

Impact of the Operation and Infrastructure Parameters to the Railway Track Capacity

Martin Kendra, Jaroslav Mašek, Juraj Čamaj, Matej Babin

Abstract—The railway transport is considered as a one of the most environmentally friendly mode of transport. With future prediction of increasing of freight transport there are lines facing problems with demanded capacity. Increase of the track capacity could be achieved by infrastructure constructive adjustments. The contribution shows how the travel time can be minimized and the track capacity increased by changing some of the basic infrastructure and operation parameters, for example, the minimal curve radius of the track, the number of tracks, or the usable track length at stations. Calculation of the necessary parameter changes is based on the fundamental physical laws applied to the train movement, and calculation of the occupation time is dependent on the changes of controlling the traffic between the stations.

Keywords—Curve radius, maximum curve speed, track mass capacity, reconstruction.

I. INTRODUCTION

THE megatrend of the market globalization brings more and more requirements of transporting goods for the medium and long distances [13]. Nowadays, the most of the goods is transported by the road. It results in a major negative impact on the environment and a high value of external costs [1]. This trend cannot be sustainable from the long-term point of view. The railway transport is considered as an environmentally friendly mode of the transport [7]. Attempts are expected to move a large part of the freight transport from the road to the railway in the future. There can be problem with the railway lines that they don't have a sufficient track capacity. UIC-GTC report, created by the Kessel + Partner Transport Consultants and KombiConsult GmbH, expects many bottlenecks on the railway lines in the European countries by 2015, especially in the western area, as can be seen in Fig. 1. It is necessary to look for the possibilities how to prevent the expected problems [3], [12].

The tracks capacity can be increased by changing various types of the infrastructure parameters resulting from their modernization. The traffic capacity depends mainly on these two categories of parameters:

- track parameters;
- train parameters.

The basic track parameters are:

- number of the track lines,
- track speed limit,
- traffic signalling system,
- track leaning ratios,
- minimum curve radius,
- track resistance (slope, curvature, crossovers, tunnel).

The basic train parameters are:

- load capacity (per axle, per usual loading meter),
- maximum train weight,
- maximum train length (in meters, in number of the axles),
- train driver (driving style, driver skills),
- pull force of the locomotive engine (indicated, circumference of the drive wheels, at coupler, adhesion).

Based on the basic knowledge about the examined railway infrastructure, we can derive these two indicators:

- maximum volume of capacity (n_{max}),
- maximum capacity of the transported wagon units per track section (N_{wu}^T) [2].

II. DEPENDENCE OF THE OBSERVED INDICATORS ON CHANGES OF THE RAILWAY INFRASTRUCTURE PARAMETERS

Description of the main parameters, which are taken from the network chart edges analysis:

- minimal transport time (T_{min}):
 - maximum of the track speed limit (V_{max});
 - minimum of the track curve radius (r_{max});
- maximum capacity (n_{max}):
 - number of the track rails (TR);
 - minimum of the track curve radius (r_{min});
 - maximum of the track speed limit (V_{max});
- maximum capacity of the transported wagon units per track relay (N_{wu}^T):
 - number of the track rails (TR);
 - minimum of the track curve radius (r_{min});
 - maximum of the track speed limit (V_{max});
 - maximum track mass capacity (M_{max});
 - maximum train length (L_{tr}^{max});
 - maximum number of axles ($N_{axle}^{max/tr}$);
 - maximum train weight (M_{tr}^{max}).

The change of the clearance profile can increase the total volume of the transported goods [9]. However, the clearance profile is a very difficult measure for mathematical definitions. In this case, we can consider it as the right measure the total number of transported wagon units [4]. Then we just recalculate the total number of the transported wagon units to the transportation performance or the total volume of the transported goods.

Assoc. prof. Ing. Martin Kendra, PhD is with the Department of Railway Transport, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia (corresponding author to provide phone: +421-41-531-3429; e-mail: martin.kendra@fpedas.uniza.sk).

Ing. Jaroslav Mašek, PhD. Ing. Juraj Čamaj, PhD., Ing. Matej Babin, PhD. and. are with The Department of Railway Transport, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia (e-mail: jaroslav.masek@fpedas.uniza.sk, juraj.camaj@fpedas.uniza.sk.).

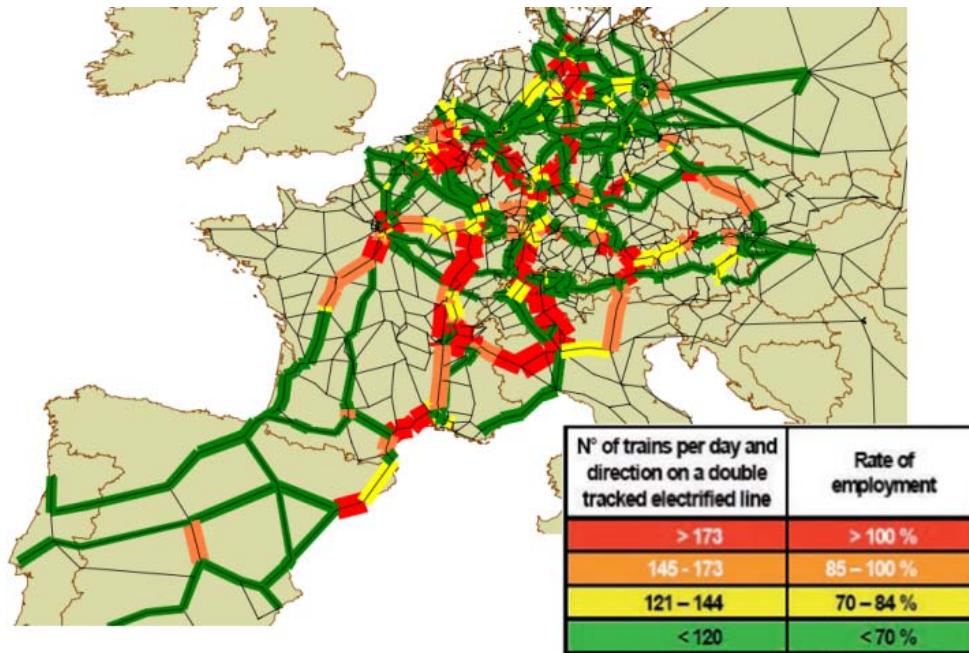


Fig. 1 Rate of railway line employment by 2015 [3]

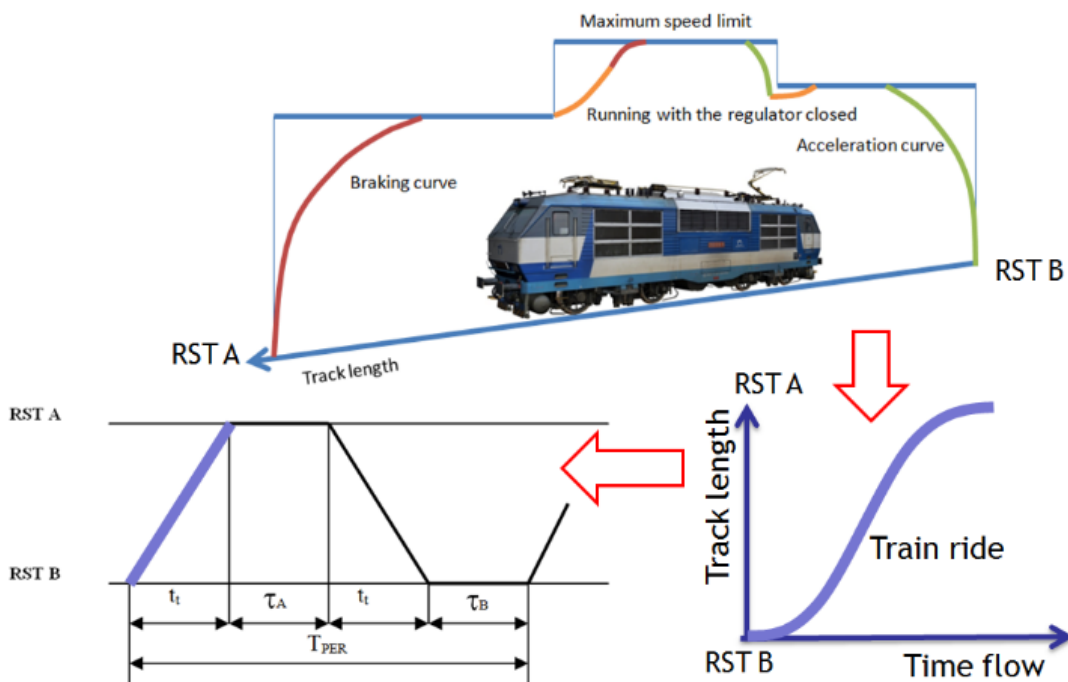


Fig. 2 Dependence between speed, time and track length. The whole train ride time depends on the size of time spend by acceleration, braking and running with closed regulator Dependence on the Minimum Curve Radius

III. EVALUATING THE MINIMAL TRANSPORT TIME

A. Dependence on the Maximum Track Speed Limit

If we simplify the train drive just to a drive with a fixed speed and zero acceleration, then the travel time is proportional to the train passed distance and inversely proportional to its maximum speed.

$$T_{min} = \frac{l}{v_{max}} \quad (1)$$

We can calculate the travel time for each track section and the total travel time on the passed track by adding the partial travel times.

$$T_{\min}^T = \Sigma T_{\min}^i \quad (2)$$

In the curve ride with the radius r (m) by a fixed speed v ($m \cdot s^{-1}$), we must add also the centripetal force to the tractive force acting in the same direction as the curve tangent [5]. The centripetal force is directed into the curve centre and it makes the trajectory curvature. Then the dimension of the centripetal force is:

$$P = \frac{m \cdot v^2}{r} \text{ [N]} \quad (3)$$

This force causes the vehicle response, which is equal to the size of the centripetal force but has the opposite direction – centrifugal force. This force is reflected at the railway vehicle on its wheel flange and it gives the vehicle curvilinear movement [6]. The centrifugal force and the vehicle weight together make the resultant into three typical aspects:

- resultant cuts the drive plane in the middle of rails – the equivalence is stabilized,
- resultant cuts the tangent point between the vehicle wheel and head of the rail – the equivalence is labile,
- resultant cuts the drive plane in general out of the rail track – the turnover of the vehicle:
 - inside the curve – the track camber is abnormally high,
 - from the outside of the track – the camber is abnormally low.

For the smooth curve ride and also the stabilized vehicle ride position we must eliminate the negatives of the centrifugal force effect [10]:

$$\sin \alpha = \frac{p}{s} \quad (4)$$

The dimensions of the superelevation can be figured out as the resultant of the vehicle gravity and the centrifugal force

which is perpendicular to the drive plane and axis of it. The pressure on the rails is the same [8].

The resultant R consists from centrifugal force P and the gravity force ($G=m \cdot g$) which acts on the ride train.

$$\operatorname{tg} \alpha = \frac{v^2}{g \cdot r} \quad (5)$$

The angle α can be described also from the range of the liaison circles of the wheel set and the superelevation.

$$\sin \alpha = \frac{p}{s} \quad (6)$$

Because the dimensions of angle α are too small, it can be written with the sufficient accuracy $\sin \alpha = \operatorname{tg} \alpha$

$$\frac{p}{s} = \frac{v^2}{g \cdot r} \quad (7)$$

From this situation, the superelevation is

$$p_i = \frac{s \cdot v^2}{g \cdot r} \quad (8)$$

For the railway needs better suits the using of the superelevation in mm and the speed in $km \cdot h^{-1}$.

Superelevation can be described theoretically and marked as p_i . The theoretical superelevation is used for the ideal situation – all the trains travel at the same speed. Generally, the trains don't ride at the same speed, however, so this equation must be transformed (slower trains can damage the lower rail in the curve superelevation). The transformation is made multiplying with $2/3$. This superelevation can be denoted as normal and sign it p_n .

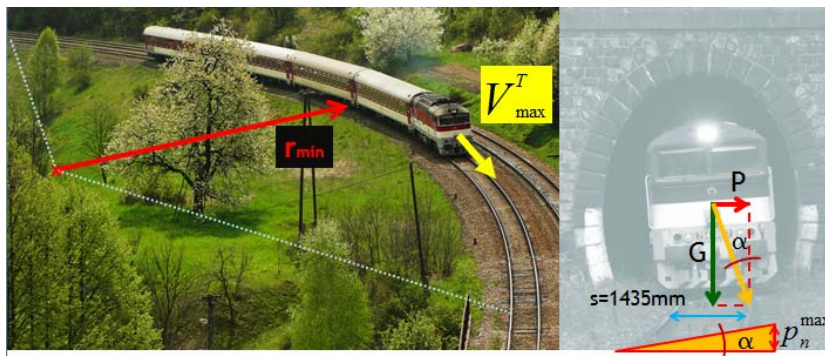


Fig. 3 The superelevation of the curve track - dependence on curve radius and maximum curve speed

$$p_n = \frac{2}{3} \cdot \frac{s \cdot v^2}{g \cdot r} = \frac{2}{3} \cdot \frac{s \cdot 3,6^2}{9,81 \cdot r} = \frac{2 \cdot s \cdot V^2}{381,41 \cdot r} \quad (9)$$

The superelevation of the curve rails can be stated by each country on its own decision. That's why we can count the maximum speed in the curve ride in the general conditions.

$$P_n^{\max} = \frac{2 \cdot s \cdot V^2}{381,41 \cdot r_{\min}} \Rightarrow V_{\max}^T = \sqrt{\frac{381,41 \cdot r_{\min} \cdot P_n^{\max}}{2 \cdot s}} = 13,81 \cdot \sqrt{\frac{r_{\min} \cdot P_n^{\max}}{s}} \quad (10)$$

IV. EVALUATING THE MAXIMUM CAPACITY VOLUME

Maximum (theoretical) volume of the capacity is proportional to the calculated time and inversely proportional to the occupation time of the track per one train.

$$n_{\max} = \frac{T}{t_{occ}} \quad (11)$$

The resulting track volume capacity is given by the volume of the capacity of the constraining section (it is the section with the lowest capacity)

$$n_{\max}^T = \min \{ n_{\max}^i \} \quad (12)$$

V. CALCULATION OF THE OCCUPATION TIME T_{occ}

A. Single Track, Simple Matched Train Diagram

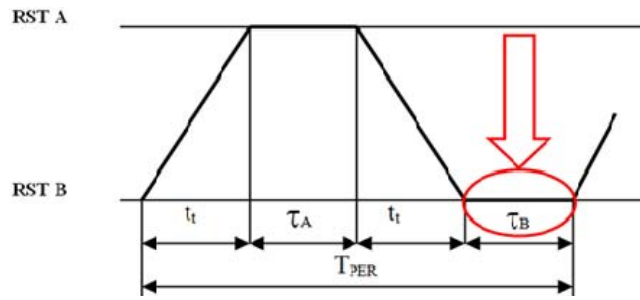
$$t_{occ} = \frac{T_{per}}{2} = \frac{2 \cdot t_t + \tau_A + \tau_B + T_{ad}}{2} \quad (13)$$

$$t_t = 60 \cdot T_{\min} = \frac{l}{v_{\max}} \quad (14)$$

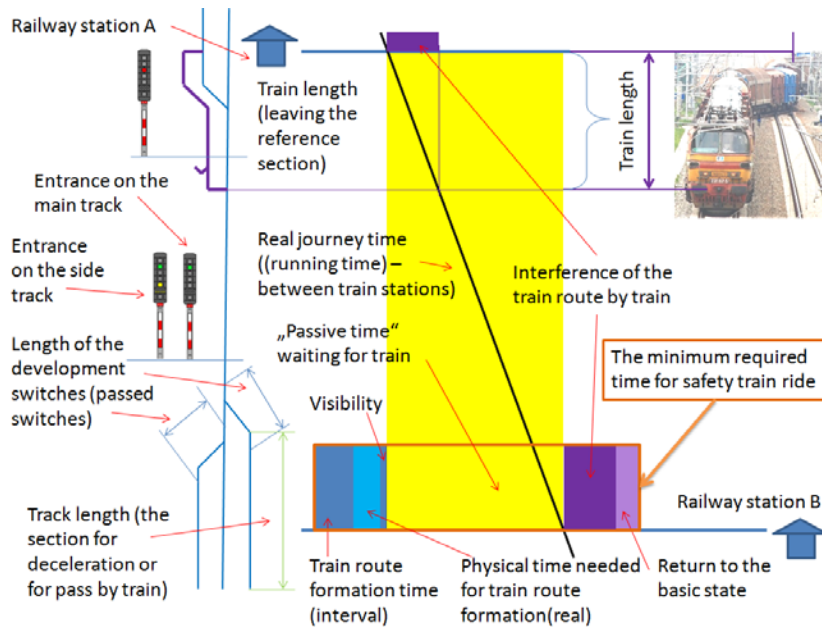
B. Single Track, Grouped, Matched Train Diagram

$$t_{occ} = \frac{T_{per}}{2 \cdot k} = \frac{2 \cdot k \cdot t_t + (k - 1) \cdot (\tau_{AB} + \tau_{BA}) + \tau_A + \tau_B + T_{ad}}{2 \cdot k} \quad (15)$$

$$t_t = 60 \cdot T_{\min} = \frac{l}{v_{\max}} \quad (16)$$



(a)



(b)

Fig. 4 The principle of the train ride and the train schedule diagram

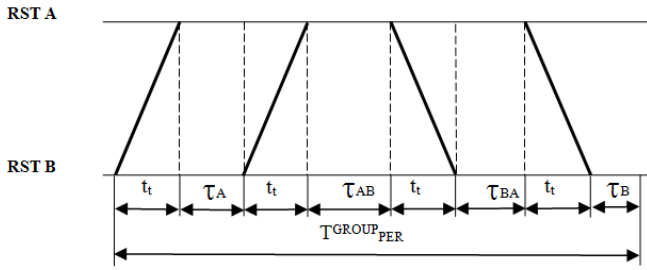


Fig. 5 Single track, grouped, matched train diagram

C. Single Track, Bunched, Matched Train Diagram

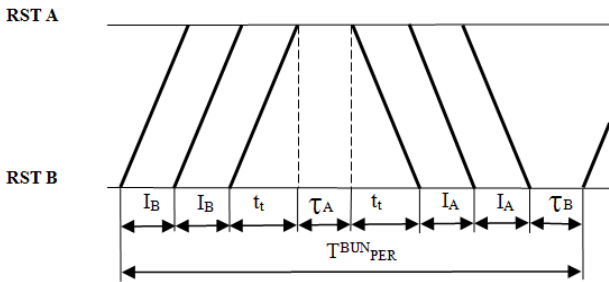


Fig. 6 Single track, bunched, matched train diagram

$$t_{occ} = \frac{T_{per}}{2.k} = \frac{2.t_t + (k-1).(I_A + I_B) + \tau_A + \tau_B + T_{ad}}{2.k} \quad (17)$$

$$t_t = 60.T_{min} = \frac{l}{v_{max}} \quad (18)$$

D. Double Track Train Diagram

$$n_{max} = 2 \cdot \frac{T}{t_{occ}} \quad (19)$$

$$t_{occ} = \frac{I_A + I_B}{2} \quad (20)$$

$$n_{max} = \frac{2.T}{\frac{I_A + I_B}{2}} = \frac{4.T}{I_A + I_B} \quad (21)$$

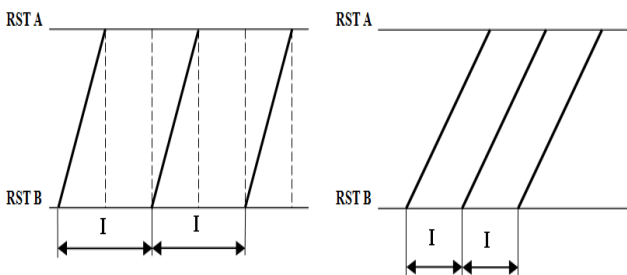


Fig. 7 Double track train diagram

VI. EVALUATING THE MAXIMUM TRANSPORTED WAGON UNITS – THE SECTION PERFORMANCE

The basic calculation of the section performance is:

$$N_{wu}^T = n_{max}^T \cdot N_{wu}^{max/tr} \quad (22)$$

VII. CALCULATING THE MAXIMUM VOLUME OF THE WAGON UNITS IN ONE TRAIN

The maximum number of wagon units can be limited by [11]:

- the maximum number of the axles in the train;
- the maximum mass capacity of the train;
- the maximum length of the train.

A. Maximum Number of the Axles in the Train

In general double axles wagon is one wagon unit, one bogie wagon (with four axles) are two wagon units.

$$N_{wu}^{max/tr} = \frac{N_{axle}^{max/tr} - N_{axle}^{loc}}{2} \quad (23)$$

B. Limit of the Maximum Mass Capacity of the Train

$$N_{wu}^{max/tr} = \frac{M_{tr}^{max} - M_{loc}}{M_{wu}^\phi} \quad M_{wu}^\phi \leq 2.M_{axle}^{max} \quad (24)$$

M_{axle}^{max} - (A – 16,0 t/axle; B – 18,0 t/axle; C – 20,0 t/axle; D – 22,5 t/axle)

C. Limit of the Maximum Length of the Train

$$N_{wu}^{max/tr} = \frac{(L_{tr}^{max} - L_{loc})}{L_{wu}^\phi} \quad (25)$$

The final maximum number of the wagon units in the train is set by the minimal value of the maximum number of the wagon units which depends on:

- maximum number of the axle in the train;
- maximum mass of the train;
- maximum length of the train.

$$N_{wu}^{max/tr} = \min \{ N_{i,wu}^{max/tr} \} \quad (26)$$

VIII. CALCULATING THE MAXIMUM VALUE OF THE TRANSPORTED GOODS AND THE TRANSPORTATION CAPACITY

For calculation of the maximum value of the transported goods and the transportation capacity we can use calculation of the maximum value of the transported wagon units – performance section. For the calculation we need:

- average used mass per the wagon unit;
- length of the section.

$$M_{goods}^{max} = N_{wu}^T \cdot M_{goods}^{\phi/wu} \quad (27)$$

$$P^{max} = M_{goods}^{max} \cdot l \quad (28)$$

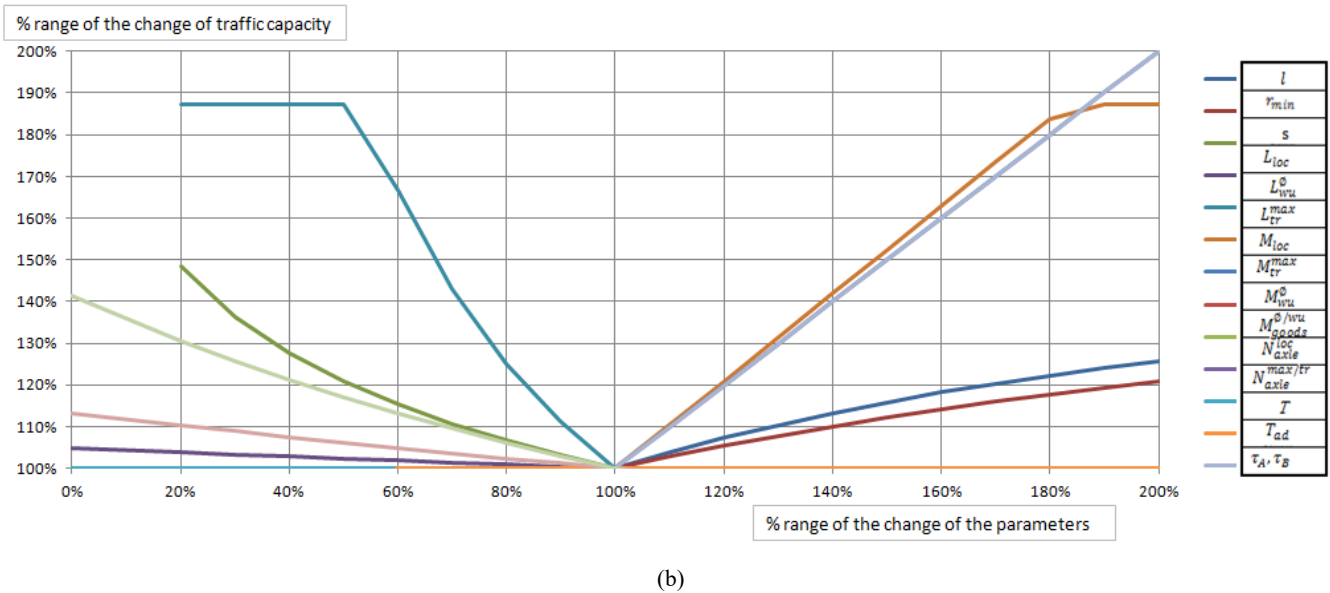
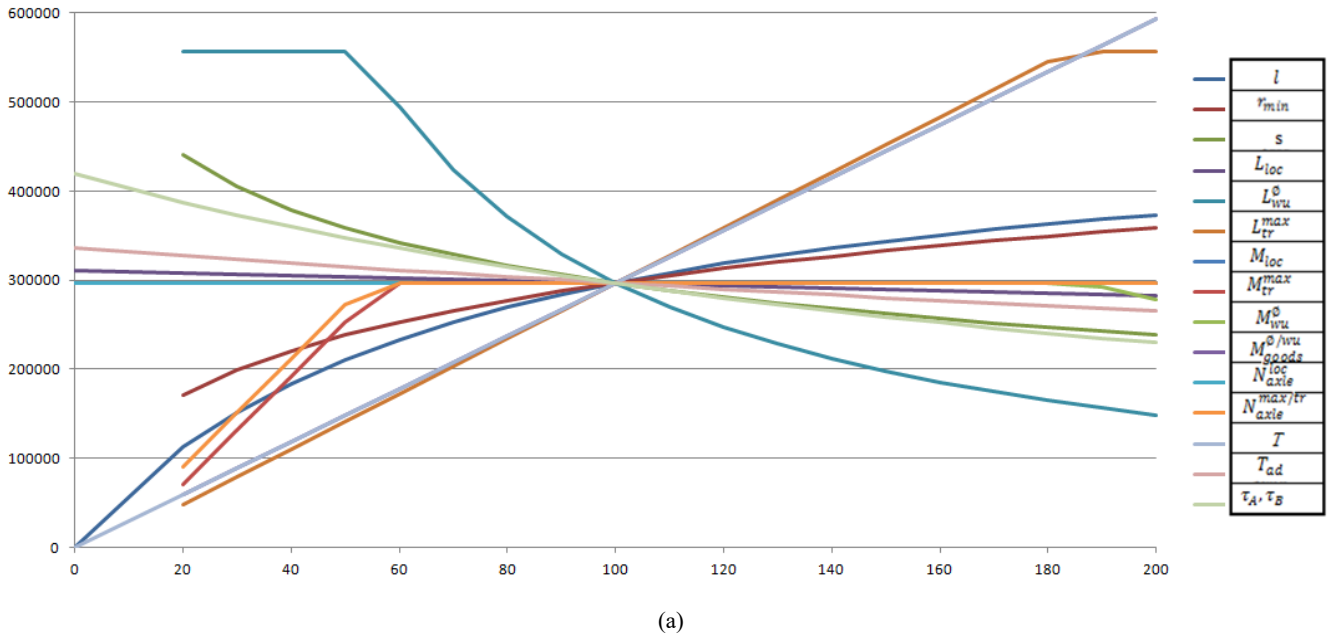


Fig. 8 (a) The percentage range of the parameters change, (b) percentage range of traffic capacity change

The parameters were changed by some abnormalities. For example, the minimization of gauge, this can be used only in case of bogie change (from abroad to normal) not in the case of track gauge reconstruction in result of the forces. In other way the time of observation or track length cannot be used. There is direct correlation between transported goods and time length or track length [4].

IX. CONCLUSION

In this century, the sustainable transport can be further developed only with the continued support and preference of the environmentally friendly transportation. The railway transport is the transport with relatively low negative external costs to the environment. To remain competitive, it must offer

quality services with a sufficient capacity. Some railway corridors in Western Europe are not able to offer the required capacity because of the increased demand for the transport. Modernization of the railway lines can change their parameters and increase their performance.

Changes could be made in the infrastructure and operation parameters. In this contribution calculations of the track capacity and the volume of the transported goods are suggested, depending on the minimum radius of curvature changes, the transport organization between stations and train parameters depending on the characteristics of the line. Calculations showed that the same percentage change in the input parameters of the track, train, and operation brings a different magnitude of increased traffic capacity. At the same

time, the maximum increase of the traffic capacity is bounded above and cannot be continuously increased without changing other parameters.

parameter	measure		unit
	before	after change	
l	15	15	km
n_{max}	84,31696936	168,8849636	trains
r_{min}	400	800	m
s	1435	1435	mm
t_{occ}	17,0784127	8,52651396	min
t_t	10,0784127	7,12651396	min
L_{loc}	18,5	18,5	m
L_{WU}^0	19,5	19,5	m
L_{tr}^{max}	400	760	m
M_{loc}	84	84	tons
M_{goods}^{max}	19795,03004	148510,6816	tons
M_{tr}^{max}	1000	1000	tons
M_{WU}^0	25	25	tons
M_{goods}^0	12	24	tons
N_{axis}^{loc}	4	4	axles
$N_{axis}^{max/tr}$	80	80	axles
$N_{WU}^{max/tr}$	19,56410256	36,64	wagon units
N_{WU}^t	1649,585837	6187,945067	wagon units
p^{max}	296 925,45	2 227 660,22	t.km
T	1440	1440	min
T_{ad}	4	0,8	min
T_{min}	0,167973545	0,118775233	hours
V_{max}^c	89,29977639	126,2889549	km/h
τ_A, τ_B	5	1	min

750,24%

Fig. 9 Green parameters are equations, white parameters do not affect the capacity, orange can't be used for logical reasons of abnormalities, yellow parameters have main influence

ACKNOWLEDGMENT

This paper is prepared with the support of the projects:

- VEGA 1/0701/14 Impact of liberalization of the rail freight market on the social costs of transport,
- This paper is prepared with the support of the project "Transfer of innovative knowledge and technology in logistics and transport processes", ITMS project code 26220220006, University of Žilina.



ERDF – European Regional Development Fund
The project is financed by funds from the EC



REFERENCES

- [1] J. Gašparík, Z. Pečený, *Grafikon vlakovej dopravy a priepustnosť sietí. EDIS, 2009, Žilina, ISBN 978-80-8070-994-5, (Chapter 5).*
- [2] J. Majerčák, J. Gašparík, M. Kendra, P. Majerčák, P. Blaho, *Železničná dopravná prevádzka Technológia železničných staníc, EDIS 2008, Žilina, ISBN 978-80-8070-887-0, (Chapter 2).*

- [3] *Study On Infrastructure Capacity Reserves for Combined Transport by 2015 prepared for International Union of Railways Combined Transport Group (UIC-GTC), Kessel + Partner Transport Consultants, KombiConsult GmbH, Freiburg/Frankfurt am Main/Paris (2004).*
- [4] M. Kendra, M. Babin, D. Barta, *Changes of the infrastructure and operation parameters of a railway line and their impact to the track capacity and the volume of transported goods, TRA 2012 Athens, Procedia - social and behavioral sciences, ISSN 1877-0428. - Vol. 48, s. 743-752.*
- [5] J. Čamaj, A. Dolinayova, *The organization of the wagon flows with respect to the economic criteria of railways companies.* In: LOGI 2011: 12th international scientific conference, November 24th, 2011 in Pardubice. Czech Republic - ISBN 978-80-263-0094-6. p. 140-148.
- [6] J. Čamaj, J. Lalinská, J. Mašek, *The management of assessment and allocation of marshalling yards and designation their catchment areas.* IN: ICIMSA 2015 International Conference on Industrial Engineering, Management Science and Applications 2015. Proceeding book. Tokyo.
- [7] E. Nedeliaková, A. Dolinayová, I. Nedeliak, *Metódy hodnotenia kvality prepravnych služieb/Methods of evaluation of the transportation services quality 1st edition.* - Žilina: Žilinská univerzita, 2013. ISBN 978-80-554-0817-0. p. 184.
- [8] J. Čamaj, J. Lalinska, J. Mašek, *Simulations of continental logistics centre from the perspective of technologist.* IN: ICIMSA 2014 International Conference on Industrial Engineering, Management Science and Applications 2014. Proceeding book of conference. Beijing: IEEE, 2014. p. 305-308. ISBN 978-1-4799-6541-0.
- [9] J. Gasparik, *Quality factors in railway infrastructure capacity management.* In Horizons of railway transport 2010: scientific papers. ISSN 1338-287X, 2010, vol. 1, no. 1, P. 22-28.
- [10] T. Skručaný, J. Gnap, *The effect of the crosswinds on the stability of the moving vehicles.* IN: Applied Mechanics and Materials. - ISSN 1662-7482. - Vol. 617 (2014), p. 296-301.
- [11] K. Lehutová, A. Križanová, T. Klieštík, *Quantification of equity and debt capital costs in the specific conditions of transport enterprises.* IN: Transport means 2013: proceedings of the 17th international conference: October 24-25, 2013, Kaunas University of Technology, Lithuania. - ISSN 1822-296X. - Kaunas: Kaunas University of Technology, 2013. - p. 258-261.
- [12] J. Vaculik, P. Kolarovszki, J. Tengler *Reliability of reading in management system based on AIDC technology for special goods and processes.* IN: International symposium on Earth science and technology 2013: proceedings: December 3-4, 2013 Kyushu university, Fukuoka, Japan. - (S.I.): CINEST, 2013. - ISBN 978-4-9902356-2-8. - p. 133-138.
- [13] B. Buková, E. Brumerčíková, P. Kolarovszki *Forwarding and logistics. /Zasielateľstvo a logistika /*. 1. edit. - Bratislava: Wolters Kluwer, 2014. - 318 p. ISBN 978-80-8168-074-8