runs [13, 14]. At the same time, the relevant issues are the application of innovative rolling stock in order to level the negative impact of transportation on the environment [15], technologies for servicing the end users [16], general issues related to the sustainable functioning of logistics system [17] and the development of systems to plan transportation routes [19–26].

2. Literature review and problem statement

The basic principle of routing the transportation is the minimization of the transport work of the rolling stock that is performed by optimizing the mileage of rolling stock when servicing customers of a retail network. This is the classical approach for solving the tasks at the last mile logistics. When applied, development of the system is based on the formation of the so-called matrix of "wins" by combining simple transportation cycles into complex ones. The most widely applied among available routing methods is the heuristic Clark and Wright algorithm and its modifications [19–26].

The task on routing a system of goods delivery to a retail network implies the formation of complex cycles of transportation based on the step-wise addition of a service point to the variant of the route formed at the previous step. It is possible to add points of delivery by including the point of delivery in the chain $(i+1; j-1)$, where i and j are, respectively, the indexes of the first and the last service points along the created service route. Alternatively, there is a variant to change the existing route by including a new point of delivery into the interval $(0; i)$ or $(j; 0)$, in which "0" denotes a point of departure. In this case, each iteration implies only one variant of change in the number and location of points of service. Consequently, the effect of the implementation of a given operation is also calculated locally for each of the iterations. In certain cases, modernization of the classic algorithm by Clark and Wright comes down to combining two alternatives for the formation of a procedure of customer service in a retail chain [19], or taking the specificity of street and road network into account [20]. For example, for its form in a tree, there are significant risks related to forming the system of routes with excessive runs of freight vehicles. To solve a given problem, paper [20] proposed an algorithm for checking the appropriateness of the inclusion of a point of service into the chain $(i+1; j-1)$ within a single "branch" of the transportation network. The results reported in [19, 20] point to the possibility of reducing the total service time in comparison with the systems based on the classical algorithm by Clark and Wright. However, there are neither quantitative nor qualitative evaluation of these algorithms in [19, 20]. At the same time, the main drawback in [19–21] is the construction of a system of transportation from the positions of the classic principle of minimizing the magnitude of transportation work with the addition of new points of delivery to the transportation cycle.

Study [22] made an attempt to optimize the sequence of service by taking into consideration the cosine of angle between the point of departure and two adjacent points of delivery in the algorithm. However, in this case, the authors only refine the order of customer service within the complex cycle in order to minimize the total mileage of vehicles by analogy with [19–21].

Within the framework of the last mile, rolling stock can be utilized based on the scenario "one route – one vehicle" or "several routes – one vehicle". Under the second variant, there is an additional condition for the work time of a vehicle, the order of servicing routes and customers within each route. Under such conditions, paper [23] proposed, as the criterion of effectiveness, to use the value of a vehicle's work extra-time along the route. The originality of the approach is, first, in determining a value for the criterion of efficiency as the maximum difference between the total time of delivery along all routes and the maximally permissible time of delivery. Second, the problem is iterative in nature, which helps arrive at an optimum of the chosen function – the general extra-time of a vehicle's work. However, in this case, forming the routes for transportation is performed without taking into consideration the level of vehicles loads, which could lead to significant fluctuations in the cost of transportation at constant values of transportation distance.

The classic statement of the problem on determining the matrix of "wins" resulting from the formation of complex cycles of transportation implies the assumption on that all arcs of the graph are equivalent. Papers [24, 25] assume that arcs of the graph may have a different weight depending on the technology to service clients in a network. The authors suggest using additional calibration parameters when estimating the matrix of "wins". Thus, they introduced a parameter λ ("a route shape parameter"), which reflects the significance of the arc that connects two clients within a new servicing cycle. The parameter μ reflects the asymmetry of distances between the existing two basic cycles, which are planned to be merged into a single complex one. In addition to these two parameters, paper [24] introduces a parameter υ that makes it possible to adjust a model based on the volume of customers' orders. In fact, these three additional elements of the model make it possible to take into consideration the emerging properties of the new delivery routes, which are formed as a result of combining simple transportation cycles. The criterion of efficiency in this case is a standard indicator, the minimum total mileage of vehicles along routes, which was applied in [25]. A special feature of the proposed element in the modernization of the Clark and Wright algorithm in [26] is the preliminary clustering of the polygon of service with the routes of transportation developed separately in each of the generated clusters. At the same time, it is not specified which principle is employed to estimate the rational number of clusters and the requirements to the quantity of customers to be serviced within each cluster. In this case, papers [25, 26] are characterized by the drawbacks of the above studies, namely the choice of the rational variant of the last mile logistics system only on the basis of the minimum value for the magnitude of mileage of vehicles.

The approaches to optimizing the last mile logistics, considered above, enable the optimization of customer service sequence at a certain polygon. However, the procedures described do not make it possible to estimate the general scenario of the functioning of a logistics system. The transportation process is certainly a key element in forming the added value to the final price of goods and the last mile logistics system should minimize the negative impact on the formation of the ultimate value of goods in a retail chain. To this end, it is necessary to explore the influence of parameters of the last mile routing system on the character of forming the added value of goods as a result of transportation. In this case, it is advisable to apply a value assessment of consequences of the implementation of transportation process within the framework of the last mile by analogy to studies [27, 28].

3. The aim and objectives of the study

The aim of this study is to determine the nature of relationship between the added value of goods and the level of vehicles' loading under condition of variability in the demand for transportation within the framework of the last mile logistics. This would make it possible to build a system of the last mile logistics at a minimum transportation cost and to warrant the planned profitability level to retail companies.

To accomplish the aim, the following tasks have been set:

– to determine the character of demand for transporting goods to a retail network using the example of a large retail company;

– to formalize the criterion for estimating the effectiveness of functioning of the system of goods transportation in small batches;

– to design and perform an experiment that would cover all possible states of the system of goods transportation to a retail network;

– to assess the impact of the transportation system parameters within the framework of the last mile logistics on the formation of the added value of goods.

4. Materials to study the functioning of the system of goods delivery to a retail network at the stage of the last mile logistics

4. 1. Determining the character of demand for goods transportation to a retail network using the example of a large retail company

Delivery of products within the framework of the last mile logistics can be carried out by separate vehicles and in small batches using the technology of multi-stop routes. Supply of products to the end consumer is typically performed through a retail network, which, accordingly, implies the larger specific weight of a given type of delivery within the framework of the last mile logistics. Thus, with respect to the predominance of small-batch deliveries, it is advisable to study the character of demand for delivery of goods using the technology of multi-stop routes.

The chosen object of research is the retail network of Bim Stores corporation in the city of Casablanca (Kingdom of Morocco). The retail chain Bim Stores in Casablanca has 40 stores that sell food products, household chemicals and light industry items. Key customers include Coca-Cola, Procter&Gamble, Reckitt Benckiser, Bel Group, and others. The logistic transportation planning system compiles a package of orders for the clients database based on the need in supply per a day in a week. The unit of order is one euro-pallet the size of 1,200×800. Delivery is performed on each weekday for all 40 shops. A possible amplitude of fluctuations in the volume of orders addressed to one recipient is 1 to 4 pallets. Preliminary analysis of statistical data has allowed us to reveal a variational character of the volume of orders, based on which we proposed a hypothesis on the possibility of describing a given parameter by the discrete distribution law. Results of hypothesis verification are given in Table 1.

Table 1

Numerical values for the probabilities of orders arrival

Indicator	Week days				
	Monday	Tuesday	Wednesday	Thursday	Friday
Type of distribution law	binomial				
Tabular value for the Chi-square criterion	7.8	7.8	7.8	7.8	6.0
Actual value for the Chi-square criterion	5.81	3.15	0.87	3.90	0.46
Number of degrees of freedom	3	3	3	3	2
Parameter of the binomial distribution law	0.64375	0.6375	0.425	0.6625	0.86875

Based on the derived numerical data for the Chi-square criterion, the hypothesis about the stochastic character of distribution of the volume of orders in a retail chain has not been refuted. We made a decision on the possibility to describe a given magnitude using the binomial law, specifically:

$$P_n(m) = C_n^m \cdot p^m \cdot q^{n-m}, \tag{1}$$

where C_n^m is the binomial coefficient; p is the probability of event occurrence; q is the opposite event, q=1–p; n is the number of independent trials, units; m are the possible values for a random magnitude, m=1, 2,..., n.

$$C_n^m = \frac{n!}{m\cdot(n-m)!}. \tag{2}$$

The obtained characteristics make it possible to perform simulation of the volume of deliveries within a retail chain. The proposed modelling tool is the embedded add-on "Generation of random quantities" in the MS Excel 2016 software.

4. 2. Procedure for constructing a system of multi-stop routes within a retail chain

When performing the procedure for constructing a system of delivery routes, the main aspect is the choice of a criterion of effectiveness. Typically, the optimization function is the minimum transportation work or the total cost of transporting a volume of order over a certain period of time. Within the framework of delivery routing, these criteria are classic and are widely used when material goods are delivered by automobiles. In this case, when goods are supplied in small batches, the technology of multi-stop routes includes such methods as the shortest connecting network, the Clark and Wright method, "genetic algorithms", "ant colony algorithm". All these methods for the optimization of routes of vehicles are aimed at the minimization of unproductive mileage when delivering material goods. This principle is basic in the performance of material supplies, as it saves energy and time resources. However, one should take into consideration the discrete character of a transportation process and the probable level of vehicles' load based on the stochastic character of demand for delivery. Based on this, we propose to apply, as the criterion of functioning efficiency of the distribution system, the cumulative excessive added value, predetermined by the transportation process at the stage of the last mile logistics:

$$R = \sum_{i=1}^{m} \Delta_i \to \min,\ \ \Delta_i \in \Omega,\ \Omega = \{k\}, \tag{3}$$

under condition

$$\overline{S_t^k} = \frac{\sum_{i=1}^{m} S_{ti}}{m} \to \min, \tag{4}$$

where R is the total increase in the excessive added value of goods as a result of transportation within the last mile logistics, %; Δ_i is the level of growth of the excessive added value due to the increasing cost of transportation, %; m is the number of routes in the distribution system at the territory of a service polygon, units; Ω is the set that reflects the list of alternative routing distribution systems of a certain number of end users; $\overline{S_t^k}$ is the average cost of transporting one ton of cargo within the k-th service system, a.u./t; k is the number of alternative variants of supply systems, units.

$$\Delta_i = \left(\frac{S_i}{S_{ti}^*} - 1\right)\cdot 100, \tag{5}$$

where S_{ti} is the cost of transporting one ton of cargo along the i-th route at an actual level of a vehicle load, a.u./t; S_{ti}^* is the cost of transporting one ton of cargo along the i-th route by a fully loaded vehicle, a.u./t.

$$S_{ti} = \frac{C_{\text{var}}\cdot l_m + C_{fix}\cdot t_{ri}}{q_n\cdot \gamma_{st}}, \tag{6}$$

where C_{var}, C_{fix} are, respectively, the variable and constant components of the cost of transportation, a.u./km and a.u./hour; l_{mi} is the length of the i-th multi-stop route, km; t_r is the time for a vehicle to return along the i-th multi-stop route, h; q_n is the cargo capacity of a vehicle, t; γ_{st} is the coefficient of static utilization of a vehicle's cargo capacity.

Calculation of S_{ti}^* is performed based on model (6) under condition that γ_{st} is equal to unity.

Typically, a retail network exploits rolling stock of similar makes, which is predetermined by the characteristics of load. Prior to the purchase of rolling stock, in the framework of a business plan, there is always an assessment of the most effective model of a vehicle among alternative variants. Based on this, we assume that the retail chain is serviced by a fleet of vehicles of the same type (cargo capacity) or the same make.

The variable and fixed components of transportation cost are typically determined based on the type of operational costs. Namely:

$$C_{\text{var}} = f\left(C_f, C_o, C_r, C_{tr}, L\right), \tag{7}$$

$$C_{fix} = f\left(C_{sal}, C_{dc}, C_{ge}, T_w\right), \tag{8}$$

where C_f is the fuel cost, a.u.; C_o is the cost of lubricants, a.u.; C_r is the cost of technical maintenance and repair, a.u.; C_{tr} is the cost of renovation and repair of tires, a.u.; L is the mileage of a vehicle over a fiscal period, a.u.; C_{sal} is the driver's salary cost, a.u.; C_{dc} is the cost of depreciation charges, a.u.; C_{ge} is the volume of general expenses over a fiscal period; T_w is the duration of a vehicle's work over a fiscal period, h.

The algorithm to construct a system of rational multi-stop routes is based on the method by Clark and Wright, which is shown in the form of a flowchart in Fig. 1. Input parameters when forming the multi-stop route is the matrix of the shortest distances between all participants within a retail network including the sender, an array of data on the volume of goods delivery to each recipient, and cargo capacity of the rolling stock. This information is entered within the framework of unit 1.

Unit 2 implies the assessment of the level of the inefficient use of rolling stock over a single transportation cycle. This unit's element

$$\left[\sum_{i=1}^{N} q_i / \left(q_n\cdot\gamma_{st}\right)\right] - \sum_{i=1}^{N} q_i / \left(q_n\cdot\gamma_{st}\right), \tag{9}$$

characterizes a general level of the inefficient utilization of rolling stock across the entire distribution network. An increase in the added value of products is achieved under meeting the following condition

$$\left(\left[\sum_{i=1}^{N} q_i / \left(q_n\cdot\gamma_{st}\right)\right] - \sum_{i=1}^{N} q_i / \left(q_n\cdot\gamma_{st}\right)\right) > 0. \tag{10}$$

In this case, the required number of transportation cycles over which all clients in the network have been serviced is derived from

$$\left[\sum_{i=1}^{N} q_i / \left(q_n\cdot\gamma_{st}\right)\right]. \tag{11}$$

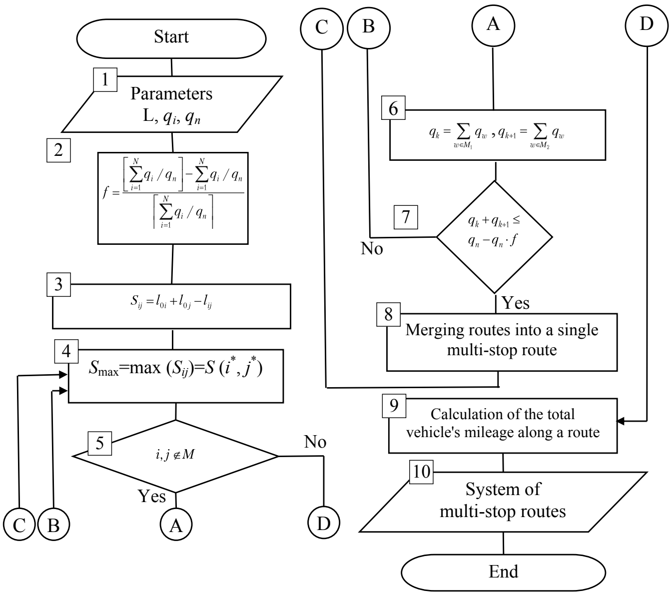

Fig. 1. Algorithm for constructing a system of multi-stop routes

It should be noted that the coefficient of cargo capacity utilization in this case is determined based on the volumetric weight of cargo and at this stage it is assumed to be equal to unity.

Parameter f describes the average size of the inefficient use of rolling stock with respect to the discrete character of transportation volumes and cargo capacity of the rolling stock. This indicator specifies the recommended volume of loading the rolling stock during formation of a batch of goods to be delivered over a single transportation cycle: $q_n - q_n \cdot f$.

Unit 3 implies building a matrix of wins from merging the pairs of simple transportation cycles into multi-stop routes. In the resulting array, one determines the maximum value of S_{ij} (unit 4).

Since the formation of a multi-stop route is performed by adding the simpler pendulum routes that service the i-th and j-th recipients, the condition must be satisfied at each iteration that the points i and j do not belong to a single route M. A given condition is checked in unit 5; in this case we merge the volumes of transportation into a single one (unit 6). The next stage involves checking the condition for meeting the constraint $q_k - q_{k+1} \leq q_n - q_n \cdot f$ in unit 7. If this expression is not satisfied, the point that is considered is not added to the multi-stop route. Otherwise, the client is included in the list of points along a multi-stop route. Following it is the next iteration in units 4–8 until the system reaches the state when points i and j belong to the earlier constructed multi-stop routes. In this case, we run the process of evaluation of the total mileage of a vehicle along this route (unit 9). The result of execution of the algorithm is the constructed system of multi-stop routes (unit 10).

5. Experimental study into functioning of the system of goods delivery to a retail network within the framework of the last mile logistics

5. 1. Characteristics of the object for the implementation of a transportation proposal

The system of goods delivery to a retail network within the framework of the last mile logistics will be the most challenging in terms of structure and functional organization when it is constructed within a large region or a large city. The number of functional relationships among elements of the system will grow in a non-linear manner if the number of clients increases. This is predetermined by an increase in the volume of information and material flows, by the discrete character of the transportation process related to customer service, and by the intensification of work of the transportation and warehouse subsystems. Given this, in our research we selected a settlement that acts as a transportation hub in the North-Western Africa, which, accordingly, requires the presence of a developed network of railroads and motor roads in order to service a sea port and to ensure the rhythmic work of freight vehicles. The consequence is the high level of economic potential in the agglomeration and a significant population density due to the developed labor market.

The city of Casablanca has all above features. General characteristic of the service polygon (the city of Casablanca, Morocco) is given in Table 2.

Table 2

General characteristics of the service polygon

Parameter of service polygon	Numerical value
City area, km^2	384
City population, thousand people	3,356
Type of street-road network	radial-circular
Number of Bim Stores customers, units	40
Density of Bim Stores customers location, units/km^2	0.104
Average radius of servicing a single Bim Stores' shop, km	1.75

Bim Stores Corporation is a major food retailer in Turkey, Morocco, and Egypt, headquartered in Istanbul (Turkey). The total number of stores in Morocco is 279. The basic principles of the company are the minimization of operational costs in order to provide discounts to the supermarkets' customers. This operational concept fully coincides with the purpose of our study. Thus, the retail chain Bim Stores in Casablanca can be chosen as the object of conducting experimental research. The developed transportation infrastructure of the Casablanca agglomeration is an additional factor in selecting it for the experimental study in the framework of construction of a rational variant of the system of delivery of goods to a retail network in a large city. This guarantees the reliability of research into extreme states of the distribution system and allows us to characterize the strategy of building a system of customer service along multi-stop routes.

5. 2. Planning a procedure for experimental research

Experimental research into the system of products distribution at a large retail company is based on the model of a street-road network and a mathematical model of the system of goods delivery within the retail chain. Model of a street-road network (using the city of Casablanca as an example) is based on the graph theory applying a standard procedure. Its general characteristics are given in Table 3.

Table 3

Characteristics of the model of a street-road network for the object of experimental research

Characteristics of a street-road network	Numerical value
Number of graph's vertices, units	63
Number of edges, units	107
Total length of graph's edges, km	305.1
Average length of a single graph's edge, km	2.85
Density of a street-road network based on the model, km/km^2	1.32

We propose to study the functioning of the system of multi-stop routes using the theory of planning extreme full-factor experiments. This makes it possible to describe the full-factor plane of the functioning of the examined object at a minimum number of experiments. Typically, when designing a full-factor experiment, one selects the plan of type 2^k. However, in the case of a hypotheses about the nonlinear character of the relationship between a function and factor attributes, it is advisable to perform the variation of factors at three levels, which is why plan we select the plan of type 3^k. Factor x_1 here is the value for the binomial distribution parameter p; x_2 is, respectively, the make of the rolling stock (vehicle's capacity in pallets). For transportation, the retail chain BIM Stores employ the following rolling stock: Fuso Canter 7C15 Duonic (cargo capacity is 10 tons) and Volvo FH 62R (cargo capacity is 14 tons). Numerical values for the limits of variation in selected parameters are given in Table 4.

The volume of orders for delivery of goods within a retail network is formed based on the character of demand (the binomial law). To acquire an array of data on each client, we perform the procedure of simulation taking into consideration the levels of variation from Table 4. Results of the simulation of the volume of orders for three variants of the variation levels are shown in Fig. 2.

Fig. 2. Result of simulation of the volume of orders for retail chain's customers

At the next stage, we derived a matrix of the shortest distances and simulated the volume of orders. Based on the designed experiment, applying the developed algorithm, we formed alternative variants for the last mile logistics. The structure and technical-operational indicators for the formed variants of supply chains at the last mile are given in Table 5.

The totality of all possible variants of transportation services is represented by 64 delivery routes from 9 alternative systems (Table 5). The variability of demand for transportation in the retail network is ensured by the fluctuation of the total volume of transportations in the range from 69 to 108 pallets per day.

Table 4

Extreme values of factors

Variation level	Parameter of binomial law	Cargo capacity of vehicle, t
Maximal	0.86875	10
Minimal	0.425	14
Medium	0.55687	12

Table 5

Technical-operational indicators for the developed systems of routes

No. of alternative delivery system	Number of routes in the system, units	Total mileage when loaded, km	Total mileage along the routes, km	Mean value of the cargo capacity utilization factor	Mean value of the mileage utilization coefficient	Total delivery time, h	Daily volume of transportation, pallets
1	7	294.2	467.0	1.00	0.63	34.76	70
2	12	414.4	722.0	0.90	0.57	50.86	108
3	5	233.7	360.7	0.86	0.65	28.73	69
4	7	284.9	468.4	0.96	0.61	37.31	108
5	9	323.4	563.0	0.93	0.57	40.84	84
6	6	246.1	398.9	0.88	0.62	31.97	84
7	5	222.0	356.1	0.94	0.62	28.67	69
8	7	284.9	468.4	0.96	0.61	37.31	108
9	6	234.3	387.1	0.92	0.61	31.62	85

6. Estimation of influence of the delivery system parameters on creation of the added value for products

As shown in models (7) and (8), the cost of transportation is a function not only of the transportation system parameters, but of the operational and cost indicators of vehicles. At certain stages of the supply chain, the minimization of transportation costs is possible through the selection of a rational make and cargo capacity of the rolling stock, for example, for trunk shipments. In turn, when delivery is performed within the framework of the last mile logistics, the task on minimizing the cost of transportation must be solved comprehensively: by choosing a supply routing system and evaluating rational variants to utilize the rolling stock. The result of the comprehensive assessment is the value for the cost of transporting one ton of cargo and the size of creation of the added value for products.

Information about the basic parameters of routes and operational characteristics of the rolling stock makes allows the estimation of cost of one kilometer and an hour of the vehicle's work. The calculation is performed separately for each route from all alternative service systems. The total number of values for the cost of one kilometer and one hour is 64, respectively, for the cost of one kilometer and one hours of the vehicle's work. In order to conveniently present results in a tabular form, we grouped them based on their belonging to the alternative delivery systems, and calculated the mean values for indicators for each service scenario individually. Results of this procedure are given in Table 6.

Table 6

Results of estimation of the transportation cost components

No. of alternative delivery system	Average cargo capacity of vehicle, t	Structure of the rolling stock fleet	Average value for the cost of one kilometer, a.u./km	Average value for one hour of work of rolling stock, a.u./hour
1	10	Fuso	0.18	2.98
2	10	Fuso	0.17	2.98
3	14	Volvo	0.32	3.63
4	14	Volvo	0.32	3.64
5	10	Fuso	0.17	2.97
6	14	Volvo	0.32	3.63
7	12	Fuso, Volvo	0.29	3.49
8	12	Fuso, Volvo	0.32	3.64
9	12	Fuso, Volvo	0.3	3.5

The availability of an array of transportation cost components for all employed makes of the rolling stock allows us to estimate the level of the created added value of goods, which is predetermined by the executed transportation process. The calculation is separate for each i-th route from the *k*-th system. The resulting Table 7 gives the mean values for S_{Ti}^*, S_{Ti}, Δ, and the summary value for R. The numerical evaluation of the given indicators is based on models (3)–(6).

Table 7

Results of determining the level of excessive added value in goods as the consequence of transportation process at the stage of the "last mile"

No. of alternative delivery system	Average cost of transporting when fully loaded, a.u./t	Average cost of transportation at the actual vehicle's loading, a.u./t	Average level of excessive creation of added value of goods, %	Total excessive added value of goods in retail chain due to transportation, %
1	2.69	2.69	0.00	0.00
2	2.31	2.79	37.03	444.5
3	3.14	3.70	19.04	95.22
4	2.93	3.04	3.81	26.68
5	2.44	2.61	7.72	69.46
6	2.90	3.44	30.00	180.00
7	3.10	3.32	7.05	35.23
8	2.93	3.04	3.81	26.68
9	2.82	3.03	12.22	73.33

Data from Table 7 show that the minimum cost of transporting one ton of goods when a vehicle's cargo capacity is fully utilized corresponds to variant No. 2 – 2.31 a.u./t. At the same time, this system of deliveries is characterized by the maximum magnitude of the average level of excessive added value for a batch of goods as a result of incomplete loading of the vehicles along routes (37.03 percent). We can assume that the degree of fluctuation in the loading level of a vehicle along all routes in the same system of transportation exerts a significant impact on the resulting cost of transportation. We calculated the root mean square deviation in the level of loading the rolling stock separately for each alternative system and derived coefficients of variation in the levels of vehicles' loads. The results are shown in Fig. 3.

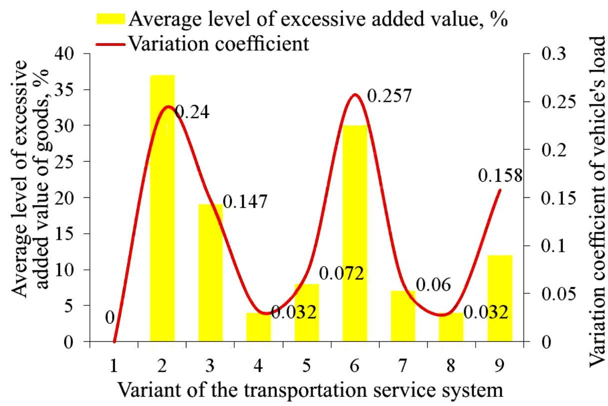

Fig. 3. Variation coefficients in the level of vehicles' load along alternative systems of transportation service

Fig. 3 shows that there is a close relationship between values of the average level of excessive added value of goods and the variation coefficient in the level of a vehicle's load. Thus, the assumption about the significant negative impact of the fluctuation in the level of a vehicle's load along the routes within the same transportation system on the cost of transportation and the size of the added value for a batch of goods is true.

Since the construction of routes in each system was based on the random distribution of the volume of order for goods at service points, the level of a vehicle's load is stochastic in character and should have a certain spread relative to the mathematical expectation. To investigate this phenomenon, we shall apply a diagram of the type "box-and-whiskers" (Fig. 4).

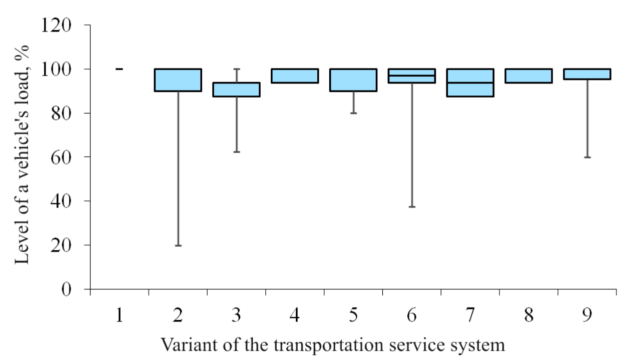

Fig. 4. Bounds of statistical significance for the level of vehicles' load for alternative transportation systems

The determined bounds of statistical significance in the levels of vehicles' load for the systems of transportation confirm the conclusion about the negative impact of the uneven loading of the rolling stock on the size of the added value for a batch of goods. The most effective from this point of view are the systems Nos. 1, 4, and 8. At the same time, the consumer of goods is concerned with the final price, which is supposed to be minimal for him (Fig. 5).

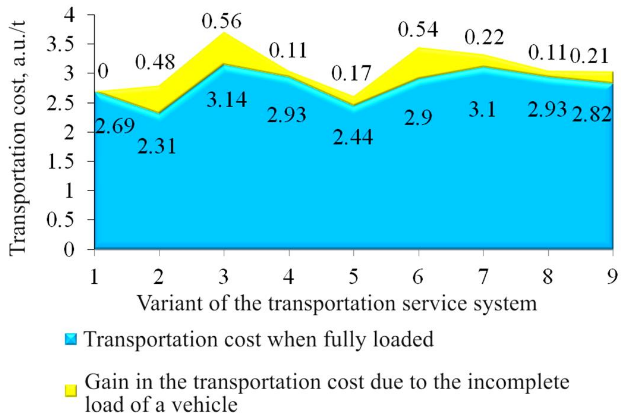

Fig. 5. Result of defragmentation of the total transportation cost for one ton of cargo for the alternative variants of supply systems

The result of graphical representation of the overall cost of transportation allows us to determine a system with the minimum value for this indicator, which is the system No. 5. This variant of the transportation system is characterized by an insignificant coefficient of fluctuation in the level of vehicles' load (<10 % according to Fig. 3) and the compactness of data variance concerning the mathematical expectation (Fig. 4).

It should be noted that the experiment involved rolling stock with varying cargo capacity, which exerts its impact on the creation of the cost of transportation. This indicator is in close correlation with the size of excessive added value to a batch of goods, due to the process of transportation (Fig. 6).

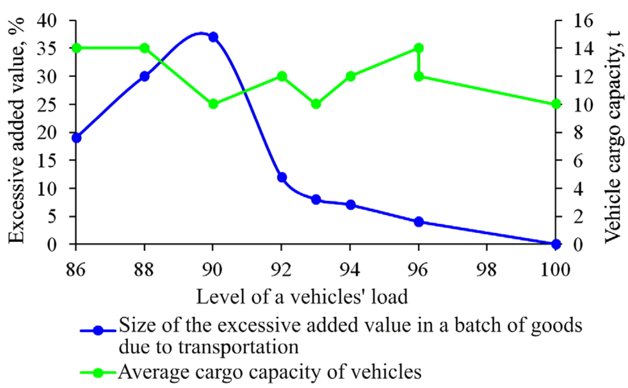

Fig. 6. Relationship between the level of excessive added value in a batch of goods and cargo capacity of vehicles

The graphical construction of dependence of the excessive added value on the average level of vehicles' load, with respect to vehicles' cargo capacity, leads to the conclusion on a significant sensitivity of the negative change in the excessive cost when using vehicles of a medium and small cargo capacity. This should be taken into consideration when constructing the systems of multi-stop routes at the last stage of the supply chain. Transportation engineers must ensure the uniform loading of vehicles along all routes within a system, which makes it possible to minimize the negative impact of the creation of the excessive added value in the general batch of goods delivered to a retail network.

7. Discussion of results from experimental study

The acquired characteristics of demand for transportation within a retail network meet modern trends in the implementation of the physical Internet. In fact, a carrier handles not a cargo, but cargo units, which in the framework of our research included transportation packages, specifically pallets. Such a type of delivery creates the discrete character of the volume of transportation, which, as shown in this study, can be generated based on a simulation toolset. This should enable the operators of transportation process and owners of retail networks to predict the maximum and minimum volumes of orders from customers and to estimate possible states of the supply chain at the stage of the last mile.

The classical approach to building the last mile logistics system based on minimizing the magnitude of transportation work does not make it possible to take into consideration the final added value of products in a retail network. The proposed approach, along with the minimization of the total added value of goods in a retail network, makes it possible to build the last mile logistics system at a minimum average cost of transportation. That would, therefore, make it possible to achieve a cumulative effect of minimizing the negative impact due to the transportation process. The ultimate cost of goods under such conditions for the construction of the last mile logistics would have a minimal gain as a result of reducing the cost of transportation and the excessive added value of goods. As shown by the results of experimental research, fluctuations in the level of vehicles' load along routes within a single system could lead to a four-fold increase in total added value of goods.

The selected service polygon for conducting our experimental research was characterized by a low density of clients' location, which certainly has its effect on the mileage of vehicles and the duration of the total service time. In the framework of future research, it is advisable to pay attention to conducting experiments at polygons with a larger number of end recipients and to pay attention to rendering a transportation service to clients based on address delivery. This segment of transportation is growing under conditions of the Internet commerce development, which leads to the trend of replacing the conventional shops in retail networks. At the same time, modelling the last mile logistics process should be performed with respect to the different motion speed of vehicles depending on a service district's location relative to the center of the city. This is absolutely relevant to most major European cities, which are characterized by the radial-circular pattern in a street-road network.

8. Conclusions

1. An analysis of orders and the frequency of deliveries to a retail company in a large city has revealed that the demand for transportation is variational. It was determined that customers' orders in a retail network are mostly those batches of goods that correspond to a transport container, which is in line with the binomial law of distribution of random variables, the value for distribution parameter p ranging from 0.425 to 0.86875.

2. We proposed applying, as the criterion of efficiency of transportation at the stage of the last mile logistics, an indicator of the minimum amount of excessive added value. This makes it possible to choose among the alternative last mile logistics systems a set of routes, which guarantee that a retail company achieves its planned profitability and warrant the planned level of retail prices for goods.

3. In the experiment that involved all possible systems of transporting goods within the framework of the last mile logistics in a large city, we investigated the character of change in the cost of transportation and the creation of added value in a batch of goods. We have established among nine systems of routes possible fluctuations in the excessive added value in the range from 0 to 444.4 percent. This is an indicator of the need to take into consideration the fluctuations in the level of vehicles' load when developing a transportation system for the last mile logistics.

4. The high efficiency of a transportation system is observed when values for the variation coefficient of vehicles' load are in the range from 0 to 10 percent. In this case, the assessment of level of the variance level of a vehicle's load relative to the mathematical expectation also exerts a significant impact on the fluctuation in the full cost of transporting one ton of cargo within a retail chain. This process is mainly observed when using for transportation vehicles of small and medium cargo capacity, which is recommended to take into consideration when constructing a service system at the last mile.

The result obtained must be considered by the subjects of the last mile logistics. Thus, when using during transportation the rented rolling stock, a transport enterprise must ensure the minimization of excessive added value in order to create a competitive image of the company in the market of transportation. Under these same conditions, a retail network can incur unplanned losses as a result of a decrease in the planned profitability of selling products to end consumers. This is predetermined by the presence of similar products in the market that can be supplied by other retail chains with a less added value. This aspect becomes even more acute in the case when a retail chain exploits its own rolling stock for transportation, which generates a negative cumulative effect both for the transport division and for the sales department.

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