VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

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A STUDY ON THE OPTIONS OF MEANS FOR RAILWAY PASSENGER TRANSPORTATION

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Introduction

Topicality of the problem. A rapid social and economic development of the European Union countries, their technical progress, world trade globalisation tendencies of the world trade, generate a huge demand for high-quality transportation services. The system of transportation services which exists today, based on road transport, faces more and more hardships to meet the demands of consumers transport needs which are rapidly increasing under the above-mentioned tendencies. The countries of the Western Europe, being concerned about safety, environment, sustainable use of the energy and other resources, use economic and legal measures to encourage and further develop transportation of passengers by railways. These countries are implementing integrated instruments for the solution of transport problems in the international level. The main instrument as an alternative for the solution of the present-day transport problems is the railway transport development. This Doctoral Thesis is devoted for the solution of the above-mentioned situations.

The research subject. The means of passenger transportation by rails. For the investigation of this subject, the main focus is the analysis will be concentrated on passenger train routes and technical analysis characteristics related to the selection of various rolling-stock combinations for specific routes on the basis of passenger numbers, rational traction options, and improvement of passenger comfort

The main goal of the work – to prepare detailed theoretical and practical solutions for the increase of the incomes and minimize the losses suffered from transportation of passengers by railways; having evaluated the technological needs for specific route sections and the dynamics of passenger flows, to improve the comfort of the passengers and, at the same time, to try to attract more passengers to use the railways. In order to achieve the aim of this study, it is compulsory to solve the following **tasks**:

1. To analyze the problems related to railway passenger transportation and methods of solutions set forth in the international research and scientific literature.
2. To investigate the existing situation in the sector of railway passenger transportation in Lithuania, to define its significance to the economy of the country.
3. To define the components of railway passenger transportation incomes and expenditures, and to define their dependence from the technical parameters of the rolling-stock.
4. To make up a mathematical model for the selection of the most rational methods for railway passenger transportation.

5. To opt the rolling-stock for specific routes for passenger transportation on the Lithuanian railways on the basis of this model by applying the extremes search method from non-linear equations with multiple variables and their limitations.
6. To prepare rolling-stock comfort characteristics improvement recommendations related to the decrease of vibrations in the carriages, selection of rational parameters for the suspension of the undercarriages at different travel speeds.

Research methods – regressive analysis, mathematical modeling and global optimization methods are used in this thesis.

Novelty of the work and its significance. The model shall minimize the losses of passenger transportation by railways taking into regard the dynamics of passenger number changes on the basis of routes, types of traction used, and all components for the incomes and losses. After optimizing the target function, most rational train options are provided for each specific route. A target function was made for the definition of rational passenger undercarriage suspension parameter definition and reduction of the carriage vibrations down to a minimum seeking to improve the indicators of smooth train motion – W.

Practical value of the work results. The results of this thesis should enable to use the most economic traction types and trains at specific routes, to optimise the rolling-stock inventory by purchasing certain new rolling-stock, to establish requirements for passenger comfort, what should enable to attract more passengers and decrease the total costs for passenger transportation by railways.

Defended propositions

1. Methodology for the selection of optimal train set for each route.
2. Model for selection of the instruments evaluating not only the technical capacities, but also all components of incomes and expenditures for railway carrying of passengers.
3. The target function is devoted for optimization of the existing parameters upon various speeds, and, at the same, minimizing of train carriage vibrations ensuring train stability and smooth motion.

Approval of the results of the work. 7 research articles have been published on the topic of this thesis: four articles at scientific magazines, included into the list of "Science Citation Index Expanded (Web of Science)", two articles – at reviewed research publications, one article – at reviewed materials of an international conference held in Lithuania. The results of the thesis research were presented at three international research conferences: at the 68th international research and practical conference *Railway Transport Development Problems and Perspectives*, held in 2008, at Dniepropetrovsk (Ukraine); the international conference *TRANSBALTICA 2009*, held in 2009, in Vilnius; the 4th international research and practical conference *Implementation of Research-Capacious Technologies in the Magistral and Industrial Railway Transportation*, held in 2008, in the Yaremche (Ukraine).

The scope of the research work. This thesis consist form: the introduction, four major chapters, and general conclusions, the list of literature and reference sources, list of publications of the author relevant to the topic of this thesis, and an addendum. The total volume of this thesis is 134 pages without addendum, there are 44 numbered formulas, 71 figures, and 36 tables. 78 literature sources have been used.

1. Analysis of the research literature

The analysis of the literature covers the results of research works, performed both nationally, and on the international level, on the topic of passenger transportation by railways. This review of the research literature is viewed on the basis of two aspects. The first aspect is the review of the research works dealing with the organizational issues of railway passenger transportation. The second aspect is the review of the research works related to the improvement of railway passenger transportation means with the purpose to attract more passengers to travel by railways, and at the same time – to increase the incomes and to minimize the losses of the transportation companies.

The research indicates that the major characteristics of the shuttle-trains are: small demands, poor profitability, improper advertising, the traditional services are boring to the users, the users think that such services are of quite a low prestige and they found alternatives to them. For this reason, and for the purpose of recovering the lost clients of the railways and attracting new clients, it is necessary to implement rational organisational and technical instruments which have to be convenient to the passengers and which insure good comfort conditions in the trains.

The analysis of the research works related to the methodology of passenger transportation, indicates that the major focus of the attention are big passenger flows and long distances. However, there are no research works on the international level investigating transportation of passengers by railways where the passenger flows and distances are not big, what is a really specific case regarding Lithuania.

The analysis of the research literature pointed out that the attractiveness of train journeys (under our, Lithuanian, conditions) decreases due to a variety of reasons, and the main reasons are the lack of comfort and lack of train routes frequency. The main factor which has a negative impact towards the passengers, is the vibrations of the train carriage. There is an undercarriage suspension system at train carriage constructions to decrease the vibrations. That is why optimizing the choice of the elements of the suspension plays a crucial role in the improvement of comfort conditions.

2. Research of the existing situation of railway passenger transportation and related perspectives

During the years of 2006–2009, the annual flow of passengers carried by railways in Lithuania via the local (national) routes was around 4.4 million. The mileage during the years of 2006–2009, increased by 23 %, the number of passengers, during the same period, decreased by 32 %. This shows that the existing means of transportation are not used rationally, the trains are moving not full. The losses are summarized in Table 1.

Table 1. Ratio of incomes from train tickets and expenditures for local (national) railway passenger sector in Lithuania between 2006–2009

Year	Incomes from tickets, thousands of LTL	Expenditures, thousands of LTL	Share of the incomes covering the expenditures, %	Deficit, %
2006	18 054.6	121 053.9	14.9	85.1
2007	20 597.5	136 955.1	15.0	85.0
2008	22 501.1	176 093.4	12.8	87.2
2009	21 548.9	177 094.9	12.2	87.8

The analysis of the existing situation shows that the main reasons resulting in losses in railway passenger sector are: small numbers of passengers, lack of modern rolling-stock, poor railway infrastructure, and unreasonable usage of rolling-stock at certain railway segments.

The existing passenger transportation rolling-stock is not optimally adapted to transportation of the passengers at local sections with a substantial fluctuation of passenger numbers and various distances. The railways stock is not adopted for a flexible transformation of various transportation means at a fluctuating number of passengers. That is why the next part of the thesis is devoted for the selection of the optimum traction and optimum formation of the train on the basis of the situations for every moment.

3. Making up of a mathematical model for the seletion of means and its application

The model will calculate profit (loss) Δ for one train kilometre. A simplified formula for the model is the following:

$$\Delta = P - I = \sum_{i=1}^{m} P_i - \sum_{j=1}^{n} I_j \ , \qquad (1)$$

where Δ represents the difference between incomes and expenditures in LTL/train km); P – total incomes for LTL/train km; I – total expenditures, LTL/train km; P_i – i incomes received from passenger ticket sales, compensations for the discounts provided and subsidies for non-received incomes; I_j – j passenger transportation expenditures including the fees for the use of the public railway infrastructure, deprecation of the rolling-stock, staff salaries, costs of materials, fuel, repair, and other costs; m – the number of incomes (in our case m = 3); n – the number of expenditures (in our case n = 7).

Having evaluated the costs of passenger transportation, the number of passengers and, based on the normative documentation, which defines the amounts of subsidies and compensations, the components of the model would be:

$$P = \Big\{ k_{kp} \times P_1 \times K(x) + k_{dot} \Big(V \times L_{reis} \times I_m \times \Big(1 + \frac{r}{100}\Big) - k_{kp} \times P_1 \times K(x) - I_k \Big) + k_{komp} \times I_k \Big\} \times \frac{1}{L_{reis}} , \qquad (2)$$

where k_{kp} is the proportionality coefficient of the passengers number (1; 1,05; 1,1; 1,15 ...); P_1 is the average ticket price in LTL, where $P_1 = \sum_{k=1}^{n_k} l_k b_{km}$ (with l_k – is the distance between stations, km; b_{km} – 1 travel cost per km, in LTL travel km cost); $K(x)$ – change of the number of passengers in the section based on the distance between stations, pcs.; k_{komp} – compensation coefficient; V – number of railway carriages in the train, in pcs.; L_{reis}– distance, km; I_m – actual costs for 1 railway carriage kilometre incurred when carrying out the obligations of the public services, in LTL; r – profitability, %; I_k – compensation of expenditures for the train in relation to discounts offered to the passengers, Lt; k_{dot} – coefficient of subsidies.

The calculations of the model are provided for electricity traction, whereas for other tractions, such calculations are made applying the traction coefficient which is a ratio of electric traction and other selected traction. Having evaluated all above-mentioned components, the model for the components of expenditures would look like that:

$$I = \left[\left(\left(\frac{E_{kel}}{R_{kel}} + \frac{E_{kt}}{R} \right) \times \frac{R_1}{R_{kel}} + \left(\frac{I_{kel}}{A_{kel}} + \frac{I_{kt}}{A} \right) \times \frac{A_{kel}}{R_{kel}} + \frac{I_{kont}}{R_{kel}} \right) + \right. , \qquad (3)$$
$$\left. \left(D_{už} + M + D_t + N + R_k + K_{iš} \right) \times f\left(Z_{vag} \right) \right] \times a$$

where E_{kel} – train traffic organization and management costs, incurred in relation to the services of railway companies carrying passengers and luggage, in LTL; E_{kt} – train traffic organization and management costs, incurred both in relation to the supervision of railway companies carrying passengers and luggage, as well as supervision of railway companies carrying freights; R_{kel} – mileage of the passenger trains (train/km); R – mileage of all trains (train/km); R_1 – reserved mileage of trains (train/km), I_{kel} – public expenditures for railway infrastructure, incurred in relation to the services of railway companies carrying passengers and luggage, in LTL; I_{kt} – public expenditures for railway infrastructure, incurred both due to the supervision of railway companies carrying passengers and luggage, as well as supervision of railway companies carrying freights, in LTL; A_{kel} – the operation scope of passenger trains, thou. Km, gross; A – the operation range of all trains (thou. km gross); I_{kont} – expenditures for contact net, in LTL; $D_{už}$ – salaries and wages, LTL/carr.km; M – expenditures for materials, in LTL/carr.km; D_t – expenditures for fuel, lubricants, in LTL/carr.km; N – deprecation of rolling-stock, in LTL/carr.km; R_k – repair expenditures, in LTL/carr.km; $K_{iš}$ – other expenditures, in LTL/carr.km; a – traction coefficient, where $a = \sqrt[T]{\prod_{t=1}^{T} \frac{a_{dt}}{a_{et}}}$ (and where a_{dt} – diesel/locomotive traction expenditures for t year, in LTL/train km; a_{et} – electric traction expenditures for t year, in LTL/train km; T – number of years; $f(Z_{vag})$ – relative number of carriages.

After making up the expression (3) for expenditure materials, fuel, lubricants, repairs in relation to time, the final expression shall be presented (4).

Having analyzed the optimization options (4), a sub-software “fmincom” from software media MATLAB (Matrix Laboratory) was selected, and it is tailored for the search of minimum values during the solution of non-linear equations with multiple variables and with limitations.

This mathematical model was put into practice for three typical passenger routes: Klaipėda – Vilnius, Vilnius – Šeštokai, and Vilnius – Turmantas. The collected statistical data shows that the number of passengers for the route Klaipėda – Vilnius reaches 100 at the beginning, and from the mid-way (Šiauliai), it decreased almost by half.

The regression equations are made from the statistics of the last six years. From the data provided, it can be seen that at the beginning of the route, the train shall consist of at least two carriages, and it is necessary to detach one carriage at the mid-way.

$$\Delta = P - I = \sum_{i=1}^{m} P - \sum_{j=1}^{n} I = \begin{Bmatrix} k_{kp} \times P_i \times K(x_1) + k_{dot}(V \times L_{reis} \times I_m \times \left(1 + \frac{r}{100}\right) \\ - k_k \times P_i \times K(x_1) - I_k) + k_{komp} \times I_k \end{Bmatrix} \times \frac{1}{L_{reis}} -$$

$$\left[\begin{array}{c} \left(\left(\frac{E_{kel}}{R_{kel}} + \frac{E_{kt}}{R} \right) \times \frac{R_1}{R_{kel}} + \left(\frac{I_{kel}}{A_{kel}} + \frac{I_{kt}}{A} \right) \frac{A_{kel}}{R_{kel}} + \frac{I_{kont}}{R_{kel}} \right) \\ \begin{Bmatrix} D_{u\check{z}} + \left(0.0086x_2^2 - 0.0686x_2 + 0.29\right) + \\ \left(0.0377x_3^2 - 0.2952x_3 + 1.285\right) \\ + N + \left(0.0338x_4^2 - 0.2645x_4 + 1.169\right) \\ + (0.022x_5^2 - 0.1726x_5 + 0.761) \end{Bmatrix} \times (0.9154x_6 - 0.1307) \end{array} \right] \times \tag{4}$$

$$(0.075x_7^2 - 0.241x_7 + 1.185).$$

Table 2 gives the total profit (loss) estimation for the mid-stations, calculated on the basis of the newly made model.

Having analyzed the data provided in Table 2, we can see that the losses can be minimized by selecting the traction and the number of carriages. Then the model demonstrates the above-mentioned options and their potential. For the infrastructure existing for today, and for the present passenger rolling-stock inventory, it would be recommended to use a combination of two railcars by detaching one from the station of Šiauliai.

At present moment, 3-carriage trains are running on this route using locomotive and diesel traction. The losses related to the operation of such trains are shown in Fig. 1.

Table 2. Mid-station profit (loss), calculated on the basis of the drafted model, in LTL

Serial Nr.	Station	Electric traction, 1 carr.	Railcar	2 railcars	Diesel, 1 carr.	Diesel, 2 carr.	Locomotive, 1 carr.	Locomotive, 2 carr.	Diesel 3 carr.	Locomotive, 3 carr.
1	Klaipėda	–	–	0	–	0	–	0	0	0
2	Kretinga	–	–	3.52	–	–22.66	–	–78.32	–294.36	–417.56
3	Plungė	–	–	–61.84	–	–139.19	–	–303.21	–941.08	–1305.08
4	Telšiai	–	–	–144.16	–	–254.83	–	–489.41	–1402.24	–1923.04
5	Šiauliai	–	–431.71	–431.71	–626.87	–626.87	–1040.37	–1040.37	–2649.00	–3567.40
6	Radviliškis	–	–394.71	–530.11	–595.47	–749.27	–1021.17	–1212.97	–3018.20	–4048.60
7	Kėdainiai	–	–310.87	–878.91	–530.19	–1162.71	–994.93	–1799.21	–4231.64	–5620.44
8	Jonava	–	–278.94	–1056.54	–507.25	–1377.23	–990.59	–2091.85	–4828.70	–6391.10
9	Kaišiadorys	–249	–248.94	–1229.34	–485.95	–1585.73	–987.29	–2375.95	–5407.40	–7137.80
10	Vilnius	–178	–178.59	–1611.91	–435.03	–2048.03	–976.57	–3006.42	–6695.14	–8800.74

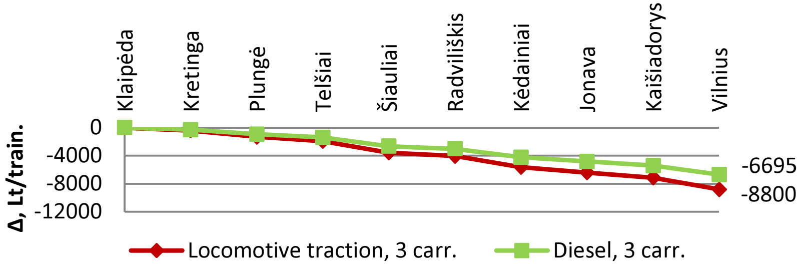

Fig. 1. Calculation of losses on the basis of a drafted model for the route Klaipėda–Vilnius, LTL/train

From the data provided in Table 2 and Figure 1, it is very easy to see that the losses can be decreased by even 37 times for the diesel traction used today, and by 49 times for the locomotive traction used today if the traction of traction units can was used with one traction unit being detached from Šiauliai. Even if two traction unites are used without detaching at the station of Šiauliai, the losses would be smaller by 4.2 and 5.5 times correspondingly. This is a very good example illustrating the flexibility of the usage of passenger transportation means for the purpose of opting the means traction and the composition of the trains what minimizes vacant places in trains and optimises the use of the organizational potential for the formation of rational-choice trains (changing of their structure) during the course of the route.

Figure 2 provides a graphic interpretation of all possible options for trains for the route Klaipėda–Vilnius on the basis of the data from Table 2. From it we can obviously see that whatever options of trains and tractions are chosen, the losses would be much smaller compared to the trains and traction options as used for today (Fig. 1).

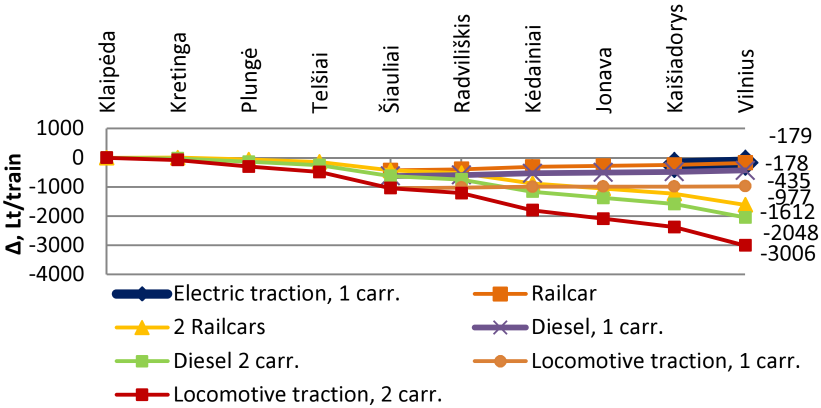

Fig. 2. Possible combinations and calculation of incomes (losses) on the made up model for the route Klaipėda–Vilnius, LTL/train

The advantage of this model – is possibile to vary the components of incomes and expenditures, to highlight the weakest points (i.e. the areas with the biggest losses and the areas where such losses can be minimized), and on this basis, to enable an exact and targeted forecasts of technical, organizational, and economic aspects of the passenger technical stock parameters and to implement the primary measures, such as purchases of new equipment, selection of best places for passenger carriage attachment and detachment, best places for technical maintenance operations, compliance and flexibility to traffic schedules, etc.

4. Comfort improvement factors at passenger trains

Based on public opinion poll results, good comfort level plays a significant role for railway passengers transportation. These results resulted in a good practical proof after AB "Lietuvos geležinkeliai" purchased a comfortable electric train EJ 575, and when, during the first year of its operation, passenger flows increased by 15 %. This train can be characterized by high-level smooth travelling conditions, i.e. very low vibration level and low sound level inside. This section will be devoted for the analysis of those factors.

Vibrations in train carriages has lots of impacts to the passengers. It has a negative impact to the general condition (state) of the passengers, it also decreases the productivity of the servicing staff. That is why it is necessary to evaluate the intensity of vibrations taking into regard their impact for humans. While trying to decrease the general level of vibrations, it is necessary to consider vibration frequencies, as 4–8 Hz vibrations are very harmful to human bodies. Vibration and noise have a significant impact to the comfort of the passengers and it is described in a variety of parameters: vibration frequency and range, noise level, air humidity and temperature, and other.

For a practical evaluation of the rolling-stock vibration level, taking into regard the convenience of the passengers, Schperling's uniform (smooth) motion indicator will be used:

$$W_z = 0.896c\left(f\right)\sqrt[10]{a^3 f^{-1}}\ , \tag{5}$$

where a – acceleration range, cm/s^2; $c\left(f\right)$ – frequency and vibration direction coefficient which has an impact toward the condition of the passenger; f – vibration frequency, Hz.

Vibration has a harmful effect on the hearing, vision, nervous system, and brain activities of the human beings.

To ensure the mandatory comfort at passenger carriages, the coefficient of uniform motion shall be $W_z = 2.0 - 2.5$.

After the generalization of the impact of vibrations to the human body, i.e. to human health and comfortable feeling in the train carriage, it is possible to state that vibration is hard to control and the mandatory norms are difficult to meet. This depends not only on the construction of the carriages, but also on the quality of the railway with the latter, being actually the main source of the vibrations. Mechanic vibrations are suppressed by various technical and ergonomic means, but the most important element in this system is the suspension of carriage chassis (undercarriage). Seeking to select the technical parameters for the chassis with the coefficient of the uniform motion not exceeding $W_z = 2.0 - 2.5,$ it is necessary for the carriage designs to have appropriate dynamic and stability coefficients when the train is going at the maximum permitted speed.

When solving the problems of optimum suspension parameters identification, it is necessary, first of all, to clarify out the issues related to the technologies for the solution of these problems. For the purpose of achieving realistic results, it is necessary to define target function components, to clarify the needs for the priorities for one or another option, whether all components shall have and make the same effect for the formation of the target function. Moreover, it is necessary to define the conditions for calculations, i.e. to select induction (irregularities) functions and chassis roll-on conditions.

The target function shall include axle-box and central suspension stage limited dynamic indicators: $K_{dva}^{\max}$ – axle-box suspension vertical dynamic coefficient; $K_{dha}^{\max}$ – axle-box suspension horizontal dynamic coefficient; $K_{s}^{\min}$ – stability coefficient defining wheel edge resistance for the accession on the rail; $K_{dvc}^{\max}$ – central suspension vertical dynamic coefficient; $A_{\kappa v}^{\max}, g$ – vertical acceleration of the body; $A_{kh}^{\max}, g$ – horizontal acceleration of the body.

These dynamic indicators have different limitary values. These values are provided in Table 3 below.

Table 3. Limitary values of the main dynamic indicators

$K_{dva}^{\max}$	$K_{dha}^{\max}$	$K_{s}^{\min}$	$K_{dvc}^{\max}$	$A_{kv}^{\max}, g$	$A_{kh}^{\max}, g$
0.8	0.38	1*	0.6	0.6	0.25

* – based on the calculation of interacting forces of rail and axle-box.

The upper values of all dynamic indicators are limited, except for the value of the stability coefficient $K_{s}^{\min}$. For this indicator, the minimum limitary value is selected. It is targeted to bring the change (dynamics) of all dynamic indicators into one range from 0 till 1, it is necessary to ration them. For this purpose, all dynamic indicators, with the exception of K_{s}, shall be increased up to their maximum limitary values, and the value of K_{s} shall be changed in such a way as to decrease the rationed indicator by increasing K_{s}, and vice versa (increase by decreasing). Having evaluated the above-mentioned changes (modifications), target function parameter vector shall be as follows:

$$\overline{\varphi} = \left[\frac{K_{dva}}{K_{dva}^{\max}} \cdot \frac{K_{dha}}{K_{dha}^{\max}} \cdot \frac{\left(K_{s}^{\max} - K_{s}\right)}{K_{s}^{\max} - K_{s}^{\min}} \cdot \frac{K_{dvc}}{K_{dvc}^{\max}} \cdot \frac{A_{kv}}{A_{kv}^{\max}} \cdot \frac{A_{kh}}{A_{kh}^{\max}} \right]^{T}. \tag{6}$$

It is obvious that dynamic indicators have different effects. Because of this reason, it is necessary to have a possibility to change the meaning of one or another component of the target function. For this purpose, each target function component must have a leverage (importance) coefficient what will provide the opportunity to strengthen its effect to the value by one of the target function components, and, at the same time, to weaken other components. For the purpose of target function value to be fluctuating in the range between 0 and 1, the sum of the leverage (importance) coefficients shall be equal to one. Finally, the target function would look like that:

$$F(\overline{\varphi}) = \sum_{i=1}^{i=6} \lambda_i \varphi_i . \quad (7)$$

During the calculations of carriage dynamic indicators at increasing travel speeds, all of them approach the permitted limits. Practice shows that the first indicator from all dynamic indicators which exceed the permitted values, is the stability coefficient (wheel edge resistance to the accession on the rail), that is why all meanings of the leverage coefficients λ_i, except for the coefficient K_s , selected as 0.1, and K_s corresponds to 0.5.

For calculations, it is recommended to select a straight-line route, because at curves, the speed is reduced not only because of dynamic parameter meanings, but by non-actuated accelerations as well, what can make the selection of the parameters more difficult.

The expression of the target function (7) depends on many parameters, and that is why it shall be expected that the surface defined by this function, will be of quite a complex form. In more generalized cases, this surface will have multiple local minimums. This, in turn, means that for the propose of defining the optimal parameters, first of all, it is necessary to find areas which have the local minimums. If such an area has more than one local minimum, then the result of the search of optimal parameters will depend from the primary values. For the definition of the motion speed, where optimum chassis suspension stage search is needed, standard values of the carriage parameters will be taken (Table 4).

Table 4. Carriage chassis parameters

Chassis parameters	Longitudinal direction	Transverse direction	Vertical direction
Axle-box suspensijon	K_{ax} = 0 kN/m F_{ax} = 0.25	K_{ay} = 0 kN/m F_{ay} = 0.25	K_{az} = 20000 kN/m V_{az} = 100 kNs/m
Central suspension	K_{cx} = 6000 kN/m F_{cx} = 0.25	K_{cy} = 6000 kN/m F_{cy} = 0.1	K_{cz} = 4000 kN/m F_{cz} = 0.1
Sliders	$K_{šx}$ = 0 kN/m $F_{šx}$ = 0.125	$K_{šy}$ = 0 kN/m $F_{šy}$ = 0.125	$K_{šz}$ = 800 kN/m $V_{šz}$ = 0 kNs/m

At first, it is necessary to solve the issue related to the selection of the speed for calculations of optimal chassis parameter search and solution of related tasks. For this purpose we will carry out a search of optimum parameters for various travel speeds, when the primary parameters are the same as selected previously. Optimal parameters will be calculated for the travel speed being v = 60 km/h.

Optimal parameters search results are provided in Table 5.

From the calculation results was determined that the limit speed for the selected carriage both with standard and optimized parameters, is 100 km/h, which is limited by a coefficient K_s (Fig. 3).

Table 5. The main dynamic indicators

	K_{dva}	K_{dha}	K_s	K_{avc}	Target function
At the primary values of the parameters	0.327	0.218	2.399	0.33	0.27943
At the optimum values of the parameters	0.287	0.183	3.21	0.286	0.10732
Difference, %	–12	–16	34	–13	–62

Graphical K_s change is show in Figure 3.

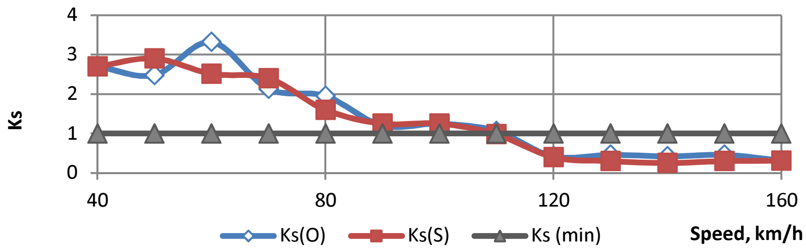

Fig. 3. Stability coefficient K_s

Experimental research. Electric train EJ 575 tests show that practical the results of these tests correlate with the calculated (estimated) results (±1.7 %), i.e. the uniform motion coefficient did not exceed the permitted (mandatory) limits. A significant part of the test results is provided in Figure 4.

During the tests of the so-called emergency (spring-type) suspension of an electric train EJ 575, from Figure 4 it can be seen that the horizontal W_h in the area of the rear carriage is the highest, but not exceeding the value of 1.75.

This means that the producer did not exceed the values of uniform motion coefficient defined under technical data sheets.

It must be emphasized that all values of *W* were recorded on the floor level. Further, this coefficient is decreased, i.e. the comfort is improved by installing quality seats in the carriages. On this basis, i.e. after the improvement comfort conditions, it becomes much more feasible to attract more passengers to chose railways.

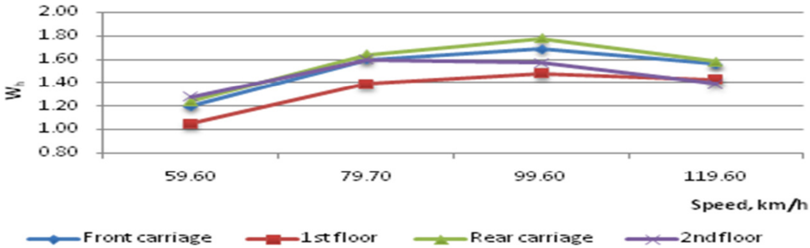

Fig. 4. Dependence of the interjacent carriage with spring suspension W_h from travel speed

The results of this thesis are well-illustrated in the charts provided in Fig. 5.

After the analysis of the data provided in Fig. 5, it can be seen that only after optimisation of the train sets and traction for the route Klaipėda–Vilnius, one carriage losses can be minimized down to 45 times, and with an increase of passengers number (15 %.) down to 100 times. After optimisation of train sets for the route Vilnius–Turmantas, the existing losses from 1 carriage/km, could turn into profit. This profit would grow even more depending of improved comfort with the increase of passenger numbers by 15 %.

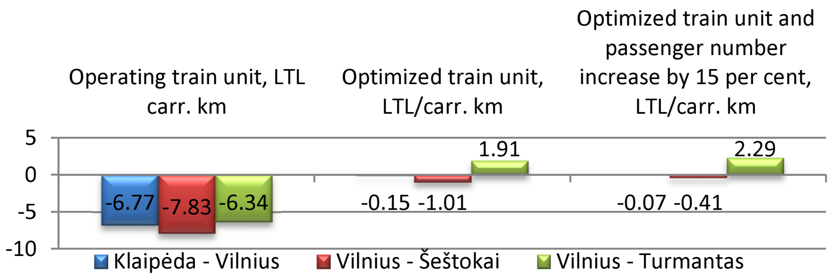

Fig. 5. One carriage/kilometre losses (profits) before and after the optimisation

From the results provided, it is possible to state that optimisation of train sets and traction, with the addition of comfort improvements in passenger carriages, can be considered really effective means for the selection of rational passenger transportation vehicles and for minimisation of losses at certain routes, and even receiving profits at some of the routes.

General conclusions

On the basis of the research results, the following conclusions can be made:

1. The main reasons for the incurred losses in passenger railway transportation are: small number of passengers, lack of modern rolling-stock, poor railway inefficient usage of the rolling-stock at certain parts of certain routes.
2. For the present moment, the rolling-stock for passenger transportation is not optimally tailored for passenger transportation at local routes, especially taking into regard the flexibility of passenger transportation means on the basis of traction types, and the fluctuating number of passengers.
3. Regression equations were made for certain routes showing passenger number dynamics.
4. A mathematical model for incomes and expenditures was made taking into consideration all possible incomes and expenditures sources.
5. After formation of train sets on the basis of an optimized variant for the route Klaipėda–Vilnius, it was found out that losses can be decreased by 4 times, and for the route Vilnius – Turmantas, even a positive result could be achieved, i.e. the incomes could exceed the expenditures.
6. Carriage vibrations is the main factor which has the greatest negative impact for passenger comfort. The main factor which results in their decrease is the uniform motion coefficient having a close relationship to the vibration frequencies, accelerations, and ranges.
7. The made up target function provides the opportunity to calculate the dynamic indicators of the carriage (vertical and horizontal axle-box indicators, minimum stability coefficient, central suspension vertical dynamic coefficient and vertical and horizontal body accelerations) at the existence of any permitted travelling speeds.
8. The research revealed that for the purpose of identification of optimum carriage parameters, the main indicator in the target function shall be the stability coefficient as this parameter limits the speed of travel.
9. Modern ergonomic measures, which should be integrated into the passenger carriages (seats, heating, various services) for the improvement of passenger comfort level, were listed.
10. During the upgrade of the railway stock, it is necessary to purchase fast-transforming passenger transportation means (e.g. modular trains) what could be in compliance to the concept of passenger transportation under the conditions of Lithuania.

The list of published works on the topic of the dissertation
In the reviewed scientific periodical publications

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Dailydka, S. 2009. Passenger transportation strategy of SC „Lithuanian Railways", in *Proceedings of the 6th International Scientific Conference „TRANSBALTICA 2009*".Vilnius: Technika, 33–41. ISSN 2029-2376.

About the author

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Keleivių vežimo geležinkeliu priemonių parinkimo tyrimas

Mokslo problemos aktualumas. Europos Sąjungos šalių spartus socialinis ir ekonominis vystymasis, technikos raida, pasaulinės prekybos globalizacijos tendencijos sukelia didžiulį aukštos kokybės transporto paslaugų poreikį. Šiuo metu egzistuojanti transporto paslaugų sistema, kurios pagrindas yra kelių transportas, jau negali tenkinti tendencingai augančių vartotojų transportinių poreikių. Vakarų Europos šalys ekonominėmis ir teisinėmis priemonėmis dėl saugos, ekologijos bei energinių ir kitų išteklių taupymo siekia skatinti keleivių vežimą geležinkeliu. Jos įgyvendina kompleksines priemones, sprendžiant transporto problemas tarptautiniu mastu. Kaip pagrindinė įgyvendinama dabartinių transporto problemų alternatyvi priemonė yra geležinkelio transporto plėtra. Šis disertacinis darbas kaip tik ir skiriamas minėtiems uždaviniams spręsti.

Tyrimo objektas. Keleivių vežimo geležinkelių transportu priemonės. Nagrinėjant šį objektą pagrindinis dėmesys teikiamas keleivinių traukinių maršrutų bei naudojamų priemonių techninių charakteristikų analizei, parenkant riedmenų derinius konkretiems maršrutams pagal keleivių skaičių ir racionaliausią trauką bei gerinant keleivių komfortą.

Darbo tikslas – parengti kompleksinius teorinius ir praktinius sprendinius, skirtus didinti pajamas bei mažinti patiriamus nuostolius iš keleivių vežimo geležinkeliais, įvertinus technologinius poreikius konkretiems ruožams bei dinamiškai kintančius keleivių srautus, gerinti keleivių komfortą ir pritraukti kuo daugiau keleivių į geležinkelių transportą. Darbo tikslui pasiekti darbe reikia spręsti šiuos ***uždavinius***:

1. Išanalizuoti pasaulinėje mokslinėje literatūroje su keleivių vežimu geležinkeliais susijusias problemas ir jų sprendimo būdus.
2. Ištirti esamą padėtį keleivių vežimo geležinkeliais sektoriuje, nustatyti jo reikšmę šalies ūkiui.

3. Nustatyti keleivių vežimo geležinkeliais pajamų ir išlaidų komponentes bei identifikuoti jų priklausomybę nuo techninių riedmenų parametrų.
4. Sudaryti keleivių vežimo geležinkeliais racionalių priemonių parinkimo matematinį modelį.
5. Modeliui taikant netiesinių lygčių su daugeliu kintamųjų ir apribojimais ekstremumo paieškos metodą, parinkti riedmenis konkretiems maršrutams keleivių vežimo Lietuvos geležinkeliais pavyzdžiu.
6. Parengti riedmenų komforto charakteristikų gerinimo rekomendacijas dėl vibracijų vagonuose mažinimo, parenkant racionalius parametrus vežimėlių pakaboms esant įvairiems greičiams.

Tyrimų metodika – darbe taikomi regresinės analizės, matematinio modeliavimo, globalios optimizacijos metodai.

Mokslinis naujumas. Sukurtas modelis minimizuoti keleivių vežimo geležinkeliu nuostolius, įvertinant keleivių skaičiaus kitimo dinamiką maršrutuose, naudojamas traukos rūšis ir visas pajamų ir išlaidų sudedamąsias dalis. Optimizavus tikslo funkciją, pateikiami racionaliausi konkretaus maršrutui traukinių variantai. Sudaryta tikslo funkcija racionaliems keleivinių vagonų vežimėlių pakabų parametrams nustatyti ir sumažinti vagonų virpesius iki minimumo, siekiant pagerinti traukinio tolygios eigos rodiklius.

Praktinė vertė. Darbo rezultatai suteikia galimybę naudoti ekonomiškiausias traukos rūšis ir traukinius maršrutuose, optimizuoti keleivinių riedmenų parką, įsigyjant naujus riedmenis, nustatyti reikalavimus keleivių komfortui. Tai leis pritraukti daugiau keleivių ir mažinti bendrąsias keleivių vežimo geležinkeliais sąnaudas.

Ginamieji teiginiai

1. Optimalių sąstatų kiekvienam maršrutui parinkimo metodika.
2. Priemonių parinkimo modelis, įvertinantis ne tik technines riedmenų galimybes, bet ir visas kitas pajamų ir išlaidų sudedamąsias dalis vežant keleivius geležinkelių transportu.
3. Tikslo funkcija skirta vežimėlių pakabų parametrams optimizuoti esant įvairiems greičiams ir iki minimumo sumažinti vagonų virpesius, užtikrinant traukino stovumą ir tolygią eigą.

Darbo rezultatų aprobavimas. Disertacijos tema išspausdinti 7 moksliniai straipsniai: keturi – mokslo žurnaluose, įtrauktuose į *Science Citation Index Expanded* (*Web of Science*) sąrašą, du – kituose recenzuojamuose mokslo leidiniuose, vienas – recenzuojamame Lietuvos tarptautinės konferencijos straipsnių rinkinyje. Disertacijoje atliktų tyrimų rezultatai buvo paskelbti trijose tarptautinėse mokslinėse konferencijose: 68-ojoje tarptautinėje mokslinėje-praktinėje konferencijoje „Geležinkelio transporto vystymo problemos ir perspektyvos“ 2008 m. Dniepropetrovske (Ukraina); tarptautinėje konferencijoje „TRANSBALTICA 2009“ 2009 m. Vilniuje; IV tarptautinėje mokslinėje-praktinėje konferencijoje „Imlių mokslui technologijų diegimas magistraliniame ir pramoniniame geležinkelio transporte“ 2008 m. Jaremče (Ukraina).

Darbo struktūra. Disertaciją sudaro įvadas, keturi skyriai ir bendrosios išvados, literatūros sąrašas ir šaltiniai, autoriaus publikacijų sąrašas disertacijos tema bei priedas. Darbo apimtis – 134 puslapiai be priedų, tekste naudotos 44 numeruotos formulės, 71 paveikslas ir 36 lentelės. Rašant disertaciją buvo panaudoti 78 literatūros šaltiniai.

Pirmajame skyriuje išanalizuoti pastarųjų metų moksliniai darbai, susiję su keleivių vežimo geriausių sąlygų paieška tiek organizaciniu, tiek komforto gerinimo požiūriais.

Antrajame skyriuje analizuojama esama padėtis Lietuvos geležinkelių sistemoje pagal atskirus maršrutus, išryškinamos problemos keleivių vežimo sektoriuje, perspektyviniai uždaviniai, keleivinio parko būklė, investicijų poreikis.

Trečiasis skyrius skirtas matematinio modelio sudarymui racionaliems traukinių sąstatams parinkti, atsižvelgiant į dinamiką ir galimą traukos rūšį. Modelio reikšmingumas parodytas keliuose būdinguose ruožuose, kur keleivių dinamika skirtinga ir gali būti panaudota įvairiarūšė trauka.

Ketvirtajame skyriuje analizuojamos įvairios priemonės keleivių komfortui gerinti. Pagrindinė iš jų – žmogaus sveikatai žalingos vibracijos poveikio mažinimas vagonuose. Sudaryta tikslo funkcija, kuri leidžia parinkti vagonų vežimėlių pakabų optimalius dinaminius koeficientus, lemiančius vagonų vibracijas esant įvairiems greičiams ir kelio sužadinimams (nelygumams).

Bendrosios išvados

Apibendrinus gautus rezultatus galima padaryti tokias išvadas:

1. Pagrindinės priežastys, lemiančios nuostolius vežant keleivius geležinkeliais – mažas keleivių skaičius, šiuolaikinių riedmenų trūkumas, prasta geležinkelių infrastruktūra, neracionalus riedmenų naudojimas atskiruose vietinio susisiekimo maršrutuose.
2. Pastaruoju metu keleivinių riedmenų parkas nėra optimaliai pritaikytas keleiviams vežti vietiniais maršrutais, naudojant lanksčią keleivių vežimo priemonių transformaciją pagal traukos rūšį ir kintamą keleivių skaičių.
3. Sudarytos regresijos lygtys pagal atskirus maršrutus, rodančios keleivių kaitos dinamiką.
4. Sudarytas pajamų ir išlaidų matematinis modelis, įvertinantis visus galimus pajamų ir išlaidų veiksnius.

5. Suformavus reiso Klaipėda–Vilnius sąstatus pagal optimizuotą variantą, galima sumažinti nuostolius apie 4 kartus, o reisui Vilnius–Turmantas gauti teigiamą rezultatą, t. y. pasiekti, kad pajamos viršytų išlaidas.

6. Pagrindinis veiksnys, mažinantis keleivių komfortą, yra vagonų vibracijos. Lemiamas jų mažinimo veiksnys yra tolygios eigos koeficientas, kuris glaudžiai siejasi su vibracijos dažniais, pagreičiais ir amplitudėmis.

7. Sudaryta tikslo funkcija leidžia apskaičiuoti vagono dinaminius rodiklius (vertikalius ir horizontalius ašidėžių rodiklius, minimalų stovumo koeficientą, centrinės pakabos vertikalų dinaminį koeficientą bei vertikalų ir horizontalų kėbulo pagreičius) esant bet kokiems leistiniesiems važiavimo greičiams.

8. Tyrimai parodė, kad nustatant optimalius parametrus važiuoklių pakaboms, pagrindiniu rodikliu tikslo funkcijoje reikia laikyti stovumo koeficientą, nes šis parametras pirmasis riboja važiavimo greitį.

9. Nurodytos pažangios ergonomikos priemonės, kurios turėtų būti diegiamos naujuose keleiviniuose vagonuose (sėdynės, šildymas, paslaugų kompleksas) gerinant keleivių vežimo komfortą.

10. Naujinant keleivinį geležinkelių parką tikslinga įsigyti greitai transformuojamas keleivių vežimo priemones (pvz., modulinius traukinius), tai atitiktų keleivių vežimo koncepciją Lietuvos sąlygomis.

Trumpos žinios apie autorių

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