Planning of Urban Freight Delivery During Peak and Off-Peak Traffic Periods

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Abstract. Paper present influence of time windows during the day on efficiency of urban freight delivery. Field research was obtained to gathering freight logistics data according to which models were build. The regression models obtained in the paper described the speed of delivery in the network during peak and off-peak periods and allow one to evaluate parameters of the freight tours process in the current scenario. Obtaining the choice of time periods has an impact on delivery tours: load capacity of a vehicle, quantity of delivery bays, etc. The results are useful for logistics operators, planners, and authorities.

Keywords: Urban · Regression analysis · Time Period · Delivery · emission

1 Introduction

The main feature of the modern development of cities is application of management approaches and methods that would allow the creation of the most comfortable living conditions for the population. It is this content that is included in the concept of sustainable development of the city from the point of view of its economic, ecological and social development. As of today, the sustainable development of transport in cities is mostly considered in terms of the development of population mobility, while the solution of issues of rational organisation of freight traffic is usually given little attention. But for the sustainable development of the city, the freight transport subsystem is no less important, since the success of forming a comfortable urban environment also depends on the quality of its functioning.

The constantly growing number of residents in cities leads to an increase in the demand for freight transportation. As a result, the number of freight vehicles on urban roads is increasing. This, in turn, becomes one of the reasons for the occurrence of traffic jams on the roads, which is reflected in the delivery time of all categories of users of the city's transport system and road safety in general.

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Furthermore, freight transport has the greatest negative impact on the environment [1, 2]. According to the UN Commission for the Sustainable Development of Settlements, the share of global greenhouse gas emissions from the operation of heavy vehicles is 22% [3]. In cities, this indicator is significantly higher due to the concentration of a large number of mobile sources of pollution in the space defined by the city boundary. On the basis of this, it can be stated that the issue of rational organisation and planning of the work of freight transport under the conditions of sustainable development of the city is an urgent task and requires research.

Recently Information and Communication Technologies (ICT), as well as the Intelligent Transport Systems (ITS) have become more popular. It supports planners and, stakeholders in general, to make the supply-chain processes more sustainable and effective. Various approaches are being developed to introduce innovative technologies into Urban Freight Transport. This allows planners to assess the situation in real time and organise the delivery taking into account the criteria used by stakeholders.

The field of the emerging technologies becomes larger and more popular.

It is possible to identify Internet of Things (IoT) that impact directly on city logistics toward a smart city logistics. In fact, in recent years, the evolution of emerging information and communication technologies (e-ICT) has opened the road to develop and implement new integrated and dynamic City Logistics solutions, allowing to improve the level and the quality of life of city users (e.g., residents, visitors). In particular, telematics can support the effectiveness of each action that can be implemented in light of the sustainability and liveability of the urban area.

IoT technology can be applied to consider the purchase of goods as information, for example, providing their availability in retailers' locations. It can also be used to forecast future end-consumer demand and flow of goods. It is useful to manage the routes in real-time and solve a Vehicle Route Problem (VRP) in advance.

2 References Review

2.1 Urban Freight and Sustainability

The physical distribution of goods carried out by freight transport in cities is the result of meeting the needs of the population, production, and construction in freight transportation. Under the conditions of high competition in the market of transport services, motor companies strive to satisfy as many requests for freight transportation as possible to maximise their profits, not disdaining various methods to successfully perform this task. As a result, the city receives an irrational loading of the transport network, and, as a result, residents are dissatisfied with the operation of the transport system [4].

To ensure the right of the urban population to a high standard of living in conditions of economic and environmental security, local self-government bodies in close cooperation with specialists in the field of transport must consider and solve the issue of optimising the city's transport system in a comprehensive manner, considering all its components, including the freight transportation subsystem.

Today, urban logistics is being researched from different sides. Due to the increase in the number of goods and their movement, there is a problem for urban logistics. Different researchers investigate this issue and identify the main areas of influence of the rapid development of goods movement in the city. There are such main problems of urban logistics: urban growth, traffic congestion and environmental problems. When they are combined, similar effects appear, such as the disruption of the urban delivery network, which is not found in the literature on developing countries. It must be said that some government agencies have adopted sustainable initiatives. They focused on distribution operations such as optimizing transport networks and logistics facilities, managing fleet size, improving facility regulation, routing, night delivery, and integer delivery systems (e.g. crowdshipping, parcel lockers). These innovative solutions, which have been successfully adopted in some countries, can be evaluated for possible implementation in other countries [5].

Many scientists are working on Green logistics issues to reduce the costs of logistic and pollution simultaneously. Many solutions are connected to new advanced green vehicles, the technology of their operations, etc. Otherwise, the network effect will have a system with a different set delivery time during the day. Given the following conditions, it is necessary to take research different scenarios of distribution during the day (peak; off-peak) was conducted to understand the behaviour of all networks to efficiency of each scenario. Thus, in some countries, time windows of distribution have been introduced, which limit the access of heavy vehicles to the city centre or determine the time period for the distribution of goods. Each city determines its own time periods for peak and off-peak deliveries [6, 7]. Due to this, Cattaruzza D. et al. consider time windows as optimisation of vehicle routes in urban logistics [8]. On the part of the government, this restriction refers to the limited access to certain special areas during certain periods.

Taniguchi, Thompson and Yamada [9] highlight the challenges of urban freight delivery during peak and off-peak periods, including congestion, environmental impacts, and safety concerns. A range of solutions to address these challenges, including the use of alternative delivery methods, such as bike and electric vehicle delivery, and the implementation of intelligent transportation systems were discussed to sustainable delivery [10]. The Holguín-Veras et al. [11] discuss the potential benefits of off-peak delivery, such as reduced congestion and improved environmental performance. Cidell and Regan [12] discuss range of strategies, including off-peak deliveries, consolidation of shipments, and use of alternative delivery methods, can be effective in reducing congestion, emissions, and other negative impacts on urban environments. However, presented works are been short in presenting direct numerical influence of peak and off-peak periods on the urban freight delivery parameters (e.g. time, speed, load factor, length of the route, etc.)

2.2 Methods of Estimating Vehicle Speed in Urban Area

The speed of the transport flow is directly influenced by the delivery time. Many factors affect this setting. Based on the work [13], experimental data from the Greenshields Linear Speed-Concentration Model can be used. Various methods can be used to determine the speed of the transport flows. In general, all methods can be divided into field and modelling methods [14–18]. The method of field research consists in obtaining actual speed values in the given space and during the specified period. This method consists in conducting direct observations.

Vehicle speed estimation can be carried out by modelling methods [19, 20]. The advantages of on-site monitoring of the speed of delivery are their greater accuracy, ease of use. The disadvantages are the high labour capacity and material cost of conducting the examinations, especially when special technical means and vehicles are used. The use of this group of methods is possible at the stage of collecting the necessary statistical information. For example, when developing models of transport flows. The second group of methods for estimating vehicle speed involves the use of models of transport flows. To establish communication between various pairs of basic characteristics of transport flow can be used: experimental data [21] and built on them functions, conclusions made during the analysis of boundary conditions, physical analogues.

At this time several approaches have been developed to estimate the speed of delivery in the conditions of urban transport networks [22]. The functioning of transport systems of large cities is largely estimated by the attributes of transport networks. Among all parameters of transport processes, the most important place belongs to speed delivery and same time of vehicles by the transport network. As indicators, which characterize the level of development of the transport network, one can accept the density of the transport network and the level of the automobile. Therefore, the average speed of delivery depends on the density of the transport network and level of automobilization [22–24]. According to this method, when the network density is increased, the speed will increase and vice versa. The level of automobilization has the opposite influence on speed of delivery. Urban delivery efficiency depends on a few factors, for example: speed of delivery, delivery quality, delivery time etc. Also, depends on this time, which may take place during peak and non-peak periods.

Traffic flow characteristics showed different behaviour in peak and off-peak (non-peak) periods. Each of these periods is observed during the day in any city. In the peak period there is a dense flow, and the movement of all vehicles in it slows down. The ability to manoeuvre there is limited. These conditions are usually observed in the morning and evening hours when everyone is going to their place of work, study, etc. The evening peak is less pronounced since the flows coming from the place of work and study, etc. can be distributed according to additional purposes of the tours (shops, cinemas, other activities).

In the non-peak period, a non-dense flow is characterized by the presence of vehicles on the road that does not interfere with manoeuvres on the road. This condition is observed when most drivers have already arrived at their main destination. The non-peak period is also can be characterized by single cars on the road. The driver can freely choose any permissible speed and save fuel at the same time [5]. Peak and non-peak periods affect the delivery time, distance, and speed of delivery.

Time limits of peak and off-peak may vary for different cities. This is due to the liveability of the rhythms of cities and the different urban traffic. The researchers considered that inhabitants have most movements in the morning and evening peak hours. During the non-peak period, the urban traffic is much less than during the peak, which leads to a reduction in delivery time and an increase the sustainability.

The aim of the paper is assessment of urban freight delivery during peak and off-peak traffic periods. The objectives of paper are:

– Form a method of assessment. Analyse and evaluate factors affecting speed of delivery,
– Determine the rate of delivery to different traffic density during the day (peak, non-peak),
– To estimate the impact of the capacity of the vehicle on the speed of delivery,
– Assess the urban delivery tours efficiency with different traffic periods.

3 Experimental Research

The survey is made through the polling of the transport industry. The Form has been used to implement the survey, see Fig. 1. The questionnaire is structured as follows. The first section contains the information of vehicle. It consists of different characteristics of freight vehicle. The second part connected to the operation of the driver and vehicle.

1. Vehicle information

1.1 Brand		1.2 Model		1.3 Capacity, t	
1.6 Plates				1.4 Capacity, m^3	
1.7 Additional information				1.5 Type of loading and unloading	

2. Operation of the driver and vehicle

2.1 Operation	2.2 Indicating of Time starting operation, **hh:mm**	2.3 Speedometer Indicator, km	2.4 Actual Time of operation, min
Starting the garage			
Ending the Garage			

3. Operation tasks

3.1 №	3.2 Location, Address	3.3 Name of pick-up or delivery point	3.4 Indicating of Time operation (starts, ends), **hh:mm- hh:mm**	2.3 Speedometer Indicator, km	3.5 Type of operation	3.6 Type of goods	3.7 Amount of goods, ton	3.8 Number of pallets (boxes), units	3.9 Notes about loading and unloading technology
1									
2									

Fig. 1. Form for record keeper

The last part connected to the routes stops on the routes where the fixation of time, and distance were made. The section "Operation tasks" has current information about all parts of the route. The record keeper paid attention for each activity. For example, changing location or vehicle utilisation rate. This person has been fixating these indicators during the delivery process.

According to the survey 36 records were explored for transportation service of different retail networks. At the set result was considered: quantity of stops on route, volume (amount) of distribution, the total distance by route, time window in which the selection was conducted, the capacity of vehicle etc. The time window of day is used to detect the "peak hour" and "non-peak hour" of the movement of vehicles and to determine its impact on the speed, which is shown in table 1. Different vehicles were used for the same freight network to establish the influence of vehicle capacity on the speed of delivery.

An experiment was carried out to conduct the research. Routes were built with different vehicles (capacity 3–10 tons, brand, from euro-3 to euro-6, type of fuel) for the retail networks. The one route was chosen with the largest quantity of retailers. Thus, 12 routes were received. Further, the received data on the routes are entered into the program "Statgraphics" [25].

Table 1. Range of data variation for speed model.

q_n, t[a]	T, min[b]	L, km[c]	V_t, km/h[d]	T, min	L, km	V_t, km/h
	peak period			non-peak period		
3	1,23	18,081	14,66	1,57	18,081	21,5
3	1,57	18,081	11,54	3,38	22,138	15,55
5	1,63	22,138	13,55	3,38	28,239	8,35
5	3,63	22,138	6,09	1,82	28,398	21,6
7,5	2,15	28,239	13,13	0,98	25,166	35,68
7,5	3,9	28,239	16,24	1,1	25,617	28,29
10	1,48	28,398	15,14	1,38	33,388	24,19
10	2,28	28,398	12,44	1,5	33,839	22,56
3	1	25,166	25,17	1,65	13,091	17,93
3	0,98	25,166	25,59	1,5	32,002	31,33
5	1,1	25,617	23,29	3	43,666	14,56
5	1,1	25,617	23,29	3,25	48,681	19,98
7,5	1,57	33,388	21,31	1,57	18,081	21,52
7,5	1,43	33,388	18,29	1,47	22,138	25,06
10	1,68	33,839	10,1	2,85	28,239	15,91
10	2,5	33,839	13,54	1,7	28,398	22,7
3	0,83	13,091	15,71	0,93	21,423	33,04
3	1,6	13,091	18,18	1,13	24,2	31,42
5	1,9	32,002	16,84	1,18	25,048	31,23
5	1,5	32,002	21,33	1,68	25,048	19,91
7,5	2,2	43,666	14,85	1,08	14,622	23,54
7,5	3,62	43,666	12,07	1,55	34,17	32,05
10	2,48	48,681	9,6	1,38	34,17	34,76
10	3,97	48,681	12,27	1,38	34,17	34,6
3	1,57	18,081	21,54	1,57	18,081	21,52
5	2,32	22,138	19,56	1,48	22,138	24,96
7,5	3,88	28,239	14,27	3,1	28,239	13,11
10	1,88	28,398	15,08	1,87	28,398	20,19
3	0,93	21,423	22,95	0,93	21,423	33,04
5	1,13	24,2	21,35	0,95	24,2	35,47
7,5	1,22	25,048	20,59	1,23	25,048	30,36

(*continued*)

Table 1. (*continued*)

q_n, t[a]	T, min[b]	L, km[c]	V_t, km/h[d]	T, min	L, km	V_t, km/h
10	1,35	25,048	18,55	2,02	25,048	17,4
3	1,17	14,622	22,53	1,25	14,622	21,7
5	1,55	34,17	22,05	1,88	34,17	28,18
7,5	1,72	34,17	15,9	1,55	34,17	32,05
10	1,55	34,17	12,05	2,55	34,17	16,4

[a]Capacity of vehicle
[b]Delivery time
[c]Length of route
[d]Route speed

4 Results

Regression and correlation analysis were used in processing the obtained data. The fol.
lowing equations are then obtained using the software "Statgraphics" for the peak hour:

$$V_t = 45,405 \cdot \beta - 1,52513 \cdot N_p - 0,945548 \cdot q_n, \tag{1}$$

where V_t – average speed of delivery, km/h; β – the empty running rate factor. The rate of empty running vehicles is the rate of vehicle-kilometres without goods or passengers; N_p – quantity of retailers, un.; q_n – capacity of vehicle, t.

And for non-peak hour the researchers also used the "Statgraphics":

$$\mathrm{Vt} = 0,395976 \cdot \mathrm{L} + 16,5456 \cdot \gamma, \tag{2}$$

where L – the length of the route, km; γ – load utilisation factor.

The parameters of statistical assess of models showed in Table 2 and the confidence intervals present in Table 3.

Models are obtained using regression and correlation analyses. On the basis of these, it is possible to construct graphs of dependence of the speed value on different coefficients. In a peak hour and a non-peak hour these indicators differ. The results indicate that in different time periods the speed of the vehicle is influenced by different indicators (Fig. 2 and 3).

The speed per peak hour is influenced by the empty running rate for road transport (Fig. 1, a), capacity of vehicle (Fig. 2, b) and quantity of retailers (Fig. 2, c).

Figure 1(a) shows the empty running rate for road transport in this research changed from 0,56 to 0,95. On the graph, see when this parameter decreases, the speed increases. If you consider that the rate of empty running vehicles is the rate of vehicle-kilometres without goods, then without goods, a freight vehicle moves more easily on the road. According to Fig. 2(b), when the capacity of a vehicle increases, the speed will decrease and vice versa. This dependence can be explained by the fact that a vehicle with a lower capacity is easier to manage and manoeuvre along urban streets. The number of retailers

Table 2. Statistical assess of models.

Indicator	Traffic period during the day	
	non-peak hour	peak hour
T-Statistic: Tabular coefficient	1,97	1,97
The empty running rate for road transport	–	11,4564
Capacity of vehicle	–	−3,04769
Quantity of retailers	–	−5,13999
The length of the route	3,59496	–
Load capacity utilization function	4,46854	–
F-Ratio: Tabular coefficient	161	161
Calculated	168,14	184,59
R-squared	90,8178	94,3759
R-squared (adjusted for d.f.)	90,5477	94,035
Mean absolute error	6,21639	3,54909

Table 3. 95% confidence interval for the coefficient in the model.

Coefficient in the model	Lower limit	Upper limit
Peak hour		
The empty running rate for road transport, β	37,3416	53,4683
Quantity of retailers, Np	−2,12881	−0,92145
Capacity of vehicle, q_n	−1,57676	−0,31434
Non-peak hour		
The length of the route	3,59496	–
Load utilization factor	4,46854	–

(Fig. 2, c) had decreased and increased during the speed increase. The greater the number of retailers, the greater the area of the urban area covered by the route. It passes through more intersections and turns than a vehicle with fewer retailers.

The speed of delivery per non-peak hour is influenced by the length of route (Fig. 3, a) and load capacity utilisation function (Fig. 3, b).

Figure 2(a) had the next dependence: when the length of the route increased, the speed of delivery also increased. With an increase in the length of the route, the manoeuvrability of the vehicle increases, space for acceleration, and braking at the end of the path when approaching the last retailer. The load utilization factor function (Fig. 2, b) has an influence on speed of delivery, such as the previous parameter.

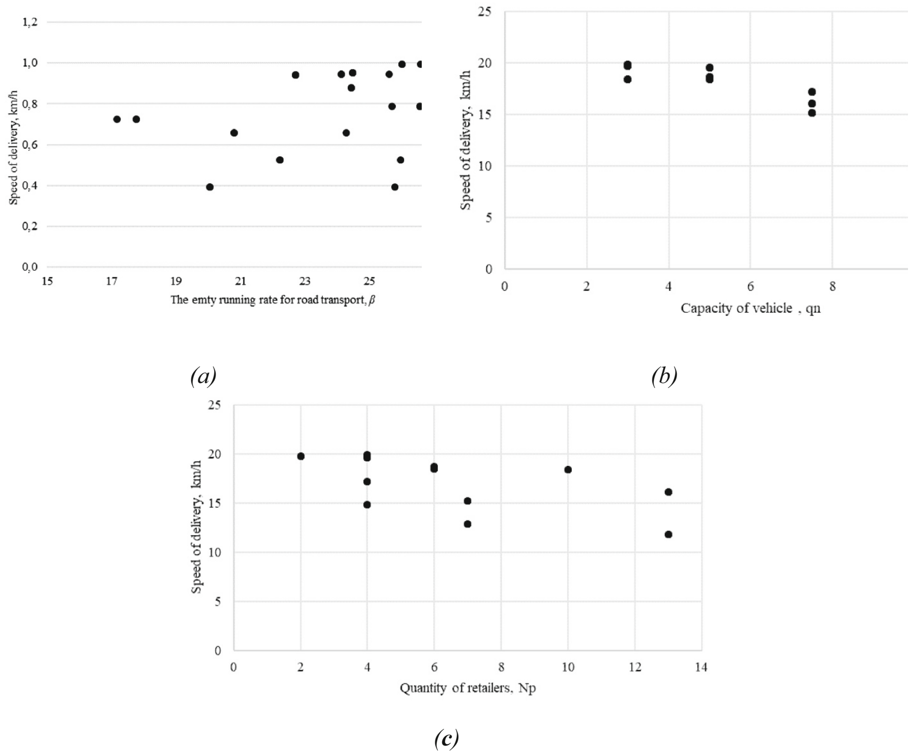

Fig. 2. The dependence of speed at peak hour on: *(a)* the empty running rate for road transport; *(b)* capacity of vehicle; *(c)* quantity of retailers.

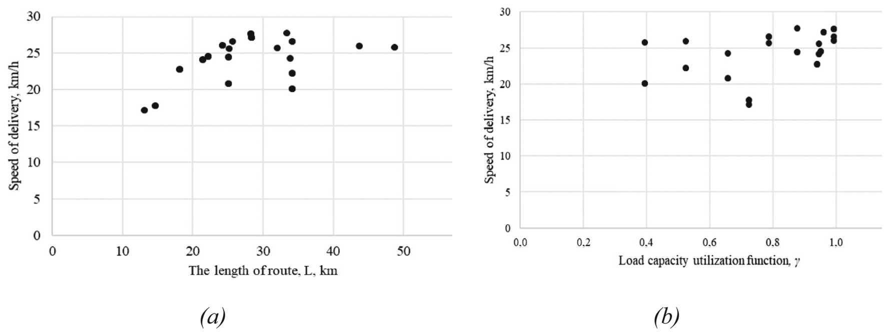

Fig. 3. Dependence of speed of delivery at peak hour on: *(a)* a length of route; *(b)* load capacity utilization function.

5 Assessment of the Efficiency of Urban Delivery Tours with Peak and Off-Peak Periods

Based on the data obtained, the value of speeds of delivery in different periods for vehicles with different carrying capacities was selected in the work. The corresponding graph is plotted in Fig. 4. It is clearly visible how the speed changes depending on the period per day under investigation. On the basis of a significant change in the speed parameter, the urban delivery tours also change. When the speed of delivery values are the highest during the non-peak period, the vehicle's delivery time will be the lowest.

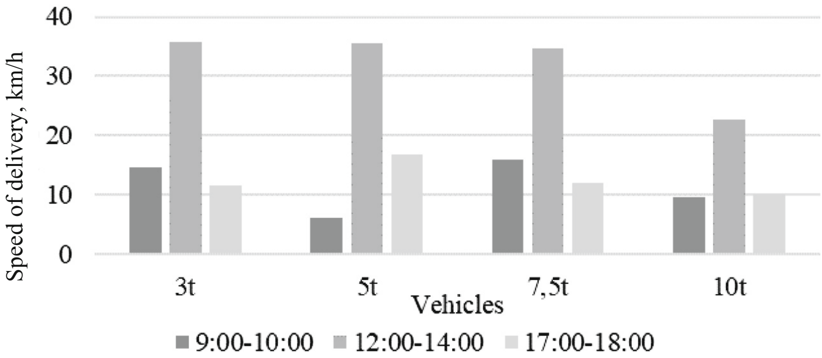

Fig. 4. The dependence of the speed of delivery on peak (9:00–10:00, 17:00–18:00) and non-peak (12:00–14:00) periods.

Therefore, the speed of delivery of the vehicle directly affects the delivery time. The average time on the route will be longer for delivery during the peak period. It should also be noted that there may come a time when it becomes unprofitable to serve the retail network without considering time periods. After all, a vehicle leaving during the peak (9:00–10:00) hour can deliver a container load during the non-peak period. When, considering the time periods, these goods will arrive at the same time, but without losing time on the road during peak hours.

6 Conclusion

This research makes it possible to use an existing improved approach to determining the speed of delivery in the logistics system. When estimating regression models, parameters such as speed of delivery, capacity of the vehicles, length of route, delivery time, etc. The model of change of time of day of transportation for peak hour and non-peak hour is constructed. With the help of the field survey, data was obtained based on retail network routes for research. Also, an experiment, which is the basis for building models. The resulting models allow one to calculate the speed of delivery of goods by vehicles. In a logistics system, it can be used to manage the delivery of goods in real time. This will allow for a more accurately determine the parameters of retail networks and predict the state of the logistics system.

The speed of delivery is one of the speeds that are calculated during operational planning. Although this speed is the main one in the operational planning of transport processes, using this approach can be used for tactical or strategic planning (for example: expanding or changing the number of retailers and determining the predicted parameters of transport operation in this case).

The method of obtaining data to build models was the use of the recording parameters in road. This research is limited by the following parameters: the example was calculated for one city, in a certain period of the year (velocity data may differ in winter and summer). Although the calculations were carried out on the example of one city, the results may be valid for other similar cities (similar in urban planning, area, etc.). The efficiency depends on the choice of travel periods. Since it depends on the delivery time, which can take place during peak and non-peak periods. The speed of delivery and time are very different in periods during the day.

Based on the vehicle results obtained, the speed of delivery depends on different parameters in different time periods. In the peak hour, the speed is affected by the empty running rate for road transport, capacity of vehicle and quantity of retailers, and the non-peak hour influenced by the length of route and load capacity utilisation function.

The analysis of scientific publications showed a different level of processing of material related to the development of freight transport under the conditions of sustainable development of cities by scientists from foreign countries and Ukrainian scientists. In our country, this direction of research is new and requires significant attention from both scientists and government officials. Conduct in-depth scientific research in the field of freight transportation under the conditions of sustainable urban development. When planning the operation of the urban freight transportation, it is necessary to consider the peculiarities of its implementation. This approach will allow local authorities to make informed decisions when planning urban spatial development and will also help to determine the list of basic requirements for entities that provide freight transportation, with the aim of optimising urban traffic. The planning of freight transport operations should be carried out consistently and thoroughly, covering all its elements and connections. An in-depth study of the demand and supply for the transportation of goods in the city will make it possible to form an effective strategy for the development of freight transport in the city. The analytical description and quantitative evaluation of the obtained results will create a basis for the development of a qualitative list of measures, the implementation of which will allow increasing the efficiency of urban freight transportation. The key aspects of the successful implementation of measures to improve the operation of freight transport are the financial support of the planned actions, their support by local self-government bodies, as well as the optimal organisation and coordination of the processes and actions of all planning participants. The implementation of such an interconnected set of actions will ensure the success of planning and implementation activities at all stages of its implementation.

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