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Road and Rail Infrastructure II

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USING RAILWAY SIMULATION AS A BASIS FOR INFRASTRUCTURE PLANNING – FOCUSING ON STRUCTURAL CHANGES AT TRAIN STATION EXITS

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Abstract

Railway simulation is a powerful tool for answering numerous questions in railway network planning and analysing. The aim of this article is to show the importance of railway simulation used for analysing different design solutions. Special focus in this article is given to the gradient design of existing train station exits. The main question is, whether structural changes result in a significant advantage in running time and capacity, compared to the existing track. The results of the simulation shall confirm the expected anticipation that can be applied in future railway route design. Without running a simulation it is not possible to prove the assumptions before investing huge amounts into the infrastructure.
To perform the simulation, a graph model of a typical train station exit was developed based on a real case study in co–operation with Austrian Federal Railways (ÖBB), using the software programme OpenTrack (by OpenTrack Railway Technology Ltd., Switzerland). OpenTrack has three input components: infrastructure, rolling stock and timetable. All these three components varied to various test gradients, freight trains and operation modes in order to identify the most suitable gradient transition form out of different variants. The results show that depending on the operation mode and the position of the signals, opposing variants have to be preferred although there are only minor differences in running time between the structural variants. In conclusion, railway simulation is a suitable method to compare different variants and especially in this case a study to confirm the expected results.

Keywords: railway simulation, gradient design, running time analysis, minimum headway time, maximum drawbar force

1 Introduction

Gradient design is an important part of the railway route study. The focus of this article is on the gradient design of existing railway tracks, especially of existing train station exits. The results shall be applied in future railway route design. The main question is, whether structural changes can lead to a substantial advantage in running time compared to the existing track. Therefore, a simulation model of a train station exit has been developed, based on a real case study in co–operation with Austrian Federal Railways (ÖBB).

2 Simulation model

2.1 Infrastructure

The analysed structural changes are shown in Fig. 1. The figure presents the existing track (variant B), as well as two new tracks based on structural changes (variant A and C). The analysed section has a length of 11,1 km. The end of the station area is both: the position of the exit signal and the position of the first gradient change. The length shown in Fig. 1 and the positioning of the signals are based on the formerly mentioned real case study. The influence of the lengths has been examined as part of a sensitivity analysis.
The model of the train station exit has two characteristic gradients. One is the gradient in the station and one is that on the free track. The gradient in the station area is fixed throughout all simulation runs with 3 ‰. For the free track, five different gradients have been chosen. These gradients represent the inclination of different mountain railway lines and vary from 8,5 ‰ to 26 ‰. In Austria, for the construction of new railway lines the gradient is limited at 8 ‰ but can be exceeded according to the infrastructure operator [1]. Existing main railway tracks in Austria have gradients up to 31 ‰ [5]. In sections, the largest gradient used in this simulation is 28 ‰.
In this article, particular attention is given to the gradient of 10 ‰. The four other gradients (8,5 – 12,5 – 18,0 – 26,0 ‰) have been examined [4], but the results are not shown in this article, as there is no significant difference to the results of the chosen gradient. The gradient difference between the variants A, B and C is set as 2 ‰. The influence of the altered gradients has also been examined as part of the sensitivity analysis.

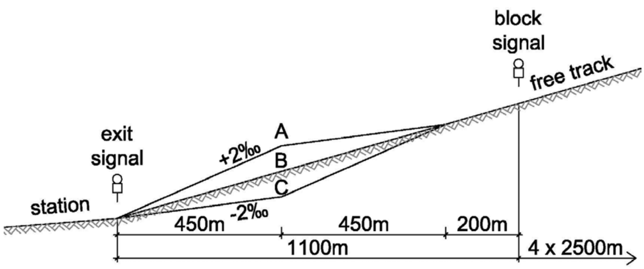


Figure 1 Train station exit in the longitudinal section

2.2 Rolling stock

For this simulation, three different freight trains have been selected. All selected freight trains have the same type of locomotive with the technical characteristics listed [4], but are not shown here. The freight trains differ in their trailer load. Therefore, the number of locomotives used depends on the trailer load, the gradient and operational rules from ÖBB. In this model, the freight trains have up to two locomotives. The length of the freight trains depends on the trailer load as well. Table 1 gives the trailer length using an average trailer load of 4 tons per meter.
Fig. 2 shows the tractive effort/speed diagram for the selected locomotive in case of single as well as double traction. For double traction the maximum drawbar force is the limiting factor, with a maximum drawbar force of 450 kN due to restrictions given by the infrastructure manager.

Table 1 Characteristic values of the chosen freight trains and schedule

freight train name	number of locomotives	trailer load	trailer length	departure time station A [hh:mm]
F.1.1000	1	1000 t	250 m	08:00
F.1.1600	1	1600 t	400 m	08:10
F.2.2000	2	2000t	500 m	08:30

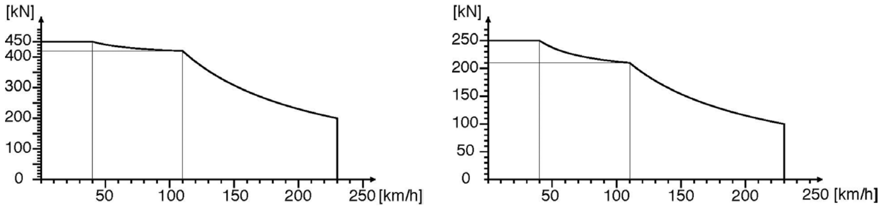


Figure 2 Tractive effort/speed diagrams: single traction (left), double traction (right)

2.3 Timetable

The freight trains operate according to the schedule. They depart at station A one after the other at fixed times. However, the differences in time between the departures are not given by minimum headway times, but are only set to make sure that the trains do not influence each other. The trains have no stop at station B, therefore there is no set arrival time.

2.4 Simulation

In order to evaluate the influence of structural changes on the running time, a simulation has been carried out. The simulation has been performed by using the software programme OpenTrack. All data on infrastructure, rolling stock and timetable is defined by the user and is processed in the software programme. The software programme calculates the train movement per second, e.g. acceleration, speed, traction and resistance [3]. At gradient transitions, the software programme calculates the average gradient over the length of the train. Finally, different diagrams can be displayed by the software to evaluate the results of the simulation – e.g. distance/time, speed/distance, and acceleration/distance.

Each freight train is examined in three different operating modes that are as followed:

1 The train starts at station A and drives towards station B.
2 The train starts at station A and has an unscheduled stop at first block signal and then continues towards station B. This only occurs if a previous train reserves the second block.
3 The train passes through station A towards station B.

The influence of the chosen length on the results is examined as part of the sensitivity analysis. For this reason, both the values of length and the gradient difference between the variants A, B and C have been doubled.

3 Results

For each operation mode, the following diagrams display the results in the figures below:
· distance/time
· speed/distance
· running time
· minimum headway time

3.1 Operation mode 1: starting

All freight trains start at station A and accelerate unlimitedly until they reach either the maximum track speed or the end of the track (Fig. 3). At the gradient transitions (variants A, B and C), the difference in speed is displayed but at the end of the track there are only minor differences in speed (less than 1 km/h).
The running times of the different freight trains roughly vary from 9 to 13 minutes (Fig. 4). The shortest running times can be achieved in variant C. The difference in running time between variant A, B and C is only in the range of seconds.

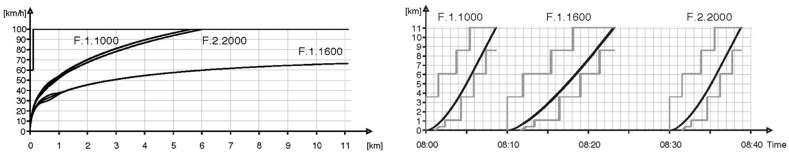
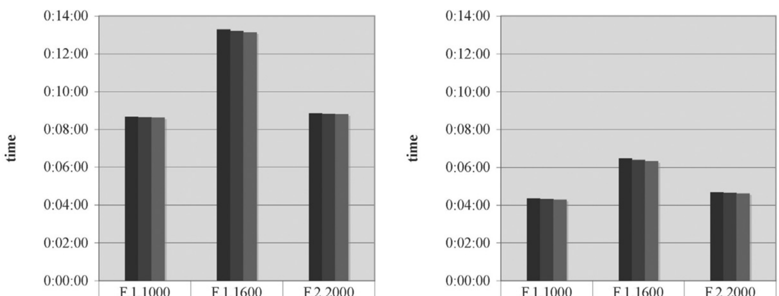


Figure 3 Speed/distance diagram (left) and distance/time diagram (right) for operation mode 1

The minimum headway times depend on the release time of the block signal at km 3,6 – that is the position of the second block signal on the free track. Fig. 3 shows the distance/time diagram with the blocking time stairway that represents the operational usage of the railway track. The blocking time ends after the train has left the section and all signalling appliances have been reset to normal position [2].



	F.1.1000	F.1.1600	F.2.2000
variant A	0:08:41	0:13:17	0:08:51
variant B	0:08:39	0:13:12	0:08:49
variant C	0:08:38	0:13:08	0:08:48

freight train

	F.1.1000	F.1.1600	F.2.2000
variant A	0:04:22	0:06:29	0:04:41
variant B	0:04:20	0:06:24	0:04:39
variant C	0:04:18	0:06:20	0:04:37

freight train

Figure 4 Running times (left) and minimum headway time (right) for operation mode 1

3.2 Operation mode 2: stop at first signal

In this operation mode, all freight trains start at station A and accelerate until they need to stop at the first block signal. After the stop, the trains start at a specified time and accelerate again until they either reach the maximum track speed or the end of the track (Fig. 5). At the

end of the track, there are only minor differences in speed between the variants A, B and C (less than 1 km/h).
The running times of different freight trains roughly vary from 11 to 17 minutes (Fig. 6). The duration of the stop is not relevant and therefore not included in these results. On one hand, the shortest running times before the stop can be achieved in variant C. On the other hand, the shortest running times after the stop can be achieved in variant A. Because the differences between variant A, B and C, in these two sections, are only in the range of seconds the data is not shown in detail. Fig. 6 shows the sum of the running times of both sections. Both together, variant C is the fastest for the freight train F.1.1000 whereas variant A is the fastest for the other two freight trains. The difference in running time between variant A, B and C is only in the range of seconds.

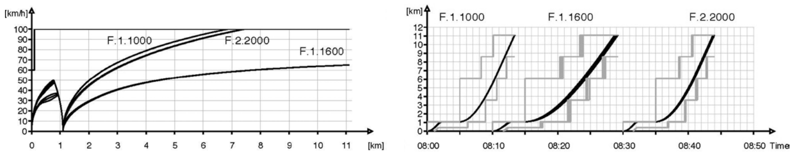


Figure 5 Speed/distance diagram (left) and distance/time diagram (right) for operation mode 2

The minimum headway times depend on the release time of the block signal at km 3,6. A train that has no stop at the signal follows the train that stops at the first block signal. Fig. 6 shows, that the minimum headway times vary from 4 to 6 minutes. The shortest minimum headway times can be achieved in variant C. The differences in minimum headway time between variant A, B and C are only in the range of seconds.

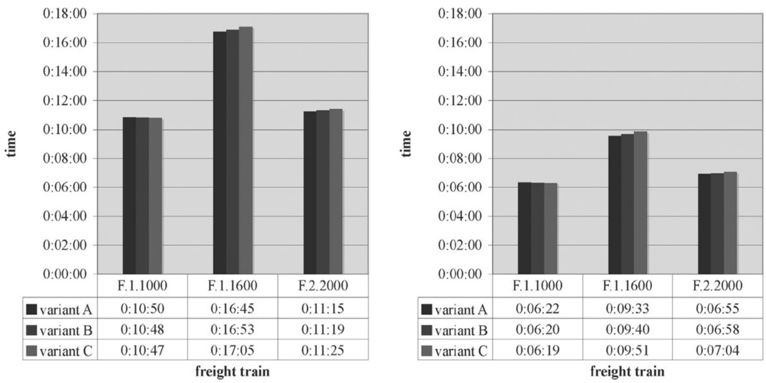


Figure 6 Running times (left) and minimum headway time (right) for operation mode 2

3.3 Operation mode 3: pass–through

In this operation mode, all freight trains enter station A on the main track with the maximum track speed of 100 km/h. For the freight trains F.1.1000 and F.2.2000, there is no difference between variant A, B and C because they can hold the maximum track speed. Whereas the freight train F.1.1600 is not able to hold the maximum track speed and continuously slows down (Fig. 7). At the end of the track, for the train F.1.1600 there are only minor differences in speed between the variants A, B and C (less than 1 km/h).
The running times of the different freight trains vary from 06:40 to roughly 07:30 minutes (Fig. 8). The shortest running times can be achieved in variant A. The difference in running time between variant A, B and C is only in the range of seconds.

The minimum headway times depend on the release time of the block signal at km 3,6. The train that passes through station A is followed by a train that starts at the exit signal from the sidetrack. Fig. 8 shows, that the minimum headway times are roughly 2,5 minutes. The differences in minimum headway time between variant A, B and C are only in the range of seconds.

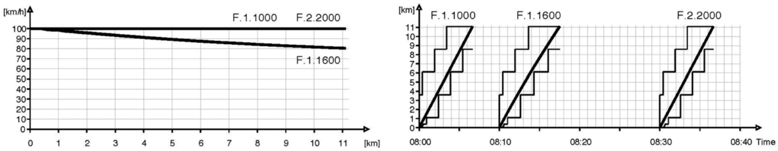
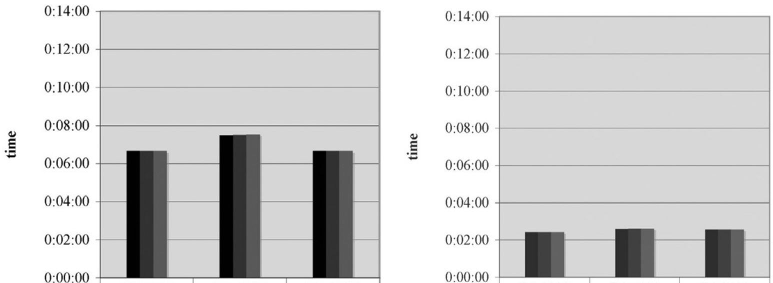


Figure 7 Speed/distance diagram (left) and distance/time diagram (right) for operation mode 3



	F.1.1000	F.1.1600	F.2.2000
variant A	0:06:40	0:07:30	0:06:40
variant B	0:06:40	0:07:31	0:06:40
variant C	0:06:40	0:07:32	0:06:40

	F.1.1000	F.1.1600	F.2.2000
variant A	0:02:25	0:02:36	0:02:34
variant B	0:02:25	0:02:37	0:02:34
variant C	0:02:25	0:02:37	0:02:34

Figure 8 Running times (left) and minimum headway time (right) for operation mode 3

3.4 Sensitivity analysis and energy consumption

A sensitivity analysis has been performed to examine the influence of the values of length and of the altered gradient on the result. For this reason, both the values of length and the gradient difference between the variants A, B and C are doubled. The sensitivity analysis is conducted only for operation mode 1.
The freight trains run similarly to the result of operation mode 1. The running times differ from the result of operation mode 1 only in seconds. Therefore, the results are not shown in detail. As with operation mode 1, the shortest running times can be achieved in variant C. Furthermore, the differences in running time between variant A, B and C are still only in the range of seconds. Because there is no significant difference to operation mode 1, the minimum headway times are not shown.
As the results of the simulation show only minor differences in running time and speed, it can be assumed that there are also only minor differences in the energy consumption. The results of the simulation confirm this assumption, based on the calculated energy consumption of each course by the simulation software.

4 Discussion

The results show that depending on the operation mode, different structural variants have to be preferred. For example, the results for operation mode 1 are in contrast to the results for operation mode 2. For operation mode 1, variant A provides the shortest running times. Whereas, for operation mode 2, shortest running times are provided by the variant C. For this operation mode, it is important to consider the position of the first block signal. In this example, the length between the last gradient change and the first block signal is shorter than the lengths of the freight trains. That means that the freight trains are standing on the gradient change while they are waiting at the block signal. In this case, the software program calculates the average gradient over the train length. So for operation mode 2, the shortest running times after the stop are provided at variant A because this variant has the lowest gradient in this section. For this operation mode, variant C would only provide the shortest running times if the signal position would be changed according to the train length.
The results of the freight train F.1.1000 are related to the results of the freight train F.2.2000. This is because, for the freight train F.2.2000 both the load and the number of locomotives of the freight train F.1.1000 are doubled. But due to the limit for the maximum drawbar force for double traction at 450 kN, the freight train F.2.2000 cannot use the entire traction power provided by the engines.

5 Conclusions

The results can be summarised as follows: There are differences in running time and speed between the three variants, but these are only minor differences. The results clearly show that depending on the operation mode, different structural variants have to be preferred. Also the position of the signals has an essential impact on the results. As a consequence, the interaction between railway line design and operation is important and should be considered in the design process.
Generally, an unscheduled stop on the free track should be avoided – especially a stop in a section with a rather steep gradient. This can be done by application of a train control system that displays not only the maximum track speed but also the recommended track speed for the following block section.
The results show that variant A is the best variant not only for operation mode 1 but also for operation mode 2 if the signal position is changed respectively. To conclude, the existing variant is still a rather good solution if the quality of operation cannot be guaranteed.

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