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# Establishing Line Throughput with Regard to the Operation of Longer Trains

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**Abstract**

The paper deals with the issue of capacity of railway infrastructure in connection with the operation of freight trains with a length of up to 740 m. First, the facts in the field of the arrangement of railway infrastructure elements that may have a potential impact on capacity will be listed. Subsequently, there will be proposed indicators that can be used for detection of possible changes in capacity, due to the operation of trains with a length of 740 m. In the last phase, several simulation scenarios will be realized in the OpenTrack program. In these scenarios 740 m long trains will be deployed on the selected routes of the model timetable. The simulation results will eventually be evaluated using previously proposed indicators.



*Keywords:* long train, railway infrastructure, simulation, time table.

## 1. Introduction

Due to the recent increase mainly in passenger transport, problems with railway line throughput are beginning to appear. This is currently reflected in the ever-increasing utilization of strategically important railway tracks (such as international freight corridors). Therefore, ways are sought to not only maximize the benefit from allocated capacity, but also to make train journeys and rail transport as such more efficient. One of the relevant steps in this direction is increasing the permissible length of trains.

One of the main assumptions in regards to the operation of longer trains (hereinafter also referred to as "LTs") is that under unaltered conditions, they will have a negative impact on line throughput. The focus of this paper is to propose indicators allowing for monitoring the changes to line throughput as a result of employing trains of 740

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metres. To make the assessment as realistic as possible, a microscopic model was created in the OpenTrack simulation software representing the key infrastructure parameters of the *status quo* of the railway network in the Czech Republic – specifically sections of the 1st railway corridor Česká Třebová–Praha and Praha–Děčín. A line of such a status was selected deliberately for infrastructure modelling, since 740-metre long trains should primarily be operated on freight railway corridors (Brejcha, 2015). Based on the simulation of longer trains operation on model infrastructure, the equipment of which represents the *status quo* of the key railway lines in the Czech Republic, it is possible to assess the impact of longer train journeys on the throughput of such lines and at the same time to look for possible pitfalls or for potential new possibilities in longer trains operation. Moreover, the selected length of the section considered will allow for monitoring the journey of a LT transiting a large area, only stopping at large freight railway hubs or specialized terminals or not stopping at all for transport reasons (Gasparik, 2017).

In line with the European Union strategy, the operation of trains of up to 740 metres, i.e. trains of unconventional length in the Czech context, should contribute to transferring a significant volume of freight transport from the road network to the railway network (strategic objectives to be achieved by 2030 and 2050).

The scientific contribution of this paper lies in proposing indicators monitoring the changes in throughput of the model line due to the operation of 740-metre trains and applying these indicators in assessing the results of different simulation scenarios involving the operation of longer trains during different times of the day and in varying numbers.

## 2. Operation of trains of up to 740 metres

Under present railway conditions, it can be assumed that permitting trains with so far non-standard parameters for railway infrastructure will elicit different reactions.

Using the national train protection system, the necessary useful track length for parking a 740-metre train is 752 metres. Far from all operating control points with track branching are equipped with a track of such a length. This fact profoundly affects the transit of trains of unconventional length as it creates difficulties in parking a LT in such an operating control point. This can have an impact on the operation of present conventional trains as well. (Schultz-Wildelau, 2018)

As noted before, most operating control points with track branching are not equipped with the required infrastructure and if there is a sufficiently long track (hereinafter referred to as "SLT") in the operating control point, it is mostly the main track which freely changes into a line track. A long-term occupation of the main track by a longer train would certainly negatively affect the throughput of such an operating control point and of the entire line, for that matter, especially during rush hours with high frequency of traffic. Other trains would need to use passing tracks and usually travel at a lower speed than the one permitted on the main track, which would adversely affect the time necessary for their passing the operating control point. (Nachtigall, 2018)

From the formula for calculating uniformly accelerated motion, or uniformly decelerated motion, for that matter, an equation can be derived for calculating this travel time increment (Equation 1).

$$\Delta t_V = t_P - t_R \qquad (1)$$

Where:

$\Delta t_V$ Time increment due to the train travelling on a passing track [s];
$t_P$ Time necessary for the train to pass the operating control point on a passing track [s];
$t_R$ Time necessary for the train to pass the operating control point on the main track [s].

From the formula for calculating uniformly accelerated motion, or uniformly decelerated motion, for that matter, an equation can be derived for calculating this travel time increment. (Bulíček, 2018)

For the subsequent steps in deriving the equation, it is a condition that the distance taken by the train on the main track is equal to the distance taken by the train on the passing track, as expressed in Equation (2) (Fig. 1). The calculation is simplified here, neglecting a potential difference between the distance covered in passing a station on the main track or the passing track, respectively, which affects the results. The reason for this simplification is the fact that in practice, this difference can occur and can have different values, but compared to the deceleration over the entire track length, the difference in the distance covered is less important. (Gašparík, 2018)

The next step is dividing the distance taken on the passing track. This can be diversified into three parts (Fig. 1):

B – Distance necessary for the train to decelerate to the speed permitted for passing the operating control point on the passing track. This part is defined by the moment the train starts slowing down and the moment its nose reaches the entry signal. It is assumed that the train decelerates uniformly and with corresponding acceleration, reaching the required speed just before the entry signal. [m]

C – Actual distance covered at reduced speed passing the operating control point. This part is defined by the entry signal on one side and the complete leaving of the reduced speed points by the train on the other side. It is assumed that only one speed is signalized for the entire passage through the operating control point, both for the passing and main tracks.

D – Distance necessary for the train to accelerate to line speed. This part starts at the moment the train completely leaves the reduced speed sections and ends when it reaches the line speed.

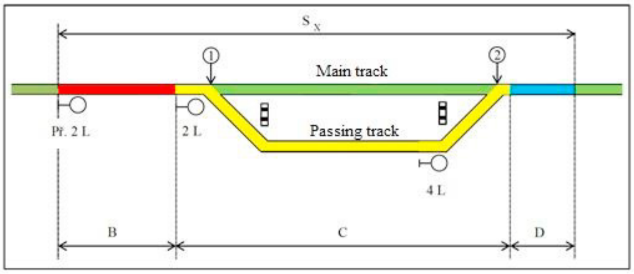


Fig. 1 Dividing the operating control point into parts covered at different speeds

The resulting time increment can be calculated by means of (1) using known quantities, and subsequently adjusted (Equation 2):

$$\Delta t_v = \frac{v_1 - v_2}{b} + \frac{C}{v_2} + \frac{v_1 - v_2}{a} - \left( \frac{\frac{{v_1}^2 - {v_2}^2}{2 \cdot b}}{v_1} + \frac{C}{v1} + \frac{\frac{{v_1}^2 - {v_2}^2}{2 \cdot a}}{v_1} \right) \tag{2}$$

Where:

b Negative acceleration (deceleration) of the train [m·s-2];
a Train acceleration [m·s-2];
$v_1$ Line speed [m·s-1];
$v_2$ Speed on the passing track [m·s-1];
C Distance to be covered at a reduced speed [m].

Table 1 shows some values obtained using the derived equation. They were calculated based on the following input parameters:

- Negative acceleration (deceleration) of the train, b = 0.5 m·s-2;
- Train acceleration, a = 0.3 m·s-2
- C section length = 1,500 m

Table 1. Time increment values depending on speed difference between the main and passing tracks

| **Line speed, $v_1$ [km·h-1]** | **Branching-off speed v2 / Δ tv [km·h-1] / [s]** | | | | |
|---|---|---|---|---|---|
| | **100** | **80** | **60** | **50** | **40** |
| **160** | 37 | 63 | 103 | 130 | 168 |
| **150** | 30 | 56 | 94 | 121 | 159 |
| **140** | 24 | 48 | 85 | 112 | 149 |
| **130** | 18 | 40 | 76 | 103 | 140 |
| **120** | 11 | 32 | 67 | 93 | 130 |
| **110** | 6 | 24 | 58 | 83 | 119 |

Since the equation considers mean acceleration, it is, to a great extent, a simplified calculation. On the other hand, it does provide a general idea of the impact of the measure. In worst case scenario, i.e. if the bypassing train was to reduce its speed from 160 $km \cdot h^{-1}$ to 40 $km \cdot h^{-1}$ in the operating control point, the time spent passing the station would increase by nearly 3 minutes. (Bažant, 2019)

The routes of trains of up to 740 metres can already be planned and implemented now. However under the present infrastructure conditions, it will be necessary to approach some mutual interactions of trains of conventional length and longer trains differently than if there were only trains of conventional length. (Sramek, 2018)

Depending on the train prioritization, line characteristics and other factors, the following two most typical operational situations involving LTs occur (Černá, 2018):

- crossing of trains in an operating control point on a single-track railway,
- overtaking of trains in an operating control point both on a single-track and double-track railway.

The standard speed for the movement of trains in a railway station (outside of the main track) is 40 $km \cdot h^{-1}$. By lengthening the train (while maintaining the speed), the time necessary for occupying different parts of infrastructure increases and the individual technological processes require more time as well, such as for instance:

- parking the train on a passing track due to overtaking (crossing),
- different transits within the station,
- emergency parking of a LT which was originally meant to pass on the main track at a relatively high speed

## 3. Simulation model creation

The main focus of this paper is a railway simulation model made in OpenTrack (Huerlimann, 2017). The model outputs will allow for monitoring the changes in passage, arrival and departure times of individual trains in a timetable created by the authors, with routes originally meant for 520-metre trains being covered by 740-metre trains. In effect, this will test the actual functionality of the throughput indicators proposed. To be able to monitor these changes, it will first be necessary to consider the outputs of a "default timetable" – a timetable with no conflicting trains and containing no longer trains. With this default timetable, other simulation outputs will be compared which already contain a certain number of longer trains. By comparing these two outputs, it will be subsequently possible to establish the delay increment of individual trains, where appropriate. The model was created and the simulation was performed in the OpenTrack simulation software.

The approach to modelling gridirons and points in the operating control points is shown in Fig. 2. The useful length of railway tracks corresponds to the actual situation on the 1st railway corridor. The points are always clearly delimited by their fouling point markers and stationings. The position of all points stationings can be seen from available plans (Tischer, 2020). As for establishing the position of station boundary marks, the two following approaches were used depending on the currently available data on the 1st railway corridor infrastructure (Chocholac, 2017):

- using the actual kilometre position of boundary marks,
- alternative approach using the distance between stationings and boundary marks.

For the purposes of the model, stations can be divided into three principal areas. The layout of the individual stations is similar to the one in Fig. 2. They include an appropriate number of running tracks (marked in green), points (marked in red) and connecting sections (marked in violet).

The points comprise three nodes and two edges. The running track includes four edges and five nodes with the following functions:

- nodes A and E serve for the positioning of starting signals for the respective direction;
- nodes B and D represent the point the train nose reaches when stopping on the given track. The edges between nodes A, B, D, and E are marked as 10 metre long;
- node C is what is called a station node. Used by OpenTrack as the reference point of the respective operating control point, this node has to be part of every track. Where a train only passes the operating control point, the passage through the operating control point is detected precisely in the moment this point is being occupied. The arrival of a train at the operating control point is detected after the train passes the station node and stops 10 metres from the starting signal. The train departure is reported at the moment the train starts moving.

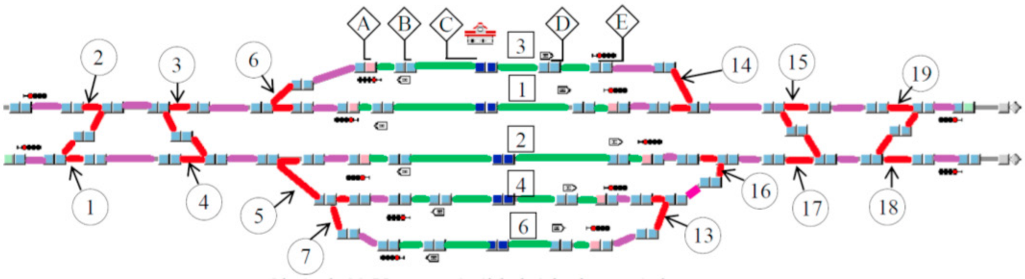


Fig. 2 Defining the principal elements of an operating control point

Table 2. General comparison of train numbers

| Train category | 1st railway corridor | | Model | |
|---|---|---|---|---|
| | Number | % | Number | % |
| **Ex** | 101 | 21 | 108 | 24 |
| **Ex TOP** | 17 | 3 | 16 | 4 |
| **Os** | 252 | 52 | 218 | 49 |
| **R** | 83 | 17 | 83 | 19 |
| **Sp** | 20 | 7 | 20 | 4 |
| **4XXXX** | 156 | 53 | 131 | 54 |
| **6XXXX** | 107 | 37 | 90 | 38 |
| **8XXXX** | 29 | 10 | 20 | 8 |
| **Freight** | **292** | **37** | **241** | **35** |
| **Passenger** | **488** | **63** | **445** | **65** |
| **Total** | **780** | | **686** | |

The model includes a 24-hour train diagram with 445 passenger trains and 241 freight trains (Table 2). For the purposes of the model, 5 categories of passenger trains were defined, which are shown in Table 3 together with the respective percentage of the overall transport. The division of freight transport into 3 categories is also provided for in Table 7. The actual train diagram of the 1st railway corridor is specific to a great extent with its total number of trains and the significantly predominant proportion of passenger transport. (Šipus, 2017) The aim of this simulation is to propose a throughput indicator; to test it, it is desirable to use a less specific train diagram.

Even though the total number of routes was reduced considerably, the timetables of the individual trains were inspired by actual connections operating on the lines of the 1st railway corridor. Mainly in terms of the passenger train stopping policy, there is an analogy with actual train categories. Most connections (of both freight and passenger transport) included in the model are long-distance ones, and that's why the nodes Česká Třebová, Praha and Děčín became the starting points for their inclusion in the model. In the model, freight transport in the section Kolín–Praha is mainly represented by trains the itinerary of which includes, in full or in part, the line in consideration (i.e. with an overlap to the Praha–Děčín branch), with an attempt at their even distribution throughout the day. These routes were identified for future implementation of 740-metre trains.

*3.1. Simulation of the operation of trains of up to 740 metres*

In the first stage a 24-hour timetable was simulated with no train of non-standard length; as such, this timetable is considered as default. On the routes identified for future implementation of 740-metre trains, trains with an overall length of 520 metres were used. With this length, they can be seamlessly parked at nearly any model station. At this stage, there are no conflicts at all in the timetable. All departures from stations and stops are delayed by 0 s, and the passages through and arrivals at transport points are calibrated to an early arrival in an interval of < 0 ; 35 > seconds. This initial output is subsequently compared with other scenarios with the aim to detect deviations from the timetable due to implementing longer trains.

A freight train of 740 metres is created by merely adding wagons. The total train mass remained the same, i.e. the original load was distributed over a greater number of wagons. This approach was taken to identify delays being only due to the increased length of trains and to keep all the other factors the same. If it was not just the train length but also the mass that would increase, it can be assumed that using a traction unit of the same power, the delays would increase significantly and the timetable would be deformed.

One of the main generators of delay in longer trains is the acceleration lag when accelerating to the increased maximum speed in the subsequent section. This is due to the fact that a train can only start accelerating once it completely leaves the reduced speed points. As a result, a 740-metre train must travel at the original (reduced) speed 220 metres more than a train of 520 metres. The development of this delay depending on the maximum permitted speed is shown in Figure 3. The authors assume that the train starts accelerating from the beginning of the section (0th km) from an initial speed of 40 $km \cdot h^{-1}$.

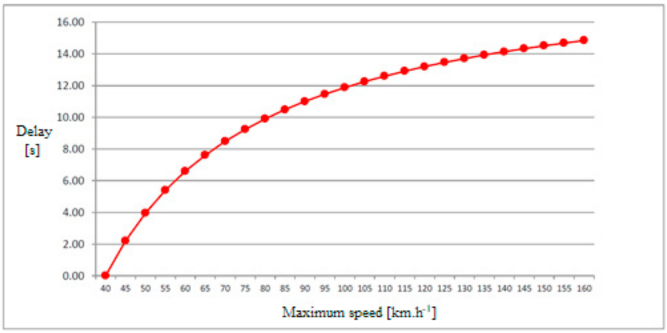


Fig. 3 Increase in the 740-metre train delay during acceleration to maximum speed

To demonstrate a morning journey of LTs, connection No. 40046 was selected passing Česká Třebová in the even direction at 8 hours 53 minutes and 33 seconds and connection No. 40005 passing Děčín in the odd direction at 10 hours 20 minutes and 14 seconds. At this time of the day, it can be assumed that the operation of interacting trains will be affected to some extent. Due to overtaking, train No. 40005 stops at Řečany nad Labem (Fig. 4, upper part) and Dlouhá Třebová (Fig. 4, bottom part).

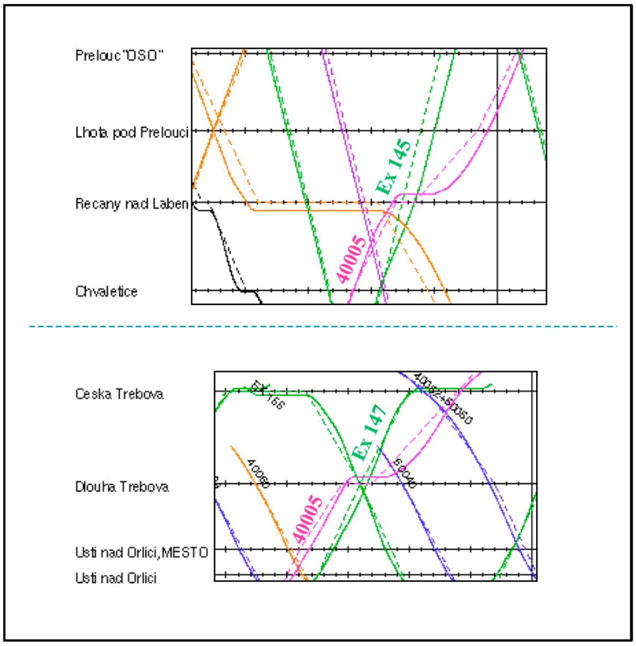


Fig. 4 Examples of overtaking interactions of train No. 40005

Both operating control points have a sufficiently long track (hereinafter referred to as "SLT") for overtaking in the odd track group the LT is parked on. However, there is a certain delay for the overtaking trains Ex 145 and Ex 147, which is reflected in the indicators considered. The values of section delay increments for the interacting trains are provided for in Table 3.

Table 3. Section delay increments in overtaking train No. 40005

| Train | Station A | $d_{in\ 740\ A}$ [min] | Station B | $d_{out\ 740\ B}$ [min] | $\Delta D_{AB\ 740}$ [min] |
|---|---|---|---|---|---|
| Ex 145 | Záboří nad Labem | 0.00 | Přelouč | 1.13 | 1.13 |
| 40005 | Záboří nad Labem | 0.47 | Přelouč | 0.97 | 0.50 |
| Ex 147 | Ústí nad Orlicí | 0.40 | Česká Třebová | 0.93 | 0.53 |
| 40005 | Ústí nad Orlicí | 1.03 | Česká Třebová | 0.72 | 0.00 |

The LT is not entirely capable of maintaining the prescribed timetable – primarily due to the late onset of acceleration, and as such it inhibits the overtaking train. Since in both instances, the departure of the LT from the overtaking station is scheduled immediately after the train is overtaken, there is an additional delay at departure as the train it is being overtaken by in the station is already delayed as well.

## *3.2. Simulation with multiple longer trains*

The focal point of this chapter is the simulation of a complete train diagram for the interval between 00:00:00 of the first day and 01:40:00 of the subsequent day. In every simulation, all scheduled trains travel their entire routes. The outputs from the simulation of the individual scenarios include looking for interactions of LTs with other trains on a double-track railway and their assessment using defined indicators. What was also assessed in the individual scenarios was the total delay increment for all trains as a result of implementing LTs on different numbers of routes. Furthermore, the development of the proposed indicators was monitored in the absence of key (in terms of longer train operation) elements of transport infrastructure.

The model simulation included the following 3 scenarios:

*1) Analysis of the outputs of a simulation scenario with LTs operated on 24 routes within a 24-hour timetable.*

In this simulation scenario, LTs were operated on 24 routes throughout the day – as such, a full tenth of freight trains were long trains. For the assessment to be of maximum relevance, it would be necessary to examine multiple scenarios with different numbers of trains; however due to the limited scope of the thesis, the number of scenarios had to be reduced, resulting in this step increase in the number of LTs.

The extent of the impact this increase in the number of trains of non-standard length had on the train diagram can be seen from Table 4 showing the number of trains becoming delayed in the given interval. The Table indicates that 74 trains, i.e. about 84% of all delayed trains, incurred a delay increment of up to one minute by the time they reached the destination station. Only two trains were delayed by more than 2.5 minutes. It is clear that the operation of longer trains has some impact on the timetable, leading to certain instability. Out of the total of 686 trains, 89 – i.e. approximately 13% – were affected to some degree (this number includes the actual longer trains as well). On the other hand in most cases, the delay was in the lowest category of the defined intervals. This quite clearly indicates that within the model timetable and with the respective model parameters, 24 journeys of longer trains spread throughout the day can be realized without major issues.

Table 4. Frequency of delay interval indicators with 24 LTs

| Delay interval | $\Delta D_{740}$ | | $\Delta d_{740}$ | |
|---|---|---|---|---|
| | [number of trains] | [%] | [number of trains] | [%] |
| < 0 ; 0.5 > | 63 | 71.6 | 74 | 84.1 |
| ( 0.5 ; 1 > | 11 | 12.5 | 9 | 10.2 |
| ( 1 ; 1.5 > | 6 | 6.8 | 2 | 2.3 |
| ( 1.5 ; 2 > | 5 | 5.7 | 2 | 2.3 |
| ( 2 ; 2.5 > | 1 | 1.1 | 0 | 0.0 |
| ( 2.5 ; ∞ > | 2 | 2.3 | 1 | 1.1 |

*2) In the second simulation scenario, LTs were implemented on 80 routes, i.e. the length of a third of all freight trains running within the 24-hour timetable was 740 metres.*

The extent of the impact of a third of freight trains reaching 740 metres is shown in Table 5. The increase in the number of trains of unconventional length naturally led to an increase in the number of trains reaching the destination station with a delay. In sum, 200 trains (including the longer ones) out of the total of 686, i.e. approximately 29%, were affected by operating LTs on 80 routes. What didn't change significantly was the proportion of categories defined by the delay increment intervals. Even though there were 3 more trains with a delay at the destination station exceeding 2.5 minutes, in the vast majority of cases this indicator didn't exceed 30 seconds and compared to the one-tenth-scenario, the proportion of this category even increased by 7%. To some extent, this is due to the fact that in the one-tenth-scenario, the trains were made longer on all routes the itinerary of which included the entire line considered. In the one-third-scenario, in addition to these trains also trains running on shorter routes were made longer, which cannot have as many interactions with the surrounding traffic during their journey. These LTs don't affect the surrounding traffic that much and as for themselves, they are only delayed due to the acceleration lag.

Table 5. Frequency of delay interval indicators with 80 LTs

| Delay interval | $\Delta D_{740}$ | | $\Delta d_{740}$ | | Increase compared to "24 out of 240" | |
|---|---|---|---|---|---|---|
| | | | | | $\Delta D_{740}$ | $\Delta d_{740}$ |
| | [number of trains] | [%] | [number of trains] | [%] | [number of trains] | [number of trains] |
| < 0 ; 0.5 > | 157 | 79 | 182 | 91 | +94 | +108 |
| ( 0.5 ; 1 > | 20 | 10 | 11 | 6 | +9 | +2 |
| ( 1 ; 1.5 > | 6 | 3 | 4 | 2 | 0 | +2 |
| ( 1.5 ; 2 > | 9 | 5 | 1 | 1 | +4 | -1 |
| ( 2 ; 2.5 > | 3 | 2 | 0 | 0 | +2 | 0 |
| ( 2.5 ; ∞ > | 5 | 3 | 2 | 1 | +3 | +1 |

*3) Establishing the impact of 80 LTs (within a 24-hour timetable) without using zeroth station SLTs in operating control points Poříčany, Český Brod, and Úvaly.*

As mentioned earlier, the model stations Poříčany, Český Brod, and Úvaly are equipped with a zeroth SLT. This chapter describes the significant impact this infrastructure has in the individual stations, conveying and evaluating the results of the simulation of a 24-hour timetable, within which it is impossible to use zeroth SLTs for parking LTs in these three stations. The fact that zeroth SLTs represented an important component of the above mentioned three stations in the scenarios with one tenth and one third of longer trains, respectively, is clearly obvious from Table 40. Like in the preceding simulation scenario, 740-metre trains were implemented on 80 freight train routes. Table 6 shows that the routes were disrupted for 230 trains, which is about 34%. The first significant change is the lower frequency of train delays in the lowest category. The deviation from the timetable wasn't reduced, on the contrary: it increased as with their indicators, these trains emerged in higher categories. As for the ΔD740 indicator, the greatest increase was in the category of trains delayed by more than 2.5 minutes with 19 new trains. There was also a large increase in the (0.5;1> category of the Δ d 740 indicator. This mainly indicates that there was no significant increase in the total number of delayed trains (compared to the variant with SLTs, the increase was 30 trains, i.e. 15%), but the delay time increased.

Table 6. Frequency of delay interval indicators with 80 LTs without zeroth SLTs

| Delay interval | $\Delta D_{740}$ | | $\Delta d_{740}$ | | Increase compared to "80 out of 240" | |
|---|---|---|---|---|---|---|
| | [number of trains] | [%] | [number of trains] | [%] | $\Delta D_{740}$ [number of trains] | $\Delta d_{740}$ [number of trains] |
| ( 0 ; 0.5 > | 154 | 67 | 177 | 77 | - 3 | - 5 |
| ( 0.5 ; 1 > | 26 | 11 | 29 | 13 | + 6 | + 18 |
| ( 1 ; 1.5 > | 11 | 5 | 13 | 6 | + 5 | + 9 |
| ( 1.5 ; 2 > | 10 | 4 | 5 | 2 | + 1 | + 4 |
| ( 2 ; 2.5 > | 5 | 2 | 3 | 1 | + 2 | + 3 |
| ( 2.5 ; ∞ ) | 24 | 10 | 3 | 1 | + 19 | + 1 |

## 4. Proposal of certain measures for the operation of trains of up to 740 metres

This section contains some measures proposed to help implement freight trains of up to 740 metres under current traffic conditions. Emphasis is put on possible modifications of routes of freight trains which were originally created for trains of conventional length (e.g. 520 metres). However, these findings can also be used as basic points of reference for creating completely new routes specifically meant for trains of 740 metres. Furthermore, this section contains an evaluation of operating control points based on changes in their throughput due to LT-related overtaking and a discussion of the possibilities of overtaking interactions featuring multiple LTs.

*1) Recommendations for the modification of routes for trains of conventional length when implementing LTs on these routes:*

The operation of longer trains under current conditions can be significantly simplified by eliminating the need of LT overtaking, which will be possible in a timetable which will be nearly parallel in nature. A parallel timetable can be created using routes of trains with the same parameters, which for 740-metre trains is currently a timetable basically containing freight transport (in full or at least in part). There is therefore a possibility to employ LTs during the night even on already existing routes calibrated for trains of conventional length. The model showed that if a LT is operated without stopping, it may well be possible to operate it on such a route without major measures being taken even in case that this route is included in the timetable section with freight transport intervals (5 minutes). The only thing to be taken into account is a slight increase in travel time due to the acceleration lag; consequently, the timetable of this LT may need to be modified accordingly.

*2) Selecting the operating control point for a longer train to be overtaken on a double-track railway:*

If a LT is to be overtaken, three factors primarily come into play parameters of the traffic in the opposite direction during the LT overtaking at the operating control point, parameters of the overtaking traffic (in the same direction) and the operating control point being equipped with a SLT for the stopping train.

The requirements for passing the operating control point can be very different for overtaking and passing trains, which can bring new possibilities in looking for suitable (possible) ways of overtaking a LT.

*3) Giving the train an adequate traction unit:*

The traction unit should be capable of fully using the speed parameters of the line even when transporting heavier cargo. If such a train is given a traction unit of insufficient power, the travel time will increase, which will negatively affect the line throughput. At the same time, a smooth transition between power supply systems needs to be ensured, i.e. using multi-current locomotives. What can also be considered is a trainset with two traction units, which should theoretically eliminate potential lack of power. An extra traction unit takes up the space of a potential freight wagon though.

*4) Using wagons with a less noisy type of brakes:*

Freight train braking is accompanied by significant sound emission and longer trains require more braking time. This can be problematic mainly for lines (operating control points) near residential areas (settlements). The braking noise level could be reduced to an extent by including vehicles equipped with a less noisy composite brake lining or a disc brake. Another possible solution involves equipping the respective line sections with noise protection walls.

## 5. Conclusion

A key component of the paper is the simulation of several scenarios for the operation of longer trains on a model line, the key parameters of which correspond to a section of the 1st railway corridor, with the outputs of this simulation being assessed using proposed indicators of throughput changes. These indicators particularly include: indicator of train delay increment at the destination station (Δ D 740), indicator of average train delay upon arrival at (or passing through) operating control points (Δ d 740) and section train delay increment (Δ D AB 740).

The focus of the first part of the simulation is isolated journeys of LTs at night, in the morning, in the afternoon and in the evening. The second part of the simulation focuses on realizing a 24-hour timetable with different proportions of trains of non-standard length. In this way, scenarios were examined implementing 24 and 80 routes of 740-metre freight trains, respectively, spread throughout the day. Furthermore, the paper also includes and assesses outputs of the simulation of a 24-hour timetable on the line in consideration without the possibility of using zeroth station tracks in the operating control points Pořičany, Český Brod and Úvaly. In parallel, it examines the vast majority of overtaking interactions involving LTs on a double-track railway, as provided for in the analytical part. Further research is necessary to assess the changes in throughput of single-track railways due to implementing LTs.

Establishing the impact of the operation of freight trains of 740 metres on the throughput of the line considered using indicators based on the train delay increment (Δ D 740, Δ d 740 a Δ D AB 740) proved to be a possible alternative, as confirmed in this paper by the outputs of the simulation model created. However, such measurement is a complex matter and to obtain a comprehensive picture of these impacts, it is necessary to monitor all the proposed indicators in parallel and ideally also in combination. At the same time, it is important to monitor the development of these indicators if not for all trains of the given timetable, then at least for those that directly interact with LTs.

The simulation results indicate that it is probably possible to realize the routes of individual LTs on a line including operating control points not equipped with passing SLTs without significantly affecting the throughput of this line. A significant factor is the frequency and structure of the surrounding traffic the LT interacts with during its journey, and also the parameters of the trains making up this traffic. The more similar the parameters of the trains close to the LT route are to those of the LT, the easier the implementation of this LT will be.

Operating control points with a passing SLT are becoming essential on lines with a higher frequency of passenger transport or at least in the sections of these lines where such higher passenger traffic is expected (for instance in the model section Praha–Český Brod). It can be expected that in these sections, LTs will need to be overtaken by faster and usually priority passenger trains. Should this overtaking happen in operating control points without passing SLTs or even without main SLTs, this would negatively affect the occupation time of passenger trains as they would have to take routes with lower speed or would have to stop for purely traffic reasons. This would not only reduce the throughput of the operating control point, but of the entire line considered.

The contribution of this paper lies in the proposal of indicators capable of capturing the change in line throughput due to implementing trains of 740 metres. Using a simulation model created in OpenTrack, it was possible to follow the actual process of interactions (on a double-track railway) involving a freight train of 740 metres, and subsequently use the proposed indicators to assess the impact of these situations not only on the longer train itself and the trains it interacts with, but also on the overall traffic on the line. Based on that, the author came up with conclusions and recommendations which could be applied in practice in operating trains of 740 metres.

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