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COMPLEX EVALUATION OF THE EFFICIENCY OF URBAN CONSOLIDATION CENTERS AT THE MICRO LEVEL

Summary. A methodical approach for the determination of economic and socio-environmental costs in the application of the city consolidation center at the micro level was proposed and tested on real data. Two options of urban delivery of small shipments are considered, in particular, for e-commerce - direct delivery and delivery through the micro-consolidation center. The system of indicators proposed in this work allows a detailed assessment of the economic component of direct and consolidated delivery, including transportation costs, the functioning of

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the consolidation center costs and costs for pedestrian delivery to the residential district customers. Socio-economic indicators allow considering the interests of other residents of the city, suffering from a dense traffic flow and harmful emissions from freight vehicles. The proposed method of integrated assessment was tested on real data of a micro district of the city. The results made it possible to estimate the proportion of each component of expenditures in the economic, socio-environmental and total costs for both delivery options. The analysis of the sensitivity of costs to changes in the input parameters showed the difference in the strength of influence, and the rating of influencing factors. The proposed method allows us to estimate the economic costs of all participants in the urban delivery process for small shipments, as well as to prove the rationality of using micro-consolidation to serve a micro district of a large city.

Keywords: urban freight delivery, urban congestion, urban consolidation center, social and environmental parameters, economic efficiency

1. INTRODUCTION

Courier and express delivery services are among the fastest growing logistics businesses in cities [1]. This leads to more supply of small volume and weight. Urban consolidation initiatives focus on this market segment. Therefore, in conjunction with the growing sustainability issues that concern both municipalities and private actors, it is reasonable to assume that urban cargo consolidation is a relevant area of research [2].

The increase in congestion in urban areas has challenged the ability to achieve a high level of efficiency in urban logistics [3]: “Although the industry has made significant progress in improving productivity and vehicle use, urban congestion imposes severe restrictions on further improvements.”

Given the relevance of the topic for Ukraine, according to a study in 2020 [4] (Traffic Index-2020, 2020), Kyiv ranks 7th place in the world for traffic congestion in the city, and in 2019, the situation was better [5]. Namely, for the conditions of a large city with high traffic density, the concept of consolidation plays a vital role [6].

2. ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

Urban distribution of goods is defined as “transportation using a wheeled vehicle and the activities related to this transportation to or within an urban environment” [7]. For the authors, this definition is incomplete since it misses the possibility of on-foot delivery, which can be part of the urban distribution, especially on the last mile.

The main goal of urban consolidation centers is to reduce the need for freight vehicles to deliver goods to urban areas (city center, an entire city or a specific large object such as a shopping center) [8].

In article [9], the issue of the supply of goods in the context of sustainable transport was raised. The article aimed to identify the delivery of goods potential to entities located in the center city of Poznan (Poland). Based on the survey, the potential of goods distribution to defined groups of entities was estimated. It was estimated from the perspective for the use of solutions of sustainable goods distribution in the city center.

In [10], an attempt was made to understand the diversity of approaches to the classification of urban consolidation centers. A classification is proposed for makro-, mini- and micro-consolidation centers (MCC), which serve respectively, the entire urban territory, the district of the city and the micro district. The latter, the micro level, involves the night delivery of goods from the vehicle to the micro-CC (MCC) and on-foot delivery of goods to customers during the daytime.

Fu and Jenelius (2018) discussed the possibility of off-peak deliveries (during the absence of congestion in the urban road network) [11]. They note that, in general, this may increase the expenses of the recipients but at the same time reduce the cost of carrier services, as well as the environment. However, overnight delivery may increase inconvenience to residents due to the increased noise pollution in the night delivery area.

Work [12] assesses the impact of freight traffic on the quality of life of urban residents. About 75% of respondents believe that freight traffic in the city causes noise pollution and congestion on the roads. A slightly smaller percentage of respondents (65.6%) think that freight transport is harmful to the environment (CO_2 emissions), and almost 60% opined that it is dangerous (road accidents).

Furthermore, Janjevic and Ndiaye (2014) confirmed that the indicators that are crucial for the implementation of consolidation projects in the urban distribution plan include the level of congestion on the roads, the level of parking on the street and the presence of streets or areas of the city with limited (or prohibited) freight traffic [2].

The term “micro-consolidation” was introduced in [8] to refer to a small regional center of consolidation in central London, which was subsequently adopted in [13].

An example of the use of micro-consolidation was described in [8], while the size of the center was small (approximately 20 by 8 meters), which predetermined its relationship to the micro level. Janjevic and Ndiaye (2014) emphasized that the consolidation of urban cargo transportation may not be carried out beyond the line (or near the line) of the city [2]. The experience of transferring the center of consolidation as close as possible to the recipients was suggested to be called micro-consolidation. Janjevic and Ndiaye also highlighted some common characteristics of “micro-consolidation” [2]. First, micro-consolidation initiatives are aimed at reducing the total number of vehicle trips made in urban areas (especially in densely built areas with increased traffic density) by combining goods near the receiving point or at the receiving point itself. In particular, it helps to reduce the costs of road accidents, which are significant for Kyiv, according to the study [14]. Second, these initiatives include the creation of logistics (that is, additional transit points) in the center of urban areas. Third, micro-consolidation initiatives are directed at delivering small and light goods (parcels), which we can group under the common name “urban light load”, as defined in [15]. The fourth general characteristic is that micro-consolidation initiatives use environmentally friendly vehicles or “soft” modes of transport (for example, on-foot delivery, cargo bikes) for the last stage of the delivery [13, 16]. Finally, micro-consolidation initiatives are generally privately owned and operated by specialized transport companies.

An example of a micro-consolidation platform could be the BentoBox system, in which packages are delivered to modular cabinets near the client's location. The client uses it as a temporary warehouse, taking the goods if necessary. Here the customer takes care of the delivery of the goods on the last mile. Tests using this technology are being evaluated in various European cities [17-20]. Also, author [21], conceptualized such “urban logistics sites” to assess applicability in Belo Horizonte, Brazil, while authors [22] showed successful complex experiments in Singapore and Beijing.

The use of joint delivery systems (JDS) described in detail in [23], is also applicable to micro-consolidation technology. Freight carriers are involved in JDS who work together to deliver and/or collect goods for and from customers using urban consolidation centers (UCC) to minimize logistics costs and social and environmental impacts. The goal of UCC is to increase the efficiency of distribution of urban goods by consolidating goods carriers, as well as reduce the negative impact on the environment, reduce congestion, and improve road safety in urban areas. UCC has been introduced in Japan, the Netherlands, Great Britain, France, and Ukraine [24-27]. Private companies with some support from municipalities operate UCC as it helps solve the social problems of the city. On the other hand, common problems with UCC include:

- loss of confidentiality of customer information,
- less flexible delivery time,
- the complexity of the transfer of responsibility for the goods, the risk of damage to the goods,
- additional costs for consolidation centers,
- the need to unify the information and management systems of all UCC participants [23].

The work [29] proposes a model based on a set of indicators that allow assessing the efficiency and effectiveness of a UCC in terms of costs, time, quality, productivity, and environmental sustainability.

Thus, the analysis of literary sources in the field of urban distribution of small shipments made it possible to identify some aspects that require further research, including applicability to large cities in Ukraine.

3. PURPOSE AND OBJECTIVES OF STUDY

This article aims to create and analyze technology for calculating the economic and socio-ecological parameters of the functioning of an urban micro-consolidation system, as well as its comparison with direct cargo delivery technology.

To achieve this goal, the following research tasks were set:

1. Determine a set of basic data affecting the economic and socio-environmental performance of direct and consolidated delivery of small shipments, considering the different density of traffic flow during the day.
2. Develop a method for integrated assessment of the effectiveness of the use of urban consolidation centers at the micro level in combination with off-peak deliveries.
3. Testing of the above method with the analysis of the sensitivity of the final performance indicators when the main influencing factors change; building a rating of influencing factors for direct and consolidated delivery technologies.

4. MATERIALS AND METHODS

4.1. The system of initial parameters affecting the economic and socio-environmental performance of direct and consolidated delivery of small shipments in the city

The urban logistics literature often traces the interest of citizens in government measures to solve the problems of urban cargo delivery to ensure the sustainability and viability of the urban environment [30-33]. However, in Ukraine, the level of concern of state structures for the health and social well-being of citizens is far from that of the developed countries, including the EU. Economic factors determine almost all spheres of life of the population, with the legislative framework contributing to this. Having studied the experience of EU countries and the United States to improve the efficiency of urban freight transport, we consider it necessary to include socio-environmental aspects in the formation of management initiatives for large cities.

In particular, work [34] described and evaluated the negative effect of freight traffic in the city (moreover, it is fundamentally the same for both freight and passenger traffic). Thus, it was proposed to consider three categories of the social and environmental consequences of urban distribution:

1. Economic losses. The main and, perhaps, the largest share of the losses associated with congestion on the roads. The study conducted in India estimated the annual cost of delays in the Indian economy to be 5.5 billion US dollars, which predetermines additional fuel consumption of 12 billion US dollars per year [35].
2. Social losses. Harm to public health, injuries and death from traffic accidents, noise pollution and vibrations, and other quality of life problems, including the loss of open spaces in urban areas due to the development of transport infrastructure.
3. Ecological losses. Atmospheric pollution by exhaust gases, dependence on non-renewable fossil fuels, distribution of automobile waste, such as waste of fuel, oils, and tires.

As seen, economic costs are probably not the only main indicator that should be considered when planning supply chains in urban environments.

To group the source data that should be collected for a comprehensive assessment of various options for urban distribution, we present a review of the distribution system through nodes and delivery processes.

Consider the scheme of urban delivery of goods in two scenarios:

1. Using MCC.
2. Without the use of MCC (direct delivery) (Figure 1).

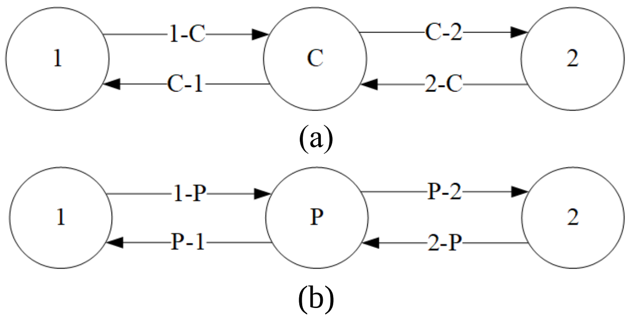


Fig. 1. Participants in the city delivery process: (a) with a consolidation center; (b) without a consolidation center (direct delivery)

As observed, the nodes of logistics processes can be:

“1” is the consignor of the cargo, from where the vehicle begins to move;

“2” - customers, clients;

“C” - MCC;

“P” is the place of parking the vehicle on delivery without MCC.

Between nodes such streaming processes are possible:

"1-C" - from the sender to the MCC (forward flow through the vehicle);

"C-1" - from MCC to the sender (reverse flow of returns, carried out by the vehicle);

"C-2" - from the MCC to the customer (direct flow, carried out on foot by the MCC courier);

"2-C" - from the client to the MCC (reverse flow of returns, carried out on foot delivery by the MCC courier or the return of the MCC courier without cargo);

"1-P" - from the sender to the vehicle parking space (direct flow carried out by the vehicle without MCC);

“P-1” - from the vehicle’s parking place to the sender (return flow of returns, carried out by the vehicle without MCC or the movement of an empty vehicle);

“P-2” - from the vehicle’s parking place to the customer (direct flow carried out on foot by the vehicle’s courier);

"2-P" - from the client to the vehicle parking area (reverse flow of returns, carried out on foot delivery by the vehicle courier or return courier without cargo).

The selection of the necessary parameters to evaluate the performance of the micro-consolidation system was preceded by an analysis of the research on the numerical estimates of various consolidation projects. Thus, in [36], the calculation of the necessary technical means and human resources for the functioning of a five-year project for the delivery of goods to a certain region of China through UCC is given. It is necessary to note the detailed description of the technology; however, its low applicability in the case of micro-consolidation.

Paper [37] proposes a mathematical model for building an optimal delivery system with the possibility of consolidation (the cross-docking technology was used). A special feature is the inclusion of both consolidated and direct shipments in the model. The objective function minimizes the total costs associated with direct deliveries and deliveries through UCC.

Work [38] is devoted to modeling the OD matrix, calculating the probability of using a particular route in urban distribution. The result of the model is to obtain the number of vehicles that deliver in a specific area of the city.

Thus, the main number of proposed numerical solutions relates to optimization models, which allow determining the best set of variables leading the objective function (model costs) to its minimum value. Since the purpose of this article is not to build a KC network, optimization models are not required here. Considered therein is one MCC and the flows of transport and cargo included in it, as well as the flow of goods and couriers that deliver goods to final consumers. The fact that the optimization models are taken as constraints in this model as the initial data allows calculating the performance of the two options for the system - direct and consolidated.

For the required level of detail, the use of 50 input parameters is proposed, with the help of which one can estimate the total costs and losses of both options for their comparison and analysis.

The total costs of urban distribution are divided into economic and socio-environmental costs (Table 1).

According to the Handbook on External Costs of Transport [39], all socio-economic costs considered in EU countries depend on the distance traveled; they can be calculated only on streaming processes.

Table 2 calculates the total cost of the proposed use of the initial parameters.

Limitations and assumptions:

1. About delivery from the MCC to the customer.

For Ukraine, where climatic conditions are rather irregular (Savchenko et al., 2021), with cold and snowy winter; however, the choice of the mode of transport for urban delivery of goods to residential districts is limited to road transport. The best practices of consolidation in

European cities (for example, [8, 10-12, 40-42], which have successfully proved themselves to be an economical and environmentally friendly solution, often use the transition to cycle transport for delivery from the CC to the client. However, in Ukraine, bicycle transport for delivery to the end user in the city can be used for only a part of the year, although presently, no infrastructure allows using bicycle transport as a means of express delivery to the full.

Since micro-consolidation belongs to the lowest level of consolidation in the city, and cycle transport is not available due to climatic and infrastructure features, it is proposed to limit the territory of micro-consolidation within a radius of 0.5 km from the MCC, allowing for pedestrian delivery from the MCC to the end user.

Tab. 1

Cost components for urban distribution

Economic costs	**Social and environmental costs**
On flowing processes	
"1-C-1", "1-P-1" - fuel and other operational materials, drivers' salaries, vehicle depreciation; "C-2-C" - wages of the staff of the day shift of the MCC; "P-2-P" - the salary of the driver of the vehicle (combining the courier function), depreciation of the vehicle	"1-C-1", "1-P-1" - costs from traffic congestion, costs from noise, losses from climate change, infrastructure costs, and losses from air pollution
In process nodes	
"1" - sending a vehicle on the route; "C" - rental of premises, salary of staff at night shift of MCC, additional costs; "2", "P" - costs are not considered	–

Tab. 2

System parameters required for calculating the economic and socio-environmental costs of direct and consolidated delivery options

Economic costs		**Social and environmental costs**
In process nodes	*On flowing processes*	
The average number of deliveries to the neighborhood per day (for day shifts and night shifts), post/day - N		
The cost of service in the MCC (the rate paid by the organizer of the MCC delivery for each customer serviced through the center), UAH/client - c_{ucc}		
Number of working days per month, days - N_d		
Number of customers, on average, served from one automotive supply, orders - c_1		
The number of orders in 1 car dispatch, orders - c_{1auto}		
	Average distance between customers, km - $l_{cc}^{1-C(P)-1}$ The average distance of zero runs, km - $l_0^{1-C(P)-1}$	

«1» The cost of sending the vehicle on the route from the sender, UAH/route: - in the afternoon - c_{preld} - at night - c_{preln}	*«1-C-1», «1-P-1»* Book value of 1 vehicle, UAH - A Calculation term of depreciation, years - t Driver salary (constant component), UAH - c_{drc} Correction factor for average speed - k_{vi} Correction factor for average fuel consumption - k_{fi} Fuel cost, UAH/l - c_f Average vehicle speed in the city, km/h - V_{auto} The ratio allowing the cost of fuel to convert to other costs of movement - k_{auto} Average fuel consumption, l/100 km - f Average distance between customers, km - $l_{cc}^{1-C(P)-1}$ The average distance of zero runs, km - $l_0^{1-C(P)-1}$ The average time to prepare for the route for the delivery of goods, h - $t_{prep}^{1-C(P)-1}$ Additional costs for return of goods,% - K_{rev} Additional costs for repeated deliveries,% - K_{abs}	*«1-C-1», «1-P-1»* Rate, UAH/Euro - S The load capacity of the vehicle - 3.5 tons. EURO-4 class. Fuel type - diesel
«C» The cost of renting space for the MCC: - constant, UAH/month - r_c - variable, UAH/order - r_v Additional costs for MCC (from the fixed cost of rent),% - r_{ad} Number of shifts MCC: - daytime n_d - night n_n Shift time, hours: - daytime T_d - night T_n The average time required for taking 1	*«C-2-C»* Average order weight for a client, kg/order - q_0 Maximum weight of consolidated courier delivery from MCC to customers, kg - q Cost of order skid to customer, UAH order - c Average courier delivery speed (on foot), km h - V_c Average time spent per client, hour/order - t_{1c} Average distance between customers, km - l_{cc}^{C-2-C} The average distance of zero runs, km - l_0^{C-2-C}	

order from the vehicle, hour/order - t_{unl}	The average time to prepare for the route for the delivery of goods, h - t_{prep}^{C-2-C}	
«2», «P» - costs are not considered	*«P-2-P»* Average distance between customers, km - l_{cc}^{P-2-P} The average distance of zero runs, km - l_0^{P-2-P} The average time to prepare for the route for the delivery of goods, h - t_{prep}^{P-2-P}	

2. About the boundary distance and the weight of delivery from the MCC to the client.

Given the conditions of micro-consolidation, it is supposed to go on foot with a load up to 0.5 km, it is necessary to limit the volume and weight of the cargo, which one courier can carry away at a time:
- cargo 20-30 kg with a walking distance of no more than 0.1 km from the MCC;
- cargo 10-20 kg with a walking distance of no more than 0.25 km from the MCC;
- cargoes up to 10 kg are limited only by the total delivery radius of 0.5 km.

Thus, in the preliminary analysis of cargo for the possibility of service through the MCC, the ratio of the weight of the cargo and the distance of delivery from the MCC to the client should be estimated. Those goods that violate the limitations set out above should be excluded from the scheme using the MCC and delivered directly without micro-consolidation.

3. On the exclusion of urgent shipments.

This concerns the evaluation of the incoming flow serving the neighborhood. Here, it is necessary to observe and survey business structures operating in the micro district. Deliveries requiring immediate delivery, “day to day”, should be excluded from the micro-consolidation scheme. An analysis of literary sources made it possible to determine that about 50% of supplies in the city are urgent ("day to day"). The remaining 50% can be delivered the next day, and even in a few days. Accordingly, about half of the deliveries to the micro district service can be removed from the micro-consolidation scheme.

4. On the exclusion of certain groups of goods.

It is obvious that completely different types of goods arrive in the micro-consolidation area. Probably, some of them involve special handling and/or special conditions of storage and delivery to the customer. Such goods should be excluded from the micro-consolidation scheme, giving them a direct delivery option to the client.

5. On the use of averages.

Due to the ubiquity of using the delivery to the place of work, study and residence, we can assume a significant variation in the companies delivering goods to the micro-consolidation zone. The scatter of the weight parameters of the cargo, the location of the sender, the parameters of the vehicles delivering and other characteristics accompanying the city distribution are impressive. In addition, this variation is not constant and is fixed at least for some time. Exact calculation of all delivery terms from each company, processing the corresponding data file and obtaining calculation results is time-consuming, and after this process is over, it is likely to get a different picture of the incoming flow. From this point of view, a one-to-one study of each of the existing deliveries should be considered ineffective, which predetermines the use of averages.

4.2. Methods of comprehensive assessment of the effectiveness of the use of urban consolidation centers at the micro level in combination with off-peak supply

Considers the proposed technology for calculating the economic costs in the nodes and flows of the process of delivery of goods to final recipients in a geographically limited micro district of the city.

1. Economic costs without using the MCC (direct delivery)

1.1. Costs in node "1".

According to the initial information, the system considers the costs of releasing the vehicle for the distribution route, and the amount of such costs depends on the time of day when the route begins. Because delivery without MCC involves day delivery, $C_j^1 = C_1^1 = c_{prel1}$, where j is the index of time of day (1 - day delivery, 2 - night delivery).

1.2. Operating costs on the flow process "1-R-1".

To understand the conditions of the movements, data on the traffic flow by time of day is needed, namely, the speed and density of the vehicle movement [43].

Fuel consumption for automobile delivery in the city is directly dependent on the speed of movement, which, in turn, is related to the density of urban traffic.

For example, in work [44], typical dynamics of urban traffic speed are shown, showing a significant decrease in speed in the morning and evening rush hours, the highest values at night, and obstructed movement during the day (Figure 2).

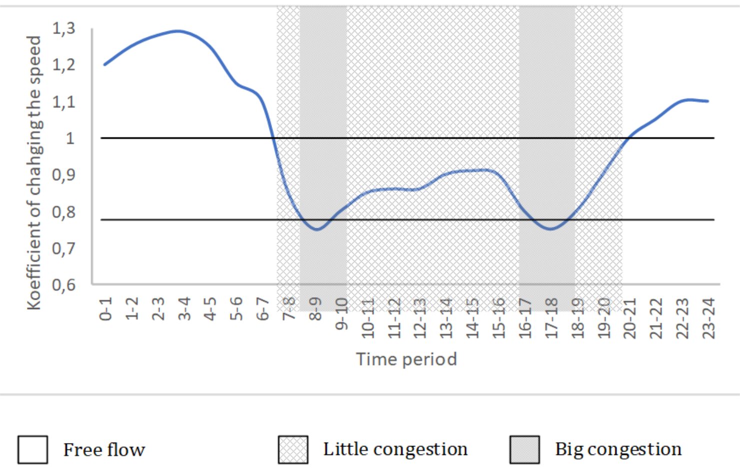


Fig. 2. Coefficients of change in the speed of movement depending on the time of day
Source: completed based on [43]

These estimates were used in this work when assigning coefficients that correct the speed of movement and fuel consumption at different times of the day - for free, difficult movement and movement under congestion conditions (k_{vi} and k_{fi}).

The cost of fuel on the route can be obtained based on the length of the route ("1-C (P) -1") and fuel consumption per 100 km (considering the corresponding correction factor).

For the calculation of the full operating costs on the route (maintenance and repair, lubricants, tires), it was proposed to introduce a factor that allows the cost of fuel to be converted into the overall operating costs of the process. Total process operational costs:

$$C_{ei}^{1-P(C)-1} = \frac{fc_f k_{fi} k_{auto}}{100}\left(2l_0^{1-P(C)-1} + l_{cc}^{1-P(C)-1}\left(\frac{c_{1auto}}{c_1} - 1\right)\right). \tag{1}$$

Index i can take three values: 1 - free movement, 2 - obstructed movement, 3 - movement in the mash.

1.3. Depreciation charges on stream processes “1-P-1” and “P-2-P”.

Depreciation charges are calculated according to a simple scheme for t years of operation of the vehicle. It is considered that in the direct delivery scheme, the vehicle is operated 12 hours of daytime, while delivery through the MCC implies both night delivery to the MCC and daytime delivery to customers that cannot be served through the MCC.

To obtain the value of depreciation for the period of the process, we define the time of the processes as "1-P-1" and "P-2-P".

The process time "1-P-1". The time of the automobile delivery site consists of the following parts:
- preparation time for the route;
- travel time from the sender to the first client;
- time to return from the last client to the sender or to base (we assume that this time is equal to the time from the sender to the first client);
- travel time between customers.

Since the travel time depends on the level of congestion, it is calculated for cases of free movement, obstructed movement and movement in the mash, for which index i is responsible.

The process time "P-2-P". The time spent on the client skidding an order in a micro district consists of the following parts:
- preparation time for the route;
- time to move from the vehicle to the client;
- time spent with customers;
- time of passage between customers;
- time to return from the client to the vehicle (we assume that this time is equal to the time of transition from the vehicle to the client).

Amortization value for the processes “1-P-1” and “P-2-P”, UAH/route:

$$C_{ai}^{1-P-2} = \frac{A}{12 \cdot 12 \cdot N_d \cdot t}\left(\begin{array}{l} t_{prep}^{1-P-1} + \dfrac{2l_0^{1-P-1} + l_{cc}^{1-P-1}\left(\dfrac{c_{1auto}}{c_1} - 1\right)}{V_{auto} k_{vi}} + \\ + \dfrac{c_{1auto}}{c_1}\left(t_{prep}^{P-2-P} + t_{1c} c_1 + \dfrac{2l_0^{P-2-P} + l_{cc}^{P-2-P}(c_1 - 1)}{V_c}\right) \end{array}\right). \tag{2}$$

1.4. The cost of driver wages in the processes "1-P-1" and "P-2-P".

Since the driver also combines the function of a courier, it is proposed to split his salary into constant and variable components. The constant component is fixed as a monthly payment, while the variable is calculated depending on the number of orders delivered.

Driver salary on the processes "1-P-1" and "P-2-P", UAH/route:

$$C_{dri}^{1-P-2} = \frac{c_{drc}}{N_d \cdot 8}\left(\begin{array}{l} t_{prep}^{1-P-1} + \dfrac{2l_0^{1-P-1} + l_{cc}^{1-P-1}\left(\dfrac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{vi}} + \\ + \dfrac{c_{1auto}}{c_1}\left(t_{prep}^{P-2-P} + t_{1c}c_1 + \dfrac{2l_0^{P-2-P} + l_{cc}^{P-2-P}(c_1 - 1)}{V_c} \right) \end{array} \right) + c_{1auto}c \,. \quad (3)$$

2. Economic costs when using the MCC (consolidated delivery)

2.1. Costs in node "1".

Delivery through the MCC implies night delivery of TC goods to the MCC, thus, the corresponding “night” parameter is used: $C_2^1 = c_{prel2}$.

2.2. Operating costs for streaming process "1-C-1".

The calculation formula coincides with that used for the “1-P-1” process; however, in the case of using the MCC, only the night-time costs are taken, that is, with free movement (which corresponds to the coefficient i = 1):

$$C_{e1}^{1-P(C)-1} = \frac{fc_f k_{f1} k_{auto}}{100}\left(2l_0^{1-P(C)-1} + l_{cc}^{1-P(C)-1}\left(\frac{c_{1auto}}{c_1} - 1 \right) \right). \quad (4)$$

2.3. Unit costs for wages of MCC employees

MCC employees perform different functions depending on the time of day: at night, goods are received from the vehicle and are prepared for daytime delivery; In the afternoon, goods are delivered to the MCC clients.

The duration of night shifts (5 hours) allows one to keep the wage of a night shift worker at the 8-hour day level. Thus, the requirement of increased salary at night will be met by reducing the time of the night shift.

Consider the parameters of the daily delivery of goods (process "C-2-C").

The process time is "C-2-C". The standard courier route for skidding goods from the ICT to clients consists of:

- preparation time for the route;
- the time of income to the first client on the route;
- time spent with customers;
- passage time between customers;
- the time of income from the last client on the route to the MCC (we assume that this time is equal to the time of income from the MCC to the first client).

Based on the time for one route, one can calculate the number of routes that one courier can carry out (accordingly, how many clients can be served) during a work shift:

$$N_{KD} = \frac{1,2N}{n_m n_c T_d}\left(t_{prep}^{C-2-C} + n_c t_{1c} + \frac{2l_0^{C-2-C} + l_c^{C-2-C}(n_c - 1)}{V_c} \right). \quad (5)$$

A factor of 1.2 is involved to compensate for sick leave (Repetition).

To calculate the required number of night shift workers to receive shipments from the vehicle:

$$N_{KN} = 1,2\frac{t_{unl}c_1N}{T_n}. \tag{6}$$

It should be noted that the estimated number of workers required to work on the night shift will be less than the day shift. This is due to the short time spent by the inspector of night orders for one order, unlike the courier, who delivers them by day. At the same time, the number of orders taken at night and delivered during the day from the MCC is the same. Thus, night receivers have time to form routes and prepare sets of orders for each route for the day shift.

In the model, an assumption is proposed, according to which an employee of any shift can rework his shift within 10% of its duration, thus avoiding the courier idle situation:

$$N_{Kj}^{*} = \begin{Bmatrix} CELL\left[N_{Kj}\right] - N_{Kj} \le 0,1; N_{Kj} \\ CELL\left[N_{Kj}\right] - N_{Kj} > 0,1; N_{Kj}+1 \end{Bmatrix}. \tag{7}$$

In the equation, the CELL designation means rounding the value to the whole up. Index j is responsible for the shift.

Specific salary of MCC employees for one route, equivalent to automobile, UAH/route:

$$C_c^{C-2-C} = \frac{2cc_{1auto}}{c_1}. \tag{8}$$

2.4. Depreciation deductions on the flow process "1-C-1"

The difference from the direct delivery option is the lack of depreciation charges for pedestrian goods delivery to the consumer, given the case of consolidated delivery, this function leaves the vehicle driver. However, in this case, the time of unloading goods in the MCC is added.

The process time "1-C-1" consists of two parts:

1) travel time on the route. In this case, the MCC accepts orders only at night; therefore, it is required to calculate the value only for the night time of day (free movement in the stream);
2) time to transfer the order to the MCC. To account for possible idle TS in the queue in anticipation of the transfer of goods, we propose to split the time required to transfer the order for the MCC into two parts:

- constant (50% of tunl);
- variable depending on the time spent in the queue at the MCC.

The variable component, depending on the magnitude of the queue at the MCC, can be calculated using the queuing theory. Depending on the estimated number of people simultaneously accepting orders for MCC at night, one should use the queuing theory for an open system with an unlimited queue for one or several service channels.

The incoming stream is the vehicle stream bringing orders for the MCC.

According to the well-known calculation method, the following input parameters are needed:

- the average number of incoming applications λ. For our task, this is the number of vehicles arriving at the MCC to transfer orders per hour. The calculation will be made for the average working hours of the MCC on the night shift.

- the average time of service application. It is equal to 50% of the total transfer time of the order at the MCC (Table 3).

Tab. 3

Calculation formulas for single-channel and multi-channel open queuing systems without queue limit

Parameter of queuing system	Single-channel queuing system	Multi-channel queuing system
Intensity of service flow	$\mu = 1/(0{,}5t_{unl})$	
Reduced injection rate	$\rho = \frac{\lambda}{\mu}$	
Probability of states	$P_0 = 1 - \rho$, $P_1 = \rho P_0$, …, $P_k = \rho^k P_0$, …	$P_0 = \left[1 + \frac{\rho}{1!} + \frac{\rho^2}{2!} + ... + \frac{\rho^n}{n!} + \frac{\rho^{n+1}}{n!(n-\rho)}\right]^{-1}$, $P_1 = \rho P_0$, $P_i(i \le n) = \frac{\rho^i}{i!} \cdot P_0$, …, $P_{n+k} = \frac{\rho^{n+k}}{n^k \cdot n!} \cdot P_0$, …
Average number of applications in the queue	$r = \frac{\rho^2}{1-\rho}$	$r = \frac{\rho^{n+1}}{n \cdot n!} \cdot \frac{P_0}{\left(1 - \frac{\rho}{n}\right)^2}$
Average waiting time	$t_r = \frac{r}{\lambda}$	

After calculating the parameters of Table 3, the time of transfer orders for MCC is defined as:

$$t_{unl}^{1-C-1} = t_{unl} + t_r \, . \tag{9}$$

Amount of depreciation for the time on the route, UAH/route:

$$C_a^{1-C-1} = \frac{A}{12 \cdot 12 \cdot N_d \cdot t}\left(t_{prep}^{1-C-1} + \frac{2l_0^{1-C-1} + l_{cc}^{1-C-1}\left(\frac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{v1}} + t_{unl} + t_r \right). \tag{10}$$

2.5. Wage costs for the driver in the process "1-C-1" and in the node "C"

In the night delivery, the cost of skidding is not considered, since interaction with the client does not occur directly. However, as in the depreciation deductions, one should consider the time of unloading in the MCC:

$$C_{dr1}^{1-C-1} = \frac{c_{drc}}{N_d \cdot 8}\left(t_{prep}^{1-C-1} + \frac{2l_0^{1-C-1} + l_{cc}^{1-C-1}\left(\frac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{v1}} + t_{unl} + t_r \right). \tag{11}$$

2.6. Unit cost of renting the MCC

The cost of renting the premises of the MCC is proposed to have fixed and variable components. Variable costs reflect the amount of cargo that will link the cost of rent with the number of shipments.

Unit cost of renting MCC, UAH/route:

$$C_R^C = \frac{1{,}1c_{1auto}\left(r_c + r_v c_1 N N_d\right)}{c_1 N N_d}. \tag{12}$$

Tab. 4

Economic costs of direct and consolidated delivery (UAH/route)

Direct Delivery	Via MCC
Costs in node "1"	
$C_1^1 = c_{prel1}$	$C_2^1 = c_{prel2}$
Operating costs at flow 1-P-1	Operating costs at flow 1-C-1
$C_{ei}^{1-P(C)-1} = \frac{fc_f k_{fi} k_{auto}}{100}\left(2l_0^{1-P(C)-1} + l_{cc}^{1-P(C)-1}\left(\frac{c_{1auto}}{c_1} - 1\right)\right)$	$C_{e1}^{1-P(C)-1} = \frac{fc_f k_{f1} k_{auto}}{100}\left(2l_0^{1-P(C)-1} + l_{cc}^{1-P(C)-1}\left(\frac{c_{1auto}}{c_1} - 1\right)\right)$
Costs depreciation on flows "1-P-1" and "P-2-R"	Costs depreciation on the flow "1-C-1" and in node "C"
$C_{ai}^{1-P-2} = \frac{A}{12\cdot 12\cdot N_d \cdot t}\left(t_{prep}^{1-P-1} + \frac{2l_0^{1-P-1} + l_{cc}^{1-P-1}\left(\frac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{vi}} + \frac{c_{1auto}}{c_1}\left(t_{prep}^{P-2-P} + t_{1c}c_1 + \frac{2l_0^{P-2-P} + l_{cc}^{P-2-P}(c_1 - 1)}{V_c}\right)\right)$	$C_a^{1-C-1} = \frac{A}{12\cdot 12\cdot N_d \cdot t}\left(t_{prep}^{1-C-1} + \frac{2l_0^{1-C-1} + l_{cc}^{1-C-1}\left(\frac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{v1}} + t_{unl} + t_r\right)$
Wages to the driver on flows "1-P-1" and "P-2-P"	Wages to the driver on flow "1-C-1" and in node "C"
$C_{dri}^{1-P-2} = \frac{c_{drc}}{N_d \cdot 8}\left(t_{prep}^{1-P-1} + \frac{2l_0^{1-P-1} + l_{cc}^{1-P-1}\left(\frac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{vi}} + \frac{c_{1auto}}{c_1}\left(t_{prep}^{P-2-P} + t_{1c}c_1 + \frac{2l_0^{P-2-P} + l_{cc}^{P-2-P}(c_1 - 1)}{V_c}\right)\right) + c_{1auto}c$	$C_{dr1}^{1-C-1} = \frac{c_{drc}}{N_d \cdot 8}\left(t_{prep}^{1-C-1} + \frac{2l_0^{1-C-1} + l_{cc}^{1-C-1}\left(\frac{c_{1auto}}{c_1} - 1\right)}{V_{auto}k_{v1}} + t_{unl} + t_r\right)$
	The cost of renting the MCC (in node "C")
	$C_R^C = \frac{1{,}1c_{1auto}\left(r_c + r_v c_1 N N_d\right)}{c_1 N N_d}$
	Wages of MCC employees (in the node "C")
	$C_c^{C-2-C} = \frac{2cc_{1auto}}{c_1}$

In addition to the standard components of the economic costs of distribution schemes, we will consider the additional costs associated with: 1) the absence of the customer in place, which determines the re-delivery; 2) the flow of returns.

According to studies [45, 46], the scale of the problem of lack of customers at the place at the time of delivery is quite noticeable: the share of primary failure in home delivery is up to 25%. This implies re-delivery, which creates additional costs, both economic and socio-environmental.

One of the advantages of using the MCC is almost zero costs for such cases. In the case of pedestrian delivery, the absence of one client on the spot in the route is practically not indicated in the total costs of the MCC. In addition, minimum cost will be incurred in case of re-delivery.

Accordingly, additional costs from the absence of a client in place are added only to a model with a missing MCC using a coefficient of 1.1, which implies an increase in total costs by 10%.

Unlike the problem of lack of customers at the time of delivery, the cost of return (reverse flow) is present in both ways of delivering cargo to the customer (through or without the MCC). For calculations, we assume that the return flow increases the cost of each delivery scheme by 5%.

So, the total economic costs of distribution (Table 4):

- without MCC:

$$C_{i1}^{1-P-2} = 1{,}15\left(C_1^1 + C_{ei}^{1-P(C)-1} + C_{ai}^{1-P-2} + C_{dri}^{1-P-2}\right), \tag{13}$$

- with MCC:

$$C_{12}^{1-C-2} = 1{,}05\left(C_2^1 + C_{e1}^{1-P(C)-1} + C_a^{1-C-1} + C_{dr}^{1-C-1} + C_R^C + C_c^{C-2-C}\right). \tag{14}$$

Socio-environmental costs (for direct and consolidated delivery options).

Consider the technology adopted in the EU countries for the calculation of social and environmental costs and losses from freight transport by road [39]. Additional initial data for the calculation are given in the corresponding column of Table 1.

1. Losses from congestion.

Losses from urban congestion depend on:

- region (large city, town, rural area). According to the authors, transportation through the MCC may be appropriate for cities with a population of at least 500000 people since the problem of congestion is usually less significant for cities with a smaller number of inhabitants;
- type of vehicle (passenger car, heavy-duty truck, articulated truck);
- type of road (highway, main road, other roads);
- degree of congestion (free flow, obstructed traffic, congestion) [5].

2. Losses from air pollution.

One of the ways to calculate losses from urban air pollution is associated with:

- EURO class used vehicle;
- type of vehicle for payload and the type of fuel used;
- type of road (urban, suburban, rural, highway).

3. Losses from noise pollution.

The degree of influence of noise on the population depends on:

- time of day (night, day);
- density of traffic flow (dense, free). To estimate the noise losses for the intermediate, obstructed motion, we proposed to use the average value between the available values;
- type of vehicle;
- region (city, suburb, rural area).

4. Losses from climate change.

Losses from climate change can be determined in two ways:

- by type of vehicle fuel (in euro cents per liter of fuel);
- according to vehicle type, EURO class, type of fuel and type of road (in euro cents per km of run).

Since the second method is more complex, it is proposed to use it to calculate losses from climate change.

5. Infrastructure losses.

Infrastructure losses depend on the type of vehicle and the roads along which the movement takes place.

Based on the above, table values are chosen for all categories of social and environmental costs.

Since all social and environmental costs are calculated depending on the distance traveled, we have costs for streaming processes “1-C-1” and “1-P-1”.

Total economic, social and environmental costs of options.

The total costs of the considered schemes for the delivery of goods in urban areas can be obtained by summing up the economic and socio-environmental components, UAH/route:
- without MCC:

$$\begin{aligned} CE_{i1}^{1-P-2} &= 1{,}15\left(C_1^1 + C_{ei}^{1-P(C)-1} + C_{ai}^{1-P-2} + C_{dri}^{1-P-2}\right) + \\ &+ E_{congi} + E_{noisei1} + E_{cl} + E_{\inf r} + E_{air} \end{aligned}, \quad (15)$$

- with MCC:

$$\begin{aligned} CE_{12}^{1-C-2} &= 1{,}05\left(C_2^1 + C_{e1}^{1-P(C)-1} + C_a^{1-C-1} + C_{dr}^{1-C-1} + C^C + C_c^{C-2-C}\right) + \\ &+ E_{congi} + E_{air} + E_{noiseij} + E_{c\lim} + E_{\inf r} \end{aligned}. \quad (16)$$

4.3 Testing the method with a sensitivity analysis of the final indicators

Analysis of numerical results.

The proposed method of calculating the economic and socio-environmental costs of direct and consolidated delivery options was applied to the district of Kyiv.

The main input parameters are given in Tables 5 and 6.

Tab. 5

Basic input data

Parameter	Units	Value
The number of deliveries in the district per day	orders / day	50
Book value of the vehicle	UAH	650000
Calculation term of depreciation charges	years	5
Cost of order skidding to customer	UAH/client	20
Day shift time	hour	7
Night shift time	hour	5
The number of shifts MCC (day and night)	pc	2
The cost of sending the vehicle on the route during the day	UAH/route	150
The cost of sending the vehicle to the route at night	UAH/route	300
Average time spent per client	hour	0,15
Average time required for accepting 1 order for MCC	hour/order	0,11
Preparation for the process "1-C-1" ("1-P-1", "C-2-C")	hour	0,5
Preparation for the process "P-2-R"	hour	0,03

Zero mileage process "1-C-1" ("1-P-1")	km	4
Zero mileage process "P-2-R"	km	0,1
Zero mileage process "C-2-C"	km	0,25
The average distance between clients on the process "1-C-1" ("1-P-1")	km	2
The average distance between clients on the process "P-2-P" ("C-2-C")	km	0,1
Cost of service in the MCC	UAH/client	30
The cost of renting a room under MCC, constant part	UAH/month	10000
The cost of renting a room under the MCC, variable part	UAH/order	7
Number of orders in 1 shipment	orders	15
Average fuel consumption	l/100 km	10
Average vehicle speed in the city	km/h	40

Tab. 6

Table values of social and environmental costs

Type of social and environmental costs	Tabular value
Costs from congestion, euro cents/km	
- free movement	0,9
- little congestion	141,3
- movement in the mash	181,3
Costs from noise, euro per 1000 km	
Day traffic:	
- free movement	107
- difficulty moving	75
- movement in the mash	44
Night traffic:	
- free movement	80,3
- difficulty moving	138
- movement in the mash	194,7
Costs of climate change, euro cents/km	2,8
Infrastructure costs, euro cents per km	0,7
Cost of air pollution, euro cents/km	3,2

Source: Handbook on External Costs of Transport, 2014

Analyze the results of the calculations (Table 7).

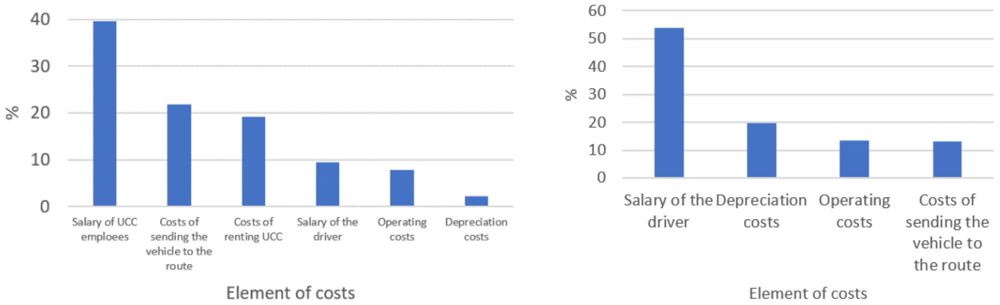
The results show that the monthly economic costs of shipping to the city's micro district are almost the same. Additional costs for MCCs arising in the consolidated delivery option are fully compensated by lower costs for streaming processes during off-peak hours (Figure 3).

For the socio-environmental costs, in the direct delivery option, the lion's share (92%) is the cost of congestion. Whereas, when delivered via the MCC, the cost of noise pollution is the most significant (59%), as the noise at night brings more discomfort to residents than during daytime (Figure 4).

Tab. 7

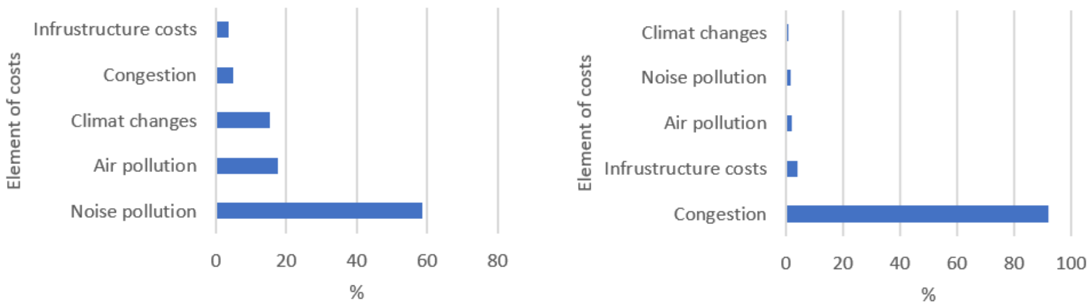
Cost of options (UAH/month)

Without MCC	With MCC
Economic costs	
109800	106300
Social and environmental costs	
224600	126100
Total costs	
334400	232400



(a) (b)

Fig. 3. Economic costs: (a) with MCC; (b) without MCC



(a) (b)

Fig. 4. Socio-environmental costs: (a) with MCC; (b) without MCC

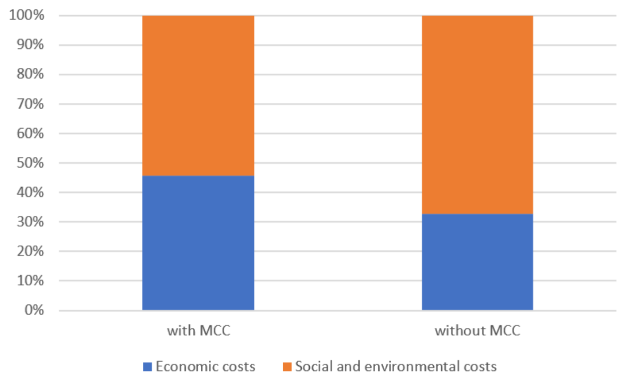


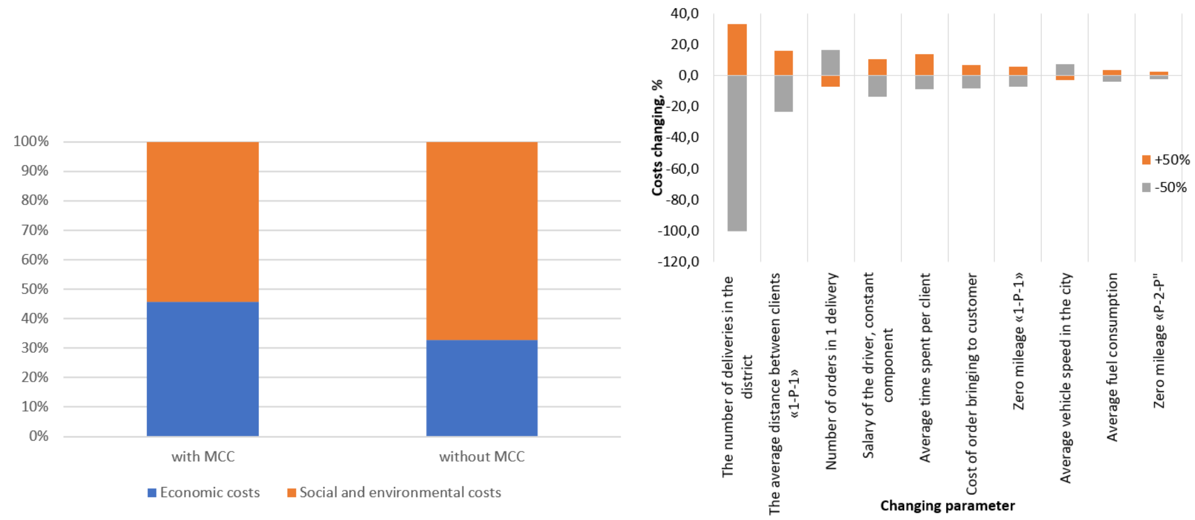
Fig. 5. Total costs of distribution

Analyzing the obtained results, it is possible to ascertain the significant socio-ecological damage from the daily distribution in the city (Figure 5). The proposed option of transferring the movement of freight transport from day to night will halve both social and environmental costs, leaving the economic costs at the same level.

Analysis of the sensitivity of performance when changing the affecting parameters

To assess the degree of susceptibility of both the economic and socio-environmental costs of consolidated and direct delivery in urban environments, the model was "run" with a change in some of the initial parameters by 50% in a smaller and larger direction to the baseline (initial).

The results obtained when changing the parameters are shown in Figure 6.



(a) (b)

Fig. 6. Rating of the parameters that mostly affect the total costs:
(a) with MCC; (b) without MCC

It can be stated that the total impact on total costs is exerted by the number of orders arriving daily in a micro district. Moreover, a change of this parameter by 50% leads to a decrease in costs by 80%, which makes this parameter unique for the model in question.

The influence of other parameters is much less. Moreover, the rating of the influence of the parameters on the total costs for different delivery options is different.

It should be noted that in the course of this study, an analysis was made of the influence of all the initial parameters on the resulting indicators. This article shows the results of only the most significant factors of influence.

5. DISCUSSION OF THE RESEARCH FEATURES AND ITS PROSPECTS

In conclusion, we note that the topic of urban consolidation is sufficiently studied theoretically and widely applicable in Europe and the United States. Dozens of successful urban consolidation projects have shown a significant improvement in the social and environmental indicators related to road traffic and living standards. In Ukraine, however, environmental and social indicators are rarely considered when making logistics decisions in the city, leading to negative consequences; in particular, congestion, a situation which worsens every year. The technology proposed in this article for urban distribution using off-peak supplies and the participation of the MCC could reduce the density of road traffic during the daytime, reducing the negative impact of freight transport on the population and the environment.

At the same time, it should be noted the complexity of the organization of the night delivery system with daytime foot spacing of orders for the city's micro district with the point use of such technology. Economic and socio-environmental indicators prove the effectiveness of urban micro-consolidation, which makes building a network of consolidating centers rational. Only in this case, all participants in the urban distribution process - shippers, carriers, MCC workers and recipients, as well as indirect participants (municipality and city residents), will feel a positive synergy effect.

It should be noted that the social and environmental external costs of urban delivery should also include losses from road accidents. Such an inclusion would favor urban consolidation technology with night (off-peak) delivery to the MCC, since overnight delivery generally carries a lower risk of accidents, at least due to fewer road users. However, in the existing method for assessing marginal costs, there is no mechanism for assessing losses from road accidents depending on the time of day. Furthermore, the option of constructing a separate building for the consolidation center is not analyzed, which would undoubtedly raise the costs of delivery through the MCC (both investment and monthly due to accounting for depreciation of buildings).

Despite such features of the proposed method, the principle of consolidation of shipments is likely to be no less effective when used at other levels - to serve the area of the city or the whole city (respectively, at the meso- and macro-level). In this case, optimization models will be needed, the target function of which should be economic and socio-environmental costs and losses. This raises the question of not only determining the required number, location, and size of consolidation centers but also building an effective system for managing the network of such centers and coordinating its participants. These tasks will be devoted to the future research of the authors in the field of urban logistics.

6. CONCLUSIONS

1. A set of baseline data has been identified that affects the economic and socio-environmental performance of direct and consolidated delivery of small shipments, considering different traffic densities during the day. Source data are classified into nodal and stream.
   To display the relationship of the time of day of the vehicle in urban traffic with the density of this stream, coefficients are proposed that correct the speed of the vehicle and fuel consumption depending on road conditions - for free movement, difficult movement and movement in the mash.
2. A technique has been developed for the integrated assessment of the effectiveness of using urban consolidation centers at the micro level in combination with off-peak deliveries. Complexity implies considering both the economic costs that accompany the distribution in the city and the social and environmental costs, such as losses from congestion, emissions of harmful substances into the atmosphere, infrastructure costs, etc.
   It was determined that it is the time of streaming processes that predetermines the fuel consumption, the driver's wages on the route and the vehicle depreciation is a component of the economic costs of delivery. Regarding social and environmental costs, almost all of them suggest different values for different degrees of traffic density. Thus, the transition to off-peak supply is reflected in the method for determining both economic and socio-environmental costs.
3. The obtained method was tested on real source data. It is shown that on a city scale, the delivery time affects both the number of vehicles on the city streets and the degree of

congestion of the city street network, which is reflected in the amount of social and environmental costs.

The sensitivity analysis of economic and socio-environmental costs allowed us to determine the main factors affecting the total costs for consolidated and direct delivery - the number of deliveries to the micro district per day, the number of orders in one car dispatch and the average distance between customers as the vehicle moves around the city. The degree of influence of each factor and the rating of influence are significantly different for delivery through and without the MCC.

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