railway line “Rail Baltica”; freight diesel locomotives; rolling-stock operation efficiency; operation costs; multicriteria evaluation methods

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STUDY OF TRACTION ROLLING-STOCK USING IN LITHUANIAN SECTOR OF RAILWAY LINE “RAIL BALTICA”

Summary. The article analyses the current traction rolling-stock used by „Lietuvos geležinkeliai“ Plc. for freight transportation. The technical data of the above mentioned rolling-stock is explored and compared, and operation costs are estimated in the article. After the assessment of the forecasts of freight flows on the constructed railway „Rail Baltica“, the algorithm for selection of freight locomotives was proposed. The efficiency of the locomotives operated on the railway is determined by three multicriteria evaluation methods: the sum of ratings, simple additive weighting, and the geometric mean method. Locomotives are valued in accordance with technical, economic and ecological parameters. The results of possible effective performance of the rolling stock have been determined by changing coefficient values of the criteria. Finally, basic conclusions are given.

ИССЛЕДОВАНИЕ ИСПОЛЬЗОВАНИЯ ТЯГОВОГО ПОДВИЖНОГО СОСТАВА НА ЛИТВОВСКОМ СЕКТОРЕ ЖЕЛЕЗНОДОРОЖНОЙ МАГИСТРАЛИ «RAIL BALTICA»

Аннотация. В статье анализируется тяговой подвижной состав железнодорожной компании Литвы АВ «Lietuvos geležinkeliai», используемый в настоящее время для перевозки грузов. Оценены и сравненные технические данные, эксплуатационные расходы выше упомянутого подвижного состава. После оценки прогнозируемых потоков грузов по старящейся железнодорожной магистрали «Rail Baltica», был разработан алгоритм подбора грузовых локомотивов. Эффективность эксплуатации локомотивов определена тремя много критерийными методами оценки: сумма рейтингов, оценка весовых коэффициентов и оценка геометрических средних величин. Рассмотрены технические, экономические и экологические параметры анализируемых локомотивов. Итоговые результаты возможного наиболее эффективного использования грузовых локомотивов был получены при подборе значений коэффициентов разных критериях. В конце статьи представлены главные выводы.

1. INTRODUCTION

The key success of the railway „Rail Baltica“ will be the ability to take over the major part of freight transportation within the Baltic states and neighbouring countries, especially the freight transported North-South direction [1, 2]. The income coming from the freight transportation makes the

largest part of revenue (about 90 %). Therefore, the economic activity of the Department of Freight Transportation of "Lietuvos geležinkeliai" Plc. (Engl. "Lithuanian Railways", hereinafter – LG) has a huge impact on the ultimate profitability of the whole company. It is essential for the business to have a sufficient number of freight locomotives and wagons in the depot for the ability to fully meet the customer demand for freight transportation. It is very important to have the traction rolling-stock well working, technically safe and reliable, having the necessary locomotive power to ensure the traction, as well as be cost-effective. Some scientific works in this significant field were published by scientists of Department of Railway Transport at VGTU [3, 4]. It is also important to estimate the diesel costs for the operation of freight locomotives before choosing traction rolling-stock for specific section [5], as well as to assess their speed capacity, traction power, railway track alignment and environment pollution, including noise [6]. Stock assessment in the economic aspect must take into account the repair costs, locomotive and locomotive crew's work at a commercial cost, the largest possible transportation load and locomotive costs [7]. Since 2003 the LG launched the programme for renovation/ modernization of freight locomotives: motorization by replacing diesel (hereinafter - the modernization M1) with the main traction generator and ancillary equipment (hereinafter - modernization M2).

Modernization by the year 2007 includes 22 units of M1 2M62 series, 16 pieces – M62 series locomotives and also 20 units of M2 2M62 series locomotives. This ensured continuity of freight locomotives work and the annual freight transportation rate increased in approximately 20%, operating costs were reduced, particularly for fuel and engine oil. The fuel consumption decreased in about 19% with locomotives modernized by M1 category and 33% with the ones modernized by M2 category.

LG company's annual assessment of the freight turnover and changes in fuel consumption for freight locomotives proves of saving about 11.5 million €. Moreover, the modernized locomotives are more powerful: they can pull the trains with over 5000 tons of weight, i. e. in 20% more than the old locomotives could. It increases the capacity of the Lithuanian Railways (hence, productivity) in 10%.

Pollution with diesel exhaust gas emissions by 2M62 series locomotives is in approximately 66% higher than these of 2M62K, 2M62M ER20CF series locomotives. Scientists from Railway Transport Department of Vilnius Gediminas Technical University performed/ conducted tests on locomotives which use biodiesel as an alternative renewable fuel.

With this experience, the acquisition of new freight locomotives is one more way for the LG company to develop a more efficient and rational freight transportation. Operation of the new generation of SIEMENS ER20CF series diesel locomotives decreases diesel costs in (40-45)% than that of the non-upgraded 2M62 diesel locomotive, the weight of the train increased from 4200 tons to 6000 tons, maintenance and repair costs decreased, the drivers had working conditions and ergonomics improved.

In order to generalize and get optimal results the tests have been carried out using special software for modelling performance of different locomotives on the section Šeštokai–Kaunas of "Rail Baltica" in traction of trains of different weight.

The author proposes the application of multicriteria evaluation methods [3, 8] to assess the proper and effective operation of freight locomotives on the railway „Rail Baltica".

2. MULTICRITERIA EVALUATION METHODS USED FOR LOCOMOTIVES

Most of the methods use a different normalization of the initial data (parameters values), or the data transformation. Quantitative methods are based on the parameters characterizing the objects being compared, statistical data or expert assessment matrix ($R = [i; j]$; $i=1, ..., m$ and $j=1, ..., n$; where m is the number of criteria and n is the number of compared objects (alternatives) of statistical data or experts estimates. In practice, no method can be formally (directly) applied. Each method has its advantages and specifics.

Application of quantitative multicriteria evaluation methods requires to determine the form of each indicator: maximized or minimized. The best values of maximized (majorised) indicators are the highest ones, while the lowest values are the best with the minimized (minorising) indicators. Most of

the methods used different specific normalisation of the initial data (parameters values) or data transformation. Methods vary according to their complexity. There were three multicriteria evaluation methods used for this study:

1. Sum of Rating – SOR method;
2. Simple Additive Weighting – SAW method;
3. Geometrical Means – GM method.

2.1. Method for the sum of ratings

Sum of Ratings (SoR) V_j for every j-object is determined by the following formula:

$$V_j = \sum_{i=1}^{m} m_{ij} \quad ; \tag{1}$$

where: m_{ij} is place of *i*-parameter for j-object $(1 \le m_{ij} \le m)$. The main requirement for the application of the method is a prerequisite of the character of maximising and minimising parameters.

Besides, rearranging minimised parameters into the maximised ones will be determined by the following formula:

$$r_{ij} = \frac{\min r_{ij}}{r_{ij}} ; \tag{2}$$

where: r_{ij} is *i*- parameter value for j-object, then the smallest value of the parameter will gain maximum value equal to one.

Calculations show this method to be the simplest and most appropriate and its application is reasonable in the initial rough assessment.

2.2. Method for the assessment of parameters

The sum of normalised values S_j of Simple Additive Weighting is calculated for each *j*-object. It is determined by the formula:

$$S_j = \sum_{i=1}^{m} \omega_i r_{ij} ; \tag{3}$$

where: ω_i is weight coefficient of the i-parameter; r_{ij} is a normalised value of *i*-parameter for *j*-object.

Initial data is normalized in this case according to the following formula:

$$r_{ij} = \frac{r_{ij}'}{\sum_{i=1}^{n} r_{ij}} ; \tag{4}$$

where: r_{ij}' – *i*-parameter value for *j*-object.

Estimates can be taken that all estimates of the parameters are the same, i. e. $\omega_i = \frac{1}{16} = 0.0625$. The largest value S_j of the criterion is the best.

2.3. Geometric mean method

The geometric mean *Пj* (method *GV*) of all the normalised values of parameters is determined by the following formula:

$$\prod_j = \sqrt[m]{\prod_{i=1}^{m} \omega_i r_{ij}'} \,. \tag{5}$$

Priority sequence of objects was determined by the Formula (5), it does not depend on simple additive waiting ϖ_i, thus, it does not have to be included into the formula. The highest value Π_j of the criterion is the best.

3. ESTIMATION OF FREIGHT LOCOMOTIVES EFFICIENCY CRITERIA

3.1. Locomotives were estimated according to the economic and ecological criteria

For the economic estimation, the following criteria for the evaluation of LG freight locomotives were used:
1) the maximum possible weight of the train capacity, t;
2) the comparative consumption of diesel fuel in g /kWh;
3) the annual cost of locomotive repairs, €;
4) the commercial costs (€) for the locomotive and its crew‘s work;
5) the comparative air pollution in kg / t (1 ton of burned diesel fuel).

Critical factors of the criteria are accepted as follows:
1) the maximum possible weight for traction – 0.10;
2) the comparative fuel consumption – 0.30;
3) the remaining three criteria shall be of the same rate equal to 0.20, i. e. all the other criteria are equally important.

The series of targeted locomotives qualify by alternatives A_i: 2M62 series locomotive qualify by A1, 2M62K – A_2 ; A_3 and ER20CF – A_4.

Locomotive series evaluation criteria qualify by R_j parameters: the maximum possible weight of the train – R_1; comparative fuel consumption – R_2 , repair costs – R_3, commercial costs of locomotive and locomotive crew’s work – R_4, comparative air pollution – R_5. R = 1 are considered to be the best indicators for diesel locomotives of the LG company brand. The objective function of the research is $R_j \to 1$.

The evaluation criteria and the coefficient weight values of the locomotives are presented in Table 1.

Table 1

Criteria and the coefficient weight values of the locomotives

Criteria	Alternative				r_y
	A_1	A_2	A_3	A_4	
R_1	0.63	0.63	0.83	1.00	0.10
R_2	0.86	0.89	0.97	1.00	0.30
R_3	0.89	0.63	0.62	1.00	0.20
R_4	1.00	0.98	0.84	0.76	0.20
R_5	0.32	0.36	0.35	1.00	0.20

After the calculations with the available data, the results obtained are summarized in Table 2. It is evident SIEMENS ERC20CF diesel locomotive has all the best criteria based on the assessment by

three multicriteria evaluation methods, when the coefficient weight values are selected by the economic aspect. The rating of other locomotives vary depending on the method of estimation, therefore, the average rating had to be derived.

Table 2

Summary of the results when the coefficient weight values are selected by the economics aspect

Locomotives	Title of the method						Average ratings	Rating
	SoR		GM		SAW			
	Rating	Value	Rating	Value	Rating	Value		
2M62	4	14.5	2	0.23	3	0.23	3.00	3
2M62K	2	13.5	4	0.22	4	0.22	3.33	4
2M62M	3	14.0	3	0.22	2	0.23	2.67	2
ER20CF	1	8.0	1	0.31	1	0.32	1.00	1

The same evaluation criteria of LG company freight diesel locomotives can be used for the estimation in an ecologic aspect as in an economic aspect, but different criteria coefficients are accepted r_y.

1) the maximum possible mass of train carriage – 0.10;
2) the comparative fuel consumption – 0.20;
3) the repair costs – 0.10;
4) the commercial costs of the locomotive and its crew's work – 0.10;
5) the comparative air pollution – 0.50.

Following similar calculations, the results are presented in Table 3. SIEMENS ERC20CF locomotive has been given the highest score, 2M62M series locomotive is in the second place, see Table 1. It must be noted with no change in the evaluation criteria, but due the coefficient importance values, the locomotive 2M62K went up from the fourth place to third one.

A complex financial economic problem whether it is better to modernize locomotives 2M62, or buy a new generation of SIEMENS ER20CF freight locomotives must be solved. In the previous calculations the initial value of the locomotive or upgrading the operating costs and the appropriate technical capabilities of the Rail Baltica have not been estimated. In order to calculate the criteria, special laboratory software was used by Vilnius Gediminas Technical University Railway Transport Department.

Table 3

Summary of research results when the coefficient weight values are selected by an ecological aspect

Alternatives	Title of the method						Average rating	Rating
	SoR		GM		SAW			
	Rating	Value	Rating	Value	Rating	Value		
2M62	4	14,5	2	0.226	4	0.202	3.33	4
2M62K	2	13,5	4	0.217	3	0.205	3.00	3
2M62M	3	14.0	3	0.223	2	0.207	2.67	2
ER20CF	1	8.0	1	0.311	1	0.385	1.00	**1**

There was simulated an operation of different locomotives on the section Šeštokai-Kaunas, trains of different weight were chosen, travel duration and fuel costs were calculated, taking into account the peculiarities of the road profile and speed limits. For comparison of the estimated fuel consumption of different locomotives in transporting trains of the mass of 1100 tons, 2600 tons and 4200 tons along the route Šeštokai-Kaunas (distance of 93.76 km), see Fig. 1.

On the account of previous calculation results, the locomotives 2M62M and ER20CF are further analysed, as they have been estimated as the best ones. The following evaluation criteria have been

selected when the weight of the train pulled along the railroad Šeštokai-Kaunas (distance 93.76 km) is 3000 tons:

1) the average technical speed of locomotive, km/h – R_1;
2) the total fuel consumption, kg – R_2;
3) the locomotive prices and the age relative value, €/year – R_3;
4) the costs of locomotive and its crew's works, € – R_4;
5) the comparative air pollution in kg/t - R_5.

Weight coefficients of the parameters:

1) the average technical speed of a locomotive, km / h – 0.10;
2) the total fuel consumption, kg – 0.30;
3) the relative value of locomotive price and age, LTL / year – 0.30;
4) the operative costs of the locomotive and its crew's work – 0.2;
5) the comparative air pollution – 0.1.

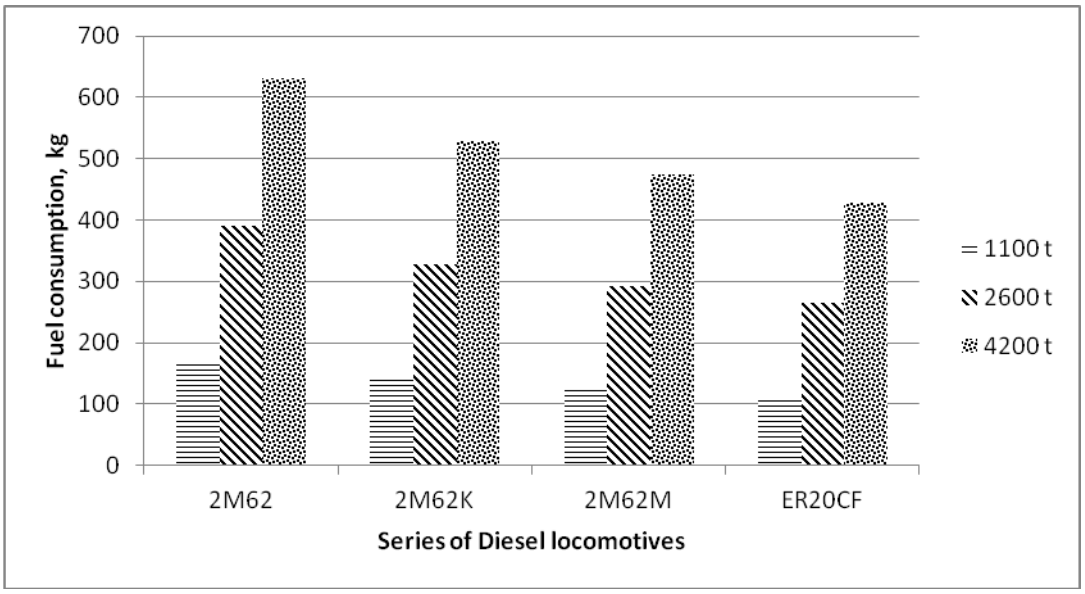

Fig. 1. Total fuel consumption by pulling the freight trains of different weight along the route of Šeštokai-Kaunas (distance of 93.76 km) according to LG company standards

Рис. 1. Общий расход топлива по нормам Литовских железных дорог при перевозке грузовых поездов разного веса по маршруту Шяштокай–Каунас (расстояние 93,76 км)

New evaluation criteria values of locomotives 2M62M and ER20CF are provided in Table 4.

Table 4

Values of criteria and weight coefficients of locomotives 2M62M and ER20CF

Criteria	Locomotives		r_y
	2M62M	ER20CF	
R_1	0.81	1.00	0.10
R_2	0.91	1.00	0.30
R_3	1.00	0.98	0.30
R_4	1.00	0.75	0.20
R_5	0.35	1.00	0.10

See Table 5 for the final generalised results obtained by processing the data by three multicriteria evaluation methods of three freight locomotives.

Table 5

Summarised results obtained through different estimation methods in applying data modelling for determining the suitability of locomotives

Locomotives	Character of the method						Average rating	Rating
	SoR		GM		SAW			
	Rating	Value	Rating	Value	Rating	Value		
2M62M	2	8	2	0.44	2	0.48	2.00	2
ER20CF	1	7	1	0.54	1	0.52	1.00	1

The data of the potential operation of locomotives on "Rail Baltica" presented in Table 5 prove the new generation locomotive SIEMENS ER20CF can deliver unrivalled performance.

4. CONCLUSIONS

1. The analysis of the traction rolling stock owned by "Lithuanian Railways" Ltd. was completed by three multicriteria methods (SOR, SAW and GM). Freight locomotives were estimated by technical, economic and ecological aspects in changing weight coefficient values of the evaluation criteria and the critical values themselves.
2. It has been found that ER20CF locomotives are the most rational for transporting freight along the „Rail Baltica“ section Šeštokai-Kaunas. Further rating is as follows: 2nd rational type of locomotive is 2M62M, the third – 2M62K, and the fourth – 2M62 series locomotives. The results obtained in modelling different freight locomotive types on the „Rail Baltica“ segment Šeštokai-Kaunas and forming the trains of different weight are compared according to the costs of acquisition or modernization of locomotives, their operation costs and ecologic indicators.
3. After the assessment of all the above aspects the most suitable freight locomotive on the „Rail Baltica“ Lithuanian sector is SIEMENS ER20CF locomotive.
4. These suggested by the author, methods are appropriate for evaluating operating efficiency of passengers traction vehicles in line „Rail Baltica” as well.

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