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THE EFFECT OF ASYMMETRIC FREIGHT TRAFFIC ON THE SELECTION OF OPTIMAL LOCOMOTIVE TRACTION ON LITHUANIAN RAILROAD

У статті розглянуто як впливає асиметричність вантажних потоків залізниць Литви у західному та східному напрямках на вибір оптимальної локомотивної тяги. На підставі аналізу даних по вантажообігу 1999 р. зроблено висновок, що раціональним рішенням є такий розподіл локомотивної потужності, щоб для західного напрямку вона була в 2,7 разів більшою, ніж для східного.

В статье рассмотрено как влияет асимметричность грузовых потоков железных дорог Литвы в западном и восточном направлениях на выбор оптимальной локомотивной тяги. На основе анализа данных по грузообороту 1999 г. сделан вывод, что рациональным решением является такое распределение локомотивной мощности, чтобы для западного направления она была больше в 2,7 раз, чем для восточного.

The paper deals with the effect of asymmetric character of the Lithuanian railroad freight traffic in western and eastern directions on the selection of optimal locomotive traction. On the basis of analysis of data on freight turnover in 1999, it has been concluded that the rational solution is such an allocation of the locomotive power, which would give to the west-bound direction 2.7 times higher power than to the east-bound one.

Introduction

In studying railroad operation, the problems of the efficient use of rolling stock and its calculation are often encountered. The research institutions of the Western countries are reluctant in publishing the data of the investigation made in this area. The analysis of ecological and some technical problems is mainly provided [1; 2]. Some problems of efficient rolling stock operation and calculation have been successfully solved, which led to more efficient use of the rolling stock, as well as reducing the cost of transportation and increasing the profit. However, much is still to be done in this field, one of the problems being the selection of optimal rolling stock traction, taking into account non – uniform character of through freight traffic in opposite directions on the railroad.

Major objective

Rational use of the rolling stock, meeting the safety requirements, helps to increase economic efficiency of transportation, which is mainly determined by the payment for freight transportation and operation costs. Therefore, general economic effect may be calculated as follows:

$$E = E_a - E_e , \quad (1)$$

where E_a – payment obtained, Lt; E_e – operation costs, Lt.

Taking into account the fuel consumed and the dependence of the time of travel on the locomotive power and the power per rolling unit mass, we will obtain the relationship between the economic effect and the locomotive power and the power per rolling stock unit mass [3]:

$$E = \frac{N}{N_t} p_a - \Big[\left(0{,}0295N + 0{,}946\right) N_t^{-0{,}333} k_d + +22{,}56 N_t^{0{,}31} k_l \Big] 445 , \quad (2)$$

where L – length of railroad section, km; N – locomotive power, kW; N_t – locomotive power per rolling stock unit mass, kW/t; k_d – fuel expenditures, Lt/kg; k_l – relative time spent, Lt/min; p_a – payment for gross ton, Lt/t.

Applying (2) to the railroad section Kena – Klaipėda ($L = 445$ km) we will obtain the relationship represented graphically in fig. 1. The graph is based on the rates valid for 1999 (i. e. payment for transporting the unit mass, fuel expenditures, time spent, with the cost of 1 gross ton being 144 Lt (4)).

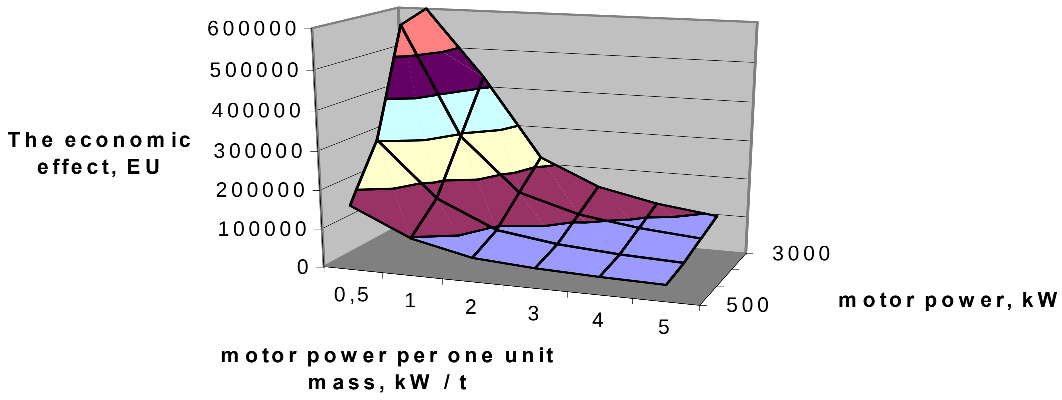

Fig. 1. The economic effect of one conditional depending on the motor power per unit mass

The analysis of limitations

As can be seen from Fig.1, graphical model has no extremums. Therefore, optimal points should be found based on limitations. Since a certain power is needed to overcome rolling resistance, there are some limitations of power per unit mass. The latter will be obtained by analysing the relationship between the allowable rolling stock mass and the locomotive power. This relationship varies depending on the road section. Joint – stock company "Lithuanian Railroads" made a survey of the above limitations. Based on its analysis, it was found that the locomotive power per unit mass depends on the power of the locomotive itself. This my be accounted for the fact that the higher the efficiency of the locomotive, the lower the safety factor needed. By approximating the relationship based on statistical data, we get the following expression of the locomotive power per unit mass:

$$N_t = 8{,}783 N^{-0{,}3134}. \tag{3}$$

There is also a limitation of the train length. If the power of a locomotive and train length are fixed, then the power per unit mass is limited as well. This constraint is also determined by the load on the axis (the higher the loading, the larger the train mass per unit length of the road). By expressing the limitation as a function of the locomotive power with respect to axis loading and power per unit mass, we will get:

$$N = \left(220{,}22 M_{ašies} - 65{,}226\right) N_t . \tag{4}$$

Then we may treat (3) and (4) as a system:

$$\begin{cases} N_t = 8{,}783 N^{-0{,}3134}; \\ N = \left(220{,}22 M_{ašies} - 65{,}23\right) N. \end{cases} \tag{5}$$

Based on an average axis loading in 1999 (127 KN) we get the following set of equations:

$$\begin{cases} N_t = 8{,}783 N^{-0{,}3134}; \\ N = 2731{,}5 N_t . \end{cases} \tag{6}$$

It is represented graphically in fig. 2.

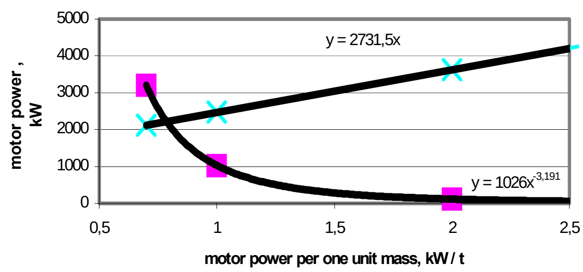

Fig. 2. Graphic form of system of equation

We can see in fig. 2 that the recommended relationship between the locomotive power and power per unit mass is shown by the strength line $y = 2731{,}5x$, while the lowest value of the power per unit mass is limited by the curve $y = 1026x^{-3{,}191}$. The fact that the above curve represents the least allowable power per unit mass is not a proof that the intersection point of the graphs in fig. 2 is an optimum. If we consider the relationship in fig. 2 as a horizontal projection of the relationships given in fig. 1, we can see that the economic effect is higher with increasing the locomotive power and decreasing power per unit mass. In the area defined, there is a set of points with similar economic effect. By connecting these points we get isolines of economic effect, which in this case resemble straight lines. By approximating a straight line, we will draw one of them beside the graphs shown in fig. 2. The results obtained are given in fig. 3.

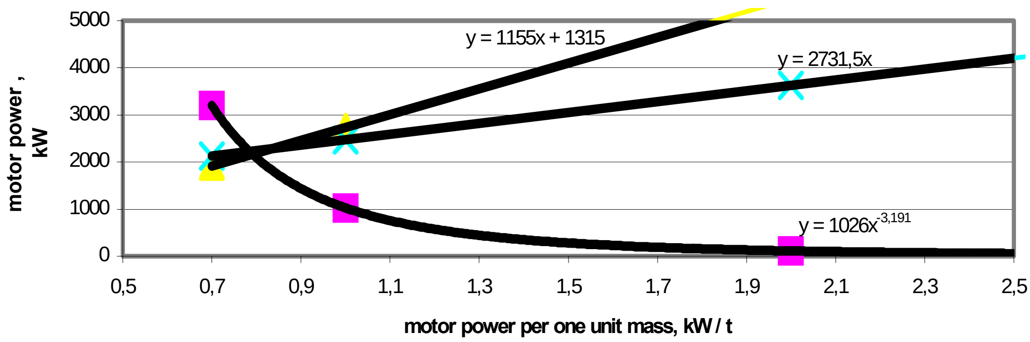

Fig. 3. Isoline with equations of limits

In fig. 3 the isoline shows that the economic effect is higher upwards from the straight line $y = 1155x + 1315$ than downwards, i. e. is increasing downwards and to the right with respect to the straight line $y = 2731,5x$. However, the economic effect is growing only if the freight turnover is sufficiently high. The relationship between rational freight turnover and the locomotive power and power per unit mass is as follows [3]:

$$A = 16,64N \cdot N_t^{-0,854}. \qquad (7)$$

By considering the data of 1999 (i. e. freight turnover, capacity of infrastructure, etc.), it was found that the relationship between optimal locomotive power and power per unit mass is as follows:

$$N = 1311N_t^{0,854}. \qquad (8)$$

The above equation, together with limitations and an isoline, is represented graphically in fig. 4.

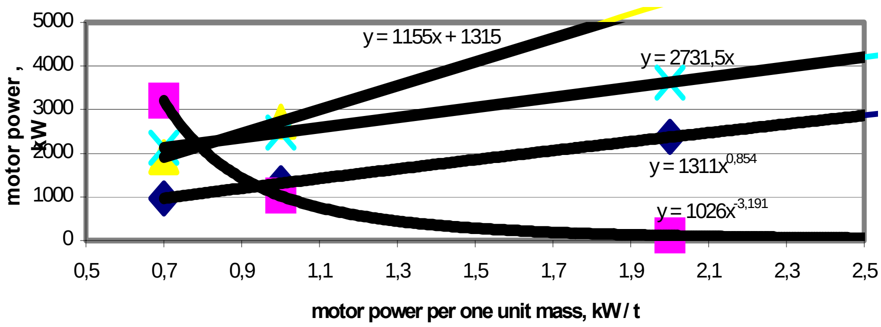

Fig. 4. Optimal motor power depending on motor power per one unit mass

In fig. 4 we can see that the required locomotive power is based on the relationship, taking into account the particular features of an infrastructure and freight turnover. Therefore, further we will consider the dependence of the optimal locomotive power on freight traffic. Based on (3), (7) and (8), a system of equations is obtained:

$$\begin{cases} N_t = 8,783N^{-0,3134}, \\ N = 2731,5N_t, \\ A = 16,64N \cdot N_t^{-0,854}. \end{cases} \qquad (9)$$

By solving the equations (9), we can get the point (the locomotive power and power per unit mass) at which the highest economic effect is achieved.

Determining traction of rolling stock based on freight traffic

By analysing the system of equations (9) we get the relationship between optimal locomotive power and freight traffic. It is given in table 1, being graphically represented in fig. 5.

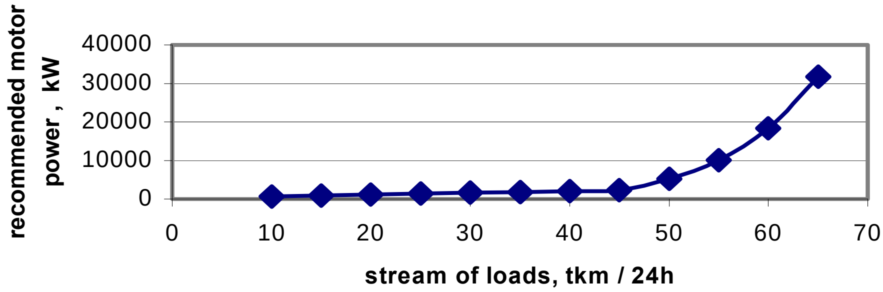

Fig. 5. Optimal motor power depending on evaluate difference of streams of loads

As we can see in fig. 5, the locomotive power should reach 2500 kW when freight turnover is 45,000 tons per 24 hours. It is hardly possible to increase freight turnover because of short arrival and departure roads. Therefore, to increase freight traffic up to 45,000 tons a day the higher speed of trains should be achieved. This in turn requires much higher locomotive power. According to the data for 1999, through traffic reached 21,800 tons per 24 hours. This means that through trains should be provided with locomotives of the power ranging from 1000 kW to 1500 kW. The average through traffic turnover (21,800 t per day) in Eastern direction makes 8,720 tons, while in Western direction it is 34,900 tons per day. This implies that the most appropriate power of East – bound locomotives would be 700 kW, while for West – bound trains it should be 1900 kW. The power required for West – bound locomotives is by 2,7 times higher than that of East – bound locomotives. The above results are obtained if freight traffic per day is evenly distributed, while East – and West – bound traction rolling stocks are made up individually, their power and number of trips not being coordinated with each other. It is hardly possible to apply the criteria stated to the actual conditions of Lithuanian railroad operation. In searching for the optimal locomotive power in both directions the arithmetically obtained average power should not be relied on for the reasons given below. To achieve the required freight turnover in Western direction $\sum A_{west}$, a certain traction power $\sum N_{west}$ is needed. When considering $\sum A_{west}$ and $\sum N_{west}$, we do not take into account the size of the available train or the power of a particular locomotive. It is assumed that the total freight turnover and rolling stock power are known. To maintain the balance of rolling stock flows (based on power), the flow of East – bound rolling stocks should be equal to the flow of West – bound rolling stocks: $\sum N_{east} = \sum N_{west}$, though freight turnover in Western direction is by about 4 times higher : $\sum A_{west} \approx 4 \sum A_{east}$. This means that the flow of locomotives in both directions is determined by freight turnover in Western direction. Therefore, it would be advantageous that the total flow of locomotives be as sparse as possible. To achieve this, rolling stocks should be made up as long as possible. Making up larger trains of lower power per unit mass, means lower total power as well. Therefore, 1900 kW locomotive power per trip in Western direction would not be appropriate for operational considerations. Power and mass of the train should be increased, while the number of trips be decreased.

Table 1

Dependence of an optimum locomotive power on freight turnover

A, 10^3 t	10	15	20	25	30	35	40	45	50	55	60	65
N, kW	673	927	1163	1301	1387	1808	2008	2240	5253	10091	18313	31687

A – turnover expected, 1000 tons per 24 h;
B – *N* – recommended locomotive power, kW.

Therefore, taking into account the asymmetry of the flows, we may see that uniform distribution of freight traffic during 24 hours is not rational from the locomotive operation perspective. By concentrating freight traffic, the number of trips may be reduced as well as the total traffic of the required rolling stock power. In this case, it would be advisable to consider a possibility to convey as transit the rolling stocks coming from Bielorussia, without re – forming them. Their mass usually ranges from 3,800 to 4,500 tons. The locomotive power and power per unit mass could be calculated from the set of equations (10) and (11):

$$\begin{cases} 4500N_t = N, \\ 1026N_t^{-3,191} = N, \end{cases} \quad (10)$$

$$\begin{cases} 3800N_t = N, \\ 1026N_t^{-3,191} = N, \end{cases} \quad (11)$$

A set (10) is used for a mass of a rolling stock being 4,500 tons, while (11) is applied when the mass is 3,800 tons. In both cases, the required number of trips may be formed from the formula:

$$R = A\frac{N_t}{N}. \quad (12)$$

The calculation data are given in table 2. It can be seen from the table, that for West – bound trains 3M62 sections should be used, while for East – bound trains 1M62 section could be applied. Thus, for the rolling stocks of 4,500 tons of mass 8 trips would be made. Based on the total economic effect and from operational considerations it is more rational to use rolling stocks of 4,500 mass in Western direction. This means that compared to the savings achieved by currently used methods the economic effect based on the approach suggested in the present paper would reach 8,924 Lt per 24 hours. For making up 4,500 t rolling stocks the shortest arrival and departure track should be determined by the formula:

$$L = L_{vag}\frac{4500}{84} + 54 + 10, \quad (13)$$

where L_{vag} – wagon length (in this case, 15 m); 84 – wagon mass, ton (with a rolling stock mass equal to 4,500 tons); 54 – length of 3M62 sections, m; 10 – reserve length, m.

Table 2

Results of calculating operational and economic characteristics

	Based on optimization results		Applying the results to currently used locomotives (of M62 sections)		Based on currently used method
Western direction					
M, t	3800	4500	3800	4500	3612
N_t, kW/t	0,732	0,703	1,16	0,98	0,8139
N, kW	2781	3163	4410/3528	4410/3528	2940/2352
R	10	8	10	8	10
E, EU/24h	1424387	1425293	1421304	1423330	1425055
Eastern direction					
M, t	872	1090	872	1090	1032
N_t, kW/t	0,732	0,703	1,685	1,349	2,849
N, kW	638	766	1470/1176	1470/1176	2940/2352
R	10	8	10	8	10
E, EU/24h	355708	355877	353889	354654	350379
ΣE, EU/24h	**1780153**	**1781171**	**177537**	**177984**	**1775434**
ΔE, **EU/24h**	4718	5736	–240	2370	0

For the wagon length of 15 m, the shortest arrival and departure track of 870 m was obtained.

Notes: mass of rolling stock, ton, R – number of trips. With two locomotive powers given, the first number refers to the power of a new locomotive, while the second is the actual locomotive power with account of engine wearing. $\sum E$ – the total economic effect of East – and West – bound trains, while ΔE – a difference between this value and that obtained by currently used 2M62 – section locomotives (therefore, it is equal to zero in the last column, $\Delta E = O$).

Conclusions

When choosing the traction for rolling stocks, freight traffic and its variation should be taken into account.

The variation of daily freight traffic can hardly be determined, however, its average value and range of variation should be defined.

In making up traction rolling stocks the asymmetric character of freight traffic in Western and Eastern directions should be taken into account.

Judging by freight turnover in 1999, with M62 sections used, it would be more economical to use 4,500 ton rolling stocks made up of 3M62 sections in Western direction, while 1M62 section would be sufficient in Eastern – bound trains. This would save 8,924 Lt daily, compared to the results obtained by currently used methods.

Taking into account the asymmetry of traffic flow in Western and Eastern directions, it can be stated that the rational West – bound locomotive power is by 2.7 times higher than that of East – bound locomotive would be.

Since the number of M62 locomotive sections used for East – and West – bound trains is different, the problem of their coming back arises. To solve this problem a number of alternatives should be analyzed, with the most efficient variant chosen (i. e. M62 sections may be taken back by the same train, they may be returned by a special train made up of sections M62, or more complex algorithm for their returning may be developed).

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