City Retail Network Influence on Transportation Expenses

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Abstract. An approach to determining the influence of retail network parameters on the share of transportation costs taking into account the density of outlets is presented. The obtained results can be used to develop recommendations for the optimal area of operation of retail delivery systems, and to estimate cargo flow volume in cities.

1 Introduction

The current state of the Ukrainian economy requires retail companies to exhibit flexibility when faced with changes in market conditions. An integrated approach to the organization and planning of logistics and marketing processes, and the ability to quickly change the existing strategy to take advantage of new opportunities, is needed to achieve financial success. Transportation of small quantities of goods is the most costly for road transport, and precisely because of this the share of transportation costs considerably raises the final price of the goods. To improve competitiveness, it is necessary to focus on meeting the needs of end-users, because, when buying a product, they always pay for its delivery.

To reach a larger market share, retail networks open new trading points, which leads to a significant increase in transportation costs at the stage of the last mile. Transportation of cargoes at this stage is carried out by a rolling stock of small and medium cargo. The small size of orders, the daily delivery of products and the variety of outlet formats leads to the need for an objective assessment of the cost of product delivery, depending on the density of the trading network.

The active development of logistics systems for the supply of consumer goods in the retail chain has led to a lack of a systematic approach to problem solving. The paper [1] analyzes the components of the material flows in the logistics system. It has been determined that, depending on the structure of the supply chain, the type of goods and their prices, the share of transportation costs can reach 15% of the total shipping costs. This statement applies to monopoly companies that own distribution channels, and does not apply to relatively small retail chains, which are the overwhelming majority in the Ukrainian consumer market. Significant influence on the delivery cost of goods has such indicators as the density of the location of consignees, which is considered in [2, 3, 4, 5], and the size of the batch of cargo [2, 6, 7, 8]. However, proposals for the improvement of a

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company-specific situation are formulated in these works for only one case, which makes it impossible to determine changing trends and further forecasting.

2 Modelling of the share of transportation costs

The purpose of the study is to identify the patterns of change in the delivery parameters of the retail network based on the share of logistics costs, while taking into account the density of the logistics network. The object of research is the process of delivering consumer goods in the logistic system of the retail trade network. The subject of the study is the pattern of influence of the density of the logistics system of the retail trade network on the share of logistics costs for the delivery of goods.

The process of delivery to the logistics system of the retail network can be represented in the form of a cybernetic model "black chest" (Fig. 1).

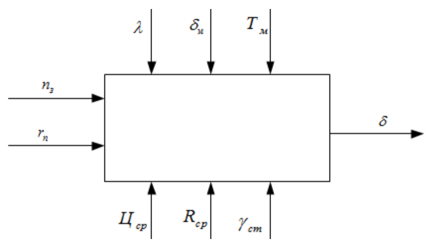

Fig. 1. Model of the process of delivery of consumer goods in the form of a "black chest"

The optimization factors are the selected number of points on the route ($n_з$), and the radius of half of the demand of the trading point (r_n).

The addition of new objects to the distribution system increases the operating costs and the costs of transporting the entire system. It has been proved that, when changing the number of objects in the system (outlets), part of the expenditures is increased, while a part of other expenditures is decreased, with an increase in income for the entire system. This allows researchers to set and solve the problem of finding the optimal correlation of these indicators.

The objective function in this case represents the share of logistics costs for the transportation of consumer goods to a new trading point (δ, %), and has the following appearance

$$\delta = [B_{mp} / (D_i + D_j)] \cdot 100 \to \min \tag{1}$$

where B_{mp} - is the cost of transportation to a new trading point of the network, UAH;
D_i - total revenue of the retail chain, UAH;
D_j - expected revenue of a new trading point, UAH;

The minimization of the objective function is achieved by optimizing the logistic parameters of the delivery process of the retail trade network. The influence of the parameters of the logistics system was considered under the following conditions: the number of points on the route is greater than one or equal to one; the order size is equal to the order amount for all trading points which are serviced, taking into account the actual number of points on the route; the sum of all arrival points on all routes equals the number of trading points in the service area, and the maximum carrying capacity of the car/vehicle is 10 tons.

The service radius actually represents the area of the city around the trading points, which "attracts" buyers, thus characterizing the density of the retail network. The structure of the trading network is complicated by the presence of its trading points in different formats, which leads to a significant change in the behavior of buyers, and this can lead to significant errors in determining the parameters of the cargo delivery process. The value that characterizes the ratio of buyers to the outlets of different formats is the radius of half of the demand, which represents the radius of customer service, at which the market share of the trading network is 50% of the market capacity. In an analytical form, the radius of half-demand can be described as follows [9]:

$$r_n = (Ц_{cp} \cdot R_{cp})/(Ц_{гр} + Ц_i) \tag{2}$$

where $Ц_{cp}$ - is the cost of the average check on the market, UAH;
R_{cp} - average radius of service for each trade point, km^2;
$Ц_{гр}$ - marginal purchase price, UAH;
$Ц_i$ - the cost of the average check of a specific trading point, UAH.

The average distance of the delivery of consumer goods (l_i, km) is a separate characteristic of each particular object in the network, because it depends on their mutual location and varies within the area of one settlement. Analytically, this can be represented as follows [10]

$$l_i = 2R_{cp}/3 \tag{3}$$

where R_{cp} – the average radius of the service area, km;

$$R_{cp} = \sqrt{\lambda^{-1}/\pi} \tag{4}$$

where λ - trade network density, unit/km^2;

The average mileage of cars between adjacent points of arrival on the route ($l_{(i-1)-i}$, km) directly depends on the density of the location points in the area of service, which can be represented as follows

$$l_{(i-1)-i} = 0,76\sqrt{\lambda^{-1}} \ . \tag{5}$$

As a result of the decomposition of the target function, the following mathematical model of the share of transportation costs is obtained:

$$\delta = \frac{\left(A_{зм} + B_{зм} \cdot q_н\right) \cdot \left[\dfrac{4 \cdot \sqrt{\dfrac{1}{\lambda}}}{3 \cdot \sqrt{\pi}} + 0,76 \cdot \sqrt{\dfrac{1}{\lambda}} \cdot \left(n_з - 1\right)\right] + \left(A_{пост} + B_{пост} \cdot q_н\right) \cdot \left[2 \cdot t_д + t_д\left(n_з - 1\right) + \dfrac{\dfrac{4 \cdot \sqrt{\dfrac{1}{\lambda}}}{3 \cdot \sqrt{\pi}} + 0,76 \cdot \sqrt{\dfrac{1}{\lambda}} \cdot \left(n_з - 1\right)}{V_T} + 2 \cdot q_н \cdot \gamma_{cm} \cdot \tau_{нр}\right]}{n_з \cdot \left(\dfrac{T_M \cdot r_П}{r_П + \dfrac{\sqrt{\dfrac{1}{\lambda}}}{\sqrt{\pi}}} + 1\right)} \tag{6}$$

where $A_{зм}$, $A_{пост}$, $B_{зм}$, $B_{пост}$ - are the coefficients of the regression model of the cost of road transport depending on the cargo capacity of UAH/km, UAH/h, UAH/tkm, UAH/tkm*h.
$q_н$ - nominal load-carrying capacity, t;
λ - trade network density, unit/km^2;

$n_з$ - number of points on the route, units;
$t_д$ - additional time for documents processing, h.;
V_m - technical speed of the car, km/h.;
γ_{cm} - static coefficient of use of cargo;
$\tau_{нр}$ - normalized time spent on the loading or unloading of cargo, h/t;
$T_м$ - the cost of commodity circulation of consumer goods in the region, UAH/t;
r_n - half-demand radius.

The cost of an average check on the market is a random value, as determined by the behavior of individual buyers. Its condition determines the way its distribution law is established, according to statistical data. This study is described in the paper [11]. As a result, it was found that the variation of values can be described by the Rayleigh distribution law, which was taken into account in experimental studies.

With a large number of factors in the model and the need to obtain an accurate result, a full-factor experiment is needed. This is an experiment that uses all possible combinations of factors at different levels.

On the basis of the obtained mathematical model, the following factors are selected, which are variables: trade network density (λ, unit/km^2), the share of turnover in the network ($\delta_м$, %), the cost of commodity circulation of consumer goods in the region ($T_м$, UAH/t), the cost of an average check on the market ($Ц_{cp}$, UAH), average radius of service in the region (R_{cp}, km), and the static coefficient of the use of cargo (γ_{cm}).

The constant factors of the system include all other factors: technical speed of the car (V_m,km/h), normalized time spent on the loading or unloading of cargo ($\tau_{нр}$, h/t), additional time for documents processing ($t_д$, h), the coefficients of regression models of the cost of road transport depending on the cargo capacity ($A_{зм}$, UAH/km, A_{nocm}, UAH/h, $B_{зм}$, UAH/tkm, B_{nocm}, UAH/ tkm*h).

An analysis of the influence of the number of points on the route and the half-demand for the share of logistics transportation costs in the retail chain indicates the nonlinear nature of the dependencies. This indicates that there are such values of the specified optimization parameters that will minimize the share of transportation logistics costs. The plan of a full factor experiment of type 2k allows the variation of factors on two levels (minimal and maximal), which are determined through the ranges of variation of the selected variables, and therefore it is necessary to establish these limits, relying on statistical research data (Table 1). The number of experiments was $2^6 = 64$.

Table 1. Levels of variation of factors

Variation level	λ, unit/km^2	$\delta_м$, %	$T_м$, UAH/t	$Ц_{cp}$, UAH.	R_{cp}, km	γ_{cm}
	x_1	x_2	x_3	x_4	x_5	x_6
Maximal	25,398	0,8	15326,2	470	16,434	1
Minimal	1,948	0,01	10382,7	100	3,569	0,4

The obtained after the transformation of the mathematical model of the share of logistics transportation cost expression needs to be solved by means of a numerical method. The method of generalized reduced gradient found solutions for/of optimization parameters when minimizing the target function. The "Search Solution" add-in in the Microsoft Excel application suite provides the ability to implement this method. The regression coefficients are obtained using the least squares method [12]. To approximate the dependence, and taking into account the nature of the change of the share of logistics costs on transportation from the selected factors, exponential and power functions are used as the most common non-linear models of regression. Coefficients of regression models were obtained for these functions.

The system of empirical equations is obtained through the transformation of the obtained coefficients for guidance in the natural form for the number of points on the route and the radius of half-demand

$$\begin{cases} n_з = 7{,}13 \cdot 0{,}005^{\lambda} \cdot 0{,}99^{T_м} \cdot 0{,}263^{\delta_м} \cdot 1{,}045^{R_{ср}} \cdot 1{,}79^{\gamma_{ст}}; \\ r_n = 0{,}129 \cdot 0{,}834^{\lambda} \cdot 0{,}078^{\delta_м} \cdot 1{,}01^{Ц_{ср}} \cdot 0{,}97^{R_{ср}} \cdot 1{,}45^{\gamma_{ст}} \end{cases} \quad (7)$$

and for the share of logistics transportation cost

$$\delta = 0{,}0034 \cdot 1{,}087^{\lambda} \cdot 0{,}999^{T_м} \cdot 0{,}013^{\delta_м} \cdot 1{,}253^{R_{ср}} \cdot 0{,}61^{\gamma_{ст}} \quad (8)$$

The information ability of regression models, defined by Fisher's criterion F-criterion [13] for the number of points on the route is 28.95, which provides sufficient accuracy for the practical needs of determining the share of logistics transportation cost. The results of the verification showed that all regression models obtained at a significance level α = 0,05 are statistically significant (Table 2).

Table 2. Assessment of the suitability of the models obtained

Indicator	Number of points on the route n, unit	Radius of half demand, r_n, km.	Share of logistics transportation cost δ, %
F-criterion calculated	28,95	2,6	32,4
F-criterion tabular	2,26	2,26	2,26
Error models, %	6,63	7,6	12,9

The obtained results show that the models can be used to determine the optimal parameters of the logistic network of retail trade in order to minimize the share of costs for the transportation of products.

During the experiment, the dependencies between the factors and parameters of the logistics system were determined (Figures 2, 3 and 4). At the chosen interval of research, the nature of the influence of the factors on the share of logistics cost for transportation is monotonous (Fig. 2). The function of the share of logistics transportations cost is the most sensitive to changes in the factors, the density of trading points and the average service radius at their maximum values. The market share ($\delta_м$) factor has a significant impact on the share of transportation costs at its minimum values.

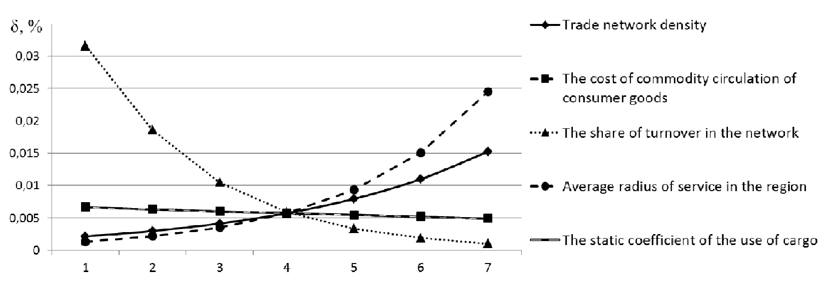

Fig. 2. Dependence of the share of transport costs from external factors

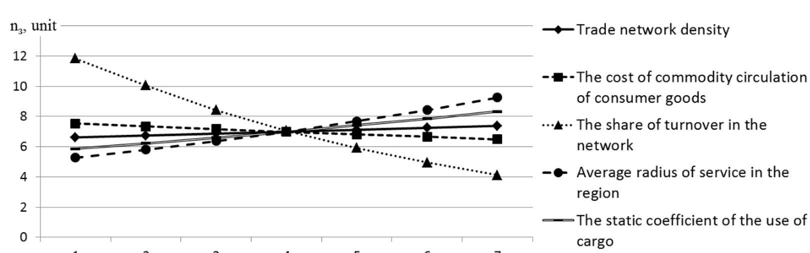

Fig. 3. Dependence of the half-demand radius on external factors

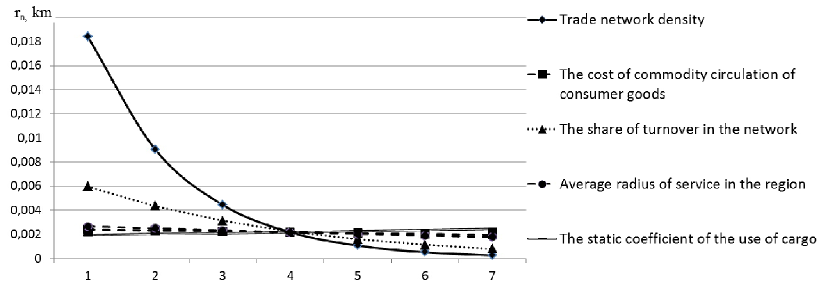

Fig. 4. Dependence of the number of points on the route on external factors

The analysis of the obtained dependencies shows that the indicator - the density of trading points - has a significant impact on the share of transport costs.

The obtained results testify that the models are suitable and provide sufficient accuracy of the parameters of the logistic system of the retail trade network for practical needs, namely the share of logistics transport costs, the number of points on the route and the radius of half-demand. These models will allow development of practical recommendations for the optimal area of the system operation and will make informational basis for prediction cargo flows on the city territory. As a performance measure, the minimum share of logistic costs for delivery was proposed. This will provide the opportunity to make a decision on the inclusion in the network of a new facility.

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