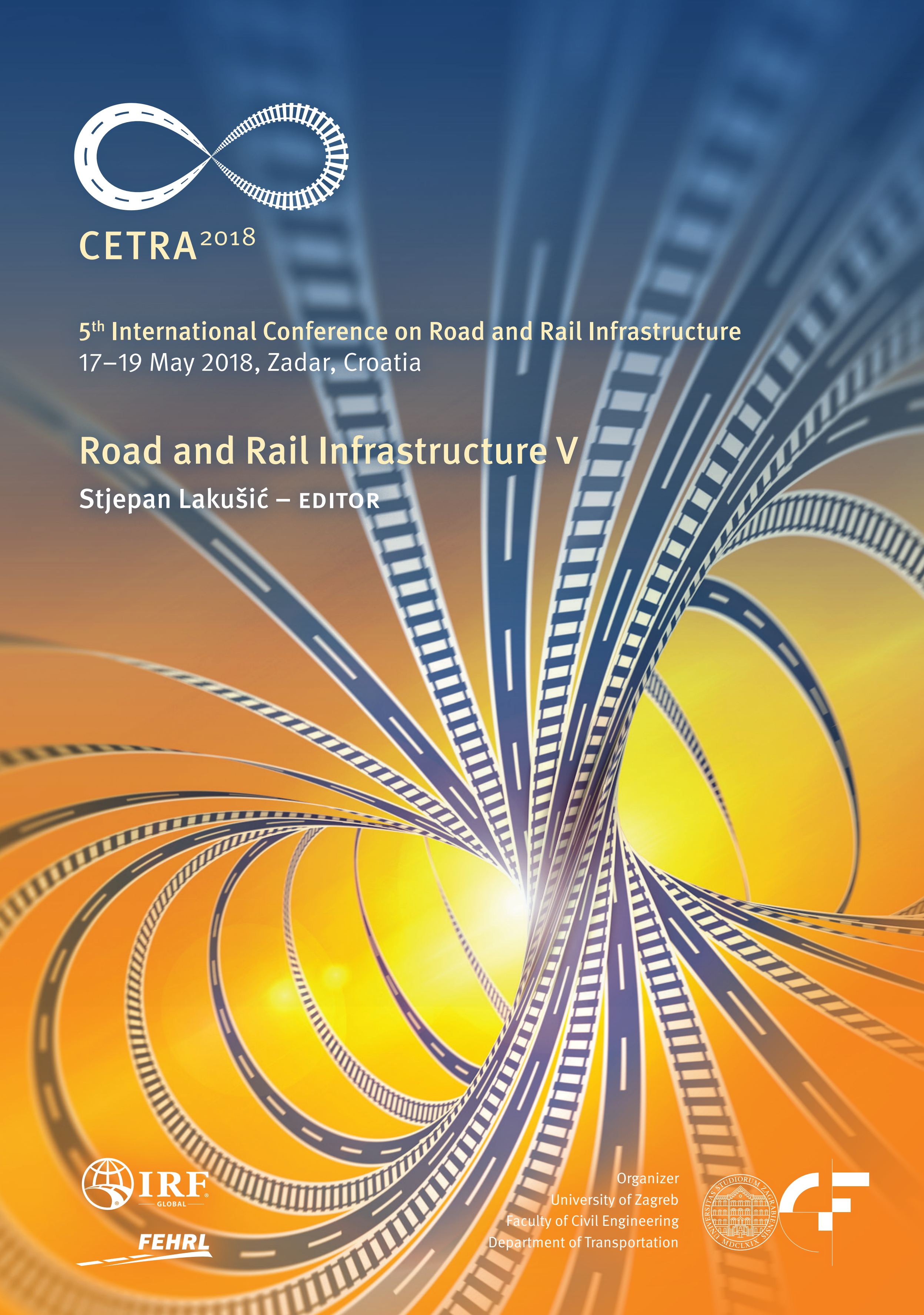

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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IMPACT OF RAILWAY TRACK PARAMETERS ON ENERGY CONSUMPTION AND GHG PRODUCTION OF PASSENGER TRAIN OPERATION

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Abstract

Constantly increasing of the people mobility requires ensuring of the sustainable transport operation. One of the priorities in this area is a reduction of the energy consumption and the GHG production by transport. Emission limits are currently applied mainly to the transport vehicles. However, technical characteristics of the transport infrastructure may also affect the energy consumption and the GHG production of the transport operation. The article analyses the impact of the changes in the railway infrastructure parameters on the change in the energy consumption of the train operation and on the GHG production in railway passenger transport. The analysis is based on the simulation in the Dynamics program at the different slope ratios of the railway track. The calculation is made for the diesel traction of the vehicles. The aim of the article is to highlight how designing of the new or reconstructing of the older track lines could affect the energy consumption and GHG production of the future railway transport system.

Keywords: diesel traction, energy consumption, GHG production, railway infrastructure, simulation

1 Introduction

Transport is an inherent part of our everyday life. The average number of journeys as well as the average passenger transport distance is constantly increasing. Increasing transport demand also requires an increasing of the transport performance [1, 2, 3]. However, transport has a very negative impact on the environment, among other things, energy consumption and greenhouse gas (GHG) emissions. Rail transport is considered as a mode of transport that is relatively at least harmful to the environment [4, 5, 6]. However, regional rail transport also often uses diesel trains in which combustion engines combust hydrocarbon fuels and produce large quantities of GHG [7, 8, 9, 10]. Regional railway transport is often operated on a transport infrastructure that is largely adapted to local geographic conditions. Curves with a small radius and larger slope are typical for these railway tracks. It increases the overall resistance forces against the movement of the trains and thus increases the overall consumption of the fossil fuels and GHG emissions [11, 12, 13]. If curve radius are made as high as possible and slope of the tracks is minimal during the planning of the new railway tracks and during the reconstruction of the existing tracks, it would require a one-time higher investment by the construction or reconstruction of the transport infrastructure but it would produce benefits as sustained reduction of the energy consumption of the operation at these lines as well as permanent reduction of GHG production [14, 15].

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2 Model situation

In this case study there was considered the railway passenger transport along one chosen valley in Slovakia. Railway track without an electrical trolley is situated along the river Poprad. This track connects 5 towns and 13 villages on the north part of Slovakia. The length of the line is 60.8 km. There are 21 stops (stations) on the track, Poprad is the first one on the beginning and the last one is Plaveč at the end of the track. Difference of altitudes between Poprad (670) and Plaveč (485) causes the track slope which reaches the highest value of 17 ‰. Average slope between end stations is 3 ‰.

Figure 1 Elevation track profile

The highest track speed limit is between Poprad and Podolínec (31.3 km) 60 km h^{-1} and between Podolínec and Plaveč (29.5 km) 80 km h^{-1} but on some sections there are the speed limits only 50 or 40 km h^{-1}. Travelling time between the end stations is about 93 minutes.

3 Vehicle technical parameters

Simulation of the energy consumption was done for a real railway vehicle used at this railway track – diesel 3 unit vehicle with series number 840 made by cooperation between Stadler, Bombardier Transportation and ŽOS Vrútky in 2003.
Diesel train unit 840 with electric power transmission has 2´ Bo´ 2' drive arrangement. Its maximum speed is 115 km.h^{-1}. It has MTU 12 V 183 TD13 combustion engine with design rate of 550 kW. Its tare weight is 58.7 t, gross weight 77.1 t and vehicle length is 38 470 mm. There are 110 seats and place for maximal 119 standing passengers.

Figure 2 Train unit 840 at Plaveč station

4 Calculation of the energy consumption and GHG production

Software Railway dynamics has been used to calculate the energy consumption of the train. The power consumption of the train has been calculated on the basis of predefined and selected values on the defined route. The software works with imported maps and elevation profile of railway routes. Based on these defaults and selected parameters (vehicle type, train weight, train length, axle load, number and location of stops) power consumption was calculated in kWh and fuel consumption in liters [16].

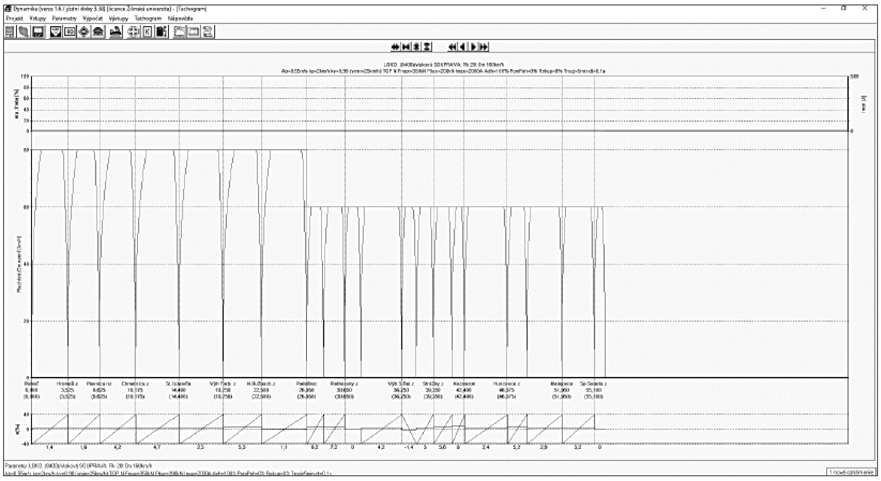

Figure 3 Output data from the software Railway dynamics

4.1 Standard EN 16258: 2012 and its using in calculations

This European Standard specifies general methodology for calculation and declaration of energy consumption and GHG emissions in connection with any services (cargo, passengers or both). The standard does not consider only the production of the secondary emissions and energy consumed during the combustion of the fuel (energy conversion from fuel to mechanical energy) but as well as primary, incurred in the extraction, production and distribution:

e_w – well-to-wheels energetic factor for defined fuel,
g_w – well-to-wheels emissions factor for defined fuel,
e_t – tank-to-wheels energetic factor for defined fuel,
g_t – tank-to-wheels emissions factor for defined fuel.

Well-to-wheels is “well on wheels” and also covered primary and secondary emissions and consumption. This factor is somewhere also called as LCA (life-cycle-analysis). Tank-to-Wheels factor is thinking only of secondary emission and consumption [17]. It is necessary to use the principle well-to-wheels for relevant evaluation of the results.
This Standard specifies general methodology for calculation and declared value for the energetic factor and factor in GHG emissions must be selected in accordance with Annex A [17].
Emission gases are composed of several individual components (gas). Each of them have different chemical and physical properties, so they otherwise participate in environmental degradation. In order to compare emissions from different activities, fuels, vehicles where emissions have different impact, one representative unit used in the comparison must be designated. This is the CO_2 equivalent which is a measure of the impact of specific emissions and likens it to the impact of CO_2. The label is CO_{2e} (equivalent) [14, 15, 18].

4.2 Energy consumption

It is appropriate to use the factors and procedure form of the EN 16 258:2012 for diesel train. The amount of consumed fuel should be multiplied by energy factor for that fuel from Appendix A of the standard to calculate the total energy consumption [16, 19].

$$E_{TF} = FC_V \cdot e_W = \left[\left(E_{ME} \cdot m_{pe} \right) \cdot \frac{1}{\rho_F} \right] \cdot e_W \quad (1)$$

Where:
E_{TF} – total energy consumed by diesel vehicles (MJ);
F_{CV} – consumed fuel of vehicle (l, dm^3);
E_{ME} – mechanical energy consumed by the movement of the train (train dynamics software result) (kWh);
m_{pe} – vehicle engine specific fuel consumption (g kWh^{-1});
ρ_F – fuel (diesel) specific weight (density) (g dm^{-3});
e_W – energetic factor “wtw” for defined fuel (MJ dm^{-3}).

4.3 GHG production

For the GHG production calculation, the consumed amount of diesel fuel should be multiplied by an emission factor for that fuel from Appendix A of the EN standard [16, 19].

$$G_{TF} = FC_V \cdot g_W = \left[\left(E_{ME} \cdot m_{pe} \right) \cdot \frac{1}{\rho_F} \right] \cdot g_W \quad (2)$$

Where:
G_{TF} – total amount of emissions produced by diesel train (gCO_{2e});
g_W – emission factor for defined fuel [$tCO_{2e.}$ MWh^{-1}).

5 Evaluation

The calculation for this model study was done on the track in bidirectional ways for the current railway infrastructure and for the model of the modified railway track. The track was theoretically modified, so stations and stops were connected directly to the sections without unnecessary slopes and curves. Necessary slopes due to different altitudes of the stations and stops were accepted. This theoretically modified track would minimize energy losses due to overcome resistances of the curves and the slopes. The length of the modified railway track was reduce to 56.2 km.

Table 1 Evaluation

Vehicle Occupancy (%)	Real track				Modified track			
	Energy consump. (MJ)	GHG prod. ($kgCO_{2e}$)	MJ km^{-1}	$gCO_{2e.}$ km^{-1}	Energy consump. (MJ)	GHG prod. ($kgCO_{2e}$)	MJ km^{-1}	$gCO_{2e.}$ km^{-1}
0	3671	279	60.4	4582	3350	254	59.6	4523
20	3785	287	62.2	4723	3457	262	61.5	4668
40	3895	296	64.1	4861	3565	270	63.4	4813
60	4013	304	66.0	5008	3671	279	65.3	4956
80	4134	314	68.0	5159	3783	287	67.3	5107
100	4251	323	69.9	5305	3887	295	69.2	5249

Table 1 describes overall results of the simulation. The table is separated into two main parts – the left side includes the results for the real track – the right side represents fictive modified track. The results were simulated for whole spectrum of capacity usage – vehicle occupancy in %. Two different aspects were calculated – energy consumption and GHG production. Both of them are expressed in absolute values as well as in the unit values. For the higher lucidity the graphical expressions of the Table 1 are at Fig. 4 and 5.

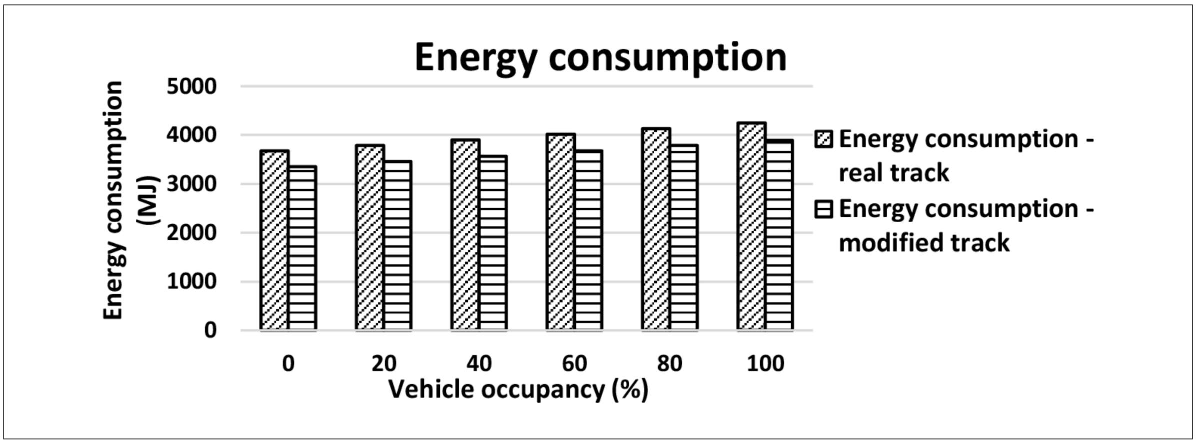

Figure 4 Evaluation of energy consumption

Evaluation of the energy consumption is included at the Fig. 4. Six cases of vehicle occupancy were simulated – from 0 to 100 % of maximum payload (passenger number). For each occupancy there are two columns – one (left) for energy consumption of the train driving on the real track and the other for consumed energy on modified track.
Amount of consumed energy reaches values from 3671 to 4251 MJ for real track and from 3550 to 3887 MJ for modified track. In the unit expression it seems from 60.4 to 69.9 MJ km^{-1} and from 59.6 to 69.2 MJ km^{-1} on the modified track. The consumption increases with increasing of occupancy for both tracks. The train reaches lower consumption on the modified track approximately of 8.6 % in absolute amount of liters and 1.1 % in unit expressions MJ km^{-1}.

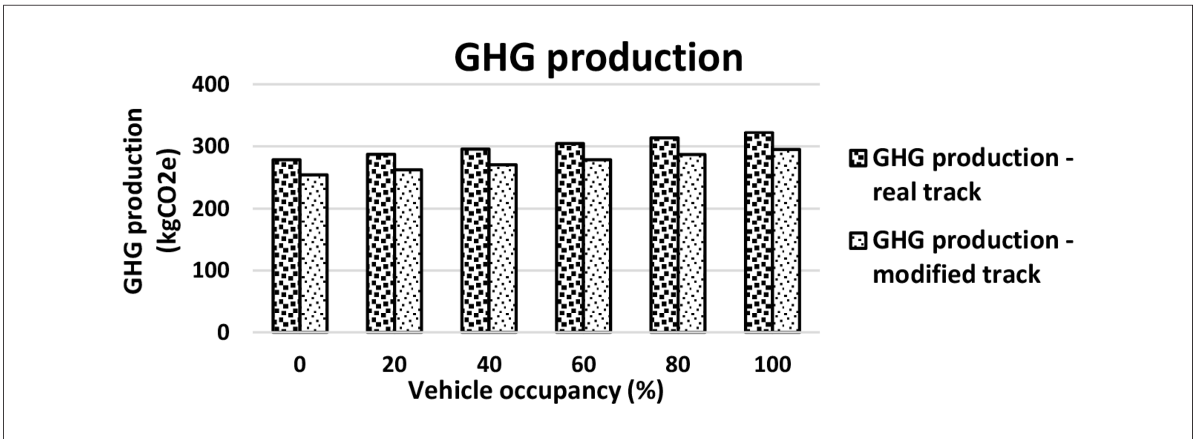

Figure 5 Evaluation of GHG production

GHG production is direct proportional to the energy consumption because the amount of CO_{2e} emitted by moving trains is coming out of the combusted litres of fuel. Production of CO_{2e} reaches values from 279 to 323 kg for real track and from 254 to 295 kg for modified track. Relative expression of produced gas is from 4582 to 5305 g km^{-1} and from 4523 to 5249 g km^{-1} for modified track. The difference between decrease of in absolute values of litres (8.6 %) and in relative expression (1.1 %) is caused by difference in the track length. The train consumes less fuel on the modified track but the track is shorter.

6 Conclusions

It could be achieve a reduction of the overall length of the railway track as well as the reduction of the resistance forces acting against the train movement by the modifying of the railway track. This one-time change in the designing of the railway track causes the longtime reduction of the energy consumption and GHG production not only in absolute values (due to shortening of the track length) but also in unit values per unit length of the track. Although the change of the energy consumption and GHG production is only in very small values (in our model it is 8.6 % in absolute terms and 1.1 % in unit values), GHG emissions could be decreased of 24-28 kg per one pair of the passenger trains. The reduction of the GHG emissions by the operation of the all trains on this track could achieve hundreds of kg per one day and tens of tons through one year. In the long term it is therefore worthwhile taking into account the designing of the new tracks and the reconstruction of the existing tracks to reduce the energy intensity of the train operation.

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