



Article

Assessing the Efficiency of Increasing the Track Speed in the Line Section Rokycany–Plzeň hl. n.

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Abstract: Using simulation in OpenTrack, this paper analyses the journey of type trainsets on model infrastructure in the line section Rokycany–Ejpvovice–Plzeň hl. n. The aim of this paper is to assess the efficiency of increasing the track speed in this section. Analyzing the output characteristics of the simulation, selected indicators were assessed which influence the efficiency of further increases in track speed. One of the simulation scenarios is using the European Train Control System Level 2 (ETCS L2) system as the necessary condition of the speed over $160 \text{ km}\cdot\text{h}^{-1}$.

Keywords: simulation; OpenTrack; energy consumption; European Train Control System (ETCS); TEN-T network

1. Introduction

Railroad transport is the most environmentally friendly mode of land transport, but in recent decades, it has been confronted with the huge expansion of individual road transport and air transport. Many international treatments and national policies have firmly entrenched the goal of lowering the modal split of individual road transport. Therefore, many countries are building high-speed lines and reducing domestic air connections. Alternatively, they are increasing the parameters of current railway lines, which is also a common way of developing the railway network, as it is cheaper than the construction of new lines. On the other hand, these changes require compliance with a number of geographical or urban restrictions of the original line. The Czech Republic is also preparing the construction of a high-speed line network (HSL) and is introducing speeds higher than $160 \text{ km}\cdot\text{h}^{-1}$ on existing lines. This implementation is conditional on implementation of the European Rail Traffic Management System (ERTMS) trackside signaling equipment (European Train Control System (ETCS) + Global System for Mobile Communication—Railway (GSM-R)). This process brings with it unresolved issues about implementation of the ERA braking model given the conditions of the Czech railways. This article presents how partial measures have small impacts, but how important they are for the final target. The line section Praha–Plzeň hl. n. (a modernized section of the 3rd national transit railway corridor, which is part of the Rhine–Danube corridor in the TEN-T network) includes the longest railway tunnel in the Czech Republic. At 4150 m long, the tunnel was commissioned on 15 November 2018 [1]. Successfully passing the pantograph tests, the Ejpvovice tunnel was authorized for operation at $160 \text{ km}\cdot\text{h}^{-1}$ on 26 September 2019 [2]. In the future, it is planned to be used for a high-speed railway network within the national Fast Connection development programme. Therefore, the design speed for the tunnel is up to $200 \text{ km}\cdot\text{h}^{-1}$ [1]. With its maximum design speed of $200 \text{ km}\cdot\text{h}^{-1}$, this line section is one of the pilot projects in the Czech Republic. Other pilot sections include: Brno–Břeclav, Kolín–Poříčany and Choceň–Pardubice on the 1st national transit railway corridor, Olomouc–Dluhonice on the 3rd national transit railway corridor, and Soběslav–Doubí and Soudoměřice–Votice on the 4th national transit railway corridor [3].

Increasing the track speed is a current trend necessary for maintaining and reinforcing the attractiveness of railway transport. At the same time however, it is connected with higher investment costs for buildings, vehicles and safety devices. For a speed exceeding $160 \text{ km}\cdot\text{h}^{-1}$ in the context of the Czech Republic, it is also necessary to amend the existing internal regulations of the railway infrastructure manager which set out the maximum speed of $160 \text{ km}\cdot\text{h}^{-1}$ so far [4]. Moreover, a track speed of more than $160 \text{ km}\cdot\text{h}^{-1}$ will only be possible for vehicles equipped with the ETCS system in accordance with the national implementation plan [5].

Considering the technical and financial challenges connected with the preparation and operation of sections at a speed exceeding $160 \text{ km}\cdot\text{h}^{-1}$, it is necessary to individually assess the efficiency and benefits of further increases in track speed in each such section. Using OpenTrack, this paper will simulate the rides through the Ejpovice tunnels at 140, 160 and $200 \text{ km}\cdot\text{h}^{-1}$. Based on the simulation results, the efficiency of such speed increase will be assessed in terms of both shortening the journey time and energy performance. Furthermore, the model will include the simulation of braking under ETCS, which also has an impact on the efficiency of driving at the maximum track speed.

The focus of this research is on the use of a simulation model in the SW OpenTrack for modeling a train run through the Ejpovice railway tunnel at speeds of $160 \text{ km}\cdot\text{h}^{-1}$ and higher. The aim is to confirm the use of a higher speed in the tunnel based on the model with regard to saving travel time, energy consumption and the effect of ascending or descending gradient. The last part of the article focuses on the train run under the full supervision of the ERTMS/ETCS which is the necessary condition for the train running over $160 \text{ km}\cdot\text{h}^{-1}$. In this area, the Czech infrastructure manager has not yet approved national values for ETCS, which can significantly affect the shape of the braking curve [6]. In Poland, found that national values are a key parameter for the safety and throughput of the railway network [7]. This article will show the effect of the ETCS on the useful length of the section with increased speed. The length of the tunnel can be compared with the research [8], which can be used to calculate the optimal section length on a track with ETCS L2. These findings about the ETCS system will help in the near future, because this system is still under development for the Czech conditions and mainly the changes in national values are highly recommended [9].

2. Materials and Methods

Modelling in OpenTrack allows for the assessment of rail infrastructure from many different perspectives. For instance, it can be used in assessing the following areas: running dynamics of railway vehicles, energy performance, operating intervals, line capacity, transport planning and the effect of changes on rail infrastructure and vehicles. From this perspective, it is quite a complex tool [9]. However, it is always necessary to define the aim of a specific model and only model those elements that are relevant for this aim. A general scheme of setting up a simulation model in OpenTrack is provided in Figure 1.

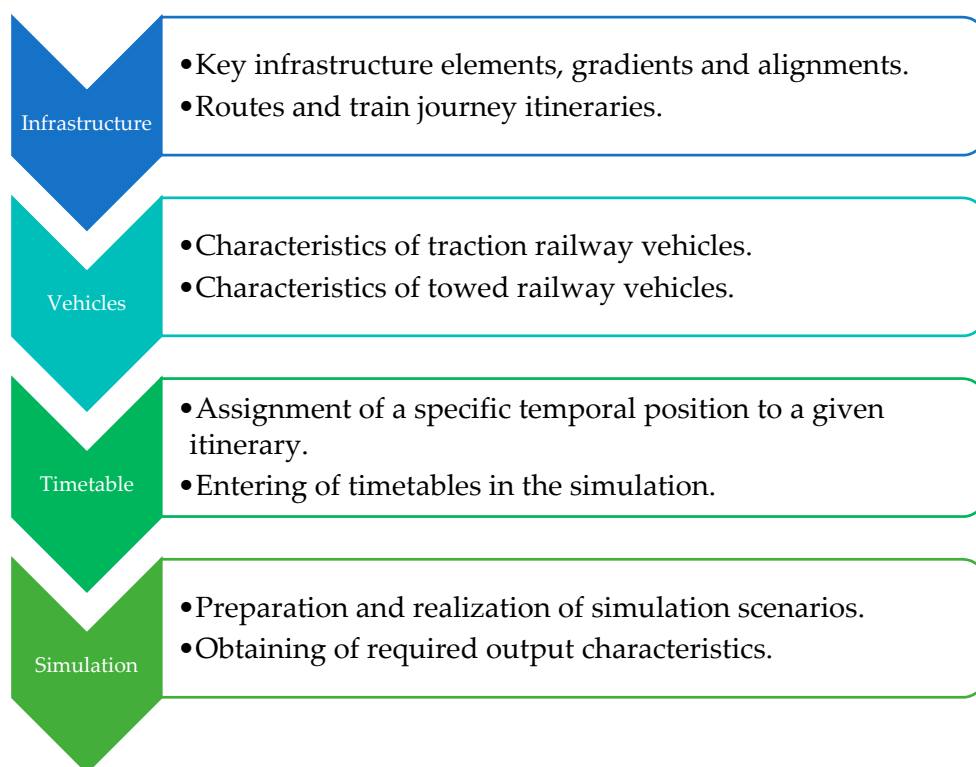


Figure 1. Schematic representation of the different stages of simulation model preparation.

In the simulation model, the infrastructure is represented by a network graph. The vertices of the graph represent the kilometre position of decisive points on the transport infrastructure [10]. The edges connecting them represent the characteristics of the individual line sections. In this case, each edge was assigned two speed profiles. One speed profile is meant for conventional trainsets (speed boards N), the other one for tilting trainsets (speed board NS). An alternative speed profile was created for the section between kilometre 93.751 at the Ejpovice railway station and kilometre 101.052 (a total of 7301 m), with track speed increased from the current $160 \text{ km}\cdot\text{h}^{-1}$ to $200 \text{ km}\cdot\text{h}^{-1}$. The model was created for the following stations: Rokycany (only the main tracks), Ejpovice (all tracks) and Plzeň hl. n. (station tracks 0, 0b, 1, 1a, 1b, 2 and 2a). The model of the Plzeň hl. n. station was designed to allow for the simulation of train service movements on the main tracks from/to the passenger station perimeter. Subsequently, itineraries were created for the envisaged train routes. In the stations Rokycany and Plzeň hl. n., the fictitious trains appear and disappear. Figure 2 shows a part of the transport infrastructure model with operation point Ejpovice tunnel (from entry signals in Ejpovice to entry signals in the Plzeň hl. n. station).

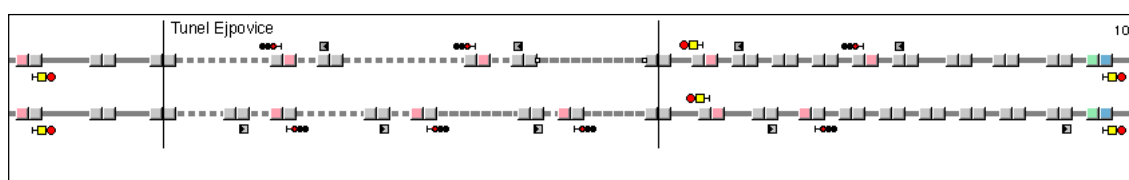


Figure 2. Model of the Ejpovice tunnel operation point.

The trains are ČD 680 “Pendolino” unit equipped with the tilting mechanism, the engine ČD 380 + 5 coaches—a representative of the modern long-distance express segment—and the engine ČD 362 + 5 coaches representing the contemporary long-distance express segment. The basic parameters of the individual reference trainsets are provided in Table 1. The parameter “maximum deceleration”

was calculated based on the actual braked mass percentage and based on the equation defined by the Decree No. UIC 544-1 [11] using the following Equations (1) and (2).

$$BWP = \frac{\text{Braked mass [t]}}{\text{Trainset weight [t]}} \cdot 100 \quad (1)$$

$$a = -(c_1 + c_2 \cdot BWP) \quad (2)$$

where:

BWP = actual braked mass percentage [%]

c_1 = coefficient 0.069

c_2 = coefficient 0.006

a = acceleration [$\text{m}\cdot\text{s}^{-2}$]

Table 1. Parameters of reference trainsets.

Reference Trainset	Maximum Speed [km/h]	Weight [t]	Braked Mass [t]	Maximum Tractive Force [kN]	Maximum Power [kW]	Maximum Deceleration [$\text{m}\cdot\text{s}^{-2}$]
ČD 680 "Pendolino"	230	417	605	200	4000	−0.939
ČD 380 + 5 Bmz	200	343	536	274	7400	−1.005
ČD 362 + 5 Bmz	140	341	419	258	3920	−0.801

These equations expect that the deceleration is a constant from maximal speed to standstill, but [7,12] show that it is a set of variables. According to [12], the deceleration limits for ETCS were calculated and set up in the OpenTrack software. Another discussed problem of braking curves is the brake build-up time. Equation (3) is commonly used, but this equation is rather far from the reality in the area of small speeds. The real shape of the braking curve is different which makes problems on the real infrastructure.

$$t_e = t_{\text{reaction}} + \frac{t_{\text{build}}}{2} \quad (3)$$

where:

t_e = total time of brake build-up [s]

t_{reaction} = reaction time [s]

t_{build} = brake build-up time— $F_b \geq 0.95$

This problem is solved in [13] with the conclusion that the specifications of the ETCS should be changed, mainly that the braking calculation should be extended for the possibility of negative values of the deceleration during the brake build-up time. This will ensure a much more accurate shape of the braking curve in the OBU compared to conventional train braking. The resulting Equation (4) expresses a possible improvement in the calculation of surveillance curves compared to the current state. After the implementation of the proposal [13] the target speed could be reached up to 22% closer to the speed restriction.

$$d_{\text{CSM/TSM}} = \int_0^{t_{\text{braking}}} v(A_{\text{safe}}) dt + \int_{t_{\text{braking}}}^{t_{\text{braking}} + T_{\text{be}} + T_{\text{bs2}} + T_{\text{driver}} + T_{\text{indication}}} v(A_{\text{est}}) dt \quad (4)$$

where:

$d_{\text{CSM/TSM}}$ = distance needed for deceleration from ceiling speed to target speed [m]

a_{safe} = value of safe deceleration dependent on gradient, adhesion, BWP

a_{est} = acceleration estimated during the traction cut off process

T_{be} = emergency brake build-up time

T_{bs2} = service brake build-up time

T_{driver} = driver reaction time between permitted speed supervision limit and SBIT_{indication} = Indication time for Indication supervision limit

a, b, c = constants from Subset 026-3

L = length of the train

Calculation of braking curves when solving the case of allusion to other limits, which can be calculated from the calculation of braking curves of the conversion calculation, which is based on Subset 026-3 [12]. In this case it is a brake build-up time for emergency brake which can be described by Equation (5).

$$T_{brake_basis_eb} = a + \frac{b \cdot L}{100} + c \cdot \left(\frac{L}{100}\right)^2 \quad (5)$$

where:

$T_{brake_basis_eb}$ = brake build-up time [s]

$a = 2.30$

$b = 0.00$

$c = 0.17$

This method described in [12] counts that the variable L is set as a $L = \max(400 \text{ m}; \text{train length})$. If we substitute into Equation (5) we can calculate the minimum brake build-up time for emergency brake in (6):

$$T_{brake_basis_eb}(400) = 2.3 + \frac{0.00 \cdot 400}{100} + 0.17 \cdot \left(\frac{400}{100}\right)^2 = 5.02 \quad (6)$$

This value is a minimum brake build-up time for emergency brake. For ceiling speed $200 \text{ km} \cdot \text{h}^{-1}$, this is the distance for brake build-up more than 270 m. If Equation (5) does not contain the condition of the minimum length of the train, the curve of EBD could be much closer to the danger point or End of Authority. Another time value added to the braking calculation is the driver reaction time. This value is stated in the Subset 026-3 as 4 s. The train running $200 \text{ km} \cdot \text{h}^{-1}$ runs more than 120 metres. This makes together nearly 400 metres of safety pillow.

In this simulation, it was not necessary to create a specific timetable. Simulation scenarios were designed to allow for the simulation of all feasible variants, which are relevant for maximum speed. Existing journey times and trainset standards were taken from the current timeTable 2019/2020 created by the infrastructure manager. An overview of existing journey times is provided in Table 2. The values in Table 2 are in seconds, because the following use of the simulation SW enables punctuality in seconds. For real timetable purposes, values are rounded to minutes with halves.

Table 2. Journey times in timeTable 2019/2020.

Reference Trainset	Rokycany–Ejpovice		Ejpovice–Plzeň hl.n		Rokycany–Plzeň hl. n.	
Direction	A [s]	B [s]	A [s]	B [s]	A [s]	B [s]
ČD 680 “Pendolino”	180	180	450	420	630	600
ČD 380 + 5 Bmz	180	180	450	420	630	600
ČD 362 + 5 Bmz	180	180	450	420	630	600

3. Results

Simulation scenarios were designed to include three variants. The first variant was based on the current operational situation (as of May 2020) with a maximum permitted speed of $160 \text{ km} \cdot \text{h}^{-1}$ in selected line sections. The second simulation variant considered an increase of track speed between km 93.751 and 101.052 to $200 \text{ km} \cdot \text{h}^{-1}$. The third variant simulated train journeys under the supervision of ETCS L2.

3.1. First Variant

The first variant is important not only for comparison with the future variant, but also served for the calibration and validation of the model, which is an integral part of every transport modelling task.

The first simulation scenario was based on current line parameters, with a maximum speed of $160 \text{ km}\cdot\text{h}^{-1}$ in the Ejpovice tunnel. The actual journey times established through the simulation of the journeys of reference trainsets are shown in Table 3. Compared to the timetable constructed, for the ČD 680 “Pendolino” unit there were time savings of 32.5% in the even direction and 21.3% in the odd direction [8]. Likewise, for the ČD 362 + 5 Bmz, the time savings were 21.9% in the even direction and 4.7% in the odd direction. This variation is related to the construction parameters of the timetable and the date the tunnel was authorized for operation at $160 \text{ km}\cdot\text{h}^{-1}$ (i.e., 26 September 2019) [2]. The journey times used for model calibration (Table 3) were based on the timetable construction. However, according to [2], this section was still not approved for the speed of $160 \text{ km}\cdot\text{h}^{-1}$, but only for $120 \text{ km}\cdot\text{h}^{-1}$. Therefore, the journey times for the timetable respected this restriction. Comparing Tables 2 and 3, we can see the impact of increasing speed to $160 \text{ km}\cdot\text{h}^{-1}$. The basic question of this research was how the journey times change if we established a speed of $200 \text{ km}\cdot\text{h}^{-1}$.

Table 3. Actual journey times (simulation of the current state).

Reference Trainset	Rokycany–Ejpovice		Ejpovice–Plzeň hl.n		Rokycany–Plzeň hl. n.	
	A [s]	B [s]	A [s]	B [s]	A [s]	B [s]
ČD 680 “Pendolino”	148	152	277	320	425	472
ČD 380 + 5 Bmz	180	190	288	299	468	489
ČD 362 + 5 Bmz	180	190	312	337	492	527

Another output of the first simulation scenario were tachographs showing the course of current train speed depending on the distance travelled. An example of such a tachograph is shown in Figure 3. On the y-axis, there is speed in $\text{km}\cdot\text{h}^{-1}$, and on the x-axis, there is distance in km. In addition to the course of speed curves of the different trainsets, the graph also includes the speed profiles defined by different types of speed boards (N, NS).

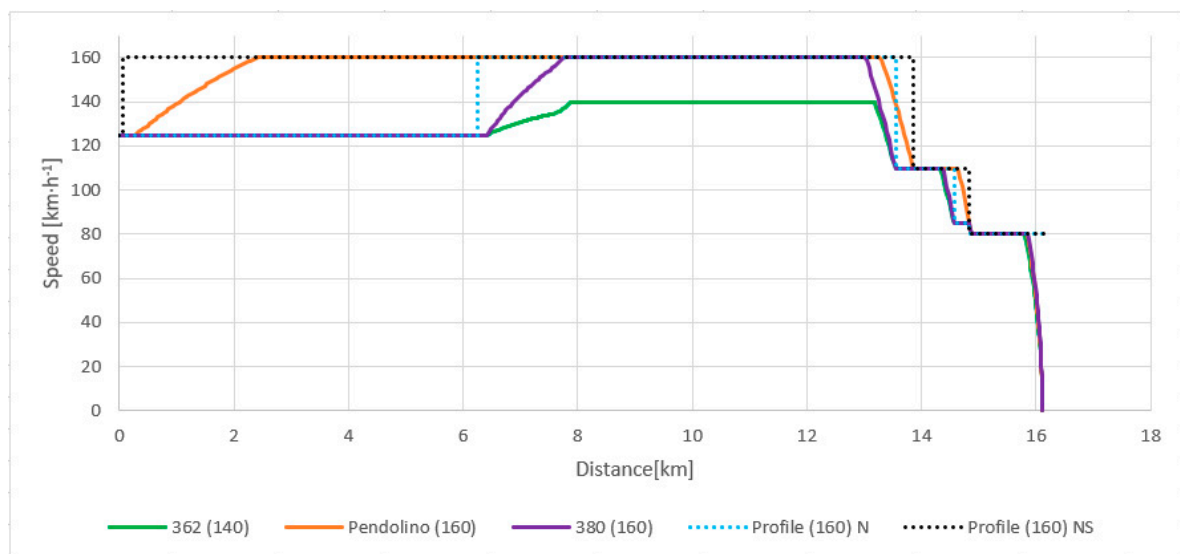


Figure 3. Tachograph for the direction Rokycany–Plzeň (speed $160 \text{ km}\cdot\text{h}^{-1}$).

The train motion equation the actual speed was used to calculate the tachograph. The actual speed of train was calculated by integrating the equation below between the integration limits (Equation (7)). The distance covered can be calculated by repeated integration, which is shown in Equation (8).

$$v = v_p + \int_{t_1}^{t_2} a \cdot dt \quad (7)$$

$$s = s_p + \int_{t_1}^{t_2} v \cdot dt \quad (8)$$

where:

v = speed [$\text{m}\cdot\text{s}^{-1}$]

v_p = initial speed [$\text{m}\cdot\text{s}^{-1}$]

t = time [s]

t_1 = initial time [s]

t_2 = target time [s]

a = acceleration [$\text{m}\cdot\text{s}^{-2}$]

s = distance covered [m]

s_p = initial distance covered [m]

3.2. Second Variant

The second simulation scenario is modified to include the speed increase to $200 \text{ km}\cdot\text{h}^{-1}$ in the section between km 93.751 and km 101.052. The aim of this simulation scenario was again to examine the possibility of reaching $200 \text{ km}\cdot\text{h}^{-1}$, the resulting time savings compared to the current situation, and the increase in traction energy consumption and its financial impacts. The tachograph showing the journey of the vehicles after increasing the track speed is shown in Figure 4. The third scenario builds on the second one, introducing ETCS L2 which also plays a role for the variables considered, as described in Section 3.

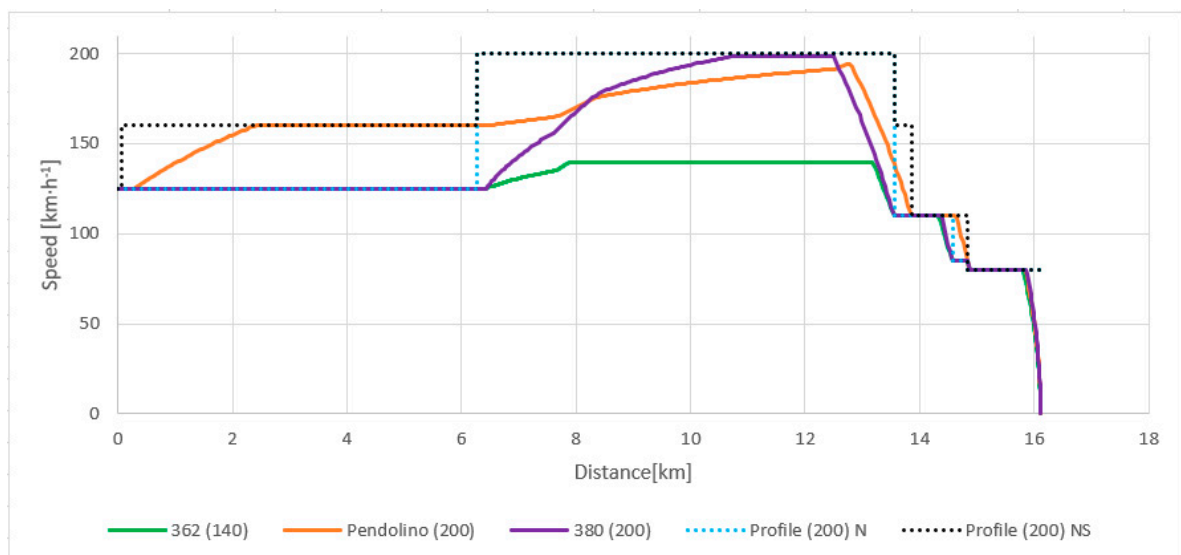


Figure 4. Tachograph for the direction Rokycany–Plzeň (speed $200 \text{ km}\cdot\text{h}^{-1}$).

The first parameter considered was the possibility to reach a speed of $200 \text{ km}\cdot\text{h}^{-1}$. In the direction Rokycany–Plzeň, the ČD 680 “Pendolino” reached a maximum speed of $194 \text{ km}\cdot\text{h}^{-1}$ and the ČD 380 + 5 Bmz reached a speed of $200 \text{ km}\cdot\text{h}^{-1}$ within a distance of 1564 m. In the direction Plzeň–Rokycany, the

ČD 680 “Pendolino” reached a maximum speed of $161.9 \text{ km}\cdot\text{h}^{-1}$ and the ČD 380 + 5 Bmz a maximum speed of $187.1 \text{ km}\cdot\text{h}^{-1}$. Table 4 shows the time savings calculated after increasing the track speed and an overview of distances where the trains can travel at a speed greater than $160 \text{ km}\cdot\text{h}^{-1}$.

Table 4. Shortening the journey times and travelling at a speed exceeding $160 \text{ km}\cdot\text{h}^{-1}$.

	Time Savings [s]		Travelling Distance at a Speed Exceeding $160 \text{ km}\cdot\text{h}^{-1}$	
	Ejpvovice–Plzeň	Plzeň–Ejpvovice	Ejpvovice–Plzeň	Plzeň–Ejpvovice
ČD 680 “Pendolino”	16	0	6.74	0.15
ČD 380 + 5 Bmz	18	4	5.22	3.95

As can be seen from the results of this simulation, the journey time is shorter mainly in the direction Ejpvovice–Plzeň, which is due to favourable gradients. The section where it is possible to travel at a speed greater than $160 \text{ km}\cdot\text{h}^{-1}$ is 7301 m long. Figure 5 is a graph representing the percentage of the section travelled at a speed greater than $160 \text{ km}\cdot\text{h}^{-1}$ versus the entire length of this section. The graph on the Figure 5 shows the utilization of the section (7301 km) by the speed between $160 \text{ km}\cdot\text{h}^{-1}$ and $200 \text{ km}\cdot\text{h}^{-1}$. Data are displayed in percentage for two trainsets in one direction.

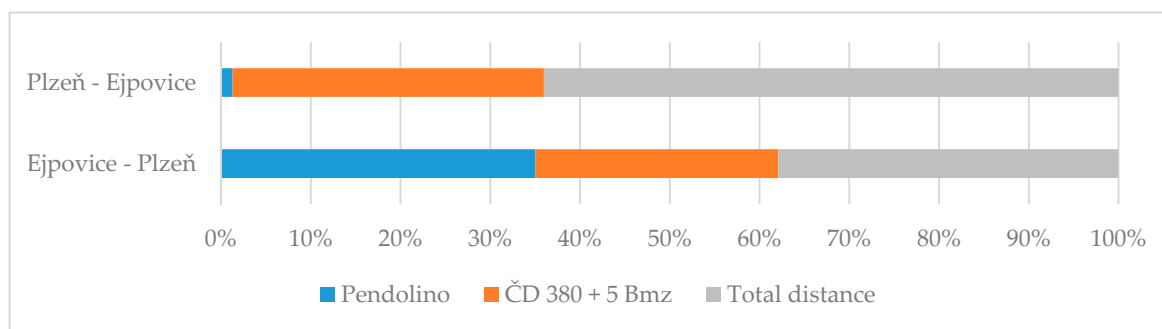


Figure 5. Graph representing the distance travelled at a speed exceeding $160 \text{ km}\cdot\text{h}^{-1}$.

Another parameter considered was the consumption of traction energy, or more precisely the development of its consumption after increasing the track speed. Table 5 shows the increase of the energy consumption if it is possible to run up to $200 \text{ km}\cdot\text{h}^{-1}$ in the tunnel.

Table 5. Energy consumption before and after increasing the track speed.

Track Speed [$\text{km}\cdot\text{h}^{-1}$]	Rokycany–Plzeň		Plzeň–Rokycany		
	Energy [MJ]	%	Energy [MJ]	%	
ČD 680 “Pendolino”	160	490.61	155	1239.72	101
ČD 680 “Pendolino”	200	761.20		1251.37	
ČD 380 + 5 Bmz	160	526.77		1206.52	
ČD 380 + 5 Bmz	200	850.86	162	1354.37	112
ČD 362 + 5 Bmz	140	369.50	— ¹	999.55	— ¹

¹—the value is not calculated, because the maximum speed of the trainset is $140 \text{ km}\cdot\text{h}^{-1}$.

If we compare the data from Tables 4 and 5, we can see that the decrease of the journey time for 16 s causes the increase of the energy consumption by approximately 60%. Figure 6 shows this situation graphically. The left graph shows the consumption for the direction Rokycany–Plzeň hl. n, while the right one shows the consumption for the direction Plzeň hl. N.–Rokycany. These graphs are

followed by the one in Figure 7 showing the consumption of traction energy for the Ejpvovice tunnels section (7301 m). The blue colour is Pendolino, orange is ČD 380 + 5 Bmz.

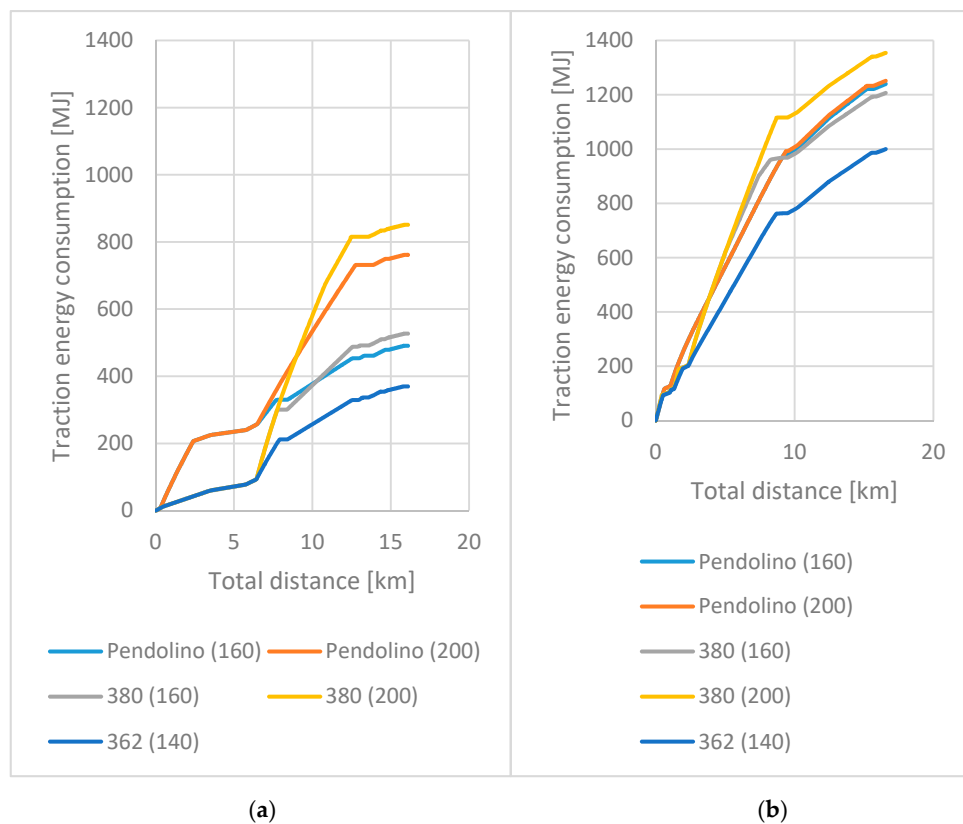


Figure 6. Total traction energy consumption for Rokycany-Plzeň (a) and Plzeň-Rokycany (b).

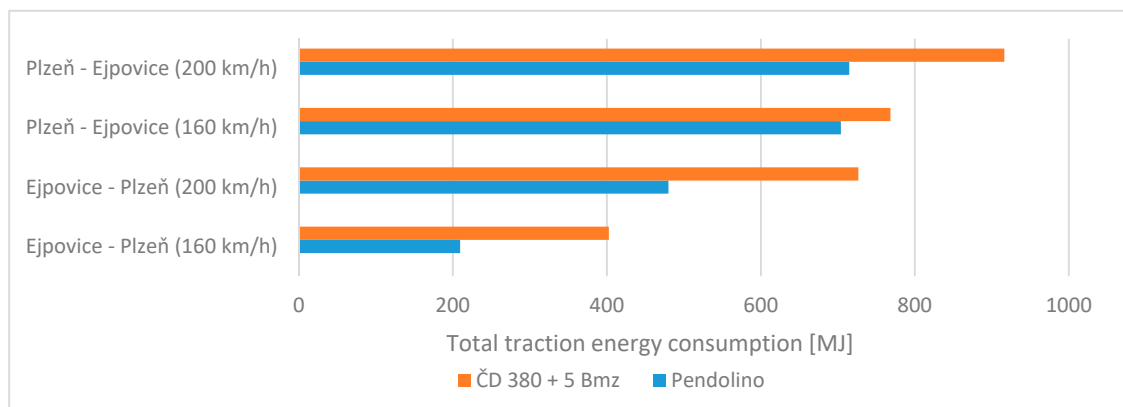


Figure 7. Comparison of the partial traction energy consumption.

Based on the results, the development of traction energy consumption (E_z) between Rokycany-Plzeň was monitored in (9).

$$E_z = E_r + E_m \cdot (s - s_r - s_b) \tag{9}$$

where:

E_z = traction energy consumption [MJ]

E_r = acceleration energy [MJ]

E_m = energy for the constant speed run [MJ]

s = total distance [km]

s_r = acceleration distance [km]

s_b = braking distance [km]

Assuming a price of € 0.09 per 1 kWh for the traction energy consumed, the additional costs of a train ride due to increasing the speed can be quantified. This value can indeed be influenced, for instance by the possibility of recuperation. However, taking into account the complexity of the calculation model and the difficulty of establishing the price for recuperated energy, this possibility was not considered. Table 6 shows the quantified costs of traction energy consumption after increasing the track speed and the increase of consumption relative to the baseline expressed as a percentage. The values in this table only pertain to the line section with track speed increased to 200 km·h⁻¹ (7301 m).

Table 6. Increase in consumption and price for the energy consumed.

	Increase in Consumption [%]		Increase of the Price [€]	
	Ejpvovice–Plzeň	Plzeň–Ejpvovice	Ejpvovice–Plzeň	Plzeň–Ejpvovice
ČD 680 “Pendolino”	129.3	1.6	6.75	0.27
ČD 380 + 5 Bmz	80.5	19.2	8.09	3.69

3.3. Third Variant—ETCS

In Section 2, the results of the simulation were presented showing that the local speed increase in the Ejpvovice tunnel is not very efficient and its impact on the journey time is insignificant. Furthermore, with an uphill gradient, the speed of 200 km·h⁻¹ is practically unattainable, and the energy consumption connected with the increased speed is not proportional to the resulting effect.

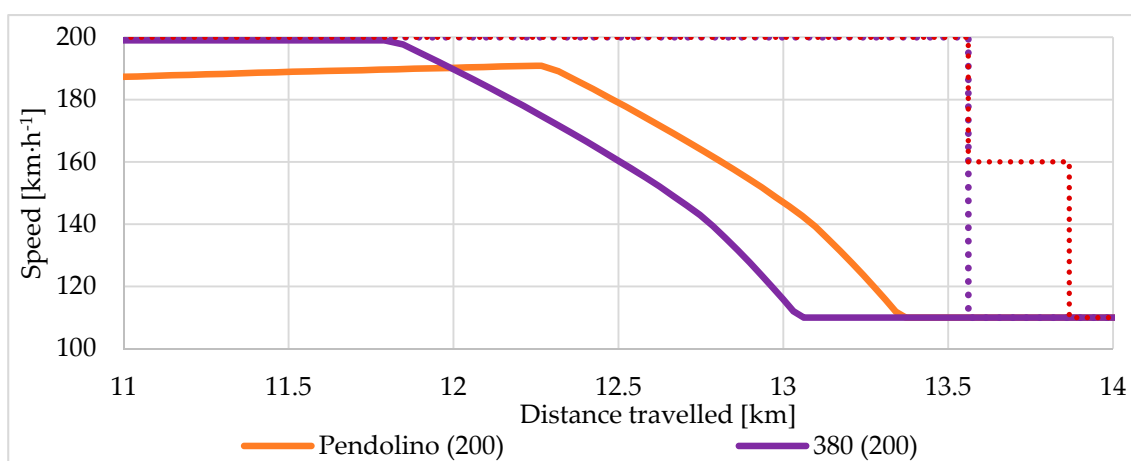
Moreover, to be able to reach a speed exceeding 160 km·h⁻¹, a vital prerequisite is the full operation of ETCS. Considering earlier findings on this subject [14–18], this fact raises a question as to what impact the speed reduction to 110 km·h⁻¹ after the tunnel in the direction of Plzeň will have on the train braking curve. The authors simulated this line section in the ERA tool [19–21], which is the official tool for generating braking curves in accordance with baseline 3. In this tool, the infrastructure (gradients and speed) was set according to the current situation and braking curves were calculated for all the three trainsets. The braking curve calculation was prepared for two different curves. The first curve was the curve SBD (service brake deceleration) and the deceleration values were used as an input into OpenTrack. The second braking curve was permitted speed (P), which is displayed by ETCS on the on board unit (OBU) and used by the locomotive drivers. Table 7 shows at what distance ahead of the speed limitation the locomotive driver has to maintain the required train speed.

Braking curve modeling was performed by inserting fictitious signal nodes in front of the main signals and nodes with a change of the track speed. This was the only way to calculate the curve for permitted speed (P) by the model correctly. This is a benefit of this research compared to the usual calculation of braking curves, because this is not a standard OpenTrack function.

Table 7 shows that all locomotive drivers will have to follow the speed limit of 110 km·h⁻¹ more than 450 m ahead of the speed limitation. This makes the useful length of the tunnel (or more specifically of the line section with a permissible speed of 200 km·h⁻¹) even shorter. This is particularly evident in Figure 8, which shows a cut-out of a tachograph for both trainsets with a maximum permissible speed of 200 km·h⁻¹. The difference between the curves is due to the different speed profiles (dot lines) for conventional (380) and tilting (Pendolino) trainsets. As was already mentioned, the calculation of the brake build-up time does not distinguish trains under 400 m. If we neglect the condition of 400 m, the time from Equation (5) will be approximately 2.8 s. That moves the braking curve more than 120 m towards the speed limit point, so that trains could run a longer distance with maximal speed.

Table 7. Distance between speed restriction and permitted speed braking curve for target speed 110 km·h⁻¹.

Speed [km·h ⁻¹]	ČD 680 “Pendolino” [m]	ČD 380 + 5 Bmz [m]	ČD 362 + 5 Bmz [m]
110	495.10	498.54	485.74
111	505.39	508.50	497.22
112	516.98	519.62	510.03
114	540.35	542.05	535.89
116	563.98	564.71	562.04
118	587.89	587.64	588.55
120	612.15	610.89	615.47
125	673.91	670.05	684.09
130	737.26	730.69	754.58
135	802.21	792.82	837.22
140	867.55	856.43	951.35
145	968.56	945.34	—
150	1050.95	1019.73	—
160	1230.58	1189.09	—
180	1663.43	1599.41	—
200	2129.30	2028.41	—

**Figure 8.** Permitted speed braking curve.

4. Discussion

The intention to increase the track speed in the Ejpovice tunnels to 200 km·h⁻¹ is in line with the fast connection development programme of the Czech Republic and the development of the TEN-T network. However, if the track speed is only increased in such a short section (7301 m) in the initial phase, the contribution of this increase towards the overall efficiency will be entirely marginal in relation to the total journey time. The greatest time savings were achieved in the direction Ejpovice–Plzeň hl. n., where thanks to favourable gradients, the journey time was shorter by 16 and 18 s for the ČD 680 “Pendolino” and ČD 380 + 5 Bmz, respectively. However, in the direction Plzeň hl. n.–Ejpovice, the effect was completely insignificant. This is mainly due to two factors. The first factor is the reduced speed within the perimeter of the Plzeň hl. n. railway station, which is limited to 80 km·h⁻¹. The other reason is the gradients, with the track ascending by up to 9‰. The speed increase, or more specifically achieving the maximum speed, is also connected with a jump in traction energy consumption. For the reference trainsets, the energy consumption in the direction Ejpovice–Plzeň hl. n. increased by 129% and 80.5% for the ČD 380 + 5 Bmz and ČD 680 “Pendolino”, respectively. In view of the insignificant shortening of the journey time, it should be considered whether it makes sense to only increase the track speed in this section. However, in the context of including the Ejpovice tunnel in the fast connection

network, the intention to increase the track speed to $200 \text{ km}\cdot\text{h}^{-1}$ is entirely justified. Another equally important effect is the fact that the entire section has to be equipped with the ETCS train protection system. Even though this system has a limiting effect on the maximum utilization of the infrastructure parameters, as mentioned in Section 3, its commissioning is completely indispensable. At the same time, the introduction of ETCS will further increase safety and eliminate the risk of human errors. This elimination is a highly monitored parameter and is essential for the HSL.

This article solves just a short part of the track, but the findings can be generalized for the upcoming process of designing of the HSL in the Czech Republic. There will be many similar cases and decisions about the longer tunnel or higher slope. Using a simulation tool as a forecast can help the decision makers to detect the most effective scenario of the HSL.

5. Conclusions

The simulation model used for this paper was designed to allow for the assessment of all relevant outputs. The aim was to examine the possibility of reaching a target speed of $200 \text{ km}\cdot\text{h}^{-1}$. The results provided for in Section 2 show that it can only be reached in the direction Ejpovice–Plzeň hl. n. None of the trainsets reached the target speed in the opposite direction. The simulation also took into account the traction energy consumption and its increase when increasing the speed, which is high. What was also assessed was that using the ETCS is a necessity, but if we count the braking curves, we should use the permitted speed instead of the service brake. Considering the costs and traction energy consumed, the efficiency of the track speed increase only in this short section (7301 m) is negligible.

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References

1. Czech Infrastructure Manager. Správa Železnic. SŽDC Zahájila Provoz V Nejdelším Železničním Tunelu v České Republice, První Vlak jím Projel 15. Listopadu. Available online: <https://www.spravazeleznice.cz/pro-media/tiskovy-servis-tiskove-zpravy-prohlaseni/zahajeni-provozu-ejpovice> (accessed on 16 November 2019).
2. Šindelář, J. Tunelem Ejpovice Se Jezdí Ode Dneška 160 km/h, Pantografově Zkoušky Vyšly. Available online: <https://zdopravy.cz/tunelem-ejpovice-se-jezdi-ode-dneska-160-km-h-pantografove-zkousky-vysly-34927> (accessed on 16 September 2019).
3. Novotný, V. Rychlost 200 km/h Na železnici V Česku O Trochu Blíž. Available online: <https://k612.fd.cvut.cz/2020/01/14/rychlost-200-km-h-na-zeleznici-v-cesku-o-trochu-bliz> (accessed on 14 January 2020).
4. Czech Infrastructure Manager. Dopravní a Návěštní Předpis. D1, Změna č. 4. Praha: Správa Železnic, S.O. 2019. Available online: <https://provoz.spravazeleznice.cz/Portal/ViewDirective.aspx?oid=870001> (accessed on 20 January 2020).
5. MDČR. Národní Implementační Plán ERTMS. Praha. 2020. Available online: <https://www.mdcz.cz/getattachment/Dokumenty/Drazni-doprava/Evropska-unie-na-zeleznici/Evropska-unie-na-zeleznici/NIP-ERTMS-2017.pdf.aspx?lang=cs-CZ> (accessed on 20 December 2019).
6. Lieskovský, A.; Myslivec, I. ATO and ETCS Can Work Together. Available online: <https://trid.trb.org/view/1098647> (accessed on 15 July 2020).
7. Koper, E.; Kochan, E.; Gruba, L. Simulation of the Effect of Selected National Values on the Braking Curves of an ETCS Vehicle. Available online: https://link.springer.com/chapter/10.1007/978-3-030-27547-1_2 (accessed on 8 June 2020).

8. Vignali, V.C. A Methodology for the Design of Sections Block Length on ETCS L2 Railway Networks. Available online: <https://doi.org/10.1016/j.jrtpm.2019.100160> (accessed on 11 February 2020).
9. Siroky, J.; Sramek, P.; Magdechova, K.; Tischler, E.; Hlavsova, P. Timetable Performance Evaluation. Transport Means—Proceedings of the International Conference. Available online: <https://www.scopus.com/record/display.uri?eid=2-s2.0-85074278851&origin=resultslist> (accessed on 22 April 2020).
10. Huerlimann, D.; Nash, A.B. *OPENTRACK. Simulation of Railway Networks*; Version 1.3.; EHT Zurich: Zurich, Switzerland, 2019.
11. UIC. UIC 544-1. BRAKES-BRAKING PERFORMANCE. 2014. Available online: <https://eshop.normservis.cz/norma/uic-544-1-6ed--1.10.2014.html> (accessed on 15 December 2019).
12. European Railway Agency, System Requirements Specifications—Part 3 (Principles), May 2016. Available online: https://www.era.europa.eu/content/set-specifications-3-etcs-b3-r2-gsm-r-b1_en (accessed on 18 May 2020).
13. Marek, J.; Myslivec, I.; Bubeník, M. Návrhy Úprav Funkčního Chování ERTMS/ETCS Při Dohledu Cíle Na Generické Úrovni, 2/2020, VTS SŽ. Available online: <https://www.spravazeleznic.cz/documents/50004227/94808101/N%C3%A1vrhy+%C3%BAprav+funk%C4%8Dn%C3%ADho+chov%C3%A1n%C3%AD+ERTMSETCS+p%C5%99i+dohledu+c%C3%ADle+na+generick%C3%A9+%C3%BArovni.pdf/3a9e0a49-084c-439d-afe2-7afb74826c59> (accessed on 5 February 2020).
14. Správa Železnic, Státní Organizace. Time Table 2019/2020. Infrastructure Manager, S.O. 2019. Available online: <https://www.spravazeleznic.cz/cestujici/jizdni-rad> (accessed on 12 December 2019).
15. Hruban, I.; Nachtigall, P.; Štěpán, O. Přínosy Zavedení ETCS z Pohledu Brzdných Křivek. Vědeckotechnický Sborník ČD. 2015. Available online: <https://vts.cd.cz/documents/168518/195360/4108.pdf/eea41bda-f586-4c65-b350-1c909599a4f9> (accessed on 15 June 2020).
16. Marek, J. Brzdný Model ERTMS/ETCS a Možnosti Jeho Optimalizace Na Úrovni Aplikace. Vědeckotechnický Sborník ČD. Available online: https://vts.cd.cz/documents/168518/233051/01_4719_Marek_Brzdny+model+ERTMS_ETCS+a+moznosti+jeho+optimalizace_kor.pdf/b12d3378-d3e6-4d06-8feb-b5ba5a15605c (accessed on 10 May 2020).
17. Nachtigall, P.; Ouředníček, J. Wider aspects of deceleration supervision in ERTMS/ETCS. *MATEC Web Conf.* 2018. Available online: <https://doi.org/10.1051/mateconf/201823500010> (accessed on 19 May 2020). [CrossRef]
18. Ouředníček, J.; Nachtigall, P. Zajištění Dohledu Nad Zastavením (Snížením Rychlosti) V ERTMS/ETCS v Souvislostech. Vědeckotechnický Sborník ČD. Available online: [https://vts.cd.cz/documents/168518/233051/11_4719_Nachtigall%2C+Ourednicek_Zajisteni+dohledu+nad+zastavenim+\(snizenim+rychlosti\)+v+ERTMSETCS+v+souvislostech_kor.pdf/bf57499e-aac1-4a0f-9ebd-b523361d694a](https://vts.cd.cz/documents/168518/233051/11_4719_Nachtigall%2C+Ourednicek_Zajisteni+dohledu+nad+zastavenim+(snizenim+rychlosti)+v+ERTMSETCS+v+souvislostech_kor.pdf/bf57499e-aac1-4a0f-9ebd-b523361d694a) (accessed on 17 May 2020).
19. Introduction to Etcs Braking Curves. European Railway Agency. Available online: www.era.europa.eu/.../ERA_ERTMS_040026_v1.2.doc (accessed on 12 June 2010).
20. Braking Curves Simulation Tool. European Union Agency for Railways. Available online: <http://www.era.europa.eu/Core-Activities/ERTMS/Pages/Braking-Curves-Simulation-Tool.aspx> (accessed on 15 June 2016).
21. Raitel, M.; Baumbusch, J.; Kielbassa, S. Construction of the New High-Speed Railway Line Ulm–Wendlingen in Karstified Rock. *Procedia Eng.* 2016, 143, 1144–1151. [CrossRef]



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