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CALCULATION OF THE MINIMAL LENGTH OF THE HIGH-SPEED LINE

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Abstract. This paper explores the minimum length of continuous sections of the high-speed line. The minimum length is examined in terms of the maximum speed of high-speed vehicles. Both traditional trainsets consisting of traction units and coaches, and train units were selected for examination. The graphs present the difference in the ability of the different vehicles to reach and use the maximum speed.

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

1. Introduction

The construction of a high-speed network is going to be a reality in the Czech Republic. After a long time of uncertainty, there is a real plan of activities that will make us part of the map of a high-speed railway. As the construction of the entire network will take a long time, this paper is trying to calculate the minimum length of a continuous line to make the high-speed traffic attractive for passengers. The OpenTrack simulation tool was used for simulation [1]. Subsequent calculations were performed in MS Excel. To find out which track length is effective for the defined maximum track speed, we analyzed rides of predefined trainsets on a hypothetical infrastructure.

The history of high-speed transport dates to the 20th century and has experienced its greatest upswing since the beginning of the 21st century. The total length of high-speed lines has already exceeded 50,000 km and it is planned to reach the target of 100,000 km in the next 15 years. As for individual countries, the most progressive country is China with its more than 35,000 km, with a view to reaching 70,000 km by 2035. Europe lags behind in this respect with about 9,000 km. The Czech Republic is still without a high-speed railway; however, pilot projects are already being implemented and some parts of the conventional infrastructure are being built to allow a speed of 200 km·h^{-1}.

With the construction of the high-speed network, there comes the question of how long a section of the high-speed line must be to allow for the maximum track speed, making efficient use of the funds invested in this infrastructure [2, 3]. In their previous research, the authors investigated the optimum distance between two stops ensuring energy reliability. At the same time, they explored the effectiveness of introducing a speed of 200 km·h^{-1} on short sections of the conventional network. This paper examines the minimum length of a section of the high-speed line, which will enable the trains to reach the planned track speed. This problem is covered by the question of the efficiency of investment into the construction and operation of this specific infrastructure. There is a clear linear correlation between the track speed and construction, noise and safety measures. At the same time, a higher track speed puts stronger demands on vehicle design, power, and traction power consumption. A littler aside is the question of the minimum length of the high-speed line.

This research can be used in the preparation of HSL network [4] constructions or overall preparation of the systematic timetables [5]. The Czech Republic is not as big as for instance China, but during the expansion of the HSL network, we can use an optimization mathematical apparatus to ensure the maximum transportability and utility of the high-speed system [6, 7]. The issue of energy efficiency is dealt with in literature [8], describing the perspective of the use of the coasting and economic modes of high-speed trains. The question of the interlocking system is answered by the ETCS because the Czech Republic is going to install this system on the main corridors, including high-speed lines [9–14].

The costsÂăof infrastructure are figuratively paid by passengers in the price of the ticket, and this price should be in accordance with the travel time and the quality of service. Another important question is energy consumption. This issue is the focus of other papers [15–17].

2. Preparation of the Simulation Model

The OpenTrack simulation software was used for the research. The authors have been using this tool for a long time with good results, and this software is a globally established simulation tool [18]. The model was designed with the emphasis on allowing all the trainset movements modelled to be performed in a very simple way. The simulation model was therefore prepared as simply as possible. The simulation model was created in two phases. In the first phase, an infrastructure model was created. The infrastructure model developed for this high-speed vehicle research consists of four tracks of 50 km each with no curves or slopes. In the second phase, the parameters of each trainset were entered. Most important are the tractive characteristics of trainsets, maximum speed, weight, adhesive weight, and vehicle resistance. As for the research trainsets, the 151.0 engine with 7 Bmz coaches, Škoda 109E with 7 Bmz coaches, Siemens Viaggio Comfort non-traction unit with Taurus engine and multiple units of the 680 ČD "Pendolino" series, AVE, and ICE 3 were chosen. For a more detailed description of the model, see previous article [19].

What is important for the actual simulation are the input characteristics of the individual trainsets. These characteristics are provided for in the following Table 1.

To calculate the rolling resistance of the individual trainsets, the Davis equation was used, as expressed in Equation 1. The individual parameters are included in the vehicle database within the OpenTrack system used for the simulation. Had there been tunnels on the line, we would have had to add resistance caused by using the tunnel. However, no tunnel was included in the model.

$$R_{LZ} = A + B * \nu + C * \nu^2 \; [N] \tag{1}$$

Where:

R_{LZ}= train air resistance [N],

ν = train speed [km·h^{-1}],

A, B, C= parameters.

The simulation was running continuously. Depending on the required accuracy [20], it was possible to establish the situation of the train in every moment in time. This is important in examining the impact of variables that can be easily included in our generic model, as appropriate. The actual train speed and distance covered can be calculated using integration according to Equation 2 and 3. The resulting values can be used to create tachograph curves or the monitored parts thereof.

$$\nu = \nu_p + \int_{t_1}^{t_2} a \cdot dt \; [m \cdot s^{-1}] \tag{2}$$

$$s = s_p + \int_{t_1}^{t_2} \nu \cdot dt \; [m] \tag{3}$$

Where:

ν = speed [m·s^{-1}],

ν_p= initial speed [m·s^{-1}],

t = time [s],

t_1 = initial time [s],

t_2 = target time [s],

a = acceleration [m·s^{-2}],

s = distance covered [m],

s_p= initial distance covered [m].

All simulations were carried out under good adhesion conditions; the value of adhesion was set at 100% of the adhesion coefficient. By setting the value of adhesion utilization, it is possible to simulate potential degraded adhesion conditions. The adhesion coefficient can be calculated according to Equation 4.

$$\mu = \frac{2.1[m \cdot s^{-1}]}{\nu + 12.2[m \cdot s^{-1}]} \; [-] \tag{4}$$

Where:

μ = adhesion coefficient,

ν = speed [m·s^{-1}].

Through the simulation, the authors intended to show the distance needed for the acceleration of each trainset. Each trainset was simulated with its maximum speed.

3. Results

The output of the simulation is quite simple: it is a distance-speed graph for each trainset, where we can observe the basic dynamic characteristics. Table 2 shows the distance necessary for a trainset to reach the speed limit.

The distance required for acceleration varies greatly. It certainly depends on the tractive power of each trainset and its weight. Based on this, a graph of the speed-distance dependence was created. Figure 1 shows this graph illustrating the curve for each trainset.

We can see that the minimum length of the high-speed line for a train to reach the limit of 200 km·h^{-1} lies between 4 and 10 km. If we consider a speed limit of 230 km·h^{-1}, this distance will increase to 8 km for ICE 3 and to 18 km for Pendolino and Railjet.ÂăOn the other hand, those values are just minimum ones. The actual length for practical useÂăshould be higher.

Another very important variable is acceleration. For the presentation of results, the trainsets were divided into two groups with a distance-speed graph created for each of them. Shown in Figure 1, the one group involves typical trainsets with a locomotive. The other group in Figure 3 contains train units. It is clear that the modern RailJet vehicles and locomotive 380 achieve much better results than a locomotive representing the older generation 151.0. Particularly at lower speeds, both these modern locomotives have dynamic properties close to those of train units.

Clearly the weakest out of the train units is Pendolino, which is mainly due to its older design and, therefore, its higher weight. Even on a straight section, Pendolino's maximum acceleration is 0.45 m·s^{-2} and declines relatively quickly. Starting at a distance of approximately 1 km (at approx. 100 km·h^{-1}), its acceleration is already lower than 0.3 m·s^{-2}.

Trainset	Maximum speed $[\mathrm{km \cdot h^{-1}}]$	Weight [t]	Maximum tractive effort [kN]	Maximum power [kW]	Maximum acceleration $[\mathrm{m \cdot s^{-2}}]$	Average deceleration $[\mathrm{m \cdot s^{-2}}]$
151.0 + 7 coaches	160	443	210	4000	0.353	-0.6
Škoda 109 E + 7 coaches	200	445	274	6400	0.560	-0.6
Siemens Viaggio Comfort	230	437	300	6400	0.627	-0.6
AVE S-102	300	355	200	8800	0.526	-0.6
Pendolino	230	384	200	3920	0.461	-0.6
ICE 3	300	463	300	8000	0.581	-0.6

Table 1. Basic characteristics of the vehicles simulated, source: Authors.

Speed	**Distance [m]**					
$[\mathrm{km \cdot h^{-1}}]$	**Engine 380**	**Engine 151.0**	**RailJet**	**AVE**	**Pendolino**	**ICE 3**
100	890	1573	737	860	970	730
160	2993	5284	2967	2610	4096	2280
200	6588		6914	4900	9400	4450
230			20804	8950	18247	7100
300						20612
330						36372

Table 2. Distance to be covered to reach the respective speed, source: Authors.

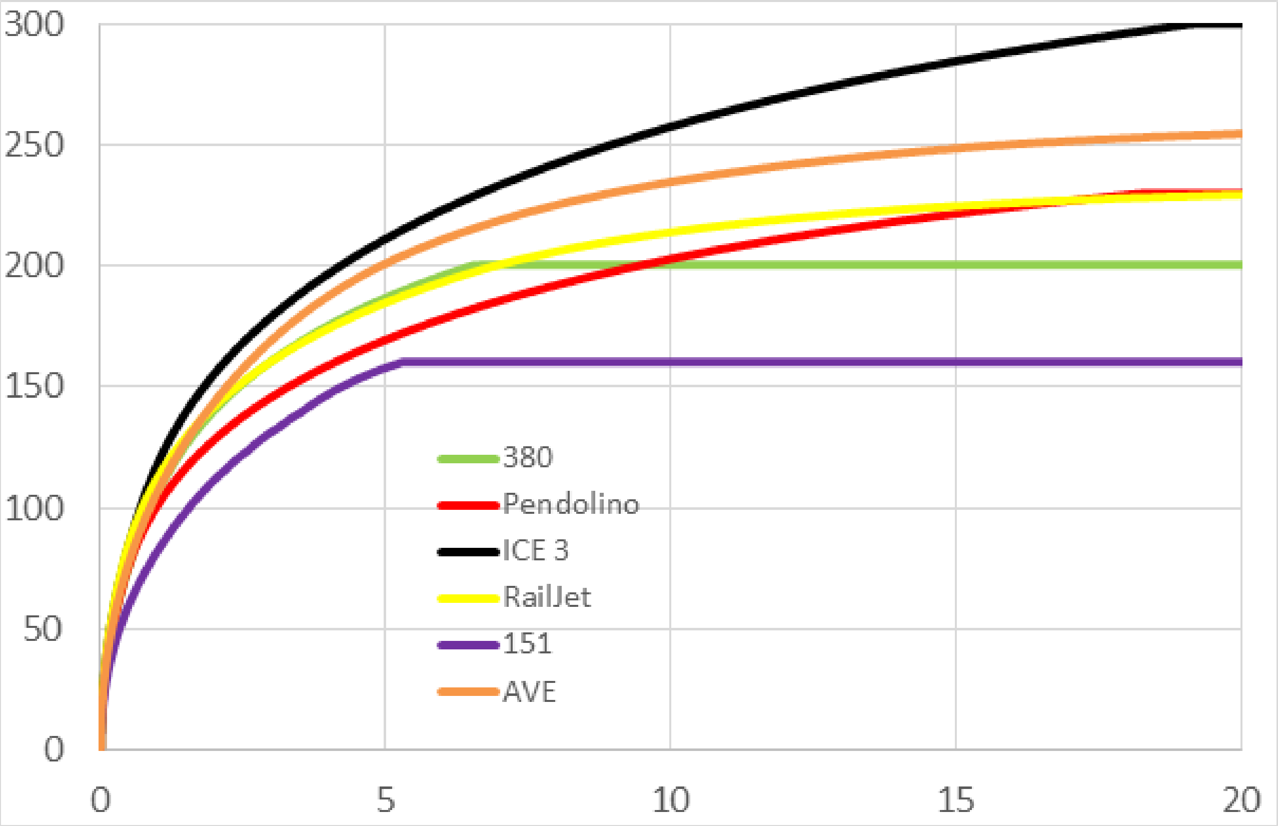

Figure 1. The distance needed for acceleration [km], source: Authors.

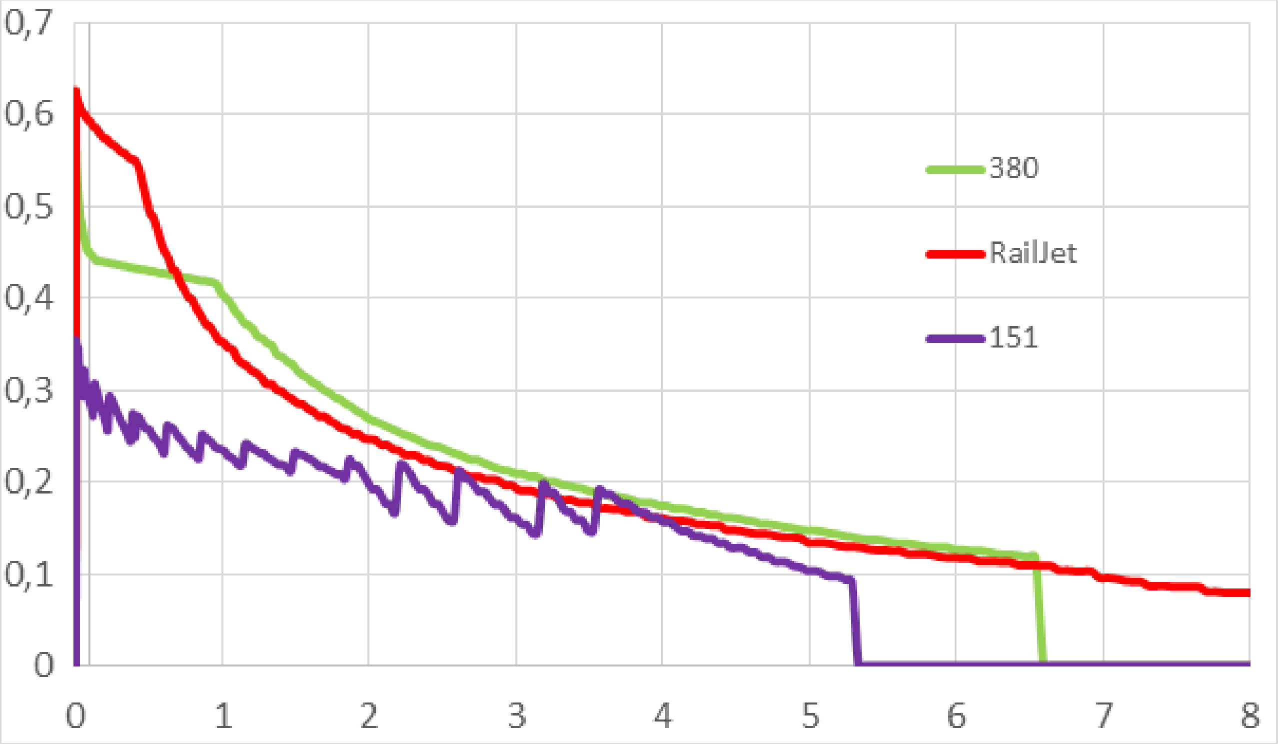

FIGURE 2. Acceleration of typical trainsets [m·s^{-2}], source: Authors.

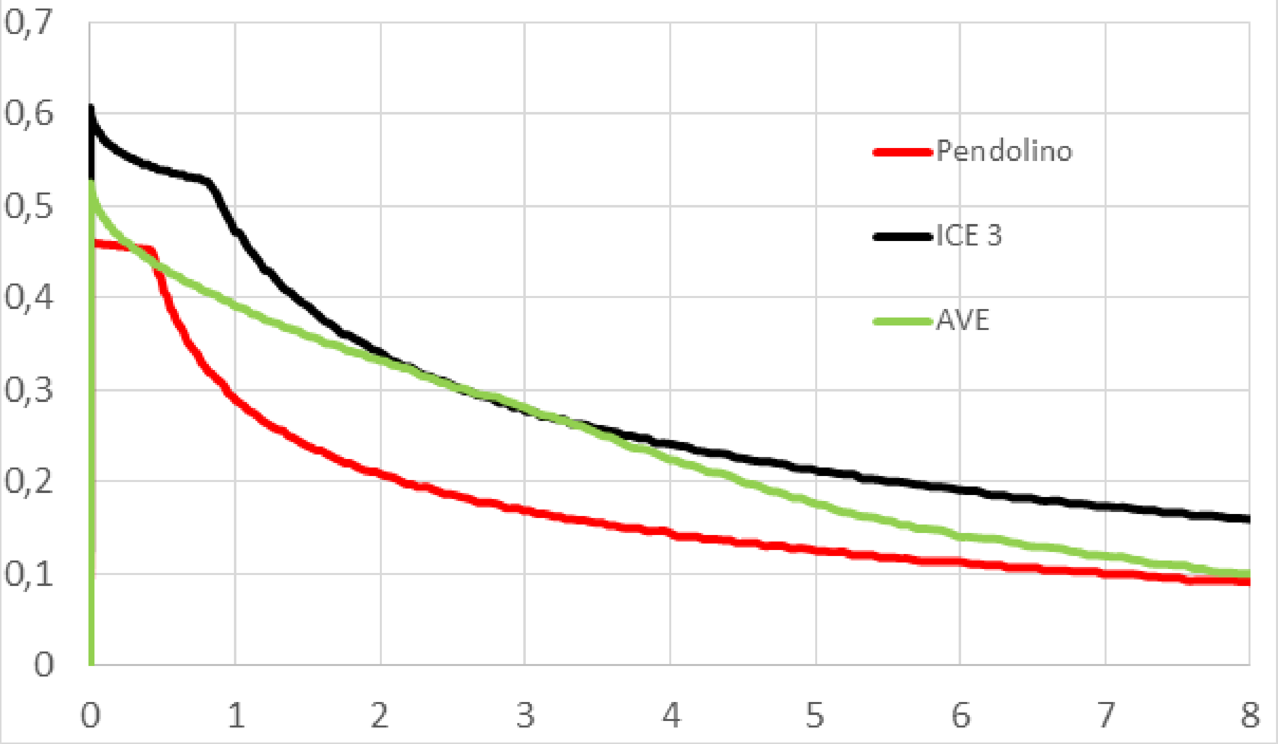

FIGURE 3. Acceleration of units [m·s^{-2}], source: Authors.

4. Conclusions

This paper explores the minimum length of a section of the high-speed line for vehicles to be able to reach the maximum speed. The simulation showed that for a maximum speed of 230 km·h^{-1}, this distance is approximately 10 to 15 kilometers. This is the distance to be covered by high-speed units to achieve this speed. An important question to be answered before the line construction is whether the line would only be used by high-speed units, or also by conventional trainsets with a maximum speed of 200 or 230 km·h^{-1}. The simulation shows that even these trainsets can achieve their respective maximum speeds in a relatively short period of time. By contrast, older models of traction units are not suitable for operation on these newly constructed lines due to their low maximum speed and traction characteristics. Encouraging is the fact that even short sections of the high-speed line are a convenient and efficient tool for the development of the railway network: not only are they parts of the high-speed network, but they can also take the strain off current conventional lines. Mainly close to major urban areas, the capacity of these lines is often saturated, and they are not able to cover the ever-increasing demand for suburban transport. Also freight railway undertakings are waiting for the clearing of these sections.

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