Enhancement of the efficiency of transportation of the company’s own cargo in operational scheduling

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Abstract. The paper considers alternatives for cargo transportation using several technological methods at the scheduling stage, i.e. development of several possible options for cargo transportation scheduling. Calculations of technical and operational performance are performed. The considered options for cargo transportation included both a pendulum route and a circular route, using both privately-owned and rented vehicles at an hourly rate. Cargo transportation costs for all the developed options are determined. A criterion for cargo transportation efficiency is proposed to show the maximum difference between the costs of cargo transportation for a pendulum route with dead return mileage of the company's own vehicles and other technological means of cargo transportation. The regression dependencies of the criterion of cargo transportation efficiency on cargo transportation distance in the range from 1 to 45 km are found. Adequacy test is conducted.

1. Introduction

It is known that “the fleet of vehicles in Russia is heterogeneous. For example, in terms of ownership, it is distributed as follows. Privately-owned trucks amount to 53% of all registered vehicles. Only 50 thousand trucks out of the total number of vehicles, which is 5.3 mln units, work at the enterprises of the Road Transport industry. The rest of the vehicles are owned by enterprises of various sectors of the economy” [3].

More than 90% of the total freight traffic in the national economy is performed by vehicles of enterprises and organizations through own-account transportation by vehicles privately-owned or those owned on other legal grounds [1].

The competitiveness of the product is largely determined by its price, which includes the transportation cost from the production place to the consumption place. Operational scheduling has significant potential for efficiency enhancement, including reduction of the transportation cost to meet practical needs. Scientists [4,7] emphasize that measures should be developed to reduce consumption of transport products at the scheduling stage of transport production (traffic) since if transportation is completed, it is simultaneously consumed, and hence transportation products are used inefficiently.

The paper considers transportation of own cargoes of companies of a non-transport profile by non-public transport vehicles on various routes, using both privately-owned and rented vehicles.
2. Main part

The objective of the study was reached through the following steps:

Step 1. Based on the initial data, several pendulum routes with dead return mileage have been designed. Options of the operational schedule for cargo transportation for each of these routes were designed using both privately-owned vehicles and vehicles rented at an hourly rate. The performance parameters and the cost of cargo transportation are calculated for the distance changing from 1 to 45 km for each option of the operational schedule.

Step 2. An alternative option for cargo transportation is developed, which uses a single, but more complex route, including all pendulum routes with dead mileage designed earlier in Step 1. An option of the operational schedule for cargo transportation is designed for a circular route by both privately-owned vehicles and vehicles rented at an hourly rate. The calculations of the performance parameters and the cost of cargo transportation are performed for distance changing from 1 to 45 km for each option of the operational schedule.

Step 3. An efficiency criterion for transportation of the company's own cargo is proposed, which shows the maximum difference between the cargo transportation cost for a pendulum route with dead mileage by privately-owned vehicles and the cargo transportation cost for a circular route. The results of the calculations (Step 3) were used to determine the numerical values of the cargo transportation efficiency.

Step 4. Regression dependencies of the cargo transportation efficiency on changes in the distance of cargo transportation in the range from 1 to 45 km are established, and the adequacy test is performed.

Step 5. The results of the study are analyzed and conclusions are drawn.

The performance of the tasks of the main production is considered for two pendulum routes with dead return mileage or a single circular route using both the vehicles owned by the company and those rented at an hourly rate.

Two pendulum routes with dead mileage ($\beta = 0.5$) are developed (Figure 1). According to [5], the performance parameters (PP) for operation of privately-owned vehicles were calculated for cargo transportation at each stage of the route. In the first option of cargo transportation, privately-owned vehicles were used (Table 1), and in the second option rented vehicles were employed (Table 2).

![Figure 1](image-url)  
**Figure 1.** Scheme of the pendulum route with dead return mileage and dead mileages: where $L_c$ is loaded mileage, km; $L_x$ is dead mileage, km; $L_{d1}$ is the first dead mileage (mileage without cargo from the parking place to the place of the first loading), km; $L_{d2}$ is the second dead mileage (mileage without cargo from the place of unloading to the parking place), km; $\Delta$ is parking place.

The for cargo transportation costs by privately-owned vehicles for pendulum routes with dead return mileage are determined according to [2], and rented vehicles are calculated by equations (1–3):

$$T_{oa} = \frac{L_c}{V_t} + T_{lu},$$

(1)
where \(T_{oa}\) is order actual time, h; \(L_c\) is cargo transportation distance, km; \(V_i\) is average road speed, km/h; \(t_{lu}\) is loading and unloading time per ride, h.

\[
T_{rt} = T_{oa,\text{aver}},
\]

where \(T_{rt}\) is rent time of the vehicle, h;

\[
C_r = T_r \cdot C_{hr} + C_{prov},
\]

where \(C_r\) is vehicle rental cost, rub; \(C_{hr}\) is rental cost per 1 hour that corresponds to the vehicle capacity, rub; \(C_a\) is vehicle arrival to the loading place that corresponds to the vehicle capacity, rub.

**Table 1.** PP results for privately-owned vehicles, \(L=L_{c1}=1\) km, \(\beta=0.5\)

| Parameters                  | Values |
|-----------------------------|--------|
| Output of vehicles in tons \(Q, t\) | 45.0   |
| Output of vehicles in ton-kilometers \(P, t\cdot km\) | 45.0   |
| Total mileage of vehicles \(L_{total}, km\) | 41.0   |
| Actual time in the order \(T_{oa}, h\) | 8.1    |

**Table 2.** PP results for vehicles rented, \(L=L_{c1}=1\) km, \(\beta=0.5\)

| Parameters                  | Capacity \(q, t\) |
|-----------------------------|-------------------|
|                            | 3.0               | 5.0               | 7.0               |
| Output of vehicles in tons \(Q, t\) | 45.0   | 45.0   | 45.0   |
| Output of vehicles in ton-kilometers \(P, t\cdot km\) | 45.0   | 45.0   | 45.0   |
| Total mileage of vehicles \(L_{total}, km\) | 28.0   | 18.0   | 12.0   |
| Actual time in the order \(T_{oa}, h\) | 7.5    | 6.3    | 5.4    |

Next, cargo transportation for a more complex route is considered, i.e. a circular route was developed (Figure 2), where the vehicle performs loading during 8 hours. In cargo transportation in the first option, privately-owned vehicles were used (Table 3), in the second option, rented vehicles of different capacity were employed (Table 4).

**Figure 2.** Circular route and zero mileages.

**Table 3.** PP results for privately-owned vehicles, \(L=L_{c1}=1\) km

| Parameters                  | Values |
|-----------------------------|--------|
| Route length \(L_e, km\)    | 3.5    |
| Turnover time \(t_e, h\)    | 0.9    |
| Total number of turnover performed by the vehicle \(Z_t\) | 9.0 |
| Output of vehicles in tons \(Q, t\) | 45 |
| Output of vehicles in ton-kilometers \(P, t\cdot km\) | 45 |
| Total mileage of vehicles \(L_{total}, km\) | 35 |
| Actual time in the order \(T_{oa}, h\) | 7.8 |
Further, the criterion of $R_E$ efficiency for all options of transportation of the company’s own cargo is determined. According to the results of calculations of the cost of vehicle loading at $T_h = 8$ h on the ring route and the criterion of transportation efficiency ($R_E$), using the Curve Fitting application of the MATLAB software product, we obtained regression equations reflecting the dependence of $R_E$ on the distance $L_e$ and the volume of cargo transportation $Q$, representing are polynomials of 2nd degree.

For $L = L_{e1} = 1; 2; ...; 29$ km

$$R = a_{00} + a_{10} \cdot Q + a_{01} \cdot L + a_{20} \cdot Q^2 + a_{11} \cdot Q \cdot L$$

(4)

where $a_{00}, a_{10}, a_{01}, a_{20},$ and $a_{11}$ are the coefficients of regression equations.

Table 5 shows the values of the coefficients of regression equations (4), (5) and the values of the corresponding p-levels.

**Table 4. PP results for vehicles rented, $L=L_{e1}=1$ km**

| Parameters                                    | Capacity q, t |
|-----------------------------------------------|---------------|
|                                               | 3.0           | 5.0           | 7.0           |
| Output of vehicles in tons $Q$, t             | 45.0          | 45.0          | 45.0          |
| Output of vehicles in ton-kilometers          | 45.0          | 45.0          | 45.0          |
| $P$, t km                                     |               |               |               |
| Total run of vehicles $L_{total}$, km         | 20.0          | 10.5          | 7.5           |
| Actual time in the order $T_{oa}$, h          | 7.9           | 6.7           | 5.8           |

Further, the criterion of $R_E$ efficiency for all options of transportation of the company’s own cargo is determined. According to the results of calculations of the cost of vehicle loading at $T_h = 8$ h on the ring route and the criterion of transportation efficiency ($R_E$), using the Curve Fitting application of the MATLAB software product, we obtained regression equations reflecting the dependence of $R_E$ on the distance $L_e$ and the volume of cargo transportation $Q$, representing are polynomials of 2nd degree.

For $L = L_{e1} = 1; 2; ...; 29$ km

$$R = a_{00} + a_{10} \cdot Q + a_{01} \cdot L + a_{20} \cdot Q^2 + a_{11} \cdot Q \cdot L$$

(4)

where $a_{00}, a_{10}, a_{01}, a_{20},$ and $a_{11}$ are the coefficients of regression equations.

Table 5 shows the values of the coefficients of regression equations (4), (5) and the values of the corresponding p-levels.

**Table 5. Values of the regression equation coefficients**

| Coefficient | Value of the regression equation coefficients for $L = L_{e1} = 1; 2; ...; 29$ km | Value of the regression equation coefficients for $L = L_{e1} = 1; 2; ...; 45$ km |
|-------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
|             | before adjustment                                                               | after adjustment                                                                |
| $a_{00}$    | 1218.56                                                                         | -73.65                                                                          |
| $a_{01}$    | 0.000015                                                                        | 0.690277                                                                        |
| $a_{10}$    | -99.15                                                                          | -1.09                                                                          |
| $a_{11}$    | 0.000145                                                                        | 0.939781                                                                        |
| $a_{20}$    | 27.78                                                                           | 50.47                                                                          |
| $a_{21}$    | 0.042825                                                                        | 0.000000                                                                       |
| $a_{10}$    | 0.000046                                                                        | 0.098062                                                                       |
| $a_{11}$    | 7.1                                                                              | 3.36                                                                           |
| $a_{11}$    | 0.000016                                                                        | 0.000000                                                                       |

Using the software STATISTICA 6.0 and [6], $a_{11}$ coefficient from equation (4) and $a_{21}$ coefficient from equation (5) were found to be insignificant, since their p-level exceeds the probability of a deviation error of the null hypothesis. The model adequacy was verified through the exception of these coefficients, and $R_E$ regression equations takes the form:

For $L$ with $L = L_{e1} = 1; 2; ... 29$ km:

$$R_E = 1218.56 - 99.15Q + 27.78L + 1.91Q^2 + 7.11QL;$$

(6)

For $L$ with $L = L_{e1} = 1; 2; ... 45$ km:

$$R_E = 50.24L + 0.39Q^2 + 3.01QL.$$  

(7)

Table 6 shows the values of the quality parameters of regression dependencies (6) and (7) with a confidence level of $P=0.95$; significance level $\alpha=0.05$; numbers of calculations $N_{calc} = 29$ and 45; numbers of independent variables $n=2$, numbers of estimated parameters $r = 5$ and 3.
Table 6. Quality parameters of regression dependencies

| Parameter                                      | Value       |
|-----------------------------------------------|-------------|
| Residual sum of squares $R_{ss}$              | 12492       |
| Determination Coefficient of $R^2$            | 0.9923      |
| Adjusted coefficient of determination $R^2_a$ | 0.991       |
| Mean squared error of the equation $S_{eq}$   | 72.15       |
| Fisher criterion, $F$                         | 1675.31     |
| Student criterion, $t$                        | 40.93       |
| Mean relative approximation error, $E_{rel}$, %| 3.0         |

As can be seen in Table 6, the values of the determination coefficient $R^2$ of the regression equation do not go beyond $[0; 1]$. This indicates a high explanatory power of this equation. The adjusted determination coefficient $R^2$ is almost similar to the determination coefficient $R^2$.

For equation (6) with $\alpha=0.05$; $d.f.1=2$; $d.f.2=26$; $F_{crit}$ (0.05; 2; 26)=0.51, and for equation (7) with $\alpha=0.05$; $d.f.1=2$; $d.f.2=42$; $F_{crit}$ (0.05; 2; 42) = 0.051. It can be seen that $F>F_{crit}$, i.e. the determination coefficients are considered significant with a confidence probability of $P=0.95$.

For $\alpha=0.05$; $N_{on}=29$ and 45; $r=5$ and 3; $t_{crit}$ (0.05; 24)=1.71 and $t_{crit}$ (0.05; 41)=1.68. It can be seen that $t>t_{crit}$, therefore the main hypothesis about the insignificance of the coefficients of regression equations (6) and (7) is rejected.

The average relative error of approximations is 3.0% and 5.0%, respectively, which indicates high accuracy of these equations.

Figure 3 presents a graphical view of the regression dependence of $R_E=f(Q,L)$ in the interval from 1 to 29 km, and Figure 4 shows its graphical view in the interval from 1 to 45 km.

![Figure 3. Dependence of $R_E=f(Q,L)$ for $L=L_c=1; 2; \ldots 29$ km.](image)
Figure 4. Dependence of $R_{E}=f(Q, L)$ for $L=L_c=1; 2; \ldots 45$ km.

The quality indicators of equations (6) and (7) allow us to claim that the established regression dependencies with a confidence probability of 0.95 adequately describe the process under study.

3. Conclusion
A potential for enhancement of the efficiency of transportation of the company’s own cargo at the operational scheduling stage was confirmed, regardless of the distance and volume of cargo transportation.

In the study, the improved operational scheduling of transportation of the company’s own cargo is achieved through the one-time development of several options of one operational schedule and selection of the lowest cost based on the proposed criterion.

The effect of distance on the efficiency of transportation of the company’s own cargo by non-public vehicles is described by polynomial regression dependencies. A high coefficient of determination of the established equations indicates their high explanatory power; the maximum approximation error is less than 15%. This suggests that the established regression dependencies with a confidence level of 0.95 are adequate to the studied process of operational scheduling of transportation of the company’s own cargo.

References
[1] Gorev A E 2008 Freight road transport: studies. allowance for stud. higher studies (Moscow: Academy Publishing Center) 288 p.
[2] Instructions on the composition, accounting and calculation of costs included in the cost of transportation (works, services) of road transport enterprises (approved by the Ministry of Transport of the Russian Federation on August 29, 1995) [Electronic resource] (Moscow)
[3] Kurganov V M 2013 Macroeconomic assessment of transport potential. Laws of logistics and statistical laws: monograph (Tver: Tver. State Univ.) 68 p.
[4] Nikolin V I 1990 Autotransport process and optimization of its elements (Moscow: Transport) 91 p.
[5] Nikolin V I 2000 Scientific basis for the improvement of the theory of road freight Dissertation, Moscow
[6] Saati T L 1991 Analytical planning. Organization of systems (Moscow: Radio and communication) 224 p.
[7] Shafirkin B I 1978 Improving the efficiency of freight transportation of the USSR transport system (Moscow: Transport) 240 p.