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IMPROVING THE EFFICIENCY OF TRANSPORTING LIGHTWEIGHT BULKY CARGO BY MOTOR TRANSPORT

Summary. The shipping process should be carried out to minimize standing time, as it affects the total vehicle mileage. The efficiency of distributing cargo on routes in modern conditions could be achieved by transporting cargo taken from several manufacturers that have mutually comparable mileages. This paper analyzes common methods of cargo distribution by routes. It was established that the approximate methods that provide near-optimal solutions to problems have become widespread. Therefore, there is no alternative to using accurate methods in the process of studying the routing problem. One such method is the branch-and-bond method. It should also be noted that it does not involve going to the same place multiple times, which takes place in a real transport scheme. Thus, the modification of accurate methods is a promising direction in solving the routing problem in the process of transporting the goods in small consignments. Consequently, this provides an opportunity to effectively use motor transport in the logistic system.

1. INTRODUCTION

The current level of development of market economic relations is largely due to throwing rates of the development of transport systems. To date, the volume of goods traffic has increased. In this regard, the role of motor transport is growing even more, as modern approaches to logistics play a major role in “on-time” transport. It is important to route the city network and fully and to a high degree meet the requirements for transport services, thus making optimal use of technical data of vehicles and ensuring low costs.

The success of such a task is necessary for the effective management of the transport process. If the criterion for evaluating the functioning of motor transport was the implementation of the transportation plan in the past, the criterion for evaluating efficiency is now the on-time delivery of cargo in the required quantity and of the right quality to the destination.

The above functions cannot be performed without the complex logistics approaches to the transportation processes. In a highly competitive environment, transportation companies should focus

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not merely on profits but also on the quality of their services and fully meet the needs of the customer. The system must be flexible and responsive to transport market demands.

The analysis of the performance of motor transport shows that, unlike other components of the transport system, it mostly moves small consignments. The growing competition in production, supply, and sale makes it even more necessary to develop the abovementioned function of motor transport in accordance with modern requirements.

2. RESEARCH METHODOLOGY AND EVALUATION CRITERIA

This paper considers the transportation of small consignments; small consignments in road transport are those with a weight from 10 to 200 kg [1, 18]. These types of shipments mainly relate to socially relevant goods, foodstuffs, household service products, mail, etc. Small consignment refers to cargo received for shipment to a particular destination; in these cases, the vehicle cannot be fully loaded. Therefore, such cargo should be moved according to the scheme of a distribution route.

In modern conditions the number of lightweight cargo shipments is growing. Consequently, the transport market demand for a continuous supply of small consignment flows to these facilities is increasing as the demand for this range of goods increases. It is useful to form the consignments according to the demanded range of goods.

The distribution routes are mostly used in in-city transportation. The most telling example of such type of shipment is the transportation of food to the retail network. An important task when transporting such goods is the issue of selecting the motive power. Motor vans or general-purpose drop-side trucks are usually used. However, the efficiency of the transportation process largely depends on what performance indicators of the motor equipment will be selected to perform the transport process. An analysis of the motive power used to date shows that it is mainly used in such shipments, and the most-used vehicles have a loading capacity of up to two tons (approximately 45%). The greater convergence of the boundaries between cities has led to the need to perform this type of transportation when moving on the in-city routes, due to their high economic efficiency [2-5, 13, 14].

Goods transported in small consignments, unlike other types of cargo, are particularly distinguished by special indicators. These may include the time of sale (e.g., bread, milk) and the difficulty of planning the shipment because the transported consignments contain a wide range of goods. Therefore, to ensure effective management of the process, it is necessary to conduct pre-marketing research.

The transportation of goods in small consignments is an expensive process. Studies show that their value is often equal to or greater than the transportation of large bulky goods at the same distance. If we consider that shipping goods in small consignments accounts for 3% of total transport work and that the cost is 35%, it becomes clear how different the result is. The improper selection of routes during shipment leads to an increase in vehicle mileage, and this increase is often more than 30%. In the development of the theory of transport processes for the delivery of foods in small consignments to the destination, more attention is shifted to the study of technical-economic indicators of motive power.

When transporting goods, the transport operation of the vehicle, which is performed per unit of time, is productive capacity. In addition, it should be noted that the operating costs for motor transport are associated with vehicle mileage. In practice, it is accepted that the work done by a vehicle should be reflected in tons or ton-kilometers. Papers [2, 3] state that we cannot take the estimated value of a ton-kilometer on a distribution route, as the turnover in this case is determined by the number of distribution points that the number of points depends on. Obviously, in this case, we must use the hourly productive capacity. Experiments have shown that the mileage utilization coefficient and the dynamic load factor on the distribution routes cannot be taken as an indicator of the optimal route selection.

The calculation of the car's hourly productive capacity is based on the following formula [4, 5]:

$$W_{ar} = \frac{q\gamma_c V_T \beta_e}{L_{er} + t_{np} V_T \beta_e} \quad , \tag{1}$$

where, W_{ar} – hourly productive capacity, t/h;

q – nominal loading capacity, t;

γ_c – static load factor;

V_T – vehicle's operating speed, km/h;

L_{er} – distance run, km;

t_{np} – vehicle parking time for the loading and unloading process, h;

β – vehicle's loaded mileage proportion.

The above equation can be written as follows:

$$W_{ar} = q\gamma_c \left(\frac{1}{\frac{L_0}{V_T} + t_{np}} \right), \tag{2}$$

where L_0 – total mileage of the vehicle, km.

The greater the value of the load factor, the greater the productive capacity of the vehicle. The coefficient γ_c is directly dependent on the class of transportable cargo. This coefficient can be increased as a result of the following measures [6]:

- The motive power must comply with shipping conditions;
- Sorting and enlarging cargo into small consignments;
- The cargo must be well-proportioned to the dimensions of the body;
- Use of vehicles with an increased body volume;
- The possibility of transforming (modifying) the existing boards.

The amount of vehicle loading-unloading time depends on the level of mechanization of operations. Therefore, when planning the pick-up and distribution routes, the focus is on the cargo value q, the total mileage L_0, and the road speed V_T. It should be noted that road speed has a significant impact on the productive capacity as the amount of useful work increases and the amount of motive power required decreases. However, due to the carrying capacity of the roads in real conditions, there is an unforeseen drop in speed, and speeding is not allowed. So, along the entire length of the route, road speed is taken as a constant value.

Based on the above, we can conclude that the productive capacity of the vehicle is a function of the transported cargo and overall mileage:

$$W_{ar}=f\,(qL_0). \tag{3}$$

It should be noted that the efficiency of transport organization depends not only on the productive capacity but also on the weight of the vehicle (in good condition). The smaller this weight, the lower the cost of carriage of one ton of cargo. Nowadays, owing to the high price of fuel, the cost of moving the car itself has increased. In the theory of vehicles, this cost is calculated only indirectly using the β coefficient.

One of the ways to increase the efficiency of the cargo transportation process is to move cargo through the combined routes. The carriage of goods in small consignments along this route has a special character, as it involves entering the same point several times during the passage of the route. This, in turn, does not meet the conditions of the classic routing task, where each point must be entered only once during the passage through the route. In addition to the above, posing the issue in a theoretical context contradicts the actual process when moving on the route [8, 9, 11, 12].

Modern requirements for solving the problem of the best possible choice of routes are steadily increasing. Therefore, there is no alternative to using accurate methods in research. In the present research, the basis for the study of different routes is a branch and bound method. As mentioned, the disadvantage of this method is that it is not possible to take into account the sub-cycles. Therefore, researchers are more likely to use approximate problem-solving methods. We have proposed a methodology that allows us to improve the classic method in such specific conditions [7, 10].

The essence of the methodology is that fictitious nodes and routes are introduced in the research on transport networks when needed.

A fictitious node (point) is an additional node that was not in the initial transport network. Also, the connection between it and the real object is fictitious. Together, they form a fictitious branch or a link as shown in Fig. 1 below.

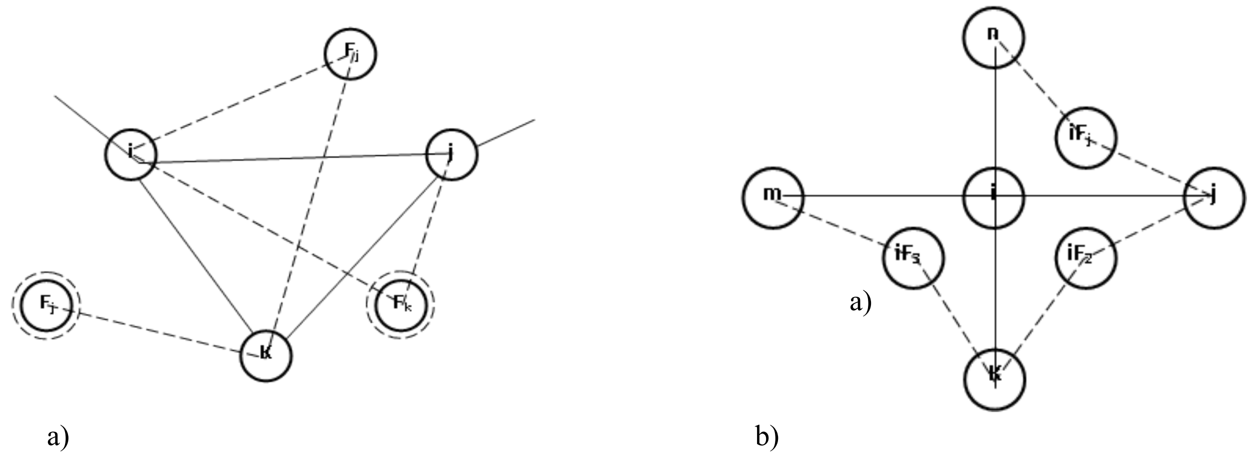


Fig. 1. The elements of a fictitious branch: a) a triangular element and b) a nodal element

The routing problem can be stated as follows. Suppose there is a transport network within which cargo must be transported. The cargo characteristic is uniform, allowing us to use one type of vehicle. In addition, there is one well-known transport company that distributes goods from one manufacturer to the customer within the trade network. It is known the amount of cargo that will be transported to one customer. Along one route, several points are provided with services. It is necessary to plan the transportation process to satisfy all customers and minimize transportation costs [15-17]. The route length or time can be used as a target function. Therefore:

$$f(L)=\Sigma \ell_i \rightarrow \min; \quad f(T)=\Sigma t_i \rightarrow \min \tag{4}$$

If there are routes of the same length, preference is given to that for which the magnitude of the transport operation is the minimum at the time of the transportation process (only the work done during the shipment of goods is intended).

3. PROBLEM SOLVING AND RESULTS

The loading capacity of a truck is one of the most important performance indicators. This is the largest amount of cargo that can be transported simultaneously by vehicle.

The loading capacity depends on the weight of the cargo (density) and its geometric dimensions. It is determined by two main passport characteristics of the vehicle:

- Nominal loading capacity
- Internal volume of the vehicle's body.

The geometric dimensions of cargo determine the degree of internal volume utilization of the vehicle body, which is measured by the ratio of usable space to the area occupied by cargo.

The volumetric weight of cargo is directly associated with the question of whether the internal volume of the vehicle body will be fully used. The maximum amount of cargo to be transported is not limited by the loading capacity of the vehicle. The body of the vehicle will be perfectly used only if the volumetric weight of the cargo is equal to the specific volumetric loading capacity. If the cargo density is lower, the loading capacity will not be fully utilized. A vehicle whose density is quantitatively equal to its specific volumetric capacity will be rationally used to transport cargo. In this case, both the loading capacity and the internal volume of the body are fully used.

If the volumetric weight of the cargo is less than the specific loading capacity of the vehicle, then special measures need to be taken to ensure that the loading capacity is fully utilized. Otherwise, the body will be filled, but the load will be partially used (e.g., when transporting soft toys or furniture). A common method is to increase the dimensions of the vehicle body.

The compact layout of cargo on the body of a vehicle also allows to use the loading capacity of the vehicle. Another very effective method of using the loading capacity is to select the vehicle for the goods to be transported. It is also effective to use specialized motive power.

We have developed the design of a variable volume body (Figs. 2 and 3) on which a copyright certificate has been obtained.

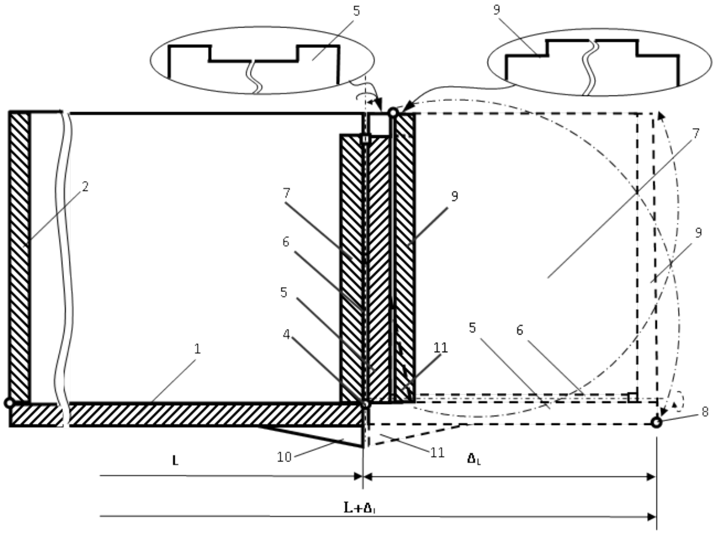


Fig. 2. The front side of the variable volume body

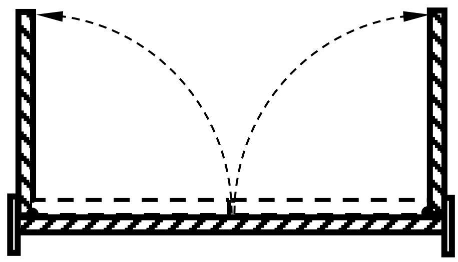


Fig. 3. The tailboards

The variable volume body comprises the front 2, the side 3, and the tailboards that are pivotally connected to the frame 1. In addition, the tailboard is composed of the additional folding walls 7, which are connected by means of the joints 6 to the frame 1. The horizontal joint is connected by a transverse load-bearing element 5, placed on the lateral edges of the body with joints 6 connected by additional side folding walls 7, and the same upper load-bearing element. The extra folding rear wall 9 is connected to the outer edge of the body 9 and the same upper load-bearing element. The extra folding rear wall 9 is connected to the outer edge of the body 9, with the side folding walls 7 (in the horizontal position 5 and the connecting joints 6) in the open position, the rear folding wall, and the side skirts 3 are in the open position. In addition, the frame 1 and the transverse bearing element 5 have interlocking elements 10 and 11.

Cargo is transported along a route that is pre-determined and, if necessary, represents the arranged infrastructure between the starting and ending points. Solving the routing problem allows us to determine the shipping distance, the direction of shipping, and the frequency of shipments.

The main routing problems include traffic organization, the minimization of delivery time to the destination, traffic safety, the efficient use of vehicles, and the implementation of shipping plans and schedules.

The optimal route scheme can be selected by choosing the length of the route or the time required to pass the route as a criterion. The optimal route of movement is selected using the“fictitious branches” method.

For example, we can choose the shortest route length as the criterion of optimality. Consider the problem of joint shipping when the main and additional routes have the same starting point – the location of the transport company. The car “Ford Transit” with a weight of 1.65 tons and a loading capacity of 1.85 tons is used to transport cargo. The weight of the first cargo is 1.8 tons, while the weight of the second one is 0.9 tons. The loading time is 0.5 hours per ton. The time to enter the point is t = 0.05 h. The operating speed is V = 30 km/h. It is proposed that the problem be solved in seven steps, the block diagram of which is given in Fig. 4.

In order to achieve effective management of the shipping process when operating along the distributed route, when we transport the cargo in small batches, it is necessary to load the rolling stock from another manufacturer on the shipping route. In this case, unlike with the pendulum-type route (loading takes place at the place of cargo unloading), the additional loading of the vehicle takes place on the road of operation of the route. In this case, there are two different kinds of cargo on the car body: the main and additional ones. Therefore, at the next point of the route, two different cargoes are already unloaded.

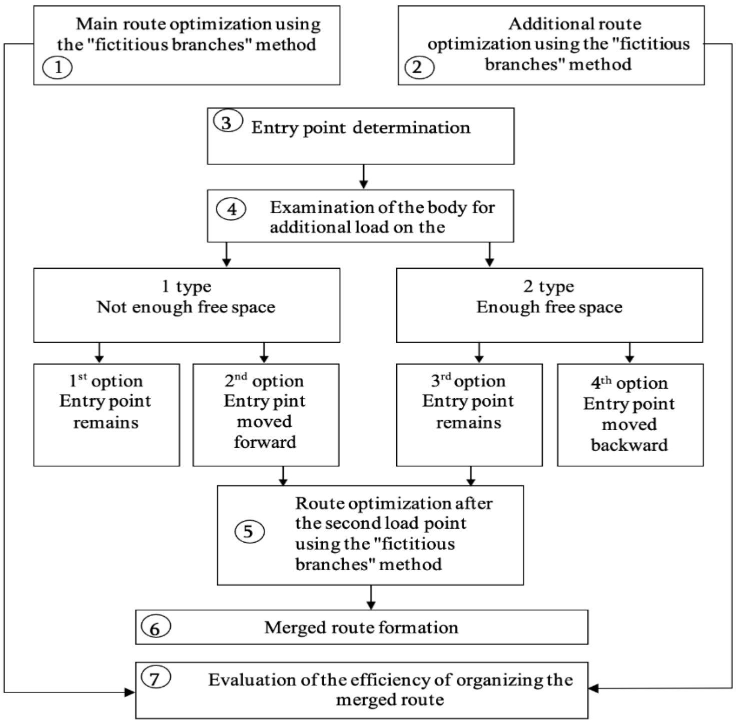
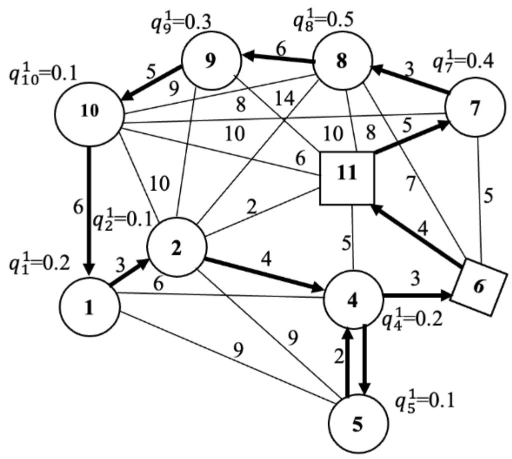


Fig. 4. The block-schematic diagram

The optimal route of the main cargo with a length of 43 km is shown in Fig. 5: 6–11–7–8–9–10–1–2–3–4–5–4–6. The road transport company is located at the sixth point, and the base of the main cargo is located at the 11th point. Additional cargo will be moved along the route with a length of 40 km according to the scheme shown in Fig. 6: 6–3–9–10–1–2–4–5–4–6. At the second stage, in order to determine the entry point to take additional cargo, we enter point 3 in the transport scheme shown in Fig. 5, where the second additional and cargo base are located. It is established that this point should be entered from point 8 (Fig. 7).

At the fourth stage, it was established that the space in the body opened up after the entry of the vehicle in the eighth point. If the space is insufficient, then a move can be made in the direction of travel on a 9-3 branch. The unloading points of the first cargo, which are located beyond the space of placement of the second cargo (Fig. 8), are added to the transport scheme as shown in Fig. 6.



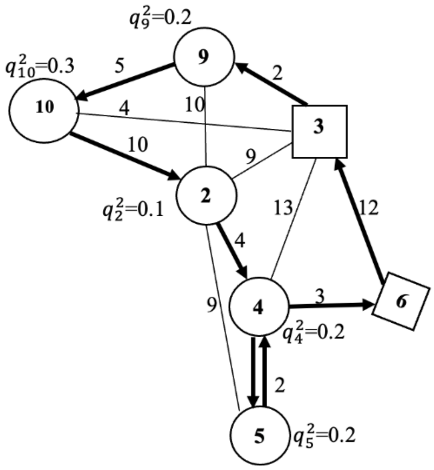


Fig. 5. Optimal delivery route for cargo
Fig. 6. Optimal route for delivering additional cargo

The joint route with a length of 44 km is obtained by adding the lengths of the distance of transporting the main cargo (until the eighth point), and the distance after is shown in Fig. 5: 6–11–7–8–3–9–10–1–2–4–5–4–6. We can distinguish four characteristic areas: the first one - zero mileage from the cargo company to the first cargo point - 11, the second - main cargo transportation from the 11th to the third point. At the seventh stage, the economic effect of the route is justified.

The full operation of the vehicle is equal to

$$P=P^{abm}+P^{mp,} \quad , \tag{5}$$

where P^{abm} – work spent on the movement of the vehicle (t.km);
P^{mp} – transport work, which is spent on the movement of cargo (t.km).

Let us give the equation from above the following form:

$$\frac{P}{P^{amp}} = 1 + \frac{P^{mp}}{P^{amp}} \tag{6}$$

Put transport work the equation (6):

$$K^{mp} = \frac{P^{mp}}{P^{amp}} = \frac{\sum_{j=1}^{n} q_{ij}\ell_{ij}}{G_{CH}L} \tag{7}$$

where q_{ij} – is the weight of cargo at the jth point of unloading, t;
L – route length, km;
G_{CH} – the weight of a properly functioning vehicle, t;
ℓ_{ij} – the distance between the i-th point of loading and the j-th point of unloading, km.

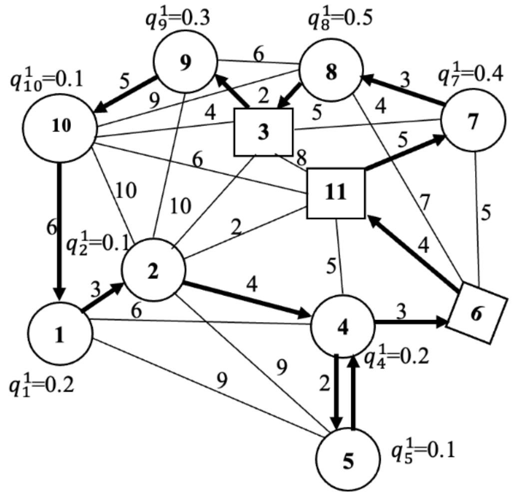


Fig. 7. Arrival for additional cargo

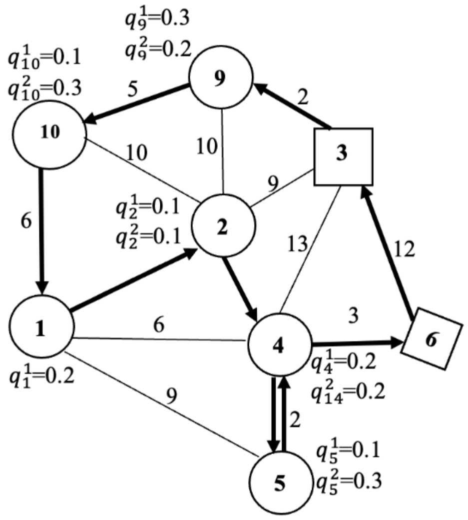


Fig. 8. Arrival route for the second cargo

The formula (7) can be transformed into the following form:

$$P=K^{Q}\gamma_{\partial}\beta \tag{8}$$

where, β – loaded mileage proportion;

γ_{∂} – dynamic coefficient of vehicle capacity utilization;

K^{Q} – coefficient of specific capacity, which is equal to:

$$K^{Q}=\frac{Q_a}{C_{CH}} \tag{9}$$

where Q_a – is vehicle capacity, t.

The proposed coefficient K^{mp} is a simple dimensionless coefficient because it does not depend on the speed of movement or the time or length of the route. It should be noted that its maximum value is obtained on the pendulum route when the reverse travel is carried out with cargo $\gamma_{\partial}\cdot\beta=1$.

$$K^{mp}=K^{Q} \tag{10}$$

The resulting equation proves the correctness of the chosen approach. In addition, increasing the coefficient of specific capacity makes the transportation process more efficient, which responds to the market demands that it is desirable to transport as much cargo as possible by small, low-weight vehicles.

To confirm this fact, we can consider several different brands of cars with different fuel consumption rates per unit load. The graphs are shown The following values can be used as estimated values: H_S – the basic norm of fuel consumption in normal conditions, l/100km; H_W – the fuel consumption rate for transport work, l/100 t·km.

As seen from the graphs, with an increase in capacity (including the use of trailers), the fuel cost per unit load decreases, which again indicates that it is better to use an indicator that takes into account the weight of the vehicle in order to evaluate the efficiency of transportation on circular routes. It should be noted that the same amount of work can be done at different times by vehicles of different capacities. Accordingly, productivity and fuel consumption will be different. The existing methodology for calculation does not take into account the mentioned circumstance. As fuel prices continue to rise, the cost of driving a vehicle is rising rapidly. This situation makes it necessary to change the approach to the assessment of the transportation process. The graphs are shown below in figures 9 and 10.

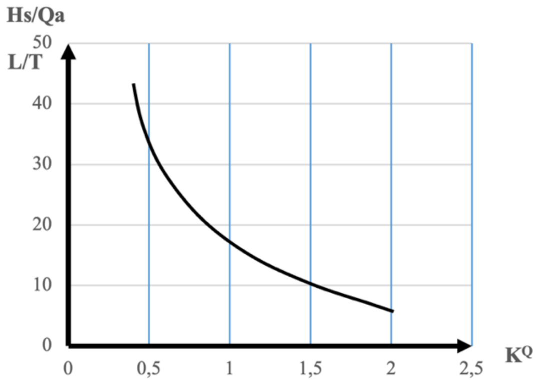


Fig. 9. Dependence of fuel consumption (per 1 ton of cargo) on the coefficient of specific load capacity

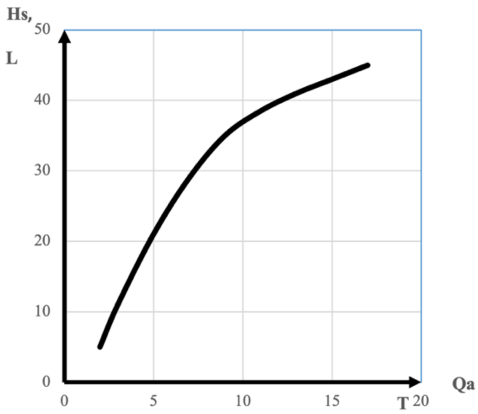


Fig. 10. Dependence of fuel consumption on vehicle capacity

Thus, the productivity calculation methodology needs further improvement. It is known from classical mechanics that power (in our case, productivity) is expressed by the formula:

$$W = \frac{P^{pm}}{t} \quad . \tag{11}$$

If we use equation (11), we can calculate the rolling stock productivity in ton-kilometers:

$$W = \frac{P^{pm}P^{abm}}{t} = \frac{K^{Q}\gamma_{\partial\beta}}{\frac{L}{V_T} + t^{np}} P^{abm} \quad , \tag{12}$$

where, V_T – technical speed, km/h;

t^{np} – time of loading and unloading operations, h;

t – traveling time.

If we divide the productivity of the rolling stock in ton-kilometers by work spent on the movement of the vehicle, we obtain the relative productivity coefficient (h^{-1}):

$$K^{W} = \frac{K^{mp}}{t} = \frac{K^{Q}\gamma_{\partial\beta}}{\frac{L}{V_T} + t^{np}} = \frac{P^{mp}}{P^{abm}t} \quad . \tag{13}$$

The analysis of the obtained formula shows that the greater the value of K^W, the greater the relative productivity of the vehicle. It is known that the highest productivity is achieved in the case of reverse travel with cargo on pendulum routes, when $\gamma_{\partial}\beta = \gamma_{c}\beta = 1$. Then, from equation (13), we find:

$$K^{W} = \frac{K^{Q}}{\frac{L}{V_T} + t^{np}} . \tag{14}$$

One can see from equation (14) that the greater the carrying capacity, the greater the productivity. This is confirmed in the case of using high-load vehicles and trailers. In addition, productivity can be increased by reducing route length or loading-unloading time. The formula is universal (13) and can be used for any route. In particular, in order to increase productivity, we should strive to increase the coefficient K^{mp} and reduce the traveling time.

We note that the criterion K^{W} excludes the inconsistency of productivity assessment in t/h and t·km/h. The graphical representation of the mentioned relationship is given in Figs. 11 and 12.

As seen from the graphs, the dependence of the relative productivity coefficient on the coefficient K^{Q} is linear. By reducing the traveling time, K^{W} increases significantly. For example, doubling K^{Q} increases the value of K^{W} from 0.25 to 2 h^{-1} (i.e., by eight times). Thus, in order to increase the value of K^{W}, we need to reduce the costs incurred for moving the vehicle. A further way to increase K^{W} is to reduce the time spent on the route. The dependence of K^{W} on time is hyperbolic.

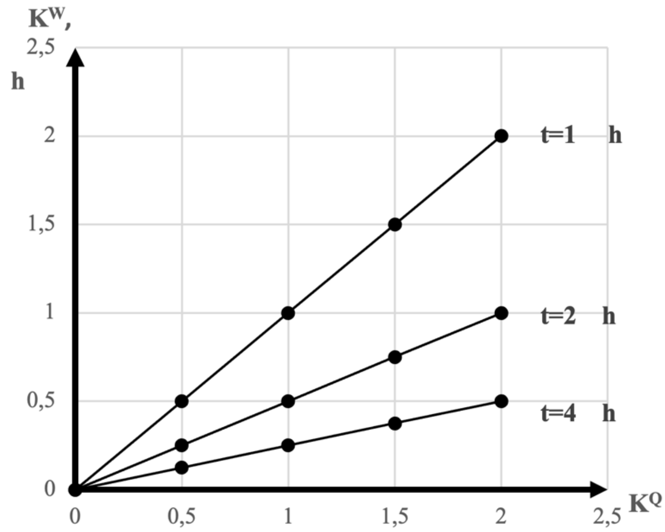


Fig. 11. Dependence of relative productivity coefficient on the coefficient of specific capacity

The time spent on the route can be expressed using three variables: length, speed, and loading-unloading time. In order to determine the influence of each of these quantities on vehicle capacity, we constructed a graph (Fig. 13).

For example, let us take the following data: length L=5 km; technical speed V_T=25 km/h; $K^{Q}=\gamma_C=\beta=0.5$; t^{np}=0.3 h. The horizontal line on the diagram corresponds to productivity K^{W}=0.250 h^{-1}. Let us increase the coefficient K^{W} by 1.2 times, and we will obtain its value K^{W}=0.31 h^{-1}. In addition, the length of the road will be reduced to 2.9 km (1.72 times), and the loading-unloading time will be reduced to 0.22 hours (1.36 times). K^{W} is most influenced by the coefficients K^{Q}, λ_{∂} and β, which are included in the magnitude of the relative transport performance of coefficient K^{mp}.

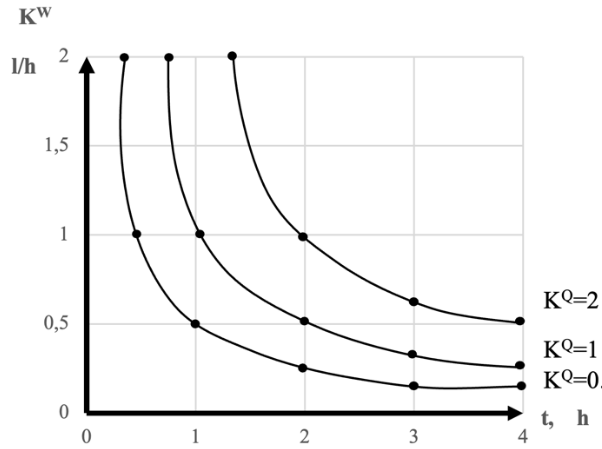


Fig. 12. Dependence of the relative productivity coefficient on time

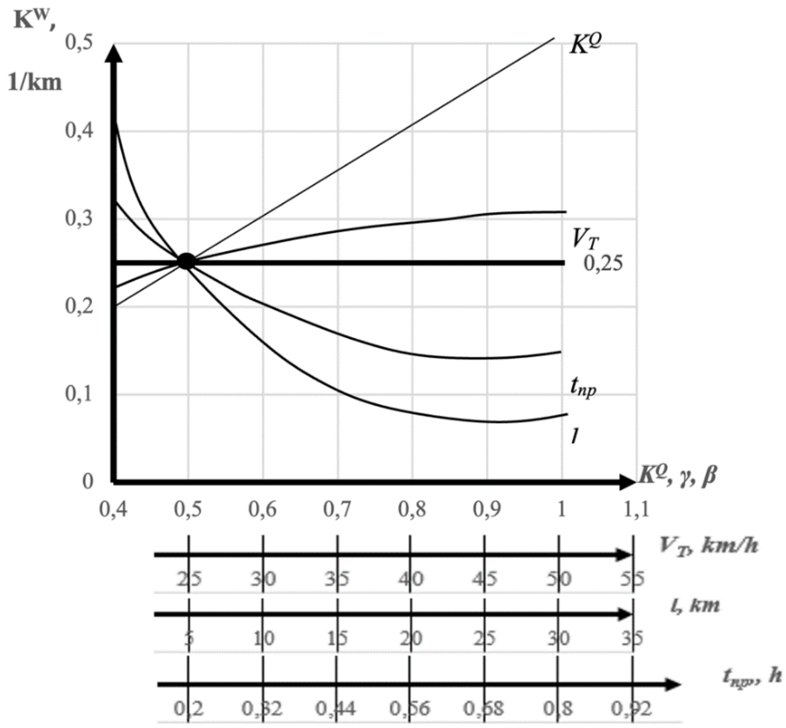


Fig. 13. Characteristic graph

We can see from the preceding discussion that, in the general case, we can get different combinations

are merged. However, it should be noted that the routes have different characteristics, particularly: the amount of cargo to be transported, the number of shipping points, the distance, the type of vehicle, and capacity. Therefore, in general, it is necessary to calculate the average technical-economic indicators. Technical-economic indicators are given in Table 1 to assess the effect obtained as a result of merging the routes.

Table 1

Technical-economic indicators

Route	T, h	W, t/h	W_P, t.km/h	L^x, km	K^Q	Z, GEL	K^W
Before merging	15,00	0,158	1,778	33,845	0,61	3067,5	0,007
After merging	13,35	0,206	1,843	7,823	0,83	2733,8	0,011

4. CONCLUSIONS

1. Tools were proposed to form a rational route when transporting goods in small consignments, thereby increasing shipping efficiency.
2. The classical branch-and-bound method was modernized, the main essence of which is the introduction of new fictitious nodes and connections in the transport network.
3. A mathematical model containing a number of new elements for connecting circular routes was developed. In particular, a coefficient for evaluating the efficiency of the transportation process was proposed, as well as the sequence of movements to pick up additional cargo by improving the routing algorithm.
4. The effectiveness and adequacy of the proposed methodology for cargo transportation in small batches in the case of two manufacturers have been determined. Merging the routes made it possible to increase the coefficient of mileage utilization by 20-25%, productivity (in t/h) by 5-25%, and productivity (in t·km/h) by 4-5%. In addition, the number of vacant runs and expenses during the route have been reduced.

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