



Laura Černiauskaitė

**COMPLEX RESEARCH AND EVALUATION OF THE
INFLUENCE OF RAILWAY ROAD PARAMETERS ON THE
TRAINS' RUNNING SPEED IN CURVES**

Summary of Doctoral Dissertation

Technological Sciences, Civil Engineering (02T)

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Vilnius „Technika“ 2004

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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The dissertation will be defended at the public meeting of the Council of Scientific Field of Civil Engineering in the Senate Hall of Vilnius Gediminas Technical University at 2.00 p.m. on December 17, 2004.

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Laura Černiauskaitė

**GELEŽINKELIO KELIO PARAMETRŲ ĮTAKOS TRAUKINIŲ
VAŽIAVIMO GREIČIAMS KREIVĖSE KOMPLEKSINIAI
TYRIMAI IR VERTINIMAS**

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GENERAL DESCRIPTION OF THE WORK

Relevance of the Research

Over the past several years, solution of issues of quality of development, modernization, reconstruction and maintenance of international railway corridors has been in focus, considering the changing needs of an individual country's residents and common needs of railway users in general. The development of railway transport systems influences the quality of life in separate countries and regions, as defined by complex equilibrium of economic, social and political factors.

The railway transport sector in countries in Central and Eastern Europe is outdated in the technical, economic, technological and organizational sense, lagging far behind modern and efficiently interacting railway transport systems of Western and Northern Europe. Their main weaknesses include low train speeds, different conditions for the use of railway networks in different countries (differing requirements for infrastructure, projecting standards and rolling stock), low-level services, noise and vibration, insufficient level of traffic safety and environmental protection. The problem of increasing train speeds is of key importance.

Development of a joint European high-speed railway network has been started, and Lithuania should join the system as well. The main goal of the Lithuanian railway sector is to increase speeds of passenger and cargo trains on main lines from the current 120 km/h for passenger trains and 90 km/h for cargo trains. The increase of train speeds is not a technical issue only – as modernization of infrastructure requires extensive investments, it becomes an economic task, as well. Modernization and development of the existing railway infrastructure requires immense investments, which have to be based on technical and economic calculations. Implementation of the Lithuanian railway infrastructure and development program will require a minimum of about 305 million litas annually in the 2001–2007 period. The goal of the work is to increase speeds of cargo trains to 100 km/h and that of passenger trains to 160 km/h. Growth of train speeds leads to reduction of passenger or cargo travel time, which produces an economic effect.

Railway tracks consist of straight sections and curves. Curves make between 20 and 35 percent of the overall railway length. Increase of train speeds on curves intensifies forces, which act on the track and train passengers, and reduces safety of all kinds of train traffic and the level of passenger comfort. This is due to the existing small curve radius and rising outer rail, which is outfitted in an effort to reduce centripetal and centrifugal forces. Therefore, the increase of train speeds leads to stricter

requirements for road construction and maintenance on curves. A key engineering task is to determine curve parameters after changes to the railway track utilization conditions, which depend on a specific country's topographic conditions, the ratio between the traffic of passenger and cargo trains, economic, social and political factors. On curved railway lines used by both cargo and passenger trains, it is necessary to verify the ratio of cargo and passenger train speeds.

The cost of increasing railway curve radius is equivalent to the cost of constructing a new railway line, therefore, it is important to determine whether it is more expedient to reconstruct existing curves or build new lines for passenger trains only. (In Lithuania, railway transport accounts for merely 2.7 percent of passenger carrying among other means of transportation, therefore, building of new lines for passenger traffic only is not projected). Meanwhile, traffic of passenger trains determines most requirements set for railway infrastructure (speed limits, station equipment and parameters of track plan and longitudinal section) and prospects for expansion of the rolling-stock depot.

All reasons stated above determine the relevance and validity of the doctoral dissertation.

Aim and tasks of the work

The aim of the work is to determine the influence of railway track parameters upon train speeds on curves, as well as to analyze and propose rational solutions for increasing train speeds on main lines of Lithuanian railways.

The following tasks were set out to achieve the aim:

- To analyze and assess the experience of foreign countries in similar researches and specify it to meet the specific needs of Lithuanian conditions;
- To analyze main factors influencing train speeds on curves of railway tracks;
- To develop an analytical algorithm for the selection of railway track curves to define the influence of existing parameters of curves upon train speeds. To design improved methods for researching existing railway track curve parameters in an effort to increase train speeds;
- To carry out pilot research of selected railway lines in order to analyze factual train speeds on railway track curves and determine the effect of existing curve radiuses, rising outer rail and positions of curve on the line upon them. To present an analysis and assessment of research data;
- To propose mathematical models for solving tasks to

- increase railway speeds on existing railway lines;
- To determine the economic effect caused by the implementation of research results.

Scientific novelty and originality of research

The work discusses main factors influencing train speeds. With the help of a detailed analysis of the experience of foreign countries in railway development, modernization, reconstruction and maintenance and research of priority railway lines in our country, the author has developed an algorithm for grouping railway track curves, which enables to determine, for the first time, the volumes of work for reconstruction of railway track plan curves and the necessary investments required to satisfy users' needs and improve life of the population. Under the proposed methods for researching railway track curves, the author researched for the first time in Lithuania and summarized – with the help of the „TRAUKA“ software – the factors defining curved sections of railway tracks that are necessary for improvement of solutions for train speed increase. The author suggests applying mathematical modeling when addressing tasks of optimizing parameters of railway track curves in modernization of railway lines. The economic effect of travel time savings for passengers has been calculated.

Main factors restricting train speeds on mixed-traffic railway lines are small-radius flat curves of railway track plan, their parameters and the position of the curve on railway line. Therefore, special research was carried out to substantiate parameters of railway track curves for reconstruction of existing railway lines to facilitate higher train speeds.

The author suggests that problems arising with the increase of train speeds should be addressed through assessment of railway track curve radius, rising outer rail, curve position on line and factual train speeds determined with the help of the special computer software „TRAUKA“. The author reasons that economic issues of railway reconstruction should be solved and decisions should be made using the analysis and conclusions of research of railway track curves.

Research object and methods

The dissertation analyzes the influence of railway track curve radius, rising outer rail and position of curve on line upon projected train speeds. Two priority railway lines in Lithuania were analyzed by the aspect. The abovementioned object of research was analyzed using theoretical, analytical and mathematical statistical methods. Computer software „TRAUKA“ was used for experimental research.

Significance of scientific work

The significance of scientific work performed is that the proposals were taken into consideration during modernization of main lines of Lithuanian railways, which led to saving of expenses related with travel time economy, and volumes of railway track curve reconstruction are linked with topographic conditions of Lithuania and specific characteristics of railway traffic are assessed (the share of haul volumes and tonnage of passenger trains in the general tonnage is forecast).

Approbation of the research

The main findings of the dissertation were presented and discussed during the following conferences:

1. 4th international conference „Environmental Engineering“, held on May 25-26, 2000 in Vilnius, Lithuania.
2. National conference „Civil Engineering and Geodesy“ held on September 29, 2000 in Vilnius, Lithuania.
3. National conference „Civil Engineering and Geodesy“ held on October 5, 2001 in Vilnius, Lithuania.
4. 7th international conference „Modern Building Materials, Structures and Techniques“, held on May 16-18, 2001 in Vilnius, Lithuania.
5. 5th conference of junior scientists of VGTU Lithuania „Lithuania without Science - Lithuania without the Future“ held on March 21, 2002 in Vilnius, Lithuania.
6. 5th international conference „Environmental Engineering“, held on May 23-24, 2002 in Vilnius, Lithuania.
7. National conference „Civil Engineering and Geodesy“ held on October 29, 2002 in Vilnius, Lithuania.
8. 4th international conference „Transbaltica-03“, held on April 10–11, 2003 in Vilnius, Lithuania.
9. 12th international conference „Railways 2003“, held on October 14–18, 2003 in Gdansk-Sobieszewa, Poland.

Publications: 3 accepted scientific publication and 6 other scientific publikations (see 23–24 p.).

The framework of the dissertation

The doctoral dissertation consists of introduction, four chapters, general conclusion, a list of references and presentations according to the dissertation theme list, a list of literature. The text of the dissertation is presented on 125 pages and modeled on computer and printed at an interval of 1.5 lines. The work includes 60 figures and 27 tables.

THE CONTENT OF THE DISSERTATION

The introduction illustrates relevance of the topic of the dissertation, describes object and methods of research, explains scientific novelty and originality of work and formulates aim and tasks for the work.

The increase of train speeds on existing mixed-traffic lines is not a new task but remains relevant today in Central and Eastern Europe, especially since the issue has not yet been addressed in a scientific approach in Lithuania.

Chapter One titled Object of Research, Work Goals and Tasks analyzes the historical evolution of train speed increases and practical opportunities to translate the task into reality. A detailed analysis has been performed into researches by foreign scientists aimed to increase train speeds through the revision of railway track parameters on existing lines of mixed traffic.

All aspects that influence train speeds on railway track have been divided into local and global factors. Local factors are restricted to their length on certain sections of a railway track (small-radius curves, short transition curves, lengths of straight sections between curves, rising outer rail, switches, stations, road structures, crossings, defects and deformations of track formations). Global factors refer to those existing throughout the railway track (type and state of track superstructure, electrification system, if there is one, alarm network and telecommunication network).

Studies by scientists of foreign countries show that small-radius flat curves of railway track have the biggest effect on train speeds. Other key parameters on mixed traffic lines include the size of rising outer rail on curve and standard values of undamped cross acceleration. Costs of increasing curve radius is identical to the cost of constructing a new line, therefore, technical and economic calculations are required to determine the feasibility of reconstructing existing curves against the construction of a new line for passenger transport only.

Consequently, an analysis was carried out into factors determining the efficiency of increasing train speeds and main indicators and methods determining a project's economic feasibility.

Chapter One contains an analysis of Lithuanian railway lines. The distribution of highest permissible speeds for passenger trains on railway lines Vilnius–Klaipėda and Kaišiadorys–Kybartai is portrayed in Figures 1 and 2.

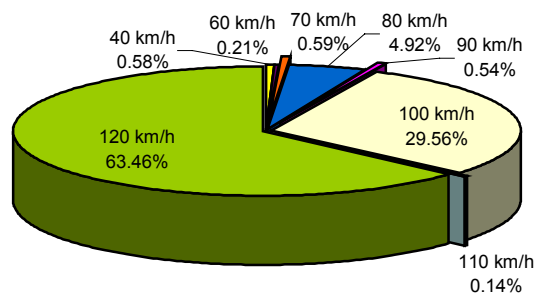


Fig 1. Distribution of highest permissible speeds for passenger trains on the railway line Vilnius–Klaipėda

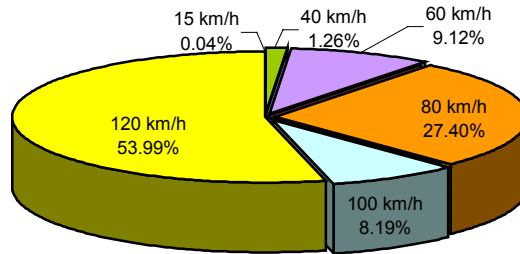


Fig 2. Distribution of highest permissible speeds for passenger trains on the railway line Kaišiadorys–Kybartai

On both analyzed railway lines, train speeds under 120 km/h account for the biggest part of the track. However, they account for merely 63.46 percent and 53.99 percent, respectively, of the overall line length.

For the analysis of flat curves of Lithuanian railway lines by their radius, the curves have been divided into 5 groups. **I** – ≤ 500 m; **II** – 501–650 m; **III** – 651–800 m; **IV** – 801–1 000 m; **V** – $> 1\,000$ m. The majority of curves are curves with radius > 1000 m (808 curves) and the least number are of curves with radius ≤ 500 m (44 curves). There are 167 and 215 flat curves of groups II and IV, respectively.

There are a total of 329 flat curves on the railway line Vilnius–Klaipėda, with overall curve length of 147.28 km, which amounts to 27 percent of the overall track length. On track I, there are 210 flat curves (92.28 km). On track II, there are 119 flat curves (55.002 km). Curves with a radius of more than 1 200 m make 44.81 percent.

There are a total of 110 flat curves on the railway line Kaišiadorys–Kybartai, with overall curve length of 38.84 km, which amounts to 16 percent of the overall track length. On track I, there are 53 flat curves (19.19 km). On track II, there are 57 flat curves (19.65 km). Curves with a radius of more than 1 200 m make 59.55 percent.

The analysis of studies conducted by scientists of various foreign countries and the two Lithuanian railway lines enabled to formulate the aim of work and plan tasks for achieving the aim.

Chapter Two is titled *Modeling of Railway Track Parameters and Train Speeds*. Increase of train speeds on curves of existing railway lines requires changing key parameters of curves. The chapter contains a detailed analysis of the influence of flat curve radius, rising outer rail and undamped cross acceleration upon train speeds. The influence of parameters of railway track curves (flat curve radius, rising outer rail and undamped cross acceleration) upon train speeds is assessed through their interdependence.

The highest permissible speed for passenger trains on every curve when the curve radius, rising outer rail and undamped cross accelerations are known values can be determined according to Formula 1 and the $v_{\max} = f(R, h, a_n)$ diagram provided in Figure 3:

$$v_{\max}^{R,h} = 3.6 \sqrt{R \left([a_n] + g \frac{h}{S} \right)}, \quad (1)$$

where h – rising outer rail, mm; R – flat curve radius, m; a_n – standard value of undamped cross acceleration equaling 0.7 m/s^2 ; S – distance between rail head axes (depends on gauge width, when gauge width is 1 520 mm, $S = 1\,600 \text{ mm}$), mm; g – free fall acceleration equaling 9.81 m/s^2 .

When rising outer rail is accepted as equaling 150 mm and standard undamped cross acceleration on curve does not exceed 0.7 m/s^2 , highest permissible train speeds are calculated by the dependence upon flat curve radius $v_{\max}^R = 4.6 \sqrt{R}$, km/h.

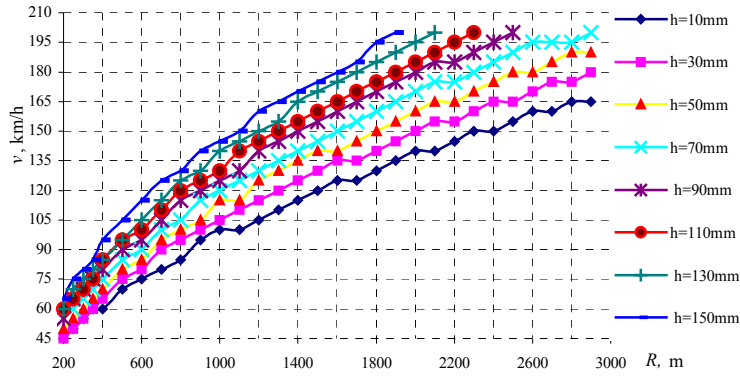


Fig 3. Dependence of highest permissible speed for passenger trains on curves upon curve radius and rising outer rail, when accepted $a_n = 0.7 \text{ m/s}^2$

Following an analysis of methods for determining the improved rising outer rail on existing mixed traffic lines, the proposed three formulas for calculation of rising outer rail are as follows:

- for passenger trains when $a_n = 0.7 \text{ m/s}^2$:

$$h_{kel} = \frac{12.5v_{\max, kel}^2}{R} - 163a_n = \frac{12.5v_{\max, kel}^2}{R} - 115; \quad (2)$$

- for cargo trains when $a_n = +0.3 \text{ m/s}^2$:

$$h_{kr} = \frac{12.5v_{\max, kr}^2}{R} - 163a_n = \frac{12.5v_{\max, kr}^2}{R} - 50; \quad (3)$$

- train stream:

$$h_{sr} = \frac{12.5v_{sr}^2}{R}, \quad (4)$$

where $v_{\max, kel}$, $v_{\max, kr}$ represents maximum speed of passenger and cargo trains on curve, km/h; v_{sr} – average train stream speed on curve, km/h; R – flat curve radius, m.

The largest value calculated by formulas 2–4 is accepted. An analysis shows that the three formulas have different range of

validity. Formula (2) applies to the range when curve radius is between 500 and 2 800 m, and the highest train speed varies in the 100–160 km/h range with intervals of 10 km/h. Formula (3) applies when curve radius is between 350 and 2 900 m, while Formula (4) applies in the broadest range of 300–4 500 m. We have determined that the general application interval of all three formulas is when curve radius is 500–2 800 m (i.e., average curve radius equals 1 500 m).

An algorithm for grouping railway track curves is proposed. Under the algorithm, curves are divided into three groups depending on projected train speeds v_{pr}^{tr} , km/h, and existing values of railway track curve radiuses R_i , m, and rising outer rail h_i , mm. This enables to determine an exact number of curve groups to be remodeled and calculate the length of curve groups.

Group I. Flat curves that satisfy the condition $v_{pr}^{tr} < v_{max}^{R,h}$, which means that existing curve parameters R_i and h_i ensure highest projected train speeds calculated with the help of „TRAUKA“ calculations v_{pr}^{tr} , km/h.

Group II. Flat curves where the existing curve radius R_i may be left unchanged and the existing rising outer rail h_i restricts highest projected train speeds v_{pr}^{tr} , km/h. A relevant rising outer rail should be equipped and lengths of transition curves should be calculated on such curves.

Group III. Flat curves that satisfy the condition $v_{pr}^{tr} > v_{max}^R$, which means that the existing curve radius R_i restricts the highest projected train speeds v_{pr}^{tr} , km/h.

The algorithm for grouping flat curves on railway line is provided in Figure 4.

Chapter Three titled *Complex Research of the Influence of Railway Track Parameters upon Train Speeds* provides methods for researching railway track curves and train speeds. The chapter contains an analysis of research data and a comparison with results of researches by other authors. Necessary data about selected objects was collected (existing curve radiuses and rising outer rail), summarized and analyzed statistically with the help of calculated statistical indicators: average value of indicator, dispersion, average square deflection, variation coefficient, actual value of arithmetic average and alteration interval. The statistical characteristics have been summarized on both lines studied and presented in Tables 1 and 2.

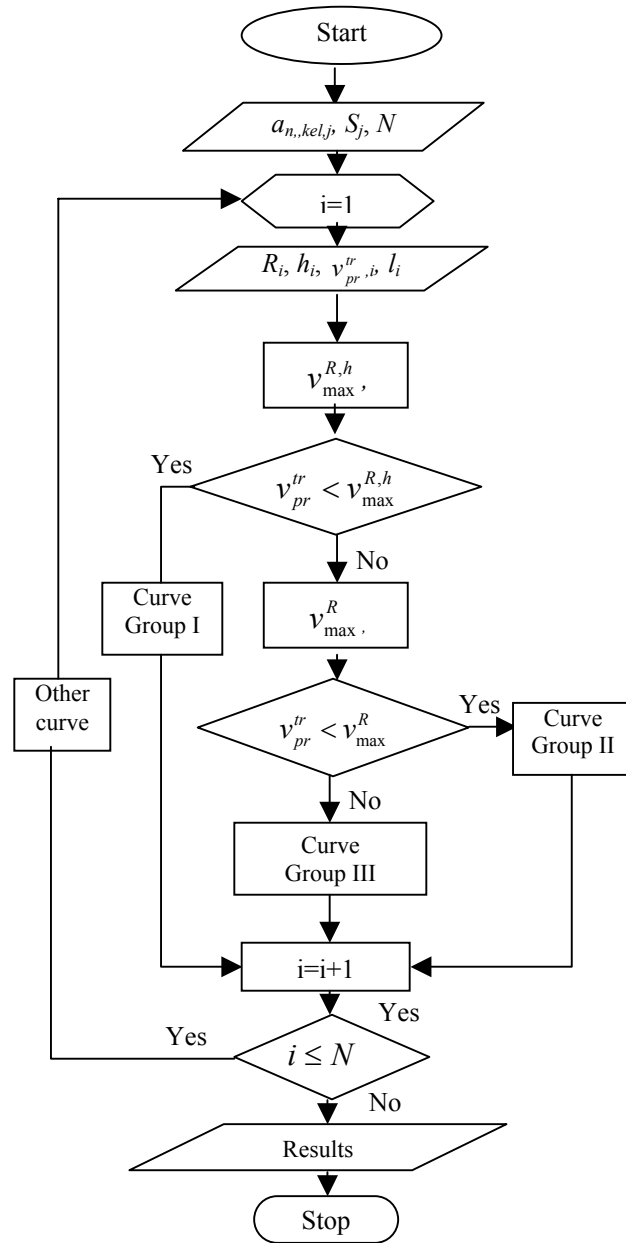


Fig 4. Algorithm for grouping flat curves on railway line

On both railway lines studied (tracks I and II), the existing curve radius and rising outer rail does not ensure a train speed of 160 km/h, as indicated on histograms and clause functions provided. They indicate that the curve radius of more than 80 percent of curves does not satisfy minimum requirements made for category I railways.

Table 1. Statistical characteristics of flat curve radius R , m on railway curves studied

Railway line	Statistical characteristics of flat curve radius, m				
	Average	Average square deflection	Variation coefficient, %	Value, when probability $p = 0,95$	
				Average	Result distribution
Vilnius–Klaipėda Track I	1 439	854	59	1 321–1 557	269–3 147
Vilnius–Klaipėda Track II	1 653	1 078	65	1 456–1 850	303–3 809
Kaišiadorys–Kybartai Track I	2 005	1 133	57	1 691–2 319	260–4 270
Kaišiadorys–Kybartai Track II	1 688	951	56	1 436–4 813	214–3 590

Table 2. Statistical characteristics of rising outer rail h , mm on railway curves studied

Railway line	Statistical characteristics of rising outer rail, mm				
	Average	Average square deflection	Variation coefficient, %	Value when probability $p = 0,95$	
				Average	Result distribution
Vilnius–Klaipėda Track I	60	29	48	56–64	3–118
Vilnius–Klaipėda Track II	54	27	50	49–59	0–109
Kaišiadorys–Kybartai Track I	55	28	52	47–62	0–111
Kaišiadorys–Kybartai Track II	49	27	55	42–56	0–107

The top permissible train speed for every curve studied has been calculated according to Formula (1). The author conducted an analysis of speed data of passenger trains on curves has been, determined alteration of curve change and developed its mathematical model on both lines.

Diagrams of dependence of train speed on existing curve radius and rising outer rail (when curve is studied as isolated) are depicted in Figures 5 and 6.

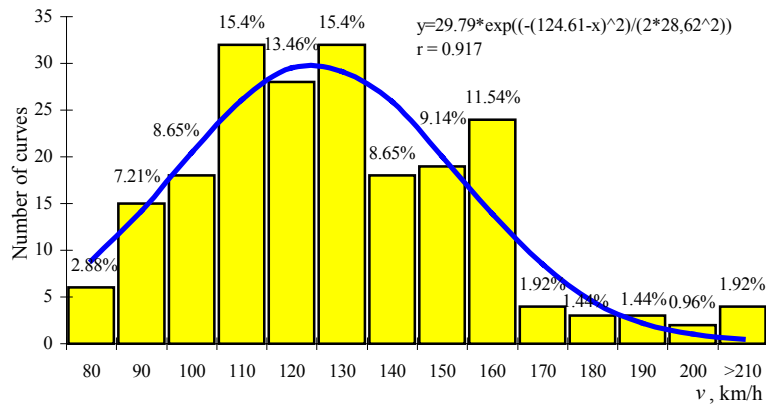


Fig 5. Diagram of dependence of highest permissible speed of passenger train on existing curve R or h on line Vilnius–Klaipėda (Track I)

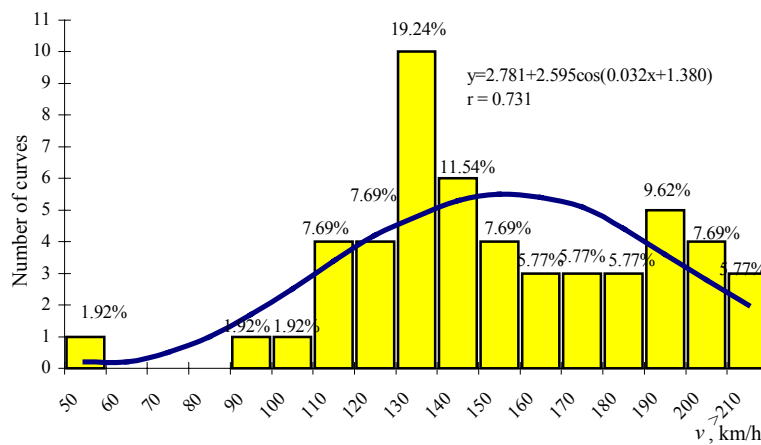


Fig 6. Diagram of dependence of highest permissible speed of passenger train on existing curve R and h on line Kaišiadorys–Kybartai (Track I)

The dominant top permissible train speeds on the railway line Vilnius–Klaipėda are 110 and 130 km/h, which passenger trains can reach on 64 curves, 30.8 percent of the overall number of curves. The lowest permissible speed for passenger trains is 80 km/h. There are 6 curves where passenger trains can go at such speeds. **As many as 80.77 percent** of all curves analyzed restrict speeds of passenger trains to 160 km/h.

The dominant top permissible speed for passenger trains on the railway line Kaišiadorys–Kybartai is 130 km/h, which trains can reach on 10 curves, 19.24 percent of the overall number of curves. The lowest permissible passenger train speed is 50 km/h. **As many as 59.61 percent** of all curves analyzed restrict speeds of passenger trains to 160 km/h.

It is important to stress the big differences in the character of rising outer rail on curves, and it will need to be determined through the assessment of factual maximum speeds of passenger and cargo trains on curves and according to the average speed of train stream.

Studies of the dependence of train speeds and time upon railway track parameters (elements of longitudinal track section, flat curve radius and rising outer rail) were performed with the help of special computer software „TRAUKA“. The results of software calculations are analyzed by diagrams of dependence of train speeds on track $v = f(s)$.

An analysis and assessment of average speed of passenger trains and time has been conducted. Results for both railway lines under research are analyzed and assessed through comparison of versions I, III and II, V of the „TRAUKA“ calculations between themselves. Results of the analysis are provided in Tables 3 and 4.

Although average train speeds on the railway line Vilnius–Klaipėda are higher than those on the line Kaišiadorys–Kybartai, the time economy differs by merely 2 percent.

Table 3. Analysis and assessment of „TRAUKA“ calculation results on track I of railway line Vilnius–Klaipėda

Calculation results	Versions			
	I	III	II	V
Train running time, minutes	257.3	215.6	250.3	170.6
Running time economy, %	16.21		31.84	
Average train speed, km/h	88	105	90	132
Increase in average train speed, %	19.32		46.67	

Table 4. Analysis and assessment of „TRAUKA“ calculation results on track I of railway line Kaišiadorys–Kybartai

Calculation results	Versions			
	I	III	II	V
Train running time, minutes	88.6	69.6	86.4	57.0
Running time economy, %	21.44		34.03	
Average train speed, km/h	84	106	86	130
Increase in average train speed, %	26.19		51.16	

The influence of curve position on railway line upon train speed has been assessed based on determination of factual train speeds on every curve. The highest factual speeds reached by trains on curves under version V of the „TRAUKA“ calculation are compared with the determined permissible train speeds on curves by existing railway track curve parameters R_i and h_i (when curve is analyzed as isolated).

An analysis of research data have been divided into three groups with the help of the computer program Kreiv_gr designed by the author.

The results of research in both railway lines under research are provided in Table 5.

Table 5. Distribution of curve number into groups, % on both railway lines analyzed

Railway line	Distribution of curve number into groups, %		
	Group I	Group II	Group III
Vilnius–Klaipėda	43.33	25.72	30.95
Kaišiadorys–Kybartai	71.15	19.23	9.62

Lengths of curve groups have been calculated, with calculation results by curve groups on both railway lines analyzed are provided in Table 6.

Table 6. Distribution of curve group lengths on both railway lines analyzed

Railway line	Distribution of curve lengths into groups, km		
	Group I	Group II	Group III
Vilnius–Klaipėda	40.842	24.373	27.06
Kaišiadorys–Kybartai	13.370	3.164	2.656

On the railway line Vilnius–Klaipėda there are a total of 119 railway track curves (**56.67 percent** of the overall number of curves), which fall into train speed zones and, according to curve parameters R and h , do not ensure realization of speeds, as calculated by the V version of „TRAUKA“ calculations. Their length totals at 51.433 km, which accounts for 55.74 percent of the length of all curves.

On the railway line Kaišiadorys–Kybartai, there are 15 railway track curves (**28.85 percent** of the overall number of curves), which fall into train speed zones and, according to curve parameters R and h , do not ensure realization of factual train speeds, as calculated by „TRAUKA“. This totals at 5.82 km, which accounts for 30.33 percent of the length of all curves.

The analysis and assessment of our research have been compared with results received by other authors. A comparison of results with those of analogous research conducted by other authors showed that the average train speed on curves is 132 km/h on railway line Vilnius–Klaipėda and 130 km/h on railway line Kaišiadorys–Kybartai in the author’s research and 130.92 km/h, 124.5 km/h and 136.1 km/h in researches by other authors. A comparison of the author’s research results with results of other surveys is depicted in Figure 7.

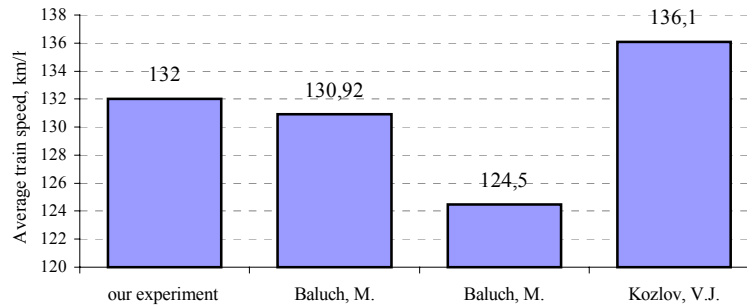


Fig 7. Average train speed on curve in surveys by various authors

The results of our surveys and those by other authors are different due to different line lengths, weight of train units, number of cars and stops, as well as other conditions.

Complex surveys were conducted to allow determining factual train speeds reached on curves, when the projected speeds are up to 160 km/h for passenger trains and up to 100 km/h for cargo trains. With these train speeds available, the author established a formula by the monogram and calculated values of rising outer rail.

The result is as follows: the value of projected rising outer rail should be in the interval 35–135 mm on the railway line Vilnius–Klaipėda and in the interval 60–115 mm on the railway line Kaišiadorys–Kybartai. The values received are close to the results received in analogous researches by other authors: other authors found that the rising outer rail should be 40–145 mm and 90–114 mm.

Results of our research are different from the results received by other authors due to different maximum speeds reached by passenger and cargo trains and the average speeds of train stream, existing curve radiuses and other parameters.

Chapter Four is titled *Application of Research Data for Solving Tasks of Increase of Train Speeds*. The chapter provides mathematical models developed to determine the influence of certain factors upon train speeds in the interval of changes. The full factorial experiment 2^3 was chosen for the modeling because the highest permissible speed for passenger trains on flat curves is linked with functional dependence of three variable indicators.

The experiment is aimed to find a mathematical model and determine whether the factors, without exceeding their permissible limits, will influence the value expressed through the highest permissible speed for passenger trains (v_{max}) on curve:

$$v_{max} = f(x_1, x_2, x_3), \quad (5)$$

where x_1, x_2, x_3 are factors marked by special symbols.

Various values of highest permissible train speeds will be received when remodeling lines of railways of various categories when there are various values of x_1, x_2 and x_3 or:

$$v_{max} = f(x_i, x_j, x_k). \quad (6)$$

After choosing a first degree polynomial and conducting a factorial experiment of plan 2^3 , mathematical models were for the first time received for practical application. The models allow calculating the highest permissible speed of passenger trains depending on the following factors: x_1 – flat curve radius R , m; x_2 – rising outer rail h , mm; x_3 – undamped cross acceleration a_n , m/s^2 when the factors (x_1, x_2, x_3) are on levels indicated in the plan matrix. In the case under research, eight different values of highest permissible speeds of passenger trains on curves were received, which were used for calculation of regression coefficients of selected mathematical models. The coefficients indicate the influence the relevant factor will have on the highest permissible train speed v_{max} . The higher the coefficient value is, the more influence it will have upon train speeds.

This way, the final mathematical model is as follows:

$$v_{max} = 200.68 + 43.57x_1 + 73.25x_2 + 31.86x_3 + 15.9x_1x_2 + 6.92x_1x_3. \quad (7)$$

The model shows that rising outer rail and curve radius will have most influence upon the highest permissible speeds for passenger trains (with these factors, the respective coefficients are 73.25 and 43.57).

In cases when undamped cross acceleration is fixed at $a_n = 0.7 m/s^2$, a factorial experiment 2^2 suffices for a mathematical model. The experiment can be expressed in the following way:

$$v_{\max} = 184.75 + 40.105x_1 + 73.245x_2 + 15.9x_1x_2. \quad (8)$$

The expression of the mathematical model shows that the train speed on curve is mostly influenced by rising outer rail in this case as well.

Proposals were made for determination of the minimum radius of curves under reconstruction with the assessment of highest speed of passenger trains and average speed of the train streams, as well as the ratio between the two indicators. Projection of a minimum curve radius on railway lines of mixed traffic required verifying the ratio of highest permissible speed of passenger trains and the average speed of train stream.

Theoretical calculations suggest that the average train speed is directly proportional to the minimum curve radius, i.e., increase of the speed would reduce the minimum radius of the curve under reconstruction. Lithuanian railways are primarily used for cargo traffic, so there is no possibility to increase the average speeds of railway stream without increasing the speeds of cargo trains. When projecting the minimum curve radius, it has to be determined based on the highest speed of passenger trains and the average speed of train stream on curves.

Proposals are made to determine the minimum projected curve radius on railway lines with mixed traffic by the graph of dependence between highest speed of passenger trains and average speeds of train streams.

A coefficient of economic effect has been determined based on investments needed for reconstruction of curves and the profits expected from saving passenger travel time per year on both railway lines analyzed.

The coefficient of economic effect is 6 percent on line Vilnius–Klaipėda and 14 percent on line Kaišiadorys–Kybartai. Investments required for reconstruction of railway track curves on these lines will pay off in 10 years if 8 high-speed daily trains are launched.

In the end of the dissertation, the author provides general conclusions and proposals, a list of the author's publications and conference reports on the dissertation topic and references.

CONCLUSIONS AND PROPOSALS

An analysis of experiences of foreign countries that aim to increase train speeds on existing railway lines leads to a conclusion that the increase of train speeds on existing railway lines mostly depends on small-radius flat curves of railway tracks. When a train is going at a high

speed on a curve with low radius, emerging forces have a negative effect on the train going conditions and the comfort of passengers. A higher curve radius or a relevant rising outer rail on curve has to be equipped to reduce the forces

1. Factors influencing train speeds on railways have been divided into two groups: local factors that are restricted by their length on a certain location of a railway line (small-radius curves, short transition curves, lengths of straight sections between curves, rising outer rail, switches, stations, road structures, crossings, defects and deformations of track formations) and global factors that exist throughout the railway line length (type and state of track superstructure, electrification system, if there is one, alarm network and telecommunication network). The dissertation addresses local factors – radius and rising outer rail of flat curves of railway track.

2. There is a functional dependence among the curve radius, rising outer rail, undamped cross acceleration and permissible train speeds, therefore, the influence of parameters of flat curves on railway track upon projected train speeds is assessed through the interdependence.

3. In order to increase train speeds on existing railway lines of mixed traffic, specialists need to assess traffic conditions of all trains because theoretical research suggests that increase of cargo train speeds by a factor of 1.6 would reduce the minimum radius of the curve under reconstruction by a factor of 1.8. Increasing the standard undamped acceleration for passenger trains from $a_{n,rel} = 0.6\text{--}1.0 \text{ m/s}^2$ (67 percent) increases the maximum train speed by more than 12 percent.

4. We propose dividing existing flat curves into three groups on the railway line under research by the value of the existing curve radius and rising outer rail, as well as the achieved (projected) train speed on curve. This enables to determine the exact influence of existing railway track flat curve parameters upon projected train speeds on curves, which allows determining the number of curves to be restructured and the length of the track to be modernized (volumes of work).

5. Results of experimental research prove the assumption that the position of curve on the railway line (distance from stations, distance between next curves and gradient incline of longitudinal section) is a significant factor influencing train speeds. Not all curves, which might restrict the projected train speed on curve by the existing values of railway track flat curve radius and rising outer rail, fall into the zone of train speed. On both railway lines analyzed, the number of railway track curves limiting the factual train speeds dropped by 20–30 percent.

6. An analysis and evaluation of results received from versions of „TRAUKA“ calculation and comparison of existing train speeds on

curves with projected train speeds an increase of the average train speed Δv_{vid} , km/h, has been determined at 46–52 percent and economy of passengers' travel time Δt , min. of 20–30 percent. Calculation of an economic effect leading from putting the research results into practice showed the investments needed for reconstruction and the expected economic effect coming from the saving of travel time by passengers. The economic effect coefficient determined on both studied railway lines indicates that the investments on the two railway lines would pay off within a decade, at average.

7. The developed mathematical models show that out of the three factors studied $v_{max} = f(x_1, x_2, x_3)$ (x_1 – flat curve radius R , m; x_2 – rising outer rail h , mm; x_3 – undamped cross acceleration a_n , m/s²) with different variations of values the biggest effect upon train speed on curves is produced by rising outer rail, while curve radius is another important factor.

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Information about the Author of the Doctoral Dissertation

Laura Černiauskaitė was born in Raseiniai in 1975–11–03. She started her civil engineering studies at the Vilnius Technical University (now Vilnius Gediminas Technical University) in 1993 and graduated in 1999.

In March 1998 through October 1999, she worked as an engineer at the statistical section of SC Lietuvos Geležinkeliai. She has been working as an assistant at the Roads Department of the Faculty of Environment Engineering since September 1999. Probationary: on November 14-21 1999 Moscow State University of Railway Engineering (MIIT), Moscow in Russia; on October 2-7 2000 Sankt Peterburg in Russia; on November 11-18 2001 (MIIT) Moscow in Russia; on March 5–9 2002 Railway scientific and technical centre (CNTK) Warsaw in Poland.

BENDRAS DISERTACIJOS APRAŠYMAS

Darbo aktualumas

Pastaraisiais metais daug dėmesio skiriama tarptautinės reikšmės geležinkelių plėtros, modernizavimo, rekonstrukcijos ir priežiūros kokybės klausimų sprendimui, atsižvelgiant į besikeičiančius atskiros šalies gyventojų ir bendrus geležinkelių kelių vartotojų poreikius. Geležinkelių transporto sistemos plėtra daro įtaką atskirų šalių ir regionų gyventojų gyvenimo kokybei, kurią apibūdina sudėtinga ekonominių, socialinių ir politinių veiksnių pusiausvyra.

Rytų ir Centrinės Europos valstybių geležinkelių transporto sektorius techniniu, ekonominiu, technologiniu ir organizaciniu požiūriu yra moraliai pasenęs ir gerokai atsilieka nuo šiuolaikinių, modernių ir tarpusavyje efektyviai sąveikaujančių Vakarų ir Šiaurės Europos geležinkelio transporto sistemų. Esminiai trūkumai: maži traukinių važiavimo greičiai, skirtingos įvairiose šalyse naudojimosi geležinkelio tinklu sąlygos (skiriasi infrastruktūrai keliami reikalavimai, projektavimo normos, riedmenys), žemas paslaugų lygis, triukšmas ir vibracija, nepakankamas eismo saugumo ir aplinkos apsaugos lygis. Labai svarbi problema – traukinių važiavimo greičių didinimas.

Pradėtas kurti bendras Europos greitųjų geležinkelio magistralių tinklas, prie kurio turi prisijungti ir Lietuva. Lietuvos geležinkelių svarbiausias tikslas – pagrindinėse geležinkelio linijose padidinti keleivinių ir krovinių traukinių važiavimo greičius. Traukinių važiavimo greičių didinimas nėra vien tik techninė problema, kadangi infrastruktūrai modernizuoti reikalingos nemažos investicijos, tai yra ir ekonominis uždavinys. Esamai geležinkelių infrastruktūrai modernizuoti ir plėsti reikia didelių investicijų, kurios turi būti pagrįstos techniniais ir ekonominiais skaičiavimais. Minimaliai Lietuvos geležinkelių infrastruktūros ir plėtros programos vykdymui 2001–2007 m. kasmet reikės mažiausiai apie 305 mln. Lt. Šių darbų tikslas – didinti keleivinių traukinių važiavimo greičius iki 160 km/h, o krovinių traukinių – iki 100 km/h. Traukinių važiavimo greičio didinimas trumpina keleivių ir krovinių kelionės laiką, o dėl to gaunamas ekonominis efektas.

Geležinkelio kelio plano kreivės sudaro nuo 20–35 proc. bendro kelio ilgio. Traukiniui dideliu greičiu važiuojant mažo spindulio kreive, išauga jėgos, kurios veikia į kelią ir traukinio keleivius, sumažėja visų tipų traukinių eismo saugumas ir keleivių komforto lygis. Tam įtakos turi esami maži kreivių spinduliai ir kreivėje neįrengta išorinio bėgio pakyla, kuri įrengiama siekiant sumažinti išcentrinės ir įcentrinės jėgos veikimą. Didinant traukinių važiavimo greičius, keliami griežtesni reikalavimai kelio konstrukcijai ir jos priežiūrai kreivėse. Labai svarbus inžinerijos uždavinys – nustatyti kreivės parametrus, pasikeitus geležinkelio kelio eksploataavimo sąlygoms, kurios priklauso nuo šalies topografinių sąlygų, keleivinio ir krovinio traukinių eismo santykio, ekonominių, socialinių ir politinių veiksnių. Veikiančiose mišraus eismo geležinkelio linijose kelio plano kreivėse būtina patikrinti keleivinių ir krovinių traukinių važiavimo greičių santykį.

Kreivių spindulio didinimo darbų kaina yra prilyginama naujos linijos tiesimo kainai, todėl reikia nustatyti, ar tikslinga rekonstruoti esamas mažo spindulio kelio plano kreives, ar geriau tiesti naują geležinkelio liniją, skirtą tik keleiviams vežti, (Lietuvoje tarp kitų

transporto šakų geležinkelių transportas užima vos 2,7 proc. keleivių vežimo dalies, todėl naujas geležinkelio linijas skirtas tik keleiviams vežti greitaisiais traukiniais tiesti kol kas nenumatoma). Būtent nuo keleivinių traukinių eismo priklauso daugelis geležinkelių infrastruktūrai keliamų reikalavimų (ribiniai greičiai, stočių įranga, kelio plano ir išilginio kelio profilio parametrai) bei riedmenų parko plėtros perspektyvos.

Visos išvardytos priežastys nusako šio darbo aktualumą ir pagrįstumą.

Darbo tikslas ir uždaviniai

Darbo tikslas: nustatyti geležinkelio kelio plano kreivių parametrų įtaką traukinių važiavimo greičiams kreivėse, ištirti ir pasiūlyti racionalius sprendimo būdus Lietuvos geležinkelių pagrindinių linijų traukinių važiavimo greičių didinimo uždaviniams įgyvendinti.

Siekiant užsibrėžto tikslo, darbe sprendžiami tokie uždaviniai:

- išanalizuoti užsienio valstybių panašių tyrimų patirtį, ją įvertinus ir pakoregavus pagal vietinius specifinius veiksnius pritaikyti Lietuvos sąlygoms;
- išanalizuoti pagrindinius veiksnius, darančius įtaką traukinių važiavimo greičiams, geležinkelio kelio plano kreivėse;
- sudaryti analitinį geležinkelio kelio plano kreivių atrankos algoritmą, aprašantį geležinkelio kelio plano kreivių esamų parametrų įtaką traukinių važiavimo greičiams. Sudaryti patikslintą esamų geležinkelio kelio plano kreivių parametrų tyrimo metodiką, siekiant padidinti traukinių važiavimo greičius.
- atlikti pasirinktų geležinkelio linijų eksperimentinius tyrimus, kuriais ištirti faktinius traukinių važiavimo greičius geležinkelio kelio plano kreivėse, ir nustatyti, kaip juos veikia esami kreivių spinduliai ir išorinio bėgio pakyla bei kreivės vieta linijoje. Pateikti tyrimo duomenų analizę ir vertinimą;
- pasiūlyti matematinius modelius esamų geležinkelio linijų traukinių važiavimo greičių didinimo uždaviniams spręsti.
- nustatyti ekonominį efektą įdiegus tyrimo rezultatus.

Mokslinis darbo naujumas ir originalumas

Darbe išnagrinėti pagrindiniai veiksniai, darantys įtaką traukinių važiavimo greičiams. Naudojantis detalia geležinkelių plėtros, modernizavimo, rekonstravimo ir priežiūros problemų įvairiose pasaulio šalyse sprendimų analize ir mūsų atliktais šalies prioritetinių geležinkelio linijų tyrimais, pagal autorės sukurta geležinkelio kelio plano kreivių grupavimo algoritmą ir parašytą kompiuterinę programą „Kreiv_gr“,

pirmą kartą tiriamose geležinkelio linijose nustatyti pertvarkomų kreivių grupių ilgiai, kreivių parametrų rekonstrukcijos darbų apimtys ir reikalingos investicijos naudotojų poreikiams ir gyventojų gyvenimo kokybei gerinti. Traukinių važiavimo greičių didinimo problemas siūloma spręsti, vertinant esamų geležinkelio kelio plano kreivių spindulį, išorinio bėgio pakylą, kreivės vietą linijoje bei faktinius pasiekiamus traukinių važiavimo greičius. Juos nustatyti naudojant specialią kompiuterinę programą „TRAUKA“, o ekonominius geležinkelių rekonstrukcijos klausimus nagrinėti ir priimti sprendimus, naudojant kelio plano kreivių tyrimo rezultatų analizę ir išdavas.

Pagal pasiūlytą kelio plano kreivių tyrimo metodiką pirmą kartą Lietuvoje tiriamose geležinkelio linijose mūsų ištirti kreivus kelio ruožus apibūdinantys rodikliai būtini traukinių važiavimo greičių didinimo sprendimams tobulinti. Veikiančių geležinkelio linijų traukinių važiavimo greičių didinimui, rekonstruojant kelio plano kreivių parametrus, pagrįsti atlikti specialūs moksliniai tyrimai.

Autorė siūlo modernizuojant geležinkelio linijas, kelio plano kreivių parametrų įtaka traukinių važiavimo greičiams nustatyti taikant matematinius modelius. Suskaičiuotas ekonominis efektas pasiekiamas dėl nustatytų keleivių kelionės laiko santaupų.

Tyrimo objektas ir metodai

Darbe tirtas geležinkelio kelio plano kreivės spindulys, išorinio bėgio pakyla, kreivės vietos linijoje įtaka projektuojamiems traukinių važiavimo greičiams kreivėse. Tiriamuoju aspektu tirtos dvi prioritetinės Lietuvos geležinkelių linijos. Išnagrinėta esamo kreivės spindulio, įrengtos išorinio bėgio pakylas ir kreivės vietos įtaka traukinių važiavimo greičiams. Pasiūlytos galimybės didinti traukinių važiavimo greičius tobulinant minimalaus projektuojamo kreivės spindulio nustatymą. Minėtas tyrimo objektas buvo tiriamas taikant teorinius, analizinius bei matematinius statistinius metodus. Eksperimentiniams tyrimams buvo naudojama kompiuterinės programos „TRAUKA“ ir mūsų sukurta „Kreiv_gr“.

Darbo aprobavimas ir publikacijos

Pagrindiniai darbo rezultatai pristatyti 5 tarptautinėse ir 4 respublikinėse mokslinėse techninėse konferencijose.

Disertacijos tema publikuoti 9 mokslo darbai, 3 iš jų – Mokslo ir studijų departamento patvirtinto leidinių sąrašo žurnaluose (žr. 23–24 psl.).

Darbo struktūra ir apimtis

Disertaciją sudaro įvadas, keturi skyriai, bendrosios išvados ir pasiūlymai ir autorės publikacijų ir pranešimų disertacijos tema sąrašas, 99 pozicijų literatūros šaltinių sąrašas ir priedai. Disertacijos tekstas –125 kompiuteriu sumaketuoti ir 1,5 intervalo eilėtarpiu išspausdinti puslapiai. Darbe yra 60 paveikslų ir 27 lentelės.

Įvade pagrindžiamas disertacinio darbo temos aktualumas, aprašyti tyrimo objektas ir metodai, nurodytas mokslinis darbo naujumas ir originalumas, darbo tikslas ir uždaviniai.

Pirmame skyriuje išanalizuotas tyrimo objektas – geležinkelio kelio parametrai bei traukinių važiavimo greičius geležinkelio kelyje ribojantys veiksniai. Analizuoti ir apibendrinti įvairių šalių mokslininkų atlikti tyrimai, skirti tiriamajai problemai spręsti, aprašyta pagrindinių Lietuvos geležinkelio linijų būklė tiriamuoju aspektu, suformuluoti darbo tikslas ir uždaviniai.

Antrame skyriuje atlikta traukinio važiavimo sąlygų geležinkelio kelio plano kreivėje analizė. Pateikti ir išanalizuoti gulsčiosios kreivės spindulio ir išorinio bėgio pakylas įtakos traukinių važiavimo greičiams tyrimai ir vertinimas. Geležinkelio kelio plano gulsčiosios kreivės spindulio, išorinio bėgio pakylas ir nenuslopinto skersinio pagreičio įtaka traukinių važiavimo greičiams vertinama naudojantis jų tarpusavio priklausomybėmis.

Sudaryti maksimalaus leistinojo keleivinių ir krovinių traukinių važiavimo greičių priklausomybės nuo kreivės spindulio ir išorinio bėgio pakylas prie norminių nenuslopinto skersinio pagreičio reikšmių grafikai. Sudaryta nomograma išorinio bėgio pakylai nustatyti ir skaičiavimo formulei parinkti, kai veikiančiose geležinkelio linijose yra mišrus traukinių eismas. Atlikta formulų analizė ir nustatytos jų taikymo ribos bei galimybės. Pagal autorės sukurta geležinkelio kelio plano kreivių grupavimo algoritmą esamas kelio plano kreivės siūloma grupuoti į tris grupes pagal tiriamoje veikiančioje geležinkelio linijoje projektuojamą pasiekiamą traukinių važiavimo greitį kreivėje, esamą kreivės spindulį ir išorinio bėgio pakylą. Tai leidžia tiksliai nustatyti pertvarkomų kreivių skaičių ir suskaičiuoti kreivių grupių ilgį.

Trečiame skyriuje sukaupta duomenų apie tiriamose geležinkelio linijose esančias kreives ir pagrindinius jų parametrus bei nustatyti leistinieji traukinių važiavimo greičiai. Šie duomenys apibendrinti ir atlikta jų statistinė analizė (sudarytos histogramos ir skirsnio funkcijos). Pateikta kompleksinių eksperimentinių tyrimų, atliktų kompiuterine programa „TRAUKA“, tiriamose Lietuvos geležinkelio linijose, rezultatų analizė ir jų vertinimas. Eksperimentiniais tyrimais nustatyti faktiniai

pasiekiami keleivinių ir krovinių traukinių važiavimo greičiai konkrečioje tiriamos geležinkelio linijos kreivėje, pagal kuriuos skaičiuotos išorinio bėgio pakylų reikšmės ir nustatyta skaičiavimo formulė bei vertinta kreivės vietos linijoje įtaka traukinių važiavimo greičiams.

Atlikta eksperimentinių tyrimų rezultatų analizė ir nustatyta, kad kreivės vieta geležinkelio linijoje daro didelę įtaką faktiniams pasiekiamiems traukinių važiavimo greičiams.

Iš skirsnio funkcijos grafikų matyti, kad yra daugiau kaip 80 proc. gulsčiųjų kreivių, kuriose keleiviniai traukiniai negali pasiekti projektuojamo 160 km/h, greičio, kai kreivės nagrinėjamos kaip izoliuotos. Atlikus kompleksinius eksperimentinius tyrimus vertinant kreivės vietą geležinkelio linijoje, nustatyta, kad mūsų tiriamose geležinkelio linijose, kreivių ribojančių traukinių važiavimo greičius atsižvelgiant į esamus kreivės parametrus, sumažėjo 20–30 proc.

Visos tirtos kreivės sugrupuotos į tris grupes naudojant mūsų sukurtą kompiuterinę programą „Kreiv_gr“: I grupė – kreivės, kurių esami parametrai R_i ir h_i užtikrina projektuojamus traukinių važiavimo greičius v_{pr}^{tr} , km/h; II grupė – kreivės, kurių esama išorinio bėgio pakyla riboja projektuojamus traukinių važiavimo greičius v_{pr}^{tr} , km/h; III grupė – kreivės, kurių esamas spindulys riboja projektuojamus traukinių važiavimo greičius v_{pr}^{tr} , km/h (žr. 5 ir 6 lenteles).

Ketvirtame skyriuje sudaryti matematiniai modeliai esant įvairioms kreivės spindulio, išorinio bėgio pakylų ir nenuslopinto skersinio pagreičio reikšmėms. Suskaičiuoti regresijos koeficientai parodo, kokią įtaką turi atitinkamas veiksnys didžiausiam leistinajam traukinių važiavimo greičiui (žr. 7 ir 8 matematinius modelius).

Pateikiami siūlymai minimalų projektuojamą kreivės spindulį mišraus eismo geležinkelio linijose nustatyti pagal sudarytą didžiausio keleivinių ir vidutinio traukinių srauto važiavimo greičių priklausomybės grafiką.

Nustatytas ekonominio efektyvumo koeficientas vertinant investicijas, reikalingas kreivių rekonstrukcijai, ir gaunamą pelną dėl keleivių kelionės laiko santaupų per metus abiejose tiriamose geležinkelio linijose.

Darbo pabaigoje pateiktos bendrosios išvados ir siūlymai, autorės publikacijų ir pranešimų konferencijose disertacijos tema bei naudotos literatūros sąrašai.

BENDROSIOS IŠVADOS IR SIŪLYMAI

Išanalizavę pasaulio šalių, kuriose siekiama esamose geležinkelio linijose didinti traukinių važiavimo greičius, patirtį, padarėme išvadą, kad didžiausią įtaką, didinant esamose geležinkelio linijose traukinių važiavimo greičius, daro kelio plano mažo spindulio gulsčiosios kreivės. Traukiniui važiuojant dideliu greičiu mažo spindulio kreive susidaro jėgos, kurios daro neigiamą įtaką traukinio važiavimo sąlygoms ir blogina keleivių komfortą. Šioms jėgoms mažinti įrengiamas didesnis kreivės spindulys arba atitinkama išorinio bėgio pakyla kreivėje.

1. Veiksnius, darančius įtaką traukinių važiavimo greičiams geležinkelio kelyje, suskirstėme į dvi grupes. 1. Lokalieji (vietiniai), kurie yra apriboti pagal ilgį tam tikroje linijos vietoje (mažo spindulio plano kreivės, trumpos virsmo kreivės, tiesių intarpų tarp gretimų kreivių ilgiai, išorinio bėgio pakyla, iešmai, stotys, kelio statiniai, pervažos, sankasos defektai ir deformacijos); 2. Globalieji, kurie yra visoje geležinkelio linijoje (viršutinės kelio konstrukcijos tipas ir būklė, elektrifikavimo sistema (jeigu tokia yra), signalizacijos tinklas, telekomunikacijos tinklas). Šiame darbe tiriamo lokaliuosius veiksniai – geležinkelio kelio plano gulsčiosios kreivės spindulį ir išorinio bėgio pakylą.

2. Tarp gulsčiosios kreivės spindulio, išorinio bėgio pakylas, nenuslopinto skersinio pagreičio ir leistinųjų traukinių važiavimo greičių yra funkcinė priklausomybė, todėl geležinkelio kelio plano gulsčiųjų kreivių parametrų įtaka projektuojamiems traukinių važiavimo greičiams vertinama naudojantis jų tarpusavio priklausomybėmis.

3. Siekiant padidinti traukinių važiavimo greičius esamose mišraus traukinių eismo geležinkelio linijose, reikia vertinti visų kreive važiuojančių traukinių eismo sąlygas, nes teorinių tyrimų rezultatais nustatyta, kad krovinių traukinių važiavimo greičių padidinimas 1,6 karto sumažintų minimalų rekonstruojamos kreivės spindulį 1,8 karto. Padidinus keleivinių traukinių nenuslopinto skersinio pagreičio normą nuo 0,6 iki 1,0 m/s² (67 %), maksimalus traukinių važiavimo greitis išauga daugiau kaip 12 %.

4. Mes siūlome esamas kelio plano gulsčiąsias kreives sugrupuoti į tris grupes, tiriamoje geležinkelio linijoje vertinant esamą kreivės spindulio ir išorinio bėgio pakylas dydį bei pasiekiamą (projektuojamą) traukinio važiavimo greitį kreivėje. Tokiu būdu tiksliai nustatoma esamų geležinkelio kelio plano gulsčiosios kreivės parametrų įtaką projektuojamiems traukinių važiavimo greičiams kreivėse, kas leidžia nustatyti pertvarkomų kreivių skaičių ir modernizuojamo kelio ilgį (darbų apimtis).

5. Eksperimentinių tyrimų rezultatai patvirtina prielaidą, kad kreivės vieta linijoje (atstumas nuo stočių, atstumas tarp gretimų kreivių, išilginio kelio profilio nuolydis) yra reikšmingas veiksnys traukinių važiavimo greičiams. Ne visos kreivės, kurios pagal esamus geležinkelio kelio plano gulsčiosios kreivės spindulio ir išorinio bėgio pakylas dydžius riboja projektuojamą traukinio važiavimo greitį kreive patenka į didžiausio pasiekiamo traukinio važiavimo greičio zoną. Abiejose tirtose geležinkelio linijose, geležinkelio kelio plano kreivių, ribojančių pasiekiamus traukinių važiavimo greičius, sumažėjo 20–30 % lyginant su tyrimų rezultatais, kai kreivės tiriamos kaip izoliuotos.

6. Atlikus traukos skaičiuotės variantų rezultatų analizę ir vertinimą, lyginant esamus vidutinius traukinių važiavimo greičius abiejų tirtų geležinkelio linijų kreivėse su projektuojamais traukinių važiavimo greičiais, nustatytas vidutinio traukinių važiavimo greičio Δv_{vid} , km/h, didėjimas – 46–52 % ir keleivių kelionės laiko ekonomija Δt , min, – 20–30 %. Skaičiuojant ekonominį efektą, gautą įdiegus tyrimo rezultatus, nustatyta, kiek reikia investuoti į kelio plano kreivių rekonstrukciją ir koks gaunamas ekonominis efektas dėl keleivių kelionės laiko sutrumpėjimo. Nustatytas ekonominio efektyvumo koeficientas abiejose tirtose geležinkelio linijose rodo, kad investicijos, reikalingos kreivių rekonstrukcijai, tiriamose geležinkelio linijose atsipirks vidutiniškai per 10 metų.

7. Sudaryti matematiniai modeliai rodo, kad iš nagrinėtų trijų veiksnių $v_{max} = f(x_1, x_2, x_3)$ (x_1 – gulsčiosios kreivės spindulio R , m; x_2 – išorinio bėgio pakylas h , mm; x_3 – nenuslopinto skersinio pagreičio a_n , m/s²) esant įvairioms jų reikšmių variacijoms, didžiausią įtaką leistinajam traukinio važiavimo greičiui kreivėje daro išorinio bėgio pakyla (kai $_{min}R = 1\,200$ m), o kitas svarbus veiksnys yra kreivės spindulys.

Laura Černiauskaitė

**COMPLEX RESEARCH AND EVALUATION OF THE
INFLUENCE OF RAILWAY ROAD PARAMETERS ON THE
TRAINS' RUNNING SPEED IN CURVES**

Summary of Doctoral dissertation

Technological Sciences, Civil Engineering (02T)

Laura Černiauskaitė

**GELEŽINKELIO KELIO PARAMETRŲ ĮTAKOS TRAUKINIŲ VAŽIAVIMO
GREIČIAMS KREIVĖSE KOMPLEKSINIAI TYRIMAI IR VERTINIMAS**

Daktaro disertacijos santrauka

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