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USE OF NEW COMMAND TYPES IN AUTOMATIC ROUTE SETTING

DISSERTATION THESIS

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Title

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Annotation

The thesis deals with the development of new functional commands for the Automatic Route Setting. It first characterizes signalling functions and the current setup of the Automatic Route Setting, the current setup of the function and then analyses the scientific knowledge in the field of the real-time railway traffic management. Both provide the basis for the design of new commands to enhance the relevance of Automatic Route Setting at higher traffic volumes when traffic conflicts between two train routes need to be resolved. The support commands algorithm has been designed for increased traffic flow, shorter operating intervals, and minimized train delays in the event of conflicting traffic situations.

Keywords

Automatic Route Setting, support commands, traffic conflict, real-time railway traffic management, Blocking time theory, train route, railway

Content

1 Introduction and aim of the dissertation

The dissertation addresses Automatic Route Setting and the commands it automatically issues to the signalling system. The analysis has shown that Automatic Route Setting in the Czech Republic generates up to six types of command. [1] The Traffic Management System, which operates at a higher hierarchical level than Automatic Route Setting, enables the input of up to 15 types of command into the signalling system. [2] In addition, there exists a range of signalling system functions (not implemented even within the Traffic Management System) that are performed routinely and can therefore be automated. [3,4]

The dissertation first analyses the possibilities for introducing additional commands into Automatic Route Setting. Subsequently, a selection of commands suitable for automation is carried out, with emphasis placed on their positive impact on railway capacity, and an algorithm for these selected commands is proposed. Finally, simulation is used to verify whether the proposed algorithm has produced a positive effect in minimising the railway capacity consumption.

The aim of the dissertation is to design and verify an algorithm for new support commands in Automatic Route Setting, with the anticipated benefit of minimising the railway capacity consumption. At the same time, the following hypothesis will be tested: "Automatic Route Setting may have a positive effect on minimising railway capacity consumption."

2 Analysis of the state of scientific knowledge

The analysis of current scientific knowledge has yielded a wide range of recommendations, which the author subsequently incorporates into the dissertation. These include, for example, the identification of potential traffic conflicts, the possibility of subdividing allocation windows into smaller intervals, the necessity of accounting for clearance times, and the consideration of track sections beyond the end point of a train route, among others. The proposed algorithm is intended to be as general as possible, ensuring applicability across all types of railway signalling systems, as well as within an European Train Control System (ETCS) environment. The analysis further indicated the need to take into account the time required for the generation of Movement Authorities (MA) and their transmission to the onboard ETCS unit. Furthermore, the possibility of train prioritisation was examined; however, the reviewed sources do not converge on a unified conclusion. Based on the analysed literature, the author concludes that strict prioritisation of only certain trains (e.g. according to category or weight) tends to have negative impacts on overall traffic development, such as the propagation of delays to subsequent trains and an overall increase in cumulative delay. The issue of minimising delay propagation and other consequences of train prioritisation in future traffic scenarios requires a comprehensive solution which, given its scope, lies beyond the remit of this dissertation.

3 Methods of Processing the Thesis

The Weighted Sum Approach (WSA) is employed to select signalling system commands for which inclusion in the group of commands for implementation within Automatic Route Setting will be proposed. The objective is to maximise the overall weighted utility derived from the automation of the selected commands in accordance with the established criteria.

The Topological Route Relation Model is used to modelling the topological relationships between two train routes.

The method of merging points into elements is employed with the aim of simplifying the identification of traffic conflicts between train routes within the station throat. It operates by evaluating the occupancy of the merged elements, thereby eliminating the need to assess each individual set of points and track section of the station throat separately. As a result, the calculations and simulations carried out in this work are simplified.

The Blocking-Time Theory is applied to model the movements of pairs of trains, for which it will be determined whether their planned journeys are mutually conflicting. A reservation window is understood as either a section of track or station track, or a single element of the station throat, created by merging points according to the method of merging points into elements.

A labelling algorithm is employed to assign merged elements of the station throat to a train route, which is defined by a start element and an end element, while the remaining elements are identified using the labelling algorithm.

The questionnaire survey is primarily used to determine the weights of the criteria, which served as input for the Weighted Sum Approach. Respondents rated each criterion on a scale from 1 to 10. In addition, the survey included several optional questions aimed at assessing respondents' attitudes towards Automatic Route Setting, identifying whether their experiences are predominantly positive or negative, and highlighting perceived shortcomings in the current Automatic Route Setting configuration.

Statistical analysis is employed in this study to evaluate measured data concerning signal aspect change delays, the practical use of signalling system functions, and to examine the dependence of Automatic Route Setting utilisation on other factors. Correlation analysis is used to verify the relationship of measured values with other criteria.

Combinatorics is employed in this study to calculate the theoretical number of traffic situations, initially determined using the combinatorial product rule for representing a train route with three points, and subsequently for representing a train route with four points. Furthermore, combinatorics is used to calculate the possible scenarios for a pair of train routes, taking into account the time separation between the pair of journeys and the sequence of route setting operations.

Algorithmizing is employed to achieve the primary objective of the study, namely the design of an algorithm for new commands for Automatic Route Setting.

Scheduling method tools are used to develop reservation systems for the occupancy of station throat elements.

Simulation is employed to verify the proposed algorithm.

4 Results of the Dissertation

This chapter presents the results derived from the dissertation. Initially, research was conducted with the aim of establishing a basis for further decision-making. Subsequently, based on the research findings, commands suitable for automation were selected. Finally, an algorithm for the chosen commands was proposed.

4.1 Research Prior to Algorithm Design

In his research, the author initially focused on the issue of direct railway traffic control and the utilisation of signalling system functions. The study revealed that 53% of all signalling system operations involve a command to set a train route. All other signalling system functions account for less than 10% each. The second most frequently used signalling system function is the input of the expected departure, which represents 9% of all signalling system operations.

The second phase of the research focused on how frequently already automated commands are executed automatically versus manually. The Edit the Train Number command is most often executed automatically (96% automatically, 4% manually). With a considerable margin, the second most frequently automated function is the Expected Departure, which was executed automatically in 53% of occurrences. This is followed functions: Train Route (automatically in 43% of cases), Request for Directional Control (automatically in 39% of cases), and Train Route with Speed Restriction (automatically in 37% of cases). The function with the lowest proportion of automatic execution is the Preliminary Level Crossing Closure, accounting for 23% of all instances. This distribution is illustrated in Figure 11.

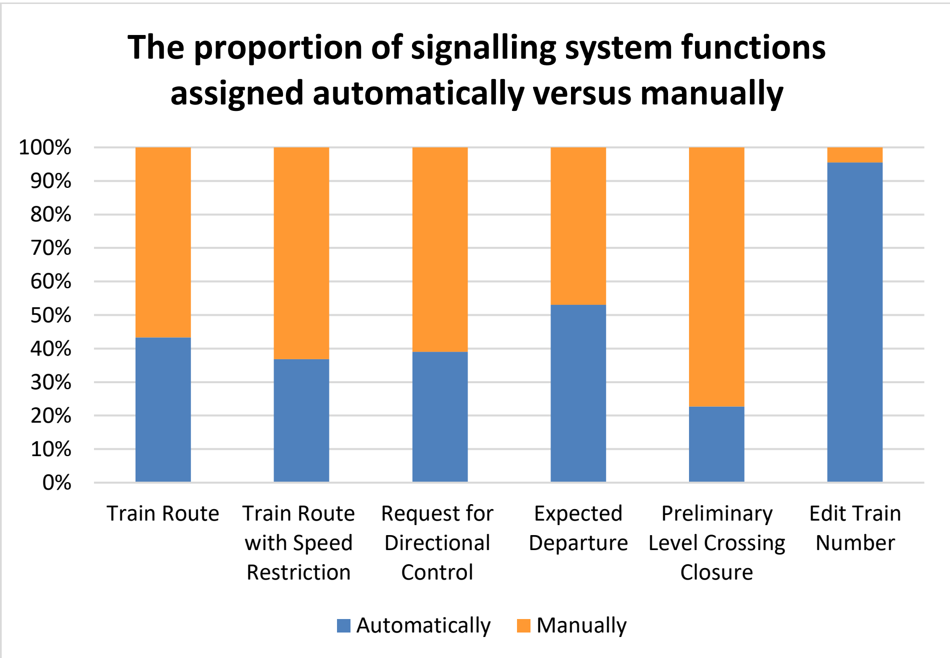

Figure 1: Chart showing the proportion of automatic and manual command usage

Source: author, using [5]

The author of the dissertation identifies the cause of the significant difference between the automatic execution of the Edit Train Number function (96%) and other automated signalling system functions (53% or less) as the ability for each dispatcher or traffic controller in the Traffic Management System to enable the automatic execution of the Edit Train Number function independently of other Automatic Route Setting functions. This allows the automatic execution of the Edit Train Number command to be enabled while all other Automatic Route Setting functions are disabled, and vice versa. The analysis indicates that users take advantage of this option. The Edit Train Number function is enabled almost continuously and is heavily used during train turnarounds at terminal stations, whereas other Automatic Route Setting functions are sometimes disabled.

The rate of enabling or disabling Automatic Route Setting (excluding the Edit Train Number function) depends on a combination of several factors. According to [6], higher utilisation of Automatic Route Setting is observed at stations located at the edges of controlled areas, as in these stations there is a synergy of automation benefits, ensuring the automatic departure of trains from the controlled area through the simultaneous automatic execution of the Expected Departure and Request for Directional Control commands together with the Train Route command. This is also demonstrated by the graph in Figure 1. Since the Expected Departure and Train Route commands are related—being used together for train routes exiting the controlled area—it can be asserted that the 53% value for the automatic execution of the Expected Departure command indicates that 53% of train routes at the exit of the controlled area were set automatically. In contrast, the average automatic utilisation of the Train Route command across all stations is only 43%. This means that at peripheral stations, the proportion of automatic execution of the Train Route command is 10% higher than the average across all stations.

The study of factors influencing the utilisation of Automatic Route Setting was conducted using correlation analysis. The analysis revealed that the greatest influence among all examined factors is the distance from the peripheral station (the above-mentioned synergy of automation benefits at the edges of the controlled area). It was observed that the further a station is from the edge of the controlled area, the lower the utilisation of Automatic Route Setting. For the other factors examined, a very weak inverse correlation was observed. The correlation coefficient values are close to zero, indicating that none of the other factors has a significant effect on the utilisation of Automatic Route Setting.

An important influence is the individual attitude of each user towards Automatic Route Setting, or more generally towards modern technologies, as revealed by the questionnaire survey. Two respondents answered "None" to the question, "Which signalling system function would you prefer to have newly automated or significantly improved compared to the current automation?" and responded "Automatic Route Setting" or "I don't know, I do not use it due to its unreliability" to the question, "Which signalling system function would you under no circumstances want to automate?" A common characteristic of these two respondents is their extensive experience in traffic management, with one indicating 31–40 years and the other 41–50 years in the field.

4.2 Selection of Commands for Automation

Functions suitable for automation were selected using the Weighted Sum Approach. As evident from the WSA results presented in Table 1, the functions with the highest overall weighted utility are Individual Point Setting (S+/S-), Preliminary Level Crossing Closure (PUP), and Directional Control (UTS).

Table 1: Results of the Weighted Sum Approach (WSA)

Signalling system function	Overall weighted utility
Individual Point Setting (S+/S-)	0,6430
Preliminary Level Crossing Closure (PUP)	0,6296
Directional Control (UTS)	0,5209
Train Route via Variant Element (VCVP)	0,4012
Train Route with an Extended Overlap (VCP)	0,4006
Cancel the Preliminary Level Crossing Closure (RPUP)	0,3870
Cancel the Train Number (ZRUSv)	0,3711
Shunting Route (PC)	0,2874
Train Route According to Sighting Conditions (VCRP)	0,2667
Cancel the Train Route (RC)	0,2369
Cancel the Expected Departure (PODJ<)	0,2262
Cancel the Request for Directional Control (ZTS<)	0,2225
Start the Train Shift (PRES>)	0,1875
Cancel the Train Shift (PRES<)	0,1630

Source: author

An algorithm for the use of the Individual Point Setting and Preliminary Level Crossing Closure functions, which have the highest overall weighted utility, is proposed in the design section of the dissertation. The author considered including the automation of the Directional Control function, which has the third-highest overall weighted utility. However, it was ultimately concluded that this function is generally not related to route setting, as it is used at the edges of controlled areas to modify track clearance and is not utilised during train route preparation. Therefore, the algorithm for Directional Control would require a separate procedure entirely independent of the algorithm for Individual Point Setting and Preliminary

Level Crossing Closure, and it is not proposed in this dissertation. Conversely, an algorithm is proposed for the Train Route via Variant Element function, which, while having the fourth-highest overall weighted utility, can in specific situations be directly related to the use of Individual Point Setting and Preliminary Level Crossing Closure. Hence, the automation of the commands Individual Point Setting, Preliminary Level Crossing Closure, and Train Route via Variant Element can be designed within a single algorithm.

4.3 Designed Algorithm

After loading the necessary inputs, the initial phase of the algorithm involves identifying conflicting train movements within a defined horizon H. The research related to the definition of the interval H is described in detail in the dissertation. During the study, the formula for determining H was modified several times, from the initial formula based on the starting premise to the final formula defining the interval H as:

$$H = \langle j_x - P_x \, ; j_x + P_{max} - P_x \rangle \quad \text{pro } x \in X, j_x \in J \tag{1}$$

where:

H	horizon interval of the traffic situation [min],
j_x	time position of train x [min],
P_x	time lead of route setting for train x [min],
P_{max}	maximum time lead for route setting [min],
x	train identifier/number [-],
X	set of scheduled trains [-],
J	set of time positions of all trains in the planned timetable [min].

In this step, it is determined for each intended train route whether another train route exists within the horizon H.

If another train route is identified, the next step verifies whether the identified route is in conflict with the original intended train route. Routes are considered to be in conflict if they require the reservation of the same station throat element at the same time. This is determined using reservation systems. For this purpose, it is necessary for the infrastructure to be divided into elements in accordance with the method of merging points into elements. Subsequently, each merged element is represented by a vertex in a network graph.

According to [7], a train route can be modelled using two points and the line segment between them. However, the author of the dissertation concluded that such a representation is no longer sufficient in view of increasing safety requirements, particularly with regard to flank protection and the overlap beyond the end of the train route. Therefore, the concept derived from [7] is extended by introducing a third point representing all elements within the train route, as well as a fourth point representing elements beyond the end of the train route.

The representation of a train route using three points is considered by the author to be a "traditional" approach to the problem, which is not always adequate. It is therefore necessary to introduce a fourth point. The fourth point constitutes a point of potential conflict only if there exists an overlap for at least one train route beyond its endpoint. The inclusion of the fourth point in the representation of a train route corresponds to a model that operates with the concept of a so-called protected zone of the train route.

In the "traditional" representation of a train route using three points, there are theoretically 16 types of traffic situations. This was determined combinatorically based on the possible combinations of three points (0, 1, 2, or 3 common points for two train routes), with each combination having two variants depending on the direction of the routes. In terms of route direction, only whether both routes are in the same or opposite direction is distinguished—hence the two variants. No distinction is made between arrival and departure routes, as this does not affect the resulting algorithm. The determination of the number n of possible combinations of train routes, which also corresponds to the number of standardised traffic situations, is presented in Equation 2.

$$n = \left[\binom{3}{0} + \binom{3}{1} + \binom{3}{2} + \binom{3}{3}\right] \cdot 2 = 16 \tag{2}$$

If a fourth point is also considered, the number of theoretically possible traffic situations increases to 32, as shown by the calculation of n_1 in Equation 3.

$$n_1 = \left[\binom{4}{0} + \binom{4}{1} + \binom{4}{2} + \binom{4}{3} + \binom{4}{4}\right] \cdot 2 = 32 \tag{3}$$

The elimination of the traffic conflict is subsequently proposed using one of four suggested solutions:

a) complete elimination of the traffic conflict by scheduling a conflict-free sequence of train movements using traffic control disposition (requiring prioritisation of train movements, with the less prioritised train experiencing an increase in delay),
b) complete elimination of the traffic conflict by rerouting the train via alternative elements where no conflict occurs (resulting in zero or only a marginal increase in delay caused by the train traversing the diverging route of a point),
c) partial elimination of the traffic conflict, where the train movement continues to be planned over the same elements, but the timing of route preparation and the subsequent train movement is rescheduled to a later time, resulting in a positive increase in delay),

d) partial elimination of the traffic conflict by rerouting the train via alternative (variant) elements where a conflict also exists, but resolves earlier than on the originally planned element (resulting in a smaller increase in delay than in case (c)).

In the proposed algorithm, the first step is to check whether a conflict exists beyond the end of the train route. Such a conflict can be resolved by using a Train Route with Speed Restriction. This function is already reliably automated, so its use in the proposed flowchart in Figure 26 is only indicated in a simplified form, without detailing all the conditions.

After checking for a conflict on element D beyond the end of the train route, the algorithm then checks whether a conflict exists within the train route itself (elements from set B). If a conflict is detected, the algorithm proceeds to evaluate the use of one of the newly proposed commands. If no conflict is found, a similar procedure is applied to the issue of track element closures within the intended train route. If a closure of any element exists, the algorithm again leads to the evaluation of one of the newly proposed commands.

The execution of the newly proposed commands—Train Route via Variant Element, Preliminary Level Crossing Closure, and Individual Point Setting—must occur precisely in the order listed. The author considered the possibility that these commands could be executed in a different order, but ultimately rejected this idea. The rationale is that if a traffic conflict at the station throat can be immediately resolved by using a Train Route via Variant Element, there is no need to apply the Preliminary Level Crossing Closure or Individual Point Setting functions. In particular, using the Preliminary Level Crossing Closure function in such a situation could be undesirable, potentially resulting in an unnecessarily long closure if the conflict is already resolved in advance by the Train Route via Variant Element. Therefore, it is always necessary to evaluate the use of the Train Route via Variant Element first.

The command Train Route via Variant Element is used to reroute a train via a variant element where no conflict exists, or where the conflict resolves earlier than on the originally planned train route.

The command Preliminary Level Crossing Closure (PUP) refers to closing a level crossing from the moment the command is issued until the crossing is released by the nearest train after the command was issued. The use of the Preliminary Level Crossing Closure function can be divided into two categories:

a) maintaining the closure of the crossing between the passage of the first train and the movement of the second train,
b) closing the crossing in advance of the nearest approaching train.

The command Individual Point Setting (S+/S–) is considered for adjusting points before it is possible to set a train route. The prerequisite is that the point, or a paired point in a track connection, is not reserved by another train movement. The allowable options for execution are:

a) generating the Individual Point Setting command before the earliest possible moment for generating the train route setting command,
b) generating the Individual Point Setting command at the originally scheduled moment for generating the train route setting command, in which case the route setting is postponed.

Based on the conducted research, the author decided that the Individual Point Setting command should be used exclusively in conflicting traffic situations. In other cases, its use is inappropriate and could delay the illumination of permissive signals by three seconds. Therefore, of the options a) and b) mentioned above, the author selects option a), which is more suitable in conflict situations. If Individual Point Setting were implemented universally, option b) would be more appropriate.

In the final phase of the algorithm, the type of train route to be used is definitively determined. For this purpose, the variables jc and jc1 have been introduced into the algorithm. The variable jc contains train routes set along the shortest path and can take the following values: 0 = no train route, 1 = Train Route, 2 = Train Route with Speed Restriction, 3 = Train Route with Extended Overlap, 4 = Train Route according to sighting conditions. The variable jc1 contains train routes set via a variant element and can take the values: 0 = no train route, 1 = Train Route via Variant Element. If jc1 = 1, the command Train Route via Variant Element is generated. Otherwise, the command to set the corresponding type of train route is generated based on the value of the jc variable.

Figure 2 shows the complete proposed algorithm.

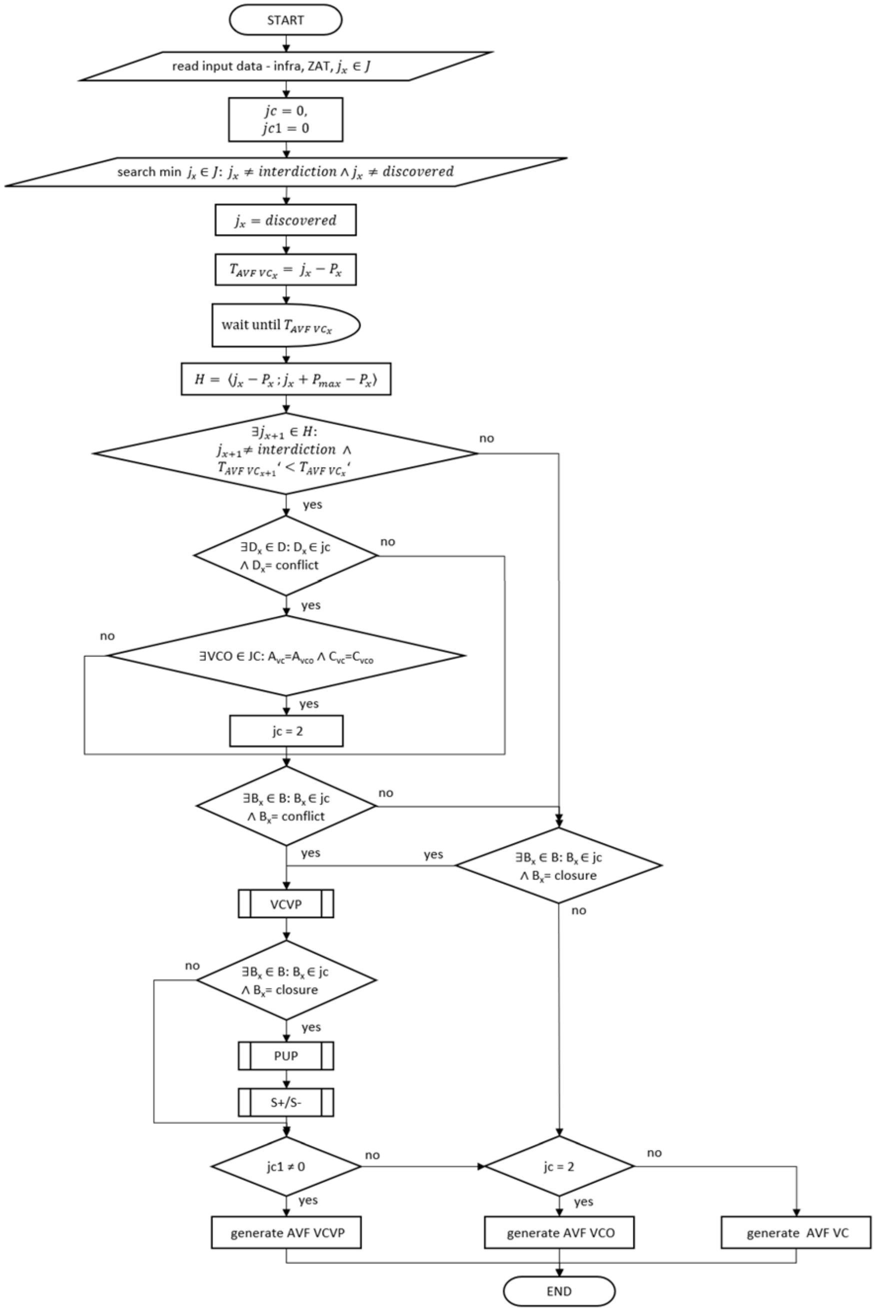

Figure 2: The proposed algorithm

Source: author

5 Verification of the Proposed Algorithm

The verification of the proposed algorithm was carried out through a simulation of operations at Zdice railway station. First, Zdice station was divided into individual elements in accordance with the Method of Merging Points into Elements. Each element corresponds to a single vertex in the network graph. The network graph of Zdice station is in Figure 3.

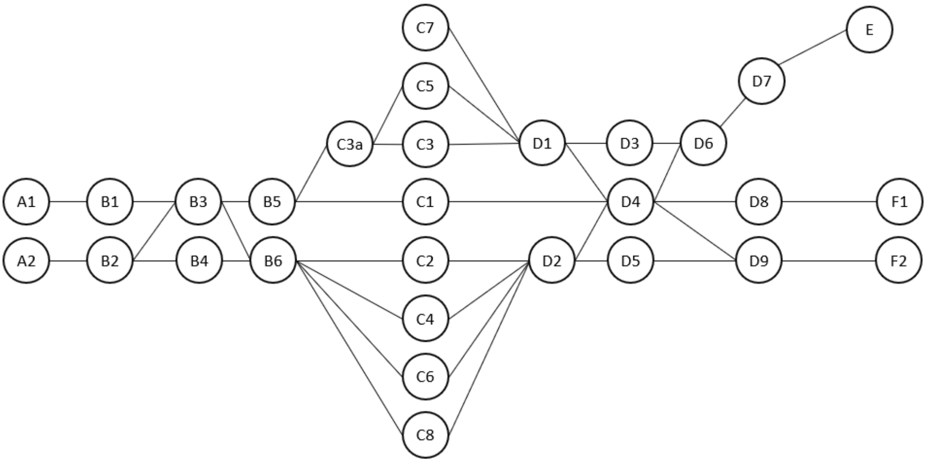

Figure 3: The network graph of Zdice station

Source: author

For each of the listed elements (graph vertices), the total occupation time is evaluated based on the conducted simulation. The simulation was performed in three variants:

- Variant 1 – simulation of the baseline automation state, where Automatic Route Setting executes only the commands Train Route, Request for Directional Control, and Scheduled Departure,
- Variant 2 – simulation of the automation state including the commands Train Route with Speed Restriction and Preliminary Level Crossing Closure (representing a partially insufficient scope of automation),

- Variant 3 – simulation of the newly proposed state, as developed in the design section of this dissertation.

The simulation variant 1 can be considered representative of foreign Automatic Route Setting implementations, as these typically include only the basic Train Route command. The analysed foreign variants of Automatic Route Setting not only lack the commands Train Route with Speed Restriction and Preliminary Level Crossing Closure—which distinguish variant 1 from variant 2—but also generally do not include the commands Request for Directional Control and Scheduled Departure, which are included in variant 1. Therefore, simulation results for foreign Automatic Route Setting variants would likely be slightly worse than for the simulated variant 1. Nevertheless, for the purposes of this dissertation, variant 1 can be regarded as a representation of “pure” Automatic Route Setting without additional support functions.

The simulated variant 2 corresponds to the state of Automatic Route Setting in the Czech Republic in 2025.

The automation of the supplementary commands Train Route with Speed Restriction and Preliminary Level Crossing Closure had a positive effect on minimising occupancy times in the simulated scenario. While in Variant 1 the total occupancy time across all elements amounted to 29,411 s, in Variant 2 this value decreased to 26,380 s, representing a time saving of approximately 10.31 %. The simulation using the newly proposed algorithms for the commands Train Route via Alternate Element, Preliminary Level Crossing Closure, and Individual Point Setting (Variant 3) resulted in an increase in total occupancy time to 26,689 s, which is a rise of 1.17 % compared to Variant 2, but still a reduction of 9.26 % relative to Variant 1. The worst results (highest total occupancy times) occurred in Variant 1 for 24 out of 27 infrastructure elements, and no element in Variant 1 achieved the best result (lowest total occupancy time). In Variant 2, the worst result was observed only for element F2, while the best results were recorded for 16 out of 27 elements. In Variant 3, the worst results were found for elements D4 and D8, whereas the best results were achieved for 11 elements. At first glance, these global results might suggest that the proposed algorithm, as simulated in Variant 3, does not provide the expected benefits for minimising route capacity utilisation, since the current state (Variant 2) shows overall better performance in the simulated scenario. However, a more detailed analysis reveals that the results are not so straightforward.

A more detailed examination of occupancy times involved separating the total occupancy times into direct occupancy times and indirect occupancy times. This distinction provides a clearer indication of the benefits of the proposed algorithm. The greatest contribution to reducing direct occupancy times was achieved in Variant 3, with a total of 5,470 s, corresponding to a time saving of 5.03 % compared to Variant 2 and 13.11 % compared to Variant 1. In contrast, when evaluating indirect occupancy times, Variant 2 proved most advantageous, as it also did for the total occupancy time. This difference is further illustrated by comparing the best and worst results achieved. For indirect occupancy times, Variant 2 recorded the best value 16 times, whereas for direct occupancy times, it recorded the best value only 3 times and the worst value 8 times. In Variant 3, the best value for indirect occupancy times was recorded only 7 times, whereas for direct occupancy times, the best value was achieved 14 times.

The differences in results between the two station yards at Zdice are also noteworthy. While at the Hořovice–Lochovice yard (elements labelled with the letter D and a number) the best results for both total occupancy time and indirect occupancy time were achieved across all elements in Variant 2, at the Beroun yard (elements labelled with the letter B and a number) the best results for total occupancy time and indirect occupancy time are more evenly distributed between Variant 2 and Variant 3. This can be explained by the fact that at the Hořovice–Lochovice yard, only train movements to/from Lochovice pass through level crossing P567, and the benefits of the PUP auxiliary functions cannot be applied to other movements. Consequently, the advantages of the newly proposed algorithm are less visible there. In contrast, at the Beroun yard, every train route passes through level crossing P281 in the yard, meaning that signal lighting delays apply to each route, which highlights the benefits of the newly proposed algorithm more clearly. For the component of direct occupancy times, this distinction does not hold; similar results were achieved at both yards.

The observed discrepancy between the direct and indirect occupancy times on the station yard elements reflects the real benefit of the newly proposed algorithm. The new algorithm reduced the total direct occupancy time by 5.03 % compared to Variant 2. This indicates that the newly proposed algorithm supported smoother train operations. A shorter direct occupancy component means that a train physically occupies a given infrastructure element for a shorter period, and therefore travels faster.

Conversely, when the indirect occupancy time increased under the newly proposed algorithm, this may indicate that:

- it took longer for the moving train to physically occupy the elements of the established train route, i.e., the train route was set ahead of the moving train earlier than in Variant 2,
- or the process of setting up the train route took longer.

The second possibility was immediately ruled out by analysing the train route setting times, which showed that while in Variant 2 the total route setting time amounted to 508 s, in Variant 3 it decreased by 52.95 % to 239 s. Compared to Variant 1, the total route setting time in Variant 3 fell by as much as 72.24 %, from 861 s to 239 s. Conversely, the total time between the route being set and the corresponding signal turning green increased slightly between Variant 2 and Variant 3 by 4.37 %, from 2 382 s to 2 486 s. The overall sum of indirect occupancy times decreased in Variant 3 compared to Variant 2 by 6.06 %, from 2 890 s to 2 715 s. The results of this analysis are presented in Table 15.

These findings indicate that the primary benefit of the proposed algorithm lies in reducing train route setting time. This enables earlier signal clearance for train movement, thereby enhancing the smoothness of train operations. Its contribution to the overall line capacity is more of a secondary effect, predominantly relevant in conflict situations where trains are scheduled with headways shorter than the operational interval; otherwise, the indirect occupancy component may actually increase.

6 Contributions of the dissertation

This chapter presents the most significant findings, which contribute to the advancement of scientific knowledge in the field addressed by this dissertation:

- Routine route setting accounts for 53% of all signalling system operations, while other functions are used only in single-digit percentages.
- The Edit Train Number is the most frequently automatically used function, with an average utilisation rate of 96%, whereas the average utilisation of other commands never exceeds 54%.
- The questionnaire survey revealed that operational staff of the infrastructure manager are also concerned with railway capacity, and they consider the positive impact on line capacity to be the most important criterion in relation to traffic control automation (more important than the frequency of use of signalling functions or the number of interactions required within the control interface).
- Among the analysed factors, the distance from the boundary of the controlled area has the greatest influence on the level of Automatic Route Setting utilisation.

- A higher level of Automatic Route Setting utilisation is observed in smaller stations. Within the analysed sample, it was found that the larger and more complex the station (i.e. the greater the number of running and converging tracks), the lower the level of Automatic Route Setting utilisation. This finding suggests scope for further research aimed at increasing Automatic Route Setting utilisation in larger stations.
- Traffic intensity was found to have only a limited effect on the level of ARS utilisation in the analysed stations (correlation coefficient −0.2058).
- Similarly, the number of train turnarounds per day has only a limited influence on Automatic Route Setting utilisation, despite the fact that Edit Train Number command is the most frequently automatically used command. This indicates that Edit Train Number command is often used independently with other automatically commands deactivated.
- All analysed factors yielded negative correlation coefficients, indicating that Automatic Route Setting is predominantly utilised in less complex operational situations.
- An approach for selecting signalling system functions suitable for automation using the Weighted Sum Approach was proposed.
- An algorithm for identifying operational conflicts at station throats was proposed, together with options for resolving or mitigating such conflicts using Automatic Route Setting.
- The application of the proposed auxiliary commands has a positive effect on minimising railway capacity consumption in traffic conflict situations.
- The benefits of the auxiliary commands were quantified using a simulation scenario based on real traffic operations at Zdice station.
- The use of auxiliary commands reduces track occupation time; the extent of the savings depends on the nature of operations

and the selected simulation scenario (in this case, a reduction of 9–11% of total occupation time and 13.11% of the sum of direct occupation times was achieved).

- In the selected simulation scenario, the proposed commands had a positive impact not only on capacity consumption indicators, but also, and more importantly, on improving train running fluidity and reducing delays (some train movements could be realised up to 5–6 minutes earlier compared to the scenario without auxiliary commands).

Practical contributions of the dissertation outputs are:

- optimisation of route-setting time,
- improved train running fluidity (routes can be set earlier in front of approaching trains, reducing the need for deceleration or stopping at restrictive signals),
- improved train reliability and punctuality, contributing to a more favourable public perception of rail transport,
- increased railway line capacity (smoother and faster train operation allows a greater number of trains to be handled within a given period, while delays can be reduced more effectively).

7 Conclusion

The dissertation first conducted an analysis of professional and scientific knowledge in the field of the study, which indicated, among other things, that the topic of the dissertation is entirely original. At the scientific level, no publication was found addressing this subject. The primary significance of this work and its contribution to scientific research therefore lies in its focus on a largely unexplored area. Consequently, this study may serve as a starting point for numerous subsequent investigations.

The aim of the dissertation (the design and verification of the algorithm) has been achieved. At the same time, the hypothesis "Automatic Route Setting may have a positive effect on minimising railway capacity consumption." was confirmed and not rejected.

References

[1] ŠTURMA, Martin. Digitalisation in Operations Management. Online. In: *Proceedings of the 11th Conference on Communication and Signalling Technology in Railways*. Olomouc, 7–9 November 2023. Správa železnic, state organisation, 2023, pp. 138-142. Available at: https://konferenceszt.cz/wp-content/uploads/2023/11/Konf_SZT_2023_Sbornik_DoplneneVydani.pdf. [accessed 2025-03-17].

[2] AŽD Praha, s.r.o. *Operating Manual – Station Signalling Equipment ESA (Part 4).* 2019.

[3] SPRÁVA ŽELEZNIČNÍ DOPRAVNÍ CESTY, state organisation. *ZTP 5/2000, Basic Technical Requirements – Integrated Operator Workstation (as amended on 26 October 2006)*. 4th edition. Railway Infrastructure Administration, state organisation, 2006. Available at: https://www.spravazeleznic.cz/documents/50004227/50157646/Z

TP+5_2000+JOP/710f52ed-e077-426b-ba55-d59ebea964ce?version=1.0 [accessed 2025-02-28].

[4] SPRÁVA ŽELEZNIC, state organisation. *SŽ Z3: Regulation for the Operation of Signalling Equipment Controlled from an Integrated Operator Workstation*. Prague: Railway Administration, state organisation, 2024. 301 pp.

[5] Signalling system archives.

[6] KUČERA, Petr and ŠTURMA, Martin. The Influence of Auxiliary Commands on the Use of the Automatic Route Setting Function. *New Railway Technology.* Brno: MiS Publishing, 2025, No. 4, pp. 15–18. ISSN 1210-3942.

[7] TESHIMA, Hisanori; HORI, Satoru; SHIMURA, Akitoshi; a SATO, Noboru. Railway track layout modelling and its application to an automatic route setting system. Online. *WIT Transactions on The Built Environment.* WIT Press, 2014, no. 135, s. 75-86. ISSN 1743-3509. Available at: https://doi.org/10.2495/CR140061 [accessed 2024-01-22].

Publications by the PhD student

Publications J_{imp}:

[I] ŠTURMA, Martin; KUČERA, Petr; KRŠÁK, Emil; BACHRATÝ, Hynek a DRDLA, Pavel. The impact of Automatic Route Setting on minimizing the negative effects of traffic conflicts. A manuscript submitted to *Transportation.*

Publications J_{SC}:

[III] KUČERA, Petr and HEŘMÁNKOVÁ, Andrea. The Use of Automation in Rail Transport to Ensure Interchanges in Regional Passenger Transport. *Communications – Scientific Letters of the University of Žilina*. 2024, Vol. 26, No. 4, pp. D82–D91. Available at: https://doi.org/10.26552/com.C.2024.0472022.

[III] KUČERA, Petr; ŠTURMA, Martin; BACHRATÝ, Hynek; and DRDLA, Pavel. Modelling Traffic Prediction at the Direct Level of TMS Systems. Online. *LOGI – Scientific Journal on Transport and Logistics*. 2025, Vol. 16, No. 1, pp. 116–127. Available at: https://doi.org/10.2478/logi-2025-0011 [accessed 2025-09-29].

[IVV] HEŘMÁNKOVÁ, Andrea and KUČERA, Petr. The Importance of Rail Transport for Transport Services in Peripheral Areas. Online. *LOGI – Scientific Journal on Transport and Logistics*. 2024, Vol. 15, No. 1, pp. 13–24. Available at: https://doi.org/10.2478/logi-2024-0002 [accessed 2024-06-11].

Publications D:

[V] KUČERA, Petr a ŠTURMA, Martin. Using the WSA method for ARS application in the Czech Republic. In: Transport Means: Proceedings of the 28th International Scientific Conference. Kaunas University of Technology, 2024, pp. 399–404. ISSN 2351-7034.

[VI] KUČERA, Petr; NACHTIGALL, Petr; ŠTURMA, Martin; and ŠOUREK, David. The Human Factor in the Context of Digitalised Railways. In: *Acta Polytechnica CTU Proceedings.* Paper presented at the conference Reflection of Modern Railways in Education and Research 2025; to be published in spring 2026.

[VII] ŠTURMA, Martin; POLACH, Vlastimil; and KUČERA, Petr. Intelligent Traffic Management Using Automatic Train Route Setting in Slovakia. In: *Transportation Research Procedia*. Paper presented at the conference Horizons of Railway Transport 2025, to be published in spring 2026.

Publications (Jost):

[VIII] KUČERA, Petr and DRDLA, Pavel. A Geographical Method for Automatic Train Route Setting. In: *Scientific and Technical Proceedings of the Railway Administration*. 2020, No. 3, pp. 3–18. ISSN 2694-9172.

[IX] KUČERA, Petr and DRDLA, Pavel. Automation of Railway Traffic Control and Possibilities for Its Optimisation. *Perner's Contacts*. Online. 2023, Vol. 18, No. 1. Available at: doi:10.46585/pc.2023.1.2378 [accessed 2024-01-03].

[X] KUČERA, Petr. Benefits of Automatic Train Route Setting in Basic Traffic Situations. In: *Scientific and Technical Proceedings of the Railway Administration*. 2023, No. 9, pp. 111–124. ISSN 2694-9172.

[XI] KUČERA, Petr and ŠTURMA, Martin. The Influence of Auxiliary Commands on the Use of the Automatic Route Setting Function. *New Railway Technology*. Brno: MiS Publishing, 2025, No. 4, pp. 15–18. ISSN 1210-3942.