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COMPREHENSIVE SOLUTION TO THE PROBLEM OF ROLLING STOCK CHOICE AND INVENTORY MANAGEMENT

The paper establishes the relationship between the distance of cargo transportation, the size of this consumption and the optimal batch of cargo, for a certain load capacity of the car, which allows to reduce the cost of freight and provide optimal choice of rolling stock, at which the total costs transportation of goods, the cost of material assets in circulation and investments in rolling stock and warehousing, reach a minimum. In the proposed model, the main factors were taken into account only the cost of order fulfillment and the cost of storing the goods. Ordering in small batches allows you to optimize the cost of ordering, and large batches — the cost of storage.
Keywords: *cargo; car; optimal; transportation; productivity; cost; system.*

У роботі встановлено взаємозв'язок між відстанню перевезення вантажу, розміром даного споживання та оптимальною партією вантажу, для певної вантажопідйомності автомобіля, що дає змогу знизити собівартість вантажних перевезень та забезпечити оптимальний вибір рухомого складу, при якій сумарні витрати, що складаються з витрат на перевезення вантажу, вартості матеріальних засобів в обігу та капіталовкладень в рухомий склад й складське господарство, досягають мінімуму. В запропонованій моделі основними чинниками враховувались тільки витрати виконання замовлення і вартість збереження вантажу. Замовлення дрібними партіями дозволяє оптимізувати витрати організації замовлення, а великими партіями — витрати збереження.
Ключові слова: *вантаж; автомобіль; оптимальний; перевезення; продуктивність; собівартість; система.*

Formulation of the problem

The main measures taken in road transport in recent years and aimed at improving production efficiency, increasing productivity are: increasing the use of vehicles, full use of their capacity and capacity, reducing empty runs, development of optimal schemes for transportation of goods, improvement technologies of organization of transportations, maintenance of rhythmicity of loading and unloading works for days.

Further development and improvement of road transport requires the training of qualified engineering and technical workers who have modern advanced means of organization, planning, implementation, analysis of the transportation process.

An important task of the organization of transportation is the choice of efficient vehicles that meet specific conditions. Technical and operational performance of the car is determined by the organization of transportation and a set of its operational properties: load capacity, use of mass, speed characteristics, fuel economy and others [1, 2].

Analysis of recent research and publications

Many scientists deal with the planning of the transport process using a mathematical and statistical study of the unevenness of cargo transportation, a comprehensive solution to the problem of selection of rolling stock and inventory management.

Thus, in [3] the authors studied the patterns of changes in the parameters of traffic during the transportation of goods. Using these laws, it is not possible to establish the relationship between the distance of transportation of goods, the size of its daily consumption and the optimal load capacity of rolling stock.

The work [4] is devoted to the methods of building logistics systems, namely the coordination of work schedules of loading and unloading points and the work of the rolling stock. The study conducted by the authors does not allow to adjust the load capacity of rolling stock and the total costs, which consist of the cost of transportation of goods, the cost of material resources and investments in rolling stock and warehousing.

The work [5] is devoted to production systems in transport. The systems presented in the work do not allow to fully obtain the dependences of the cost of maintaining the stock on the amount of stock, as well as to investigate the change in the amount of stock over time and determine the value of the delivery interval.

Formation of the purpose of research

The purpose of the work is to solve interrelated problems to determine the specialization and selection of rolling stock capacity, which provides low transportation costs and high productivity of the car.

Main material presenting

Dependences of the prime cost of transportations on loading capacity of a rolling stock and the size of the parties of the brought freights allow to specify and comprehensively analyze models of management of stocks and a choice of vehicles.

The cost of transportation of goods depends on the conditions of their delivery. Consider three cases [6].

In the case where the batch size q exceeds the load capacity of cars available $q > q_a \cdot \gamma_{\text{ст}}$, the cost of transportation does not depend on the size of the consignment, ie the cost of delivery of 1t of cargo in this case is constant

$$S_T^{(1)}(q) = a_1, \quad q > q_a \cdot \gamma_{\text{ст}}, \tag{1}$$

where $\gamma_{\text{ст}}$ — coefficient of static capacity of the car.

This factor is equal to the ratio of the mass of cargo transported in one flight to the minimum load capacity of the car

$$\gamma_{\text{ст}} = \frac{P_e}{q}. \tag{2}$$

If the size of the consignment, and accordingly the frequency of delivery is consistent with the load capacity of the car selected from a number $q > q_a \cdot \gamma_{\text{ст}}$, the cost of delivery of 1t of cargo depending on the load capacity of the car can be determined by the formula of the cost of transportation routes [7].

$$\bar{l}_{(i-1)-i} = 0 \;\; \text{і} \;\; q_a \cdot \gamma_p = q_p, \tag{3}$$

where $\bar{l}_{(i-1)-i}$ — the average distance of the car between adjacent points of delivery;

γ_p — load utilization factor.

There is a relationship between these ratios

$$\gamma_{\text{ст}} = \gamma_p (1 + k_c), \tag{4}$$

where k_c — a factor that takes into account the amount of the associated fee.

In this case, the dependence of the cost of delivery of 1t of cargo on the size of the consignment of cargo is served by the function

$$S_T^{(2)}(q) = a_2 + \frac{b_2}{q} + c_2 q, \qquad q = q_a \cdot \gamma_{\text{ст}}. \tag{5}$$

The cost of delivery of 1t of cargo is carried out on the routes of delivery $(q = q_a \cdot \gamma_{\text{ст}})$, depending on the average size of the consignment, calculated by the formula

$$S_T^{(3)}(q) = a_3 + \frac{b_3}{q}, \qquad q < q_a \cdot \gamma_{\text{ст}}. \tag{6}$$

The cost of preserving products consists of: the cost of self-preservation; costs due to natural reduction; losses due to reduced consumer quality of products and costs associated with the freezing of funds invested in stored products (stocks) [7].

The coefficients given in expressions (1, 5, 6) are estimated by formulas

$$a_1 = \left(\frac{C_{км} \cdot l_н}{\delta \cdot T_н} + C_{пос} \right) \cdot t_T ; \qquad (7)$$

$$a_2 = \frac{1}{(1+k_c)} \left\{ \frac{l_{(i-1)-i}}{g_p} \cdot a_{км} + \left(\frac{l_н}{T_н} \cdot a_{км} \right) \cdot \left[t_T (1+k_c) + \frac{t_3}{g_p} \right] + \left(2\bar{l}_i - l_{(i-1)-1} \cdot b_{км} \right) \right\} ; \qquad (8)$$

$$b_2 = \frac{a_{км}}{1+k_c} \cdot \left(2\bar{l}_i - \bar{l}_{(i-1)-1} \right) \cdot b_{км} ; \qquad (9)$$

$$c_2 = \frac{1}{1+k_c} \left\{ \frac{\bar{l}_{(i-1)-i}}{g_p} \cdot b_{км} + \left(\frac{l_н}{T_н} \cdot b_{км} + b_{пос} \cdot \delta \right) \cdot \left[t_T (1+k_c) + \frac{t_3}{g_p} \right] \right\} ; \qquad (10)$$

$$a_3 = \frac{1}{1+k_c} \left\{ \frac{C_{км} \cdot \bar{l}_{(i-1)-i}}{g_p \cdot \delta} + \left(\frac{l_н \cdot C_{км}}{T_н \cdot \delta} + C_{пос} \right) \cdot \left[t_T (1+k_c) + \frac{t_3}{g_p} \right] \right\} ; \qquad (11)$$

$$b_3 = \frac{C_{км} \cdot \left(2\bar{l}_i - \bar{l}_{(i-1)-1} \right)}{g \cdot (1+k_c) \cdot \delta} , \qquad (12)$$

where $C_{км}$ — costs per 1 km

$$C_{км} = C_{зм} + \frac{C_{пост}}{V_T} , \qquad (13)$$

$$C_{км} = a_{км} + b_{км} \cdot g_a \cdot \gamma_{ст} , \qquad (14)$$

$C_{зм}$ — changes in costs per 1 kilometer of the car, UAH / km;

$C_{пост}$ — fixed costs for 1 hour of car operation, UAH / hour;

$$C_{пост} = a_{пос} + b_{пос} \cdot g_a \cdot \gamma_{ст} , \qquad (15)$$

$T_н$ — time of stay of the car in an outfit, hours;

$l_н$ — zero mileage for the whole day of the car, km;

δ — coefficient,

$$\delta = \frac{T_м}{T_н} ,$$

$T_м$ — working time on the route, hours;

t_T — time spent on loading and unloading 1t of cargo, hours;

V_T — technical speed of the car, km / h;

t_3 — additional time for each arrival at intermediate points, hours;

$\bar{l}_{(i-1)-i}$ — distance of run of the car between adjacent points of delivery of freight, km.

In case $q < q_a \cdot \gamma_p$ also additionally take into account the change in the cost of delivery depending on the size of the consignment, but for the conditions of the route of delivery. Formula (10) determines the optimal average batch size for several consumers included in one route, and the batch size for each consumer should be chosen in proportion to demand [8].

Since the choice of car capacity for delivery of goods on routes is an extreme task, and the value of the optimal capacity of the car depends on the average size of the consignment, it is of interest to solve the problem of choosing the size of the consignment and car capacity:

$$\left.\begin{aligned}\frac{\partial S(q_p, q_a\gamma_p)}{\partial q_p} = 0\\ \frac{\partial S(q_r, q_a\gamma_p)}{\partial (q_a\gamma_p)} = 0\end{aligned}\right\} q_r = q\,. \tag{16}$$

The dependence of the total costs per 1t of transported cargo on the average batch size q is given by the equation

$$S_T(q) = a + \frac{b}{q} + cq\,. \tag{17}$$

To determine how it depends on the load capacity of the car $q_a\gamma_p$ total costs, it is necessary to replace the function in equation (17) $S_T(q)$ an appropriate formula that reflects the dependence on this value of the cost of delivery.

Differentiating equation (16) of the dependence of the cost per 1t of cargo transported, respectively q_{ponm} and $q_a\gamma_{ponm}$, and equating to zero, we arrive at the expressions [9]

$$q_{ponm} = (1+k_T)\sqrt{\frac{\left[a_{в.з}(1+k_c) + \frac{C_{км}}{\delta}\left(\bar{l}_{(i-1)-i} + \frac{l_н}{T_н}t_з\right) + C_{пос}t_з\right]r}{\left[0{,}5C_{зб} + C_{тар}k_T k_{пв}(1+k_c)\right]}}\,, \tag{18}$$

$$q_a\gamma_{ponm} = (1+k_T)\sqrt{\frac{q_p\left(r\bar{l}_i - \bar{l}_{(i-1)-1}\right)a_{км}}{b_{км}\bar{l}_{(i-1)-1} + \left(\frac{l_н}{T_н}b_{км} + \delta b_{пос}\right)\left[t_T(1+k_c)q_p + t_з\right]}}\,. \tag{19}$$

Sizes $C_{км}$ and $C_{пост}$ in equation (18) depend on the load capacity of the car.

Expression (15) determines the optimal load capacity of the car on the routes of transportation.

This system (18—19) is most easily solved by the iterative method.

Setting the full load capacity of the car according to formula (18) find the corresponding optimal size of the average batch of cargo, and then according to formula (18) — the corresponding optimal load capacity. The calculations are repeated until two consecutive calculations lead to the choice of the same load capacity: this load capacity and the corresponding average batch size are optimal.

When delivering goods in revolving containers (containers), in addition to the above, the costs associated with the removal of containers from circulation are also taken into account.

The cost of maintaining stock x per unit time

$$S_{зб}(x) = x \cdot C_{зб} + C_{тар} \cdot q_T \cdot k_{п.в}\,, \tag{20}$$

where $C_{зб}, C_{тар}$ — the cost of storing 1t of products and containers per unit time;

q_T — mass of container in one batch of delivery, t;

$k_{п.в} = {t_{в.т}}/{t_q}$ — coefficient that takes into account the frequency of container removal;

$t_{в.т}, t_q$ — time intervals, respectively, between the next removals of containers and regular deliveries of products.

Because

$$q = q_T + q_n = \left(1 + \frac{1}{k_T}\right) \cdot q_T\,, \tag{21}$$

where q_n — mass of products in one batch of delivery, t;

$k_T = \frac{q_T}{q_n}$ — tare ratio, then

$$S_{зб}(x) = x \cdot C_{зб} + \frac{C_{тар} \cdot k_{п.в} \cdot k_T}{1 + k_T} \cdot q. \quad (22)$$

The simplest inventory management model is a model in which the cost of fulfilling the order does not depend on the size of the shipment.

But a more common case is when the cost of ordering a consignment of cargo size q.

$$S_{зам}(q) = a_{в.з} + b_{в.з} \cdot q, \quad (23)$$

where $a_{в.з}$ та $b_{в.з}$ — constant values.

Using the obtained dependences, the cost model can be presented as follows:
the cost of organizing the order of the consignment

$$S_{зам}(q) = \begin{cases} a_{в..з} + b_{в..з} \cdot q, & q > 0; \\ 0, & q = 0. \end{cases} \quad (24)$$

Therefore, the cost of delivery of 1t of cargo when delivered to the consumer is determined by the expression

$$S_m(q) = \begin{cases} a_1, & q > q_a \gamma_{ст}; \\ a_2 + \frac{b_2}{q} + c_2 q, & q = q_a \gamma_{ст}; \\ a_3 + \frac{b_3}{q}, & q < q_a \gamma_{ст}. \end{cases} \quad (25)$$

and the cost of maintaining x the stock per unit time

$$S_{зб}(x) = \begin{cases} C_{зб} x + pq, & x \geq 0 \\ pq, & x < 0 \end{cases} \quad (26)$$

Consider the simplest model of inventory management of homogeneous products with a known constant demand with intensity r [10]. The unknown value in this case is the size of the delivery q, associated with the size of the consignment of imported products

$$q_n = q(1 + kr). \quad (27)$$

With determined demand and supply there is no need for stock insurance — the order is repeated after the stock is reduced.

The current value of the stock at time t characterizes the function

$$x(t) = q_n - rt. \quad (28)$$

From the condition $x(t_д) = 0$ determine the delivery interval

$$t_д = \frac{q_n}{r}. \quad (29)$$

For each delivery interval, the dynamic problem is solved independently, that is, a sequence of independent static problems (models) is considered.

In the first model, only the cost of order fulfillment and the cost of storage are important. Frequent orders in small batches increase the cost of organizing the order, and rare, carried out in large batches — the cost of storage.

Based on the specific conditions, it is possible to establish the relationship between the distance of cargo transportation, the size of its daily consumption, the cost of cargo and the optimal carrying capacity of rolling stock, in which the total costs of transportation costs warehouse and warehousing, reach a minimum. Mathematical and static methods made it possible to construct a table for tabl. 1.

Table 1. The relationship between the distance of transportation of goods, the size of this consumption and the optimal batch of cargo, for a certain load capacity of the car

Transportation distance, $l_в$, km	The optimal batch size, which corresponds to the load capacity of the car, t					
	1	2,5	5	10	20	60
5	1100	525	100	45	11	1,2
10	2900	800	230	60	16	1,8
25	8300	1700	450	115	90	3,3
50	17500	3100	800	210	52	5,8
100	35000	6000	1500	350	100	11
200	70000	11000	3000	750	190	2,1

Conclusions

Based on the specific conditions, it is possible to establish the relationship between the distance of cargo transportation, the size of its daily consumption, the cost of cargo and the optimal carrying capacity of rolling stock, in which the total cost of transportation, cost of goods in circulation and capital investment warehouse and warehousing, reach a minimum.

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КОМПЛЕКСНЕ РІШЕННЯ ЗАДАЧІ ВИБОРУ РУХОМОГО СКЛАДУ ТА УПРАВЛІННЯ ЗАПАСАМИ

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Реферат

Основними заходами, прийнятими на автомобільному транспорті в останні роки і спрямованими на підвищення ефективності виробництва, підвищення продуктивності праці, були: організаційні заходи для збільшення використання транспортних засобів, більш повне використання їх вантажопідйомності та місткості, скорочення порожніх пробігів, розробка оптимальних схем перевезення вантажів, вдосконалення технології організації перевезень, підтримання ритмічності вантажно-розвантажувальних робіт за добу. Подальший розвиток та вдосконалення автомобільного транспорту вимагає підготовки кваліфікованих інженерно-технічних працівників, які мають сучасні передові засоби організації, планування, впровадження, аналізу транспортного процесу. Важливим завданням організації перевезень є вибір ефективних транспортних засобів, які найкраще відповідають конкретним умовам. Технічні та експлуатаційні характеристики автомобіля визначаються організацією перевезення та сукупністю його експлуатаційних властивостей: вантажопідйомність, використання ваги, швидкісні характеристики, економія палива тощо.

Метою роботи є вирішення взаємопов'язаних задач щодо визначення спеціалізації та вибору пропускної здатності рухомого складу, що забезпечує низькі транспортні витрати та високу продуктивність автомобіля.

Виходячи з конкретних умов, можна встановити взаємозв'язок між відстанню перевезення вантажу, величиною його щоденного споживання, вартістю вантажу та оптимальною вантажопідйомністю рухомого складу, при якій сумарні витрати, що складаються з витрат на перевезення вантажу, вартості матеріальних засобів в обігу та капіталовкладень в рухомий склад й складське господарство, досягають мінімуму.

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