THE USE OF AUTOMATION IN RAIL TRANSPORT TO ENSURE INTERCHANGES IN REGIONAL PASSENGER TRANSPORT

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Resume
This paper deals with the use of automation in rail transport to provide transfer links in public passenger transport. The methods of railway transport management in the Czech Republic are presented and their suitability for the use of automation in regional passenger transport is assessed. The authors consider the impact of automation only from a technological point of view. In this paper, the authors propose a modification of the train departure using a layout criterion and time stops to provide transfer links using the Automatic Route Setting System. The authors consider the use of the Real Time Rescheduling considering the traffic on the railway line, as well as the traffic connections of the public line transport. The paper proposes the use of automation software to improve the quality of public passenger transport.

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1 Introduction

Quality public passenger transport is one of the tools for development of regional areas [1]. For the development of the rail passenger transport, research and innovation in key areas such as digitalisation, automation of rail operations, sustainable solutions, safety, and increasing the availability of rail transport services to customers must be continuously pursued [2].

Important factors for regional public transport include, among others, the provision of transfer links, the temporal and spatial continuity of connections, and the minimisation of the number of transfers. Passengers often associate transfers with inconvenience and the threat of missing a connection service. This reduces the competitiveness of regional public passenger transport compared to the car transport [3].

The different modes of public transport should be interconnected, including trains and regional buses. In [4], the authors propose a simulation model to be able to assess the timing of public transport connections in terms of passenger transfer. The model can indicate connections (pairs of trains and buses) with insufficient operational stability (high risk of connection loss). The second important feature of the proposed model is the ability to verify the impacts of possible schedule adjustments (for example, changing the selected service in time) from a comprehensive point of view. This is to prevent that removing one transfer complication does not create a new one. The synchronisation of the public transport connections at the nodes of lines with longer intervals between connections is simulated in [5].

In this paper, the authors propose using the Automatic Route Setting System (ARS) to automatically modify the departure of a passenger train from each transport point along its route. Thus, in the case of delays, it is possible to guarantee transfer links under specified criteria. The links are modelled from the micro-perspective of the transfer and from the macro-perspective of the whole railway line and transport network. The authors' proposal is based on their knowledge of the issues in the Czech Republic.

2 Ensuring regional public transport

According to [6], the provision of regional transport services should be based on the requirements of passengers, the requirements of transport customers, transport authorities, and transport demand modelling.

***Table 1** Guaranteed transfer times at selected transfer hubs in the Pardubice Region*

Line	Connection	Departure	Waiting at the bus stop	Waiting time [min]	Line/train	Connection	From the direction	Arrival
620606	1	14:02	Hermanuv Mestec, nám.	2	620710	23	Chrudim	13:58
620700	101	7:33	Chrudim, aut.st.	6	700703	101	Chroustovice	7:28
840118	104	12:43	Policka, aut.st.	10	Os 15320	x	Svitavy	12:31
620706	15	18:15	Chrudim, aut.st.	5	Sp 1467	x	Pardubice	18:11
700970	47	19:15	Letohrad, aut.nadr.	15	LE 7181	x	Usti nad Orlici	18:58

In the regional public transport, the key elements of quality are, in particular, the frequency of services and their appropriate timing, travel times, reliability and travel comfort [7]. Geographic extent, the range of regional public transport services, and walking distance to stops are cited as other important aspects [8]. The latter is generally longer for the rail stops than for the bus stops due to the routing of rail lines [9].

Another important factor in regional public transport is the number of transfers, the continuity of connections, and the provision of transfer links [10]. The most important factors in the choice of a transfer or non-transfer journey are identified as:

a) travel time,
b) waiting time for transfer,
c) transfer walking time,
d) transfer information,
e) fares,
f) security,
g) comfort [11].

The willingness of public transport users to use connecting routes increases if the continuity of connections for the planned transfer is guaranteed. The travel time is more important than waiting and walking time for transfers, especially for commuters [12]. In the Czech Republic, there are guaranteed connections and specified transfer times at each transfer hub. For example, in the Pardubice Region in the document "Guaranteed transfer times Pardubice Region" [13]. An example of transfer times at selected transfer hubs in the Pardubice Region is given in Table 1.

The second and third rows of Table 1 show the waiting times for transfers between bus routes. The next three rows of Table 1 show the waiting times for train/bus transfers.

The planning is a key process in public transport. Passengers are informed about how best to use the system for their individual travel needs. Carriers offer journey planning apps on their websites or through mobile apps. For a given travel request, these apps usually offer one or more possible routes [14].

The choice of transport mode is also influenced by the delay in public transport connections [15]. A single public transport delay can influence an individual's behavior (e.g., mode choice), especially if the real-time travel information provides advance warning of potential delays. Therefore, riding on time is always one of the most important factors, and the delays are usually negatively associated with passenger satisfaction [16].

Delays or cancelations of individual trains affect the planned journey of passengers. Measures are needed to maintain the passenger satisfaction and ensure efficient operations in the event of an emergency. These measures should lead to a return to scheduled operations and they allow the passengers directly affected to continue their journey, as well. Dynamic passenger guidance in the rail transport is the optimal management of current traffic to transport all the passengers appropriately in the event of a delay/emergency. Through the targeted implementation of demand-side measures, passenger flows on the rail network can be effectively managed. The effectiveness of the chosen measures depends on the acceptance of alternative connections by passengers and the provision of information. However, the most critical factor for optimal management is knowledge of passenger decision-making behavior [17].

3 Tools to automate public transport operations

Equipping the lines with the Automatic Route Setting System (ARS) is necessarily required for the authors' proposal. In this section, the basic tools for implementation, including links to ARS, are presented.

The basic application for operational traffic management is the Traffic Management System (TMS). The TMS application is used by the infrastructure manager's staff for, among other things, the overview and editing of planned traffic (train routes). Some TMSs even allow for the resolution of traffic conflicts that arise. Data from the TMS are used to support the direct level of traffic management [18].

Based on the train path data, received from the TMS, the Automatic Route Setting System (ARS) gives commands to the interlocking to set the train route. The ARS is one of the tools to make more efficient use of infrastructure by automatically generating commands to control the train movements in real time. This will shorten the transfers between trains and, consequently, lead to a more efficient timetable [19]. The dispatcher has the possibility to intervene in the ARS, e.g. by manually changing or modifying the data of the selected train in the TMS if the traffic situation requires it [20].

In the Czech Republic, the ARS is called "Automaticke staveni vlakovych cest (ASVC)". It generates a command to set a departure train route, usually 2 minutes before the expected departure of a train with a stay at a traffic point longer than 1 minute, otherwise 5 minutes in advance. The issue of entry train routes is not the subject of this paper. The user can set the layout criterion (e.g. waiting for another train to pass or waiting until a defined time). The ARS will wait for this criterion to be met before issuing the command to set a train route [21].

Information from the TMS is also transmitted to the train control systems. These are the highest level of automation in train control. There are 5 Grades of Automation (GoA):

- GoA0 - no automation,
- GoA1 - driver leads the train, automation of signaling equipment,
- GoA2 - automation tools control the train, driver supervises their operation,
- GoA3 - automation tools fully lead the train, train driver presents on the train and qualified to intervene in case of emergency,
- GoA4 - train with no human staff present [22].

One of the train guidance systems is the Connected Driver Advisory System (C-DAS), where the Energy Savings and Driving Strategy (ESDS) module calculates the optimal speed profile for the driver to follow [23]. While C-DAS only issues recommendations for driving and braking, the higher level of automation in the form of Automatic Train Operation (ATO) generates driving and braking commands directly to the train without the driver having to confirm the command. The main function of the ATO is to generate a train path that specifies the speed profile on a given route, considering the timetable and the characteristics of the train and infrastructure [24].

In the Czech Republic currently (year 2024) is applied "Automaticke vedeni vlaku" (AVV). This differs from the European ATO over ETCS mainly in that AVV, unlike ATO over ETCS, does not work with actual dynamic data and AVV requires the driver's interaction, who is still responsible for the train [25]. The AVV system will be applied in the Czech Republic on majority of the selected lines, only on the line Kralupy nad Vltavou - Decin state border is the implementation of the European ATO over ETCS is foreseen [26].

A separate section is the possibility of the so-called self-organisation of transport, where the intelligent trains decide on their own journey. Decision making is based on knowledge of the train's own timetable and the ability of the train to interact with other trains in the area (mutual transfer of information about the location and forecast of the next journey). This would eliminate the traffic conflicts and achieve the desired (optimal) traffic development. This model is based on the European SORTEDMOBILITY project [27] and has been published in [28].

These train control system tools achieve the train running prediction in cooperation with ETCS and ARS and thus provide the valid input data for decision making and, at the same time, are able to implement the train running according to plan - thus maximising the benefits of the authors' proposal.

4 Safeguarding and controlling traffic on lines of a regional character in the Czech Republic

The operation of the national and regional railway network in the Czech Republic is controlled according to the following regulations:

- "SZ D1 PART ONE" Traffic and signaling regulations for lines not equipped with a European Train Controller,
- "SZ D3" Regulation for the simplified rail traffic management,
- "SZ D4" Regulation for the control of rail traffic on lines equipped with radio-blocking,
- "SZDC (CD) D40" Prescription for the organisation of rail transport on the lines Liberec - Tanvald - Zelezny Brod; Tanvald - Harrachov; Smrzovka - Josefuv Dul [26].

For application of any of the automation levels, it is necessary to equip the lines and stations with electronic signaling equipment. At 31 December 2022, 7.389 km of lines (out of 9.355 km) and 459 transports (of which 360 transports were included in the DOZ - remotely controlled signaling equipment) met this requirement in the Czech Republic [29].

The application of automation tools is currently (2024) not possible on lines controlled according to the "SZ D3" regulation due to the absence of station and line signaling equipment. On 7 July 2020, a collision of two passenger trains occurred on the line Nejdek - Potucky controlled according to the "SZ D3" regulation (2 persons killed, 22 injured, damage over 1 million EUR). The contributing factor to the accident was found to be, among others, the absence of signaling equipment that would eliminate the possible failure of the human factor [30]. For this reason, the Railway Administration developed a concept aimed at preventing similar incidents. The concept proposes 4 solution options (options 0-3). In variant 2, the implementation of ETCS on lines controlled according to SZ D3 is foreseen. In variant 3, it is foreseen to transfer the control from the "SZ D3" to the "D1" regulation with the addition of category 3 signaling equipment, including ETCS and DOZ [31]. Out of a total of 1.751 km of lines controlled according to the 'D3' regulation, it is assumed that variants 2 and 3 will be applied on up to 1.231 km of lines [32]. Therefore, an increase in the proportion of lines suitable for application of automation of selected activities can be expected.

For the regional character lines in the Czech Republic, the use of ETCS LS STOP for lines with less than 45 trains/day or ETCS L1 LS for busier lines controlled according to the D1 regulation is considered [33]. According to [34], the increase in safety in these lines in the Czech Republic is estimated at 296 million EUR.

5 Modelling the transfer links in the railway traffic control automation

The authors propose that the ARS function will automatically modify the departure of a passenger train from each point on its route. Modifications will be allowed only with a positive increment of the departure time, i.e., delay of the train compared to the regular timetable; departure of passenger trains with a headway is not allowed with respect to the timetable. The train departure time so adjusted must be respected:

- arrival times of connecting public transport connections (train and, within the integrated transport system, bus connections),
- the minimum transfer time at the interchange hub,
- the maximum waiting time at the interchange hub,
- the arrival time of the oncoming delayed service at the crossing,
- time stops (suggestions from the authors of the paper).

The resulting system proposed by the authors combines 2 distinctive levels, the solution of transfers within the interchange and at the same time it also respects the traffic in the surrounding transport network, so that more important interchanges are not disconnected elsewhere, or there is no unwanted transfer of train delays on the single-track line.

5.1 Micro view - interchange hub

The authors' proposed system must respect minimum transfer and waiting times at each interchange. Waiting time in railway transport in the Czech Republic is determined for each station by the "Connections between passenger trains" [35]. In the case of the integrated transport system, waiting times are set at selected transfer points and connections are guaranteed, for example, in [36].

The authors consider automatic departure modification if inequality (1) is satisfied; otherwise, a dispatcher decision is required.

$$\max(A) + t_{IT} \leq t_{WT}; \ A \in \{1;n\}, \quad (1)$$

where:
A is the set for the arrival times of connecting links [number],
n is the number of incoming connection connections [number],
t_{IT} is the transfer time [minutes],
t_{WT} is the waiting time [minutes].

Figure 1 shows a train waiting (in black) at a

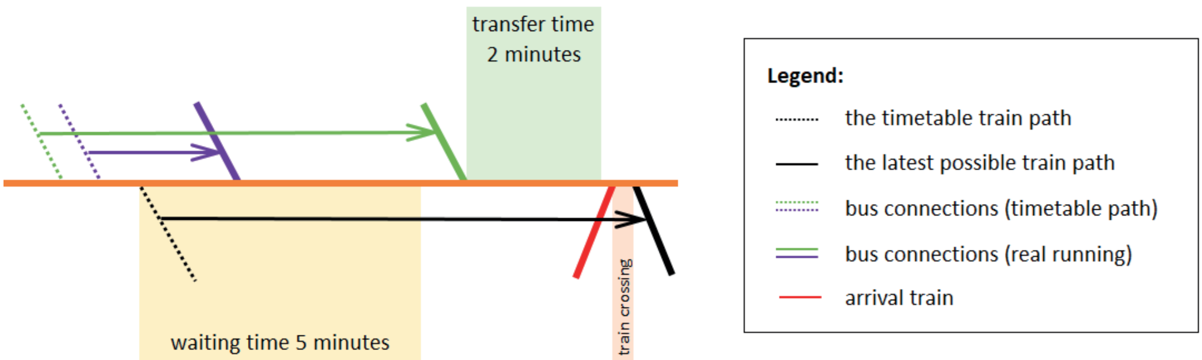

Figure 1 *Train path shift on departure from a transfer junction while maintaining all the transfer links and train crossings on a single-track line*

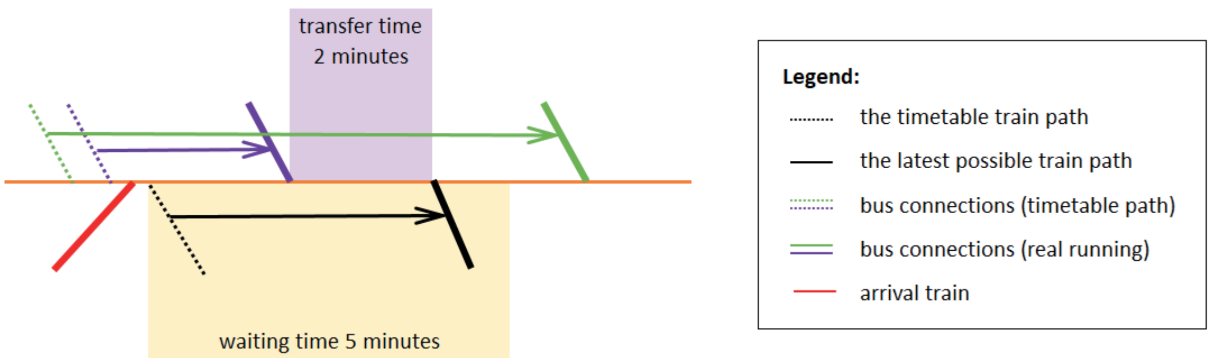

Figure 2 *Shifting the train route while maintaining part of the transfer links*

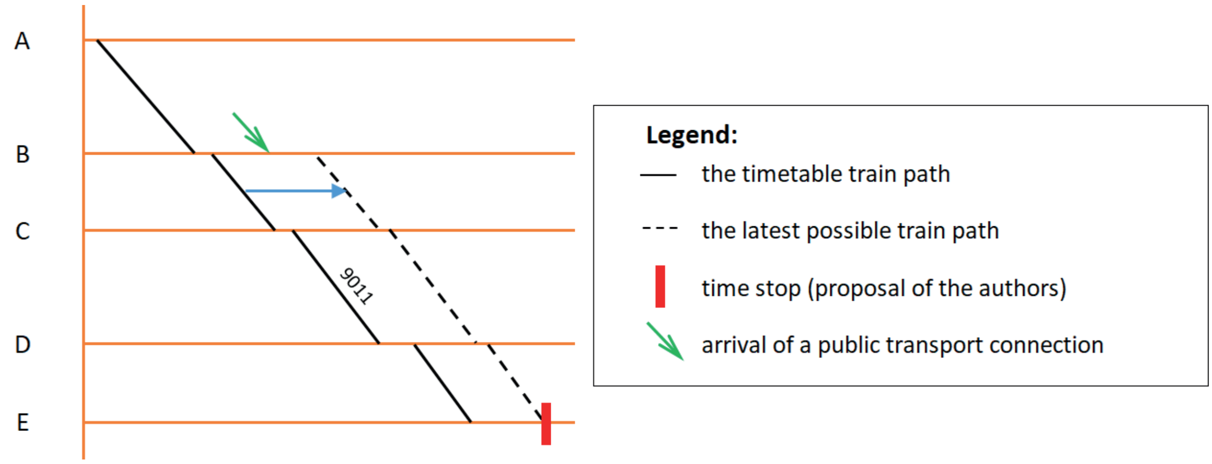

Figure 3 *Modification of the train route while maintaining the transfer link and the time stop*

fictitious interchange for a connecting line transport service. Even the transfer from the green line beyond the 5 minutes waiting time is maintained when waiting for a delayed oncoming train (in red).

In contrast, Figure 2 shows that the transfer from the green connection of public line transport is not maintained when the coming train is on time (in red), as the waiting time is not met. Thus, the black train only waits for the slightly delayed purple public line transport service connection.

Information about waiting for a delayed connection must be known at the transfer station before the ARS instructs to set the train route (in the Czech Republic, depending on the length of train stay, either 2 minutes or 5 minutes in advance). If this information arrives, then the authors propose to insert an appropriate layout criterion in the TMS for the train departure from the transfer point, which would adjust the train departure time to meet the required continuity.

5.2 Macro view - the whole railway line or transport network

When automatically editing the departure time from a transport point, it is necessary to consider the possible consequences on the line or on the entire public passenger transport network. The authors propose the creation of a "time stop" that defines a time condition that takes priority over the preservation of other links. Train routes are edited in an attempt to preserve passenger transfers and no route may exceed the defined time stop. This time stop can be the latest arrival time at a central interchange hub (e.g., an integrated timetable interchange hub) to preserve all the connections to the backbone lines, or, e.g., the latest arrival time to catch the start of school.

The dynamic prospective traffic modelling is designed by the Real Time Rescheduling using the ARS layout criteria. The inputs to the model are the initial timetable of each train service, which has a well-defined route, and the current location and timetable of the connecting public line transport services. The route modification must respect all the constraints based not only on the train parameter, but on the transport network, as well. Especially on single-track lines, the capacity constraints of the single-track section are crucial, as can be seen from [37].

In the Czech Republic, the principle of Real Time Rescheduling together with ARS was used in [38]. It assumes that the current location of the delayed connection is known and that the expected arrival to the transfer point will be calculated from this location and the forecast of the next journey. According to this value, the prospective traffic will be modified to ensure interchange connectivity while avoiding unwanted traffic conflicts on the railway line (especially on a single-track line). If a traffic conflict arises, it must be identified and resolved immediately [39]. The resolution of traffic conflicts within the Real Time Rescheduling is presented in [38]. In contrast to [38], the authors work exclusively with the adjustment of train stays at traffic points; in [38] the modelling of travel times according to a set of variables is also considered. These variables often cannot be quantified in traffic until the last moment, and then the proposed model might not provide valid results. The relationship between the Real Time Rescheduling and ARS (including the consideration of constants for signaling equipment operation) is published in [40].

Figure 3 shows a possible shift of the train route to meet the condition of maintaining the time stop and at the same time to maintain the transfer link from the delayed public service connection at station B. The delay can be achieved due to the time margin at station E and due to the shortening of stays at the connecting stations. The connection from the delayed public service connection will therefore be maintained.

Modifications of the train paths must also consider technological times (for example, operating intervals or minimum turnaround times at the destination station). Figure 4 shows an illustrative example where, due to

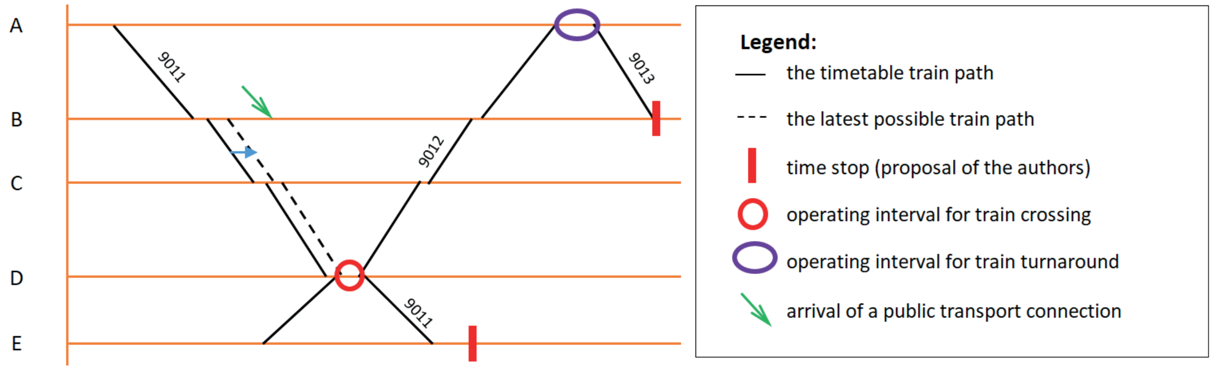

Figure 4 *Possible modification of the train route if time stops are preferred without providing a connection link*

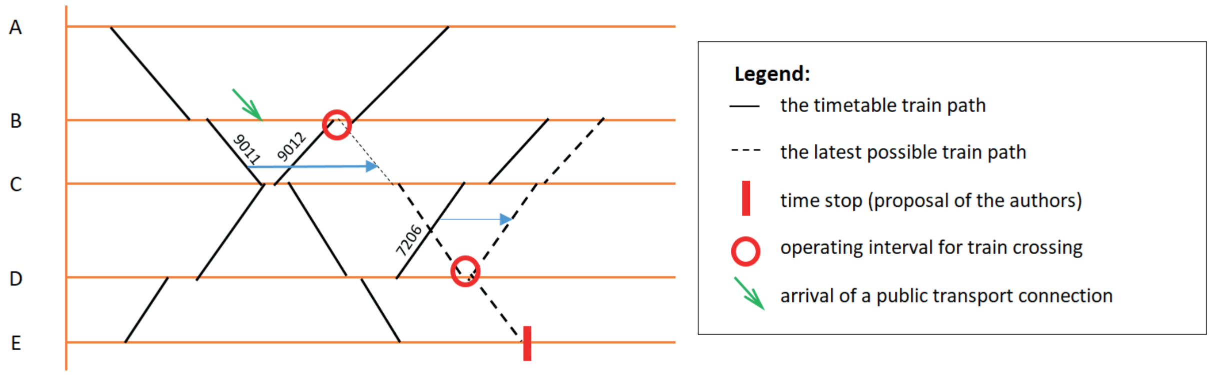

Figure 5 *Modification of the train route while maintaining the coupling with a train crossing relocation on a single-track line*

the need to run train 9012 on time, it is not possible to provide a connection at station B from the public line service to train 9011. Train 9012 at station A turns into train 9013, which cannot be delayed due to the set time stop, and at the same time the crossing of trains 9011 and 9012 cannot be rescheduled because the time stop of train 9011 at station E would not be respected.

If the time stops are not violated, then it is possible to delay the oncoming train or to transfer the crossing to an adjacent station with a track branching that allows the crossing of trains. An illustrative example is given in Figure 5, where the crossing of trains 9011 and 9012 is moved from station C to station B, while the train 7206 is delayed while maintaining the crossing with train 9011 at station D. The delay of train 7206 is possible as there is no time stop for this train.

The detected train departure value will be incorporated into the TMS using the ARS layout criterion. By incorporating the layout criterion, the train route will be adjusted in all operational applications, and the delayed train route will be known in advance and can be reacted to. The calculation presented by the authors works only with the possibilities of reducing stays at the transport stations or with crossing overlays. These tasks can be solved automatically by the ARS function without the application of additional automation software.

Reduction of journey times in intermediate sections is only possible with the ERTMS, which works with additional data - e.g. the current speed and position of the train, train parameters, etc. This makes it possible to calculate in an informed way that the train will reduce the journey time. Thus, it is possible to use the algorithm presented in [40], which depends on the detection of the current train position (continuously, or at least cyclically detected, train position at short intervals, for example, 30 seconds).

The ARS function itself does not know the current speed and traction characteristics of the train; the position can be determined at least approximately from the signaling equipment according to the occupied track section, but the exact kilometric position within the track section is not known. If the track sections are so short that a moving train occupies the next section at short intervals (e.g. every 30 seconds), then the conclusions of [41] can be considered even for the ARS alone without ERTMS, where the application of the Real-Time Rescheduling had positive benefits on the path capacity indicators, as well. Figure 6 shows a simplified block diagram of the authors' proposed methodology.

The output of this paper can be used in the Czech Republic for example on the line No. 183 Klatovy - Zelezna Ruda-Alzbetin (commuting to Klatovy, connection to Pilsen, connections in Janovice nad Uhlavou, ARS is applied). After adding the ARS it can be used for example on the line No. 194 Ceske Budejovice - Cerny Kriz (commuting to Ceske Budejovice and train connections there, bus connections in other stations).

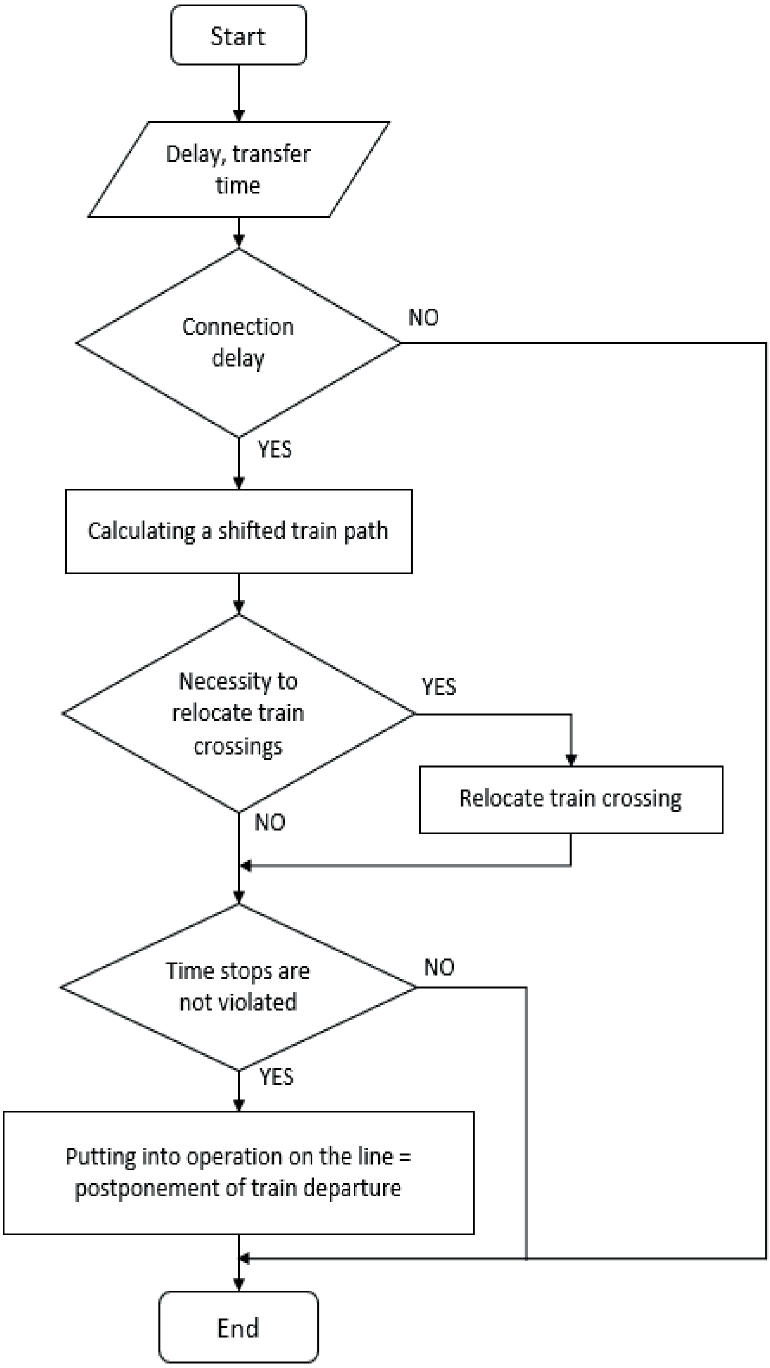

Figure 6 *Block diagram of the proposed methodology*

6 Conclusion

Providing the reliable transfers is an important factor in encouraging the public to use public transport. This is particularly important in remote regions, where the frequency of public transport services is usually lower, and missing a connection would mean a long wait for the next service. Therefore, when the delays occur, it is necessary to coordinate rail traffic with the operation of public transport services to maintain maximum transfer links according to the planned timetable.

The authors come up with a proposal for automatic provisioning of transfer links in an autonomous railway tool environment with emphasis on the Automatic Route Setting System (ARS). They propose a methodology for when the ARS will preserve a planned transfer link and when it is appropriate to break the transfer link to avoid losing other (more important) links. The authors propose the creation and use of the time stop, which represents the highest level of decision criterion - the time stop can only be violated exceptionally after the intervention of the dispatching apparatus.

The proposed methodology works exclusively with the modification of the stays of public transport connections at the transport points and the change of the train running order, as these modifications can be done with only the knowledge of the timetable and selected time constants (transfer and waiting times). In the second stage, it allows the use of other automation tools for modelling the journey times, for which it is necessary to know other input data (traction characteristics of the train, etc.).

The proposed methodology would allow for the selection of the optimal option to ensure maximum transfer links. At the same time, essential supra-regional transfer links would be maintained, and commuting to centres would not be delayed (e.g., with regard to the start of school). For these essential criteria, the authors foresee the use of the time stop. The proposed measures would increase the quality and attractiveness through reliable connections even when the regional public transport links are delayed.

The outputs of this paper support the provision of transfer links in peripheral areas where this is particularly important with lower frequency services. When a public transport connection is delayed, according to the proposed algorithm, it is decided whether the connection would wait for the arrival of the delayed connection or not; whether the possible waiting would not cause more problems elsewhere. Other aspects in the network are taken into account (e.g. crossings on single-track lines, access to the centre of the region, etc.). In practice, the outputs would enable automatic updating of dynamic prospective transport, which are a prerequisite for further decision-making by dispatchers. The authors will further discuss other aspects of the public transport system in peripheral areas and the external influences (delays, transfers, etc.) on operations on lines with a degree of automation of routine operations.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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