

Use of Simulation for the Design of an Operational Concept on a Regional Line

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Abstract: The paper focuses on the design of an operational concept for the Nymburk–Jičín regional line and its simulation using OpenTrack software, both under the current infrastructure conditions and with anticipated modernization, particularly in the area of security system. It includes an analysis of the current state of the line, the development of several operational concepts, their simulation, and proposed changes necessary for effective implementation. The model setup covers individual elements on the track, stations and interstation sections, including the creation of train routes and timetables. The outcome is a proposal for multiple operational concepts and associated measures for their implementation. The final chapter of the paper deals with proposals for measures that are necessary or suitable for the successful implementation of individual concepts.

Keywords: Infrastructure, regional line, railway infrastructure, simulation, timetable

1. Introduction

The OpenTrack software enables the creation of a detailed track model suitable for simulating real-world rail traffic [1]. This model allows for defining specific vehicle models, from which trains can be generated and operated according to predefined timetables under various external operating conditions, with the capability to simulate different traffic irregularities [2]. The simulation model was developed using a range of data sources, including actual Tables of Track Conditions (railway operational manuals, known as the Sectional Appendix in the UK), train diagrams, station plans, and passenger timetables [3].

To build the simulation model, three categories of input data were required:

- Infrastructure data,

- Vehicle data,
- Timetable data.

Based on these inputs, the application generates a simulation of vehicle movements on the railway network, following the timetable within a defined time frame. This simulation is presented as an animation that allows monitoring of train movements and signaling equipment operation [4]. The outputs are available in both graphical and textual formats, focusing on individual trains, stations, or the entire transportation network. OpenTrack proves to be an invaluable tool for analyzing railway infrastructure, vehicles, and signaling systems. It assists in creating timetables, evaluating impacts of vehicle and infrastructure failures, and assessing train delays [5]. Additionally, it helps determine the capacity of lines and stations and can be used to estimate train energy consumption.

The model consists of several interconnected components that collectively define the infrastructure and traffic on the Nymburk–Jičín line. Building the model requires defining vertices (network nodes), edges (connections between nodes), operating control points, and halts (small, unmanned passenger stations, typically consisting of a basic platform, used solely for boarding or alighting of passengers) [6,7]. The model is organized into stations and inter-station sections, with the station model always beginning at the distant signal of the home signal device for non-terminal stations..

In OpenTrack, vertices represent specific points within the railway model where attribute changes occur along an edge or where signaling devices are located. These vertices serve a dual purpose: marking direction, changes (such as in mileage), or signaling validity for a specific direction (e.g., a signal) [8]. Attributes for each vertex are configured using the "Vertex Inspector" tool. The sequence of vertices follows a schematically accurate mileage sequence.

In the model, vertices are consistently used at the start, radius change, and end points of curves; at halts; at the beginning and end of platforms at halts; at line speed changes; and at mileage changes within inter-station sections [9].

Changes in track curvature (curve radii) are always marked by vertices. Each vertex attribute includes a corresponding kilometer point, accurate to the nearest meter (as specified in the Kilometer Point field). Additionally, each vertex is labelled (Vertex Name field) by its function: "ZO" for the beginning of a curve, "KO" for the end of a curve, or "KO=ZO" for a vertex that marks both the end of one curve and the beginning of another with a different radius.

The model does not incorporate transition curves (also known as spiral easements). Consequently, the real starting points of transition curves are represented as the starting points of curves within the model [10]. The precise location of each curve is determined and adjusted based on the Tables of Track Conditions. Halts are represented by three vertices in the model: the halt's

location, the start of the platform, and the end of the platform, with each vertex attribute displaying the kilometer point to the nearest meter (Kilometer Point field).

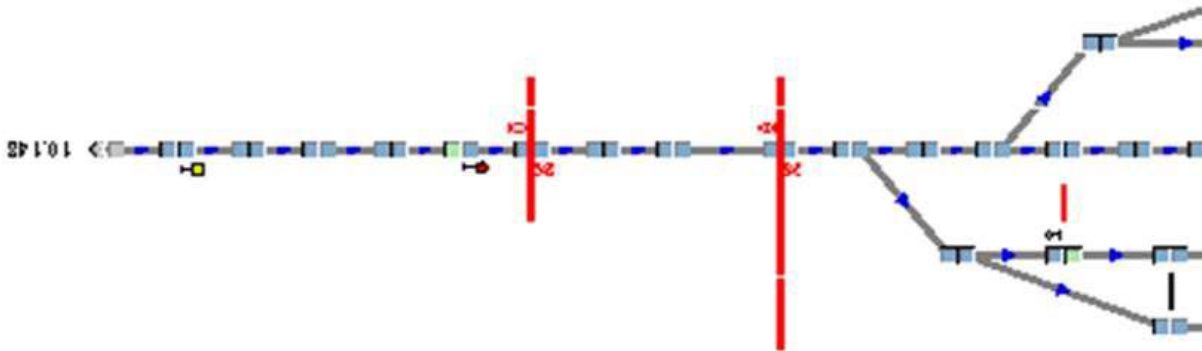


Fig. 1 Schematic of Křinec Station used in the simulation of operational concepts - cutout. Source: SW OpenTrack

In stations, junctions, and passing loops, the model incorporates vertices for the locations of signal devices with distant signals, train path endpoints, switches (referred to as points in UK terminology) and their fouling points, level crossings, derails, track ends, and other critical locations (see Fig. 1).

Edges connect these vertices to create a network that supports traffic simulations, with edge lengths calculated from vertex data provided for the vertices it connects, with an accuracy of one meter [11]. The so-called "Edge Inspector" is used to set vertex attributes. In inter-station sections and the first station track, curve radius (in meters) is specified within the attributes or marked as "None" if the section is straight (Radius field). These radius values are listed and adjusted according to the Tables of Track Conditions. The setup of stations, junctions, passing loops, and halts is managed in the Station Database and the Station Areas.

Station and junction data, such as the names of stations, junctions, passing loops, and halts, along with their abbreviations, are entered into the Station Database in the model [12]. Abbreviations are in four capital letters without diacritics (e.g., ROZD for Rožďalovice Station), and the elevations are also included. Additionally, abbreviations for halts begin with a lowercase "z" (e.g., zPSEV for the Pševs Halt), for junctions with a lowercase "o" (e.g., oKAME for the Kamensko Junction), and for passing loops with a lowercase "v" (e.g., vBARV for the Bartoušov Passing Loop). These abbreviations are subsequently used in the timetable design model, train diagrams, and other related applications.

In OpenTrack, routes represent available paths between main signals (configured through the Routes menu in the Routes Inspector) or shunting signal devices (configured through the Shuntings menu in the Routes Inspector), as well as paths leading to the model's endpoints. Each route consists of a sequence of vertices and edges. Although all possible routes between main signals are configured in the model, shunting routes are omitted, even when the model includes shunting signals.

Timetables in OpenTrack are managed under the Courses/Services menu, where it is possible to assign a train number, specify the train composition, and define a timetable. Additionally, it is possible to set itineraries that trains can follow [13]. Once a timetable is defined for an individual train, generating a timetable interval that applies to an entire group of trains becomes straightforward.

2. Current State of Operation and Infrastructure on the Selected Nymburk – Jičín Railway Line

The Nymburk–Jičín railway line, designated as Line 061, is a non-electrified, single-track route. The section from Nymburk Main Station to Veleliby is classified as a national railway, while the section from Nymburk Town through Veleliby to Jičín is considered a regional railway [14]. The line is currently operated by Správa železnic, s.o., and connects two district towns across regional borders, with the regional border running between Rožďalovice and Mlýnec stations. Consequently, passenger transport on this line is jointly overseen by the Central Bohemian Region and the Hradec Králové Region. The Nymburk–Jičín line is part of both the S21 Nymburk–Jičín route and the T2 (Praha–) Nymburk–Jičín (–Turnov) route (see Fig. 2).

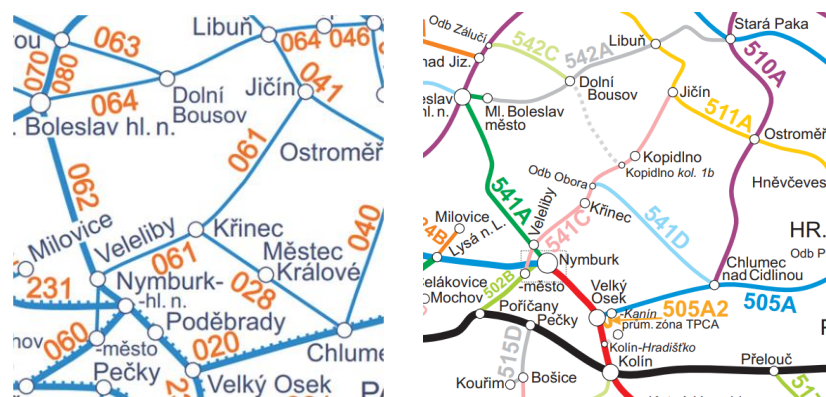


Fig. 2 Line 061 Nymburk–Jičín (according to the Timetable) and section 541A and 541 C (according to the Tables of Track Conditions). Source: www.spravazeleznic.cz

According to the 2024 Timetable, effective from 10 December 2023, 13 passenger trains are scheduled on working days in the direction from Nymburk Main Station to Jičín on the S21 line. In the opposite direction, there are 12 passenger trains and one express train. Additionally, four pairs of passenger trains operate on the Nymburk Main Station–Rožďalovice section (with one train extending to Kopidlno). Several special (relief) passenger trains also run on this line.

In the printed timetable, the line is identified as number 061. In the Tables of Track Conditions, the Nymburk–Veleliby section is marked as 541A, and the Nymburk Town–Jičín section as 541C. The permissible load class is C3 on the Nymburk Main Station–Veleliby section (20 t / 7.2 t) and C4 on the Nymburk Town–Jičín section (20 t / 8 t). The standard length of a passenger train, including

traction units, is 55 meters, while the standard length of a freight train, including traction units, is 308 meters. The maximum permissible length of a freight train, including traction units, is 565 meters.

The Nymburk Main Station–Veleliby and Nymburk Town–Veleliby stations are secured by an automatic signal box (block post), while the Veleliby–Jičín section is managed via telephone communication. Plans are underway to integrate the line into the Central Dispatching Centre in Prague, with modifications already in progress along the Kopidlno–Jičín section [15].

The maximum permitted line speed of $100 \text{ km}\cdot\text{h}^{-1}$ is only achievable on the short Nymburk Main Station–Veleliby section. For the remainder of the line, the maximum speed is limited to $70 \text{ km}\cdot\text{h}^{-1}$. Several speed reductions are necessary in some areas due to factors such as lower elevation of directional curves, smaller curve radii, inadequately dimensioned train meets, or a combination of these factors [16,17]. The speed profile differs slightly in each direction; the figure below shows the speed profile for the Nymburk Main Station–Jičín direction (see Fig. 3).

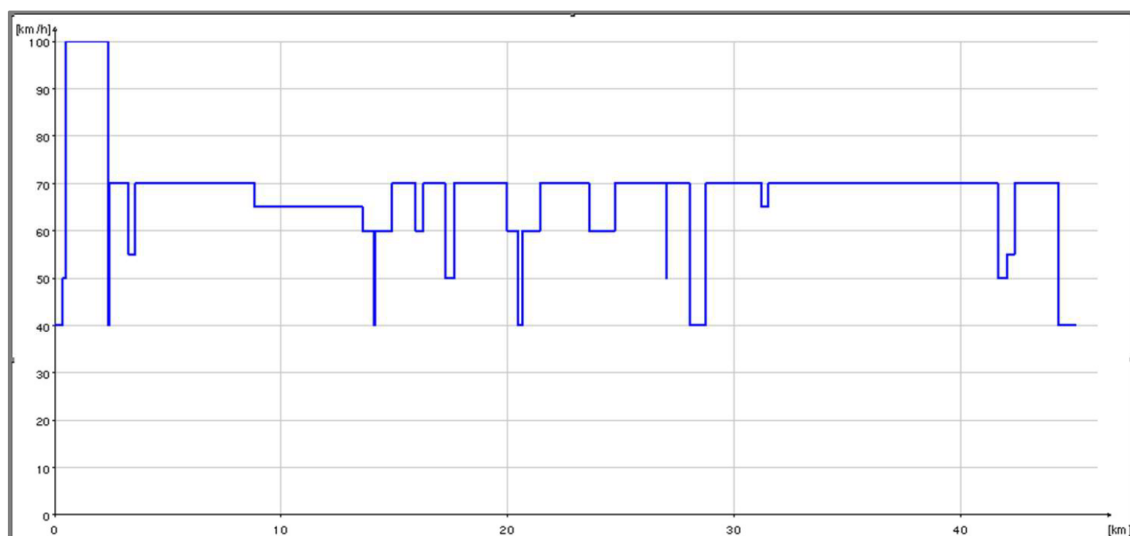


Fig. 3 Speed profile of the line Nymburk–Jičín. Source: SW OpenTrack

Due to the unavailability of a longitudinal profile, a new one was constructed using multiple sources. The primary reference was the Tables of Track Conditions, which provided gradient data for the inter-station sections. Additionally, video footage from a track run was analyzed to identify changes in the track gradient profile. Elevation data was gathered from mapy.cz and aerial laser scanning data from the Geoportal of the Czech Geodetic and Cadastral Office. The gradients were then simplified to highlight only the most significant elements of the gradient profile. The key section in terms of gradients is between Kopidlno and Jičín. The minimum elevation along the line is 190 meters above sea level at Nymburk Main Station, and the maximum is 292 meters above sea level at Nemyčeves Station. The line's steepest gradient reaches 17.1 ‰. The route features 7 railway stations, 2 junctions, 1 passing loop, and 10 halts.

3. Design of the Operational Concept

According to Directive SM 124, an operational concept is defined as follows: 'An operational concept requires a general understanding of train schedules and regular (clock-face) intervals. Unlike a detailed timetable, it does not require specific information about the movement of rolling stock or service connections. This concept is particularly useful for planning under anticipated conditions.' The proposed operational concepts are all designed to ensure regular meeting of passenger trains at a single station, Rožd'alovice, which is located approximately halfway along the line, with the meeting scheduled around the 30th minute [18]. Given this requirement, and assuming service to all halts and stations on the line, the journey time for trains traveling to and from Nymburk is approximately 26 minutes, while the journey time to and from Jičín is approximately 32 minutes.

Additionally, it is crucial to facilitate efficient transfers at Nymburk Main Station, particularly between Platform 1 and the island platforms (Platforms 2 and 3) via the underpass. For an experienced passenger, a minimum transfer time of 2 minutes is achievable, though an ideal transfer time would be closer to 5 minutes. These constraints mean that in some of the proposed concepts, trade-offs will be necessary [19]. For example, some halts along the line may not be served, trains may need to wait longer than usual at specific stations, or rapid turnarounds may be necessary. However, all proposed concepts adhere to the core principle of scheduling train meetings or turnarounds at Rožd'alovice Station around approximately the 30th minute.

3.1 Concept 1

Concept 1 is based on the current state of the infrastructure, where Category I station signaling equipment remains in place at Rožd'alovice and Křinec stations.

Stanice, zastávka	Směr Nymburk–Jičín		Směr Jičín–Nymburk	
	Takt 1 (Os)	Takt 2 (Os)	Takt 1 (Os)	Takt 2 (Os)
Nymburk hlavní nádraží	odj. SS:00	odj. LL:00	příj. SS:55	příj. LL:55
Veleliby	příj. SS:04	příj. LL:04	odj. SS:51	odj. LL:51
	odj. SS:04	odj. LL:04	příj. SS:47	příj. LL:51
Jikev	odj. SS:08	odj. LL:08	odj. SS:45	odj. LL:47
Oskořímek	odj. SS:12	odj. LL:12	odj. SS:43	odj. LL:43
Křinec	příj. SS:18	příj. LL:18	odj. SS:37	odj. LL:37
	odj. SS:18	odj. LL:18	příj. SS:37	příj. LL:37
Ledečky	odj. SS:23	odj. LL:23	odj. SS:31	odj. LL:31
Rožd'alovice	příj. SS:26	příj. LL:26	odj. SS:29	odj. LL:28
	odj. SS:33	odj. LL:33	příj. SS:28	příj. LL:28
Mlýnec	odj. SS:38	odj. LL:38	odj. SS:23	odj. LL:23
Kopidlno	příj. SS:43	příj. LL:43	odj. SS:19	odj. LL:19
	odj. LL:01	odj. LL:44	příj. SS:01	příj. LL:18
Pševy	odj. LL:04	odj. LL:47	odj. LL:57	odj. LL:14
Bartoušov zastávka	odj. LL:07	odj. LL:50	odj. LL:54	odj. LL:11
<i>Výhybna Bartoušov</i>	<i>příj. LL:09</i> <i>odj. LL:10</i>	<i>příj. LL:52</i> <i>odj. LL:53</i>		
Žitětín	odj. LL:11	odj. LL:54	odj. LL:52	odj. LL:09
Jičíněves	odj. LL:14	odj. LL:57	odj. LL:50	odj. LL:07
Nemyčevy	odj. LL:18	odj. SS:01	odj. LL:46	odj. LL:03
Nové Místo u Jičína	odj. LL:21	odj. SS:04	odj. LL:42	odj. SS:59
Jičín	příj. LL:25	příj. SS:03	odj. LL:39	odj. SS:56

Fig. 4 Proposed timetable according to Concept 1. Source: authors

This concept fully aligns with existing operations on connecting lines and is designated to integrate smoothly with them. Under this concept, only passenger trains are operated, and all stations and halts along the line are served, with trains stop at halts upon request. Passenger services run in two interleaved two-hour intervals: one interval optimized for speed, while the other is slower due to the need for trains to meet at the Bartoušov Passing Loop. These intervals are identical between Nymburk Main Station and Kopidlno, but they are staggered by one hour. The primary advantage of Concept 1 is that it can be implemented almost immediately, given the current infrastructure (see Fig. 4).

3.2 Concept 2

Concept 2 is designed for implementation following infrastructure modernization, specifically when Křinec and Rožďalovice stations are upgraded with Category III station signaling equipment. These upgrades will enable faster train meets, with Rožďalovice Station playing a key role. This concept includes three variations: one involving only passenger trains, and two that incorporate both express and passenger trains. In Concept 2, not all stations and halts along the line are served. Veleliby Station is typically bypassed, as it can be serviced by trains on the Nymburk Main Station–Mladá Boleslav line. Similarly, the Jikev halt is skipped due to its considerable distance from the nearest served village. Trains stop at all other halts only upon request.

However, Concept 2 has some limitations. It cannot be implemented immediately and requires the completion of infrastructure upgrades.

Concept 2 is further developed into three distinct variants (A, B, C), each tailored to different operational scenarios. Variant A maintains connections to the R10 service at Nymburk Main Station, both to and from Prague and Hradec Králové. Trains run at hourly intervals between Nymburk Main Station and Rožďalovice, offering passengers a convenient schedule. Variant B builds on Variant A by converting a fast passenger train into an express train that stops only at major settlements along the route. This variant could serve as a transitional phase towards the planned R26 express train service on the Příbram–Jičín route, especially before the Nymburk–Praha East VRT–Praha–Příbram line becomes fully operational. Variant C is an extension of Variant B, designed for a scenario where the R26 service is fully operational along the entire Příbram–Jičín route. In this case, express trains would bypass Nymburk Main Station, continuing from Veleliby to Nymburk Town and then via the Prague East VRT Terminal to Příbram. This variant introduces an express train that serves only larger settlements and continues directly to Prague. Transfers at Křinec Station to and from Městec Králové remain available every two hours.

3.3 Concept 3

Concept 3 is designed for implementation following infrastructure modernization, when all stations will be equipped with Category III signaling systems. The primary goal of this concept is to facilitate the smooth operation of passenger trains without unnecessary delays while maximizing service to stations and halts along the line. This concept serves as a potential alternative to Concept 2, Variant A.

Under this concept, passenger trains operate along the entire line at regular two-hour intervals, supplemented by additional passenger trains also running at consistent two-hour intervals. Specifically, two additional services are introduced: one operating between Nymburk Main Station and Rožďalovice, and the other between Jičín and Kopidlno. Consequently, trains run between Rožďalovice and Kopidlno stations only once every two hours, with the Mlýnec halt also served on this schedule. This arrangement ensures that stations and halts with the highest passenger demand are served at hourly intervals, providing a highly convenient option for passengers. At Nymburk Main Station, guaranteed connections are available to and from the R10 service in both directions. Additionally, connections to trains in other directions are possible at Jičín Station, while transfers to and from Městec Králové can be made at Křinec Station within the two-hour interval.

4. Simulation and Evaluation with Action Proposals

The timetables for the proposed concepts were simulated using OpenTrack simulation software. Passenger trains were represented by 814 series units currently operating on this line, while 845 series units, used by ARRIVA for the current R 26 service, were employed for express trains.

Simulations were conducted with adhesion set to "Bad" (Adhesion Outside menu) and driving mode (Performance) set to 95%. This driving mode set to 95% means that the traction vehicles operate at 95% of their maximum acceleration, deceleration, and speed capacity [20]. Consequently, in the simulation, trains never reach the maximum speed of $70 \text{ km}\cdot\text{h}^{-1}$, instead operating at $66.5 \text{ km}\cdot\text{h}^{-1}$. This conservative setting was applied to ensure that the timetable remains stable across varying weather conditions and different driving styles of train drivers [21].

Travel times were then validated against the existing timetable and compared with videos available on the YouTube platform, particularly to account for the effects of stops on request.

This simulation approach was chosen for the following reasons:

- 1) The speed in the simulation is capped at 95%;
- 2) Adhesion conditions are set to "Bad," meaning only 80% of the actual vehicle adhesion value is used in the simulation;
- 3) Trains stop at halts only upon request, allowing the passing-through time to compensate for any delays;

- 4) All values for passenger trains are based on 814 Regionova units and 845 units for express trains. It is anticipated that more modern vehicles would exhibit improved speed, acceleration, and adhesion performance.

The accompanying figure illustrates the simulated timetable for Concept 1 from 6:00 to 14:00. Figure 5 demonstrates that passenger trains meet as scheduled at Rožďalovice Station and Bartoušov Passing Loop, arriving at the destination stations according to the timetable. Additionally, it shows the smooth integration of passenger and express trains (marked in purple) on the Nymburk Main Station–Veleliby–(Mladá Boleslav) line, as well as passenger trains on the Křinec–Odbočka Obora–(Chlumeck nad Cidlinou) line. These trains are effectively synchronized with the trains from Concept 1, ensuring they operate without interfering with each other.

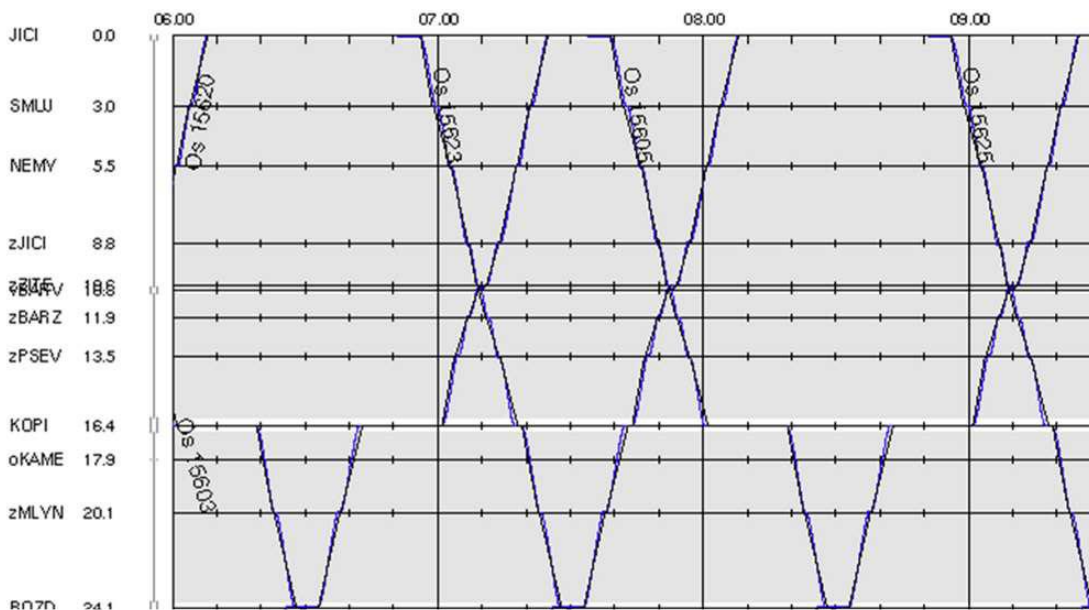


Fig. 5 Train Diagram for Nymburk Main Station–Jičín according to Concept 1 - cutout.

Source: authors based on SW OpenTrack

5. Results and Discussion

The line's capacity can be enhanced through four groups of measures, which can be further subdivided:

- Operational and organizational measures
- Construction and reconstruction measures
- Safety equipment upgrades
- Rolling stock modifications

Within operational and organizational measures, some approaches could be particularly effective for certain concepts, namely shortening station operating intervals and reducing train dwell times at

stations. Shortening station operating intervals could only be implemented under current conditions and within Concept 1, particularly where Category I signaling equipment is in place at Křinec and Rožďalovice stations. Shortening station operating intervals could only be implemented under the current conditions and with Concept 1, particularly where Category I signaling equipment is in place at Křinec and Rožďalovice stations. This measure is particularly beneficial and highly effective at Rožďalovice Station by adding a pointsman (switchman), enabling that each pointsman to manage a single station track branching area. This setup would reduce lengthy switching times between track branching areas when trains are scheduled to meet.

Among construction and reconstruction measures, the following changes could improve some of the concepts: modifying station track branching areas, building passing loops, making directional adjustments to the line, and constructing appropriate platforms.

While modifying the station track branching area is not essential, it could enhance timetable stability for Concept 2 at Jičín Station. Installing a switch at the beginning of the junction of the Nymburk–Jičín and Ostroměř–Jičín lines would create a double-track section approaching Jičín Station. Additionally, doubling the connecting track between the former Jičín ÖNWB and BCB stations and the Jičín local railway station would facilitate train passing, particularly when Nymburk–Jičín trains are delayed by a few minutes, preventing these delays from affecting trains in the opposite direction. Directional adjustments to the line could be applied in several sections where speed is limited by factors such as lower elevation of directional curves, smaller curve radii, undersized transition curves, or a combination of these. For example, at Křinec and Rožďalovice stations, speed is currently reduced to $40 \text{ km}\cdot\text{h}^{-1}$. It would be beneficial to eliminate these sections and increase the speed to at least the standard $70 \text{ km}\cdot\text{h}^{-1}$ in both directions across the line. Platform upgrades would also be beneficial almost along the entire line, with the most crucial improvement being the construction of platforms at a standard height of 550 mm above the top of the rail.

Regarding safety equipment, recommended upgrades include modernizing station signaling equipment and centralizing remote control operations. Station signaling upgrades have already been partially completed on the Kopiclno–Jičín section and are scheduled to continue. For Concepts 2 and 3, upgrading the station signaling equipment at Rožďalovice and Křinec stations to Category III is necessary. This upgrade would reduce the technological time required for train meets by six minutes compared to current conditions, allowing this time to be used for securing transfers at Nymburk Main Station to the R 10 service in both directions. For rolling stock, the following modifications would support some of the concepts: modernizing traction vehicles, upgrading rail cars, and introducing bi-directional trainsets. The current vehicles simulated are sufficient for all proposed concepts in terms of acceleration and maximum speeds.

6. Conclusion

The paper analyzes the Nymburk–Jičín railway line, focusing on its current infrastructure, operations, and regional connections. Based on this analysis, a model of the line was developed using OpenTrack software, simulating five variants of three operational concepts. These operational concepts are designed to align with the existing state of infrastructure. Concept 1 can be implemented immediately, while Concepts 2 and 3 require upgrading station signaling equipment to Category III, at least at Rožd'alovice Station. All concepts aim to enhance passenger experience by ensuring at least hourly trains, ideally at consistent intervals, and by maintaining connections to other trains at junction stations whenever possible. Additionally, the designs incorporate measures to reduce minor delays. In the final scenario, where the R26 service is introduced, Variant C of Concept 2 is deemed the most effective. The analysis also highlights that while the concepts align with current infrastructure or planned upgrades in station signaling equipment, further enhancements are possible, which could improve timetable reliability, reduce travel times, and increase station attractiveness beyond merely accelerating train meets at Rožd'alovice Station.

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