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Efficiency of Increasing of the Track Speed Using Simulation in Opentrack

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Abstract

In this paper the simulation in SW OpenTrack is used to analyze the ride of predefined trainsets on model of hypothetic infrastructure in order to find out what the track speed is effective in terms of shortening the driving time, traction energy consumption and other operational indicators. The next studied variable was the distance between two stops. The simulation results then provide recommendations for future modifications to the infrastructure.

Keywords: High-speed line, OpenTrack, simulation, track speed.

1. Introduction

Increasing the track speed and construction of new high-speed lines raises, inter alia, the question of the efficiency of the money spent on the construction and operation of this infrastructure. Any higher track speed requires more demanding construction and noise and safety measures, leading to increased construction costs. At the same time higher speeds place additional demands on vehicle design, power and traction power consumption, resulting in increased operating costs. Last but not least, it is the distance between the stopping points that influences whether vehicles can fully utilize their performance parameters.

The total investment intensity (fixed costs) as well as the total operating costs (variable costs) depend on the optimization of all these parts. In the preparation of the article, a simulation was carried out in OpenTrack SW, which aimed to determine the minimum distance between two stopping points in order to be able to effectively use vehicle parameters.

2. State of the art

The significance of this research can be used in the preparation of high speed lines (HSL) network (Marek 2015) constructions and also in increasing speeds over 160 km·h-1 on selected sections within the conventional network (Sůra 2020). In this respect, China has the biggest expansion of the HSL network in recent years. The size of the territory and the high population and population density force the use of an optimization mathematical apparatus to create the maximum transportability of the territory using plans for stopping of the high-speed trains (Wang 2018; Wang, Penq, Liu, Wang 2020). The issue of energy efficiency is then dealt with in the literature (Fernández-Rodríguez, 2018), where this problem is examined from the perspective of the use of the coasting and economic modes of high-speed train in relation to the probability of delay and its subsequent elimination.

From the point of view of interlocking systems, the exclusive operation of any communications based train control (CBTC) system is expected when preparing new HSL. In Czech conditions it's a fact that for speed increases on current infrastructure, this will be handled by mixed traffic during the migration period, and trains with speeds higher than 160 km·h⁻¹ will only be allowed to use it under the supervision of ETCS L2. The issue of supervision of stopping or reducing the train speed in the conditions of Czech conventional rail is discussed in the literature (Marek 2015; Nachtigall 2016; Hruban, Nachtigall, Štěpán 2015; Nachtigall, Ouředníček 2019; Marek 2019; Nachtigall, Ouředníček 2018).

The scientific contribution of this paper lies in the compilation of a general model in which the input parameters can be changed arbitrarily and subsequently the required outputs can be monitored. The results of the model can be used to observe the effectiveness of increasing track speeds both on fictitious infrastructure and in real situations.

3. Materials and Methods

Choosing the right method for data collection is an essential prerequisite for obtaining reliable results. In the case of this research, a simulation in the OpenTrack software tool was chosen. Compared to analytical methods, there is an advantage in train dynamics and also in the OpenTrack SW it is possible to simulate the behavior of individual trainsets under different input conditions. Model preparation and selected simulation scenarios are described in the following subsections. Figure 1 shows a worksheet in the OpenTrack SW, showing the four tracks used, each for one trainset.

Figure 1. Graphical layout of the simulation model

3.1. Preparation of the simulation model

The OpenTrack software was used for the preparation of the simulation model, which is intended not only for simulation in the area of determining track capacity and timetable stability, but also for detailed simulation of individual vehicle trips. The model was designed with the emphasis on allowing all modelled train movements to be performed in a single simulation. This solution makes it easier to edit the infrastructure inputs and also facilitates a comprehensive analysis of simulation results. The simulation model was created in two successive phases (Huerlimann, Nash 2019).

The first phase is the creation of an infrastructure model. The infrastructure is represented in the model by a network graph. The vertices of the graph are double vertex points that represent the kilometer position of points on the infrastructure where their parameters change. The edges joining these vertexes carry information about infrastructure parameters. The infrastructure model developed for this high-speed vehicle research consists of a total of 200 kilometers of tracks. For each trainset of vehicles, a 50 km track was created with zero slope and zero directional changes in the track guidance. A separate speed profile has been created for each high-speed trainset, which is determined by the maximum possible design speed of the vehicles. Each 50 km track is further divided into 30 sections where track parameters can be independently adjusted. For each track, two fictional stations had to be created (originating and destination station). The creation of stations in the model is very important for the timetable reasons. For securing correct function of the model there are two advisory points on each track. At the first advisory point the trainset enters the model and at the second advisory point fictitiously disappears. At the same time, individual paths are defined between these advisory points in the model, according to which itineraries are then created.

In the second phase, it is necessary to enter the parameters of each trainset. Most important are tractive characteristic of engine, maximum speed, weight, adhesive weight and vehicle resistance. Coaches or units are then assigned to the engines. All trainsets are simulated simultaneously and different maximum speeds in interval of 30 minutes. In the Table 1 is an overview of used trainsets with basic parameters. The average deceleration was set up for 0.6 m.s-2.

Table 1. Parameters of the trainsets

Trainset	Maximal speed [km ·h⁻¹]	Weight [t]	Maximal tractive effort [kN]	Maximal power [kW]	Maximal acceleration [m ·s⁻²]
Š 109E	200	445	274	6 400	0.560
Railjet	230	437	300	6 400	0.627
Pendolino	230	384	200	3 920	0.461
ICE 3	330	463	300	8 000	0.581

Š 109E – Škoda 109E + 7 coaches, Railjet – Siemens Viaggio Comfort, Pendolino – ČD 680

For the simulation itself, output characteristics were chosen in OpenTrack software, which are key for the results. These characteristics are: acceleration, driving time, maximum speed (point of reaching it and point where the braking starts) and specific consumption of traction energy. These results were then exported from the OpenTrack to MS Excel, for further research.

An integral part of any model should be its validation. Thus, a practical check that the model corresponds to reality. As this is a fictitious infrastructure, the validation was only partially performed. On the graphical output of the train running it was verified that the model contains no errors or deviations that would affect the simulation results

3.2. Simulation scenarios

The goal of the simulation set by the authors is to evaluate the efficiency of the consumption traction energy at reaching individual maximum speeds. However, the model is designed so that all scenarios can be simulated in one simulation. This simulation is divided into partial steps, i.e. individual simulation scenarios. In each simulation scenario, a different maximum speed is always set for each train set. The basic speed is 160 km·h^{-1}, which is gradually increased by 10 km h^{-1} up to 230 km·h^{-1}. From a speed of 230 km·h^{-1} it is then increased at 20 km·h^{-1} up to a speed of 330 km·h^{-1}, which is the top speed of the ICE 3 units.

Simulation scenarios can also be modified in the future and possibly supplemented with additional input data. In addition to the possibility of adding intermediate stations and adjusting the track speed, the authors designed the model to simulate other external influences that affect the dynamics of the train. It is mainly the possibility of adjusting the slope and directional conditions, simulating the resistance to travel in the tunnel and influencing the train's movement by changing the adhesion conditions on the track. This arrangement allows the use of model also for further simulations in the field of research of driving parameters of high-speed vehicles. All inputs can also be monitored stochastically with defined probability distributions. This option can be used for multiple simulations of the timetable and its deviations. For the purposes of this research, all variables were monitored deterministically. The purpose of these simulation scenarios after this research is not to verify the operational concept or to check the stability of the timetable but only to test the dynamic characteristics of the vehicle at different line speeds.

To obtain the required output characteristics it was necessary to use the function for exporting data to MS Excel in the OpenTrack software. The data is recorded in this form, for each train run, in one second increments. In one step the state of the train is known exactly, i.e. its current speed, travelled distance, consumed energy and current acceleration. All of these were subsequently processed and evaluated by the authors.

4. Results and Discussion

The performed simulation provided the authors with the data needed to evaluate the efficiency of spent traction energy in relation to driving time, the price of consumed traction energy and other parameters. The first subsection is devoted to the evaluation of simulation results which will serve as a basis for the calculation of other characteristics. The second subsection is devoted to the evaluation of the possible acceleration to the target speed for individual trainsets. The third subsection deals with the evaluation of traction energy consumption and its importance for determining the optimal spacing of stops for individual types of trainsets (Ke, Haitao, Cai, Zhengyou, Lihua 2017).

4.1. Evaluation of simulation results

After running all simulation scenarios, the data was exported to MS Excel. The basic characteristics needed for further calculations are: target speed [km·h^{-1}], time needed to reach target speed [s], distance needed to reach target speed [km], energy consumption for acceleration to target speed [kWh], distance required to stop [km]. These characteristics for the maximum design speed of each trainset are given in Table 2.

Table 2. Basic output characteristics of each trainset

Trainset	Maximal speed	Acceleration			Deceleration	
	[km ·h^{-1}]	Time [s]	Distance [km]	Energy [kWh]	Time [s]	Distance [km]
Š 109E	200	189	6.59	276	94	2.62
Railjet	230	415	20.80	605	107	3.40
Pendolino	230	402	18.25	393	107	3.40
ICE 3	330	540	36.37	1,135	154	7.07

Š 109E – Škoda 109E + 7 coaches, Railjet – Siemens Viaggio Comfort, Pendolino – ČD 680

Based on these characteristics, which were always determined for speeds from 160 km·h^{-1} to the maximum design speed of the trainset in steps of 10 km·h^{-1}, additional indicators were calculated, which are related to the total distance travelled. These indicators include: distance required for starting and stopping [km], distance travelled at constant speed [km], time required for starting and stopping [s], total energy consumption [kWh], total travel time [s], energy per 1 km of driving [kWh], and energy per 1 km of driving at maximum speed [kWh].

4.2. Dependence of traction energy consumption

Based on the results, the development of traction energy consumption (E_z) between two stopping points was monitored in (1). The simulation results were generated for the distance of 50 km, which was chosen because it was necessary to reach the maximum speed for all trainsets at all simulated speeds. The development of traction energy consumption was monitored in the length from 10 to 300 km.

$$E_z = \frac{E_r + E_m \cdot (s - s_r - s_b)}{3,6} \qquad (1)$$

Where s is total distance, s_r is an acceleration distance and s_b is braking distance. The E_r is an acceleration energy and E_m is energy for the constant speed run. In case that $s \leq s_r + s_b$, then the value was calculated manually. On the Figure 2 is a graph of a dependence between traction energy consumption per 1 km for the stopping distance from 10 to 300 km.

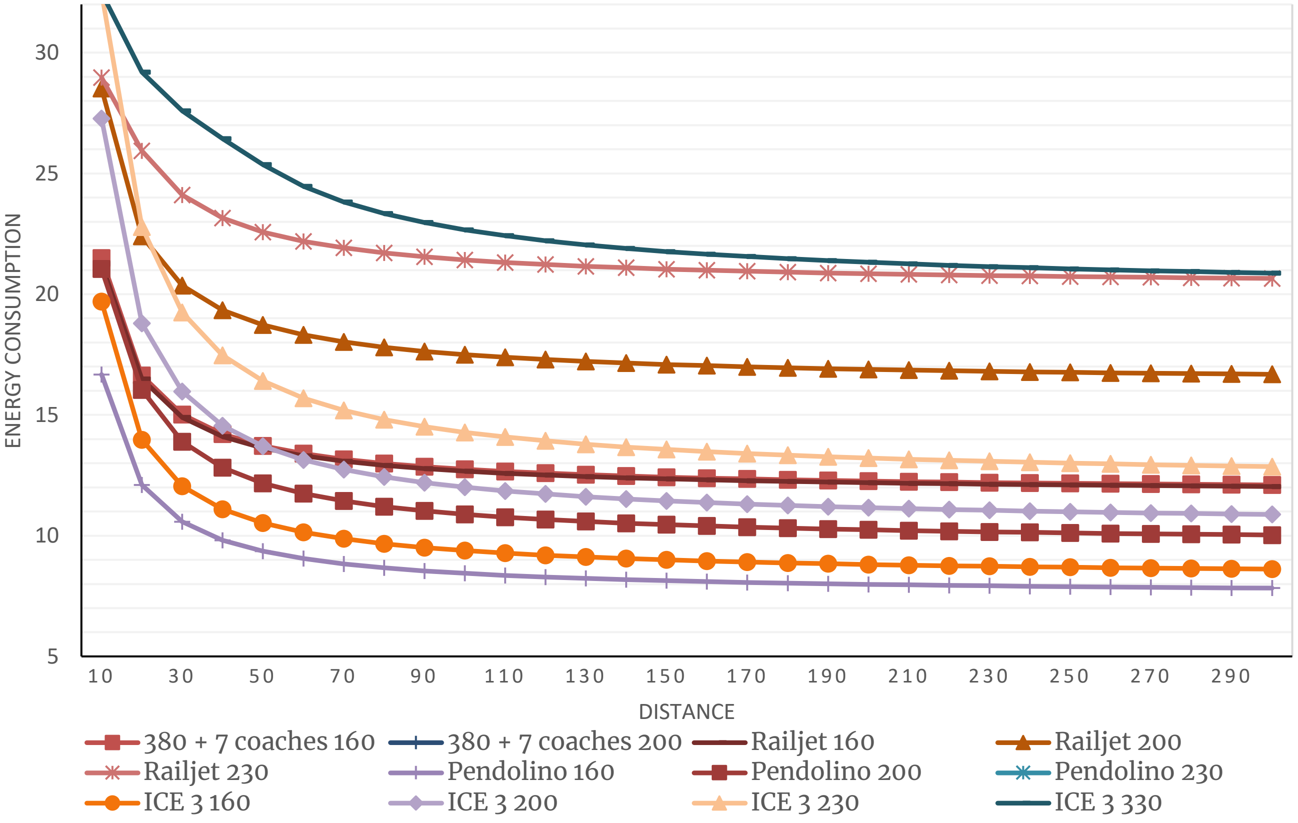

Table 2. Basic output characteristics of each trainset

It is clear from the shape of the curves that, depending on the speed, there is the largest decrease in specific consumption per kilometre driven in the range from 30 to 70 km. At the same time, it is clear that high-speed units such as the Pendolino and ICE 3 achieve better traction energy consumption values than conventional sets. The authors tried to describe the individual curves using mathematical analysis tools and to interpolate the functions. However, the required reliability value was not achieved for any of them, therefore it was necessary to calculate all partial values manually. The following subsection describes the procedure and results of considerations for the possibility of determining the optimal distance of stops.

4.3. Optimal distance of stops

Another researched variable was the optimal distance between two stopping points. On the one hand is a geographical limit of two stops and on the other hand are parameters of used trainsets. This research was performed for each trainset and maximum speed separately. It was determined that the total energy consumption E_c, which is given by (2), consists of the energy needed for acceleration E_r and the energy needed to run the train at a constant speed E_j. Due to the difficult quantification, the energy required for braking the vehicle or the regenerative energy E_b was set equal to 0. This is the energy that is most dependent on the specific characteristics of the technical equipment of the trainsets and track, but also on individual national regulations. However, the authors are aware of its importance and it is assumed that it will be included in the calculation in the case of processing specific case studies

$$E_c = E_r + E_j + E_b \qquad (2)$$

Based on (2) all (integers) values of specific consumption per km in the interval from 0 - 300 km were calculated. For calculating all values the interval halving method was used. The authors decided to determine the recommendations for the optimal distance of stops by determining the share of the consumption of traction energy needed for acceleration of the train E_r in the total energy consumption E_c. By determining the exact value of the share, a specific distance value can be calculated. To recommend the optimal distance of stops, the authors chose the values of 20, 30 and 40%, which are listed in Table 3.

From the values given in Table 3, as well as from other calculated values, it is possible to determine a specific value of the distance, which is related to the share of energy consumed for acceleration. This method helps to determine the values of the optimal distance of stops. However, when designing a specific solution, it is always necessary to proceed from the restrictive conditions given by the project.

Table 3. Recommended distances of stops [km]

Trainset	Š 109E			Railjet			Pendolino			ICE 3		
%	20	30	40	20	30	40	20	30	40	20	30	40
160	57	35	25	56	35	24	78	48	33	76	46	31
170	61	38	27	61	38	26	86	53	37	82	50	34
180	65	41	29	66	41	29	94	59	41	88	54	37
190	71	45	32	71	45	32	104	65	45	95	58	40
200	77	49	35	78	50	36	114	72	50	102	63	43
210				88	56	41	126	80	57	108	67	46
230				144	94	69	160	102	74	123	76	53
250										139	87	61
270										158	100	71
290										182	116	83
310										216	139	100
330										271	177	129

Based on the analysis of the simulation output data, specific values of the distances needed to reach the maximum speed, and the amount of energy actually consumed were determined. From the performed simulation, but also from the common train motion equation, it is clear that the greatest energy consumption occurs during acceleration. The authors therefore compiled a model that determines how far the train must run between two stops in order achieve the specific value of traction energy consumption for a kilometre. The share of the acceleration energy was set up for 20, 30 and 40%. If this share of the total energy consumption is 40% then train must run at least 25 - 31 km at 160 km·h^{-1}, 35 - 43 km at 200 km·h^{-1}, 53 – 69 km at 230 km·h^{-1} and at a speed of 330 km·h^{-1} at least 129 km. However, if we reduce this share to 20%, the distance at a speed of 160 km·h^{-1} must be at least 56 - 78 km, at a speed of 200 km·h^{-1} 77 - 114 km, at a speed of 230 km·h^{-1} 123 – 144 km and at a speed of 330 km·h^{-1} at least 271 km. The location of stations and stops is crucial for the consumption of traction energy, but their location is mainly influenced by economic, demographic and geographical factors. By improving the technical parameters of the track and vehicles, we can significantly increase the efficiency of the use of consumed traction energy by using new technologies.

4.4. Factors influencing efficiency of increasing the track speed and energy consumption

The line speed increasing and building HSL is a phenomenon that contributes primarily to shortening travel times and increasing the attractiveness of passenger rail transport against air transport and individual transport. In the case of HSL, one of the decisive factors is the consumption of traction energy, which is such an integral part of the operating costs (Zhengyong, Zheng, Haitao 2016). There are many approaches in the world to solve the problem of optimizing traction energy consumption. The usual tool for research in this area is simulation. However, the simulation itself cannot be used for optimization. There must be used some MCA tool, genetic algorithm or, for example, fuzzy logic. The building and operation of a HSL network is influenced by a number of factors and those factors are determining the operating concept. The chosen operating concept then affects the total costs, where the consumption of traction energy is included. The key factors that directly or indirectly affect traction energy consumption can be divided on Wang, Penq, Liu, Wang 2020; Zhang, Jia, Wang, Xu 2019; Żurkowski 2018; Chen, Guo, Ai, He 2019; Blanquart, Koning 2017; Siroky, Sramek, Magdechova, Tischer, Hlavsova 2019; Zhang, Zhu 2018; Raithel, Baumbusch, Kielbassa 2016):

1. Technical - track.

- Slope profile and track alignment (track resistance).
- Speed profile.
- Concepcion a layout of stations.
- Technical equipment in stations.
- Track and station interlocking system.
- Support for ATO (automated train operation).
- Electric traction system.

2. Technical – vehicle.

- Maximum speed.
- Total weight.

- Traction efficiency.
- Vehicle resistance.
- Tractive characteristics.
- Possibility of recuperation.
- Grade of automation (GoA0 – GoA4).

3. Technological.

- Conception of the timetable.
- Conception of traffic control.
- Stopping strategy.
- Automated operation of the railway traffic.
- Connection with other modes of transport and transfer nodes.
- Railway traffic (segregated, mixed).
- National and international regulations.
- Utilization of a track capacity.

4. Socioeconomics.

- Size of an agglomeration.
- Distance and shape of agglomeration.
- Traffic demand.
- Economic power of the region or country.
- Local conditions (build costs and running costs of HSL).

5. Conclusions

The right choice of maximum track speed is a crucial issue when planning the construction of a HSL. This parameter has a significant effect on the network building cost, used vehicles or the consumption of traction energy. The efficiency of the use of traction energy is thus one of the key factors influencing the total cost of operating a HSL. In this work, a simulation in the OpenTrack SW was used to determine the actual values of traction energy consumption for individual trainsets during its acceleration and driving at the maximum speed.

From a technological point of view, it is possible to increase the efficiency of traction energy consumption by optimizing the timetable and the use of ATO systems and railway dispatching. When creating an energy-optimized timetable, the key is in the stopping strategy for each train, but also in non-use of the shortest allowed running times, which increases consumption rapidly. The tools for automating a train operation makes possible to run a train in the ideal time position, with optimal use of the energy consumption, at the same time it can be connected to the train protection system and thus contribute to the overall safety of the railway traffic. The contribution for the traffic management is in elimination of erroneous decisions of the human factor in the field of traffic control. With the increasing speed of transport, it is necessary to use automated functions that will prevent unnecessary energy losses and possibly security risks. The issue of traction energy efficiency is a complex problem. This paper shows a possible approach to measuring the efficiency of traction energy consumption at different distances and at different track speeds. The values determined by this method can be used as a basis for planning timetables on HSL and in the preparatory phases of projects.

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