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Human Resource Efficiency in Sustainable Railway Transport Operation

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Abstract: This manuscript deals with research in the field of human resource efficiency in the operation of railway transport, which is currently a very actual and important topic. The correct efficiency and organization of the work of employees in railway operations have a significant impact on sustainable railway transport and the sustainable functioning of the transport sector. This research investigated two fundamental principles of railway transport operation control: local control and remote control. Local control involves physically managing transport processes from a traffic office within the station, with a focus on direct supervision. In contrast, remote control, which relies on optical cables, allows for system operation even during malfunctions. The article compares these control methods from technological and economic perspectives. Notably, local control requires a larger number of qualified employees, impacting efficiency. This research reveals that remote control, facilitated by a relay room and traffic office at each station, enhances teamwork, providing an immediate response to situations and enabling dynamic operational adjustments. Moreover, the article assesses the required personnel for optimal staffing, considering factors such as track configuration, departing trains, and reporting district size. Economic indicators, particularly wages, show significant savings with remote control, impacting stations with excluded passenger movement more pronouncedly. The findings highlight the efficiency and economic advantages of remote control in railway transport. The specific contribution of the research to the sustainability of transport and sustainable rail transport is presented in the discussion of the manuscript.

Keywords: railway transport; sustainable operation; local control; remote control; traffic safety; efficiency

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1. Introduction

There are two basic principles of railway transport operation control. The first is called local control. It is a method of traffic control when the interlocking system either does not allow for remote control or permits remote control but is locally operated for operational and technological reasons (exclusion, retention of knowledge, etc.). Local control can be applied to all categories of station and line interlocking systems. In the case of local control, as the name implies, the supervision of transport processes is conducted through the physical occupation of transport points (stations) by specialized personnel. The necessary number of specialized employees is determined based on the type and complexity of transport or local work in the transport department. Finally, the number of employees is also influenced by the interlocking system category at each station.

The second way of control is called remote control and it is a totally different way of railway transport operation in comparison to the previous one. Remote control cannot be implemented for the first and second categories of the interlocking system. This limitation arises from the need to staff stations with rail branching by specialized employees. The third category of the interlocking system typically allows for remote control, but specific conditions regarding stretched optical cables must be met, including the requirement for enough circuiting. The rounding of the optical cable occurs when the integrity of the optical cable is compromised. This feature facilitates data transfer over another branch, thereby ensuring the safety of railway traffic. The disadvantages and advantages of remotely controlled stations are the opposite of locally controlled stations, as discussed above. This research is focused on the comparison of these types of controls from a technological and economical point of view.

The increasing requirements for traffic safety in railway transport due to the issue of rational decision-making in the management of applied device operation processes is becoming more and more important. The most difficult operational decisions that consider safety requirements in the railway transport system are those that need to be taken with information considering the technical conditions of the system facilities, as well as the possibility to implement maintenance and reparation activities [1].

Safety production is an eternal theme of railway transport. The implementation of standard operations by railway employees should be strengthened, for it is a central task of basic rectification and construction for railway safety. However, there are still some prohibited phenomena in the on-site operations conducted by employees of some units, such as "breach of regulations and violation operations", which is threatening the production safety of railway transport. Violation operation is the main cause of accidents [2].

The safety of railway transport is directly influenced by transport performance, determined by the number of passenger and freight trains. Decreasing the transport volume in railway transport is influenced by several factors. The most important factors are strong competition from road transport, higher costs and prices in rail transport, the non-flexibility of rail transport, and others [3].

Railway transport is generally connected to the mobility of people and goods; therefore, operation technology influences the economic indicators of an area and the way of control can influence it too. Railway transport is one of the important aspects that, on the one hand, contributes to the economic development of a region, but on the other hand, can reduce the quality of life with a disproportionate use of transport modes, mainly in larger agglomerations. In the view of society, regional transport is an important contribution to improving the quality of life of the citizens in the region, as well as its competitiveness and the optimal use of public resources [4].

It is also necessary to consider all extraordinary situations and ways to sustain operation. It is necessary to deal with the operation of the remote-controlled railway section during a crisis in a situation when it is necessary to personally visit and service all the stations. For this purpose, the heuristic method algorithm is used to find the minimal time to service the railway section and how to allocate and deploy the service staff (dispatchers), including basic modifications to this decision-making problem [5].

The introduction of the article focuses on a broader approach to railway operation, from which specific hypotheses can also be formulated.

Hypothesis 1. *Remote control of railway traffic operation leads to a significant reduction in workforce requirements compared to local control, without negatively impacting operational efficiency.*

Hypothesis 2. *Railway stations with remote control systems require fewer physical staff but must maintain a minimum presence due to specific operational and technical factors, such as track configuration, the number of regular train departures, and the need for passenger assistance.*

Despite the absence of explicitly formulated hypotheses, the advantages of remote control in railway operations are confirmed throughout the research, with limitations and constraints also being mentioned. The results, based on the application of the methodology within a case study on a specific railway line, provide exact outcomes, such as the reduction in the number of employees needed for operation control and the associated cost savings for the infrastructure manager.

2. Materials and Methods

As a follow-up to the above-mentioned resolved issue, it is important to be inspired and take into account important publications that deal with research in the field of railway transport and transport processes. It mainly concerns the transport system of railway passenger transport and the concept of transport service [6–10], as well as the issue of railway infrastructure capacity, including optimization, modeling and simulation processes [11–13]. Publications [14,15] contain other important and useful information regarding the modeling of transport processes and infrastructure. The issue of human resource efficiency in railway transport operation, which has not yet been dealt with in detail, is closely related to the mentioned publications. Therefore, it is necessary to deal with it in detail, precisely in connection with the current research in this area.

To begin with the mentioned issue, it is necessary to determine the advantages and disadvantages of both types of controls. The advantage of local control is certainly the physical occupation of stations. Although this has no direct benefit for the flow of traffic, it proves advantageous in resolving situations arising from traffic. Thanks to this, the specialized employee in the given traffic room can manage trains with written orders and visually check them. Furthermore, they can check track clearances or provide information to passengers. The transport employee can also ensure the smooth transfer of passengers to alternative, usually bus transport, and organize it accordingly. In the case of registered transport, they can report or record the departures and arrivals of alternative transport services in transport documentation.

Furthermore, they can perform emergency service using the emergency service board if it is installed in the given transport hall, thereby ensuring an earlier restoration of operation in the given transport hall. The disadvantage, which has become much more apparent in recent years and contributes to the decline of this style of control, is the number of professionally qualified employees required for this type of control [16–24].

Local control is a method of train regulation in which operational staff coordinate the movement of railway vehicles directly from the traffic office within the specified control area. One notable drawback of this approach is its impact on traffic fluidity. With local control, the operational employee generally has only a limited view of the traffic situation in neighboring transport facilities, rather than a comprehensive one. Typically, the primary tool available to personnel for monitoring traffic in adjacent areas is the Train Track Position application. This application displays the completed traffic schedule on the left side of the screen and anticipated movements on the right, with a green line indicating the current time, as shown in Figure 1.

Nevertheless, a limitation of the application is that train position data are updated with a 180 s delay rather than in real time. Another significant shortcoming is that local control staff lack access to information regarding signal changes, track occupancy, safety indicators, and faults or failures at neighboring stations. These limitations are compounded by the fact that communication among operating staff across different stations occurs in real time but relies solely on telephone calls. This reliance on phone communication can make explaining and understanding operational issues more challenging, requiring more time than if dispatchers were in a shared room and able to address problems collaboratively. As a result, in any non-standard situation (such as reverse direction running, staff redeployment, exceptional incidents, equipment faults, system failures, lockouts, active safety labels, or delays for connecting trains), such information must be relayed immediately, necessitating timely phone notification to operating employees at the affected stations.

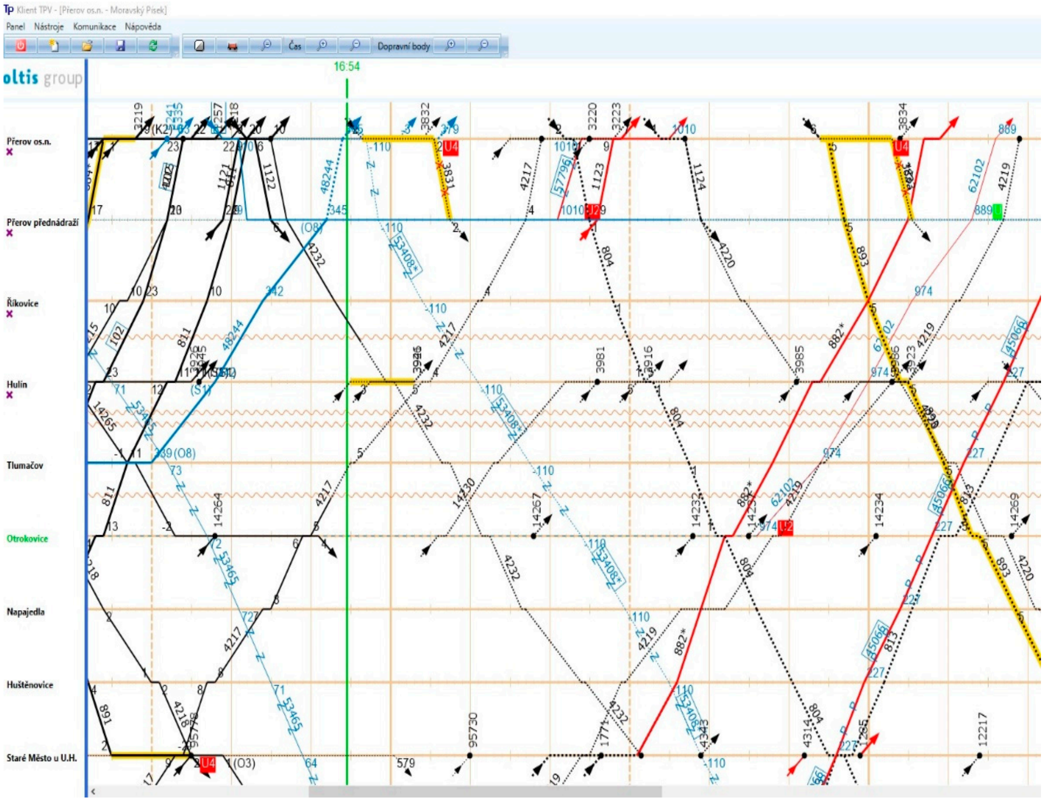

Figure 1. Train Track Position application. * used for a train that does not run every day.

Given the high frequency of actions required by both standard and exceptional operational situations, telephone communication of updates on specific conditions within each transport facility is typically omitted. This leads to misconceptions at nearby stations regarding the operational status of the affected station, a misunderstanding worsened by the outdated application, which displays train positions with a delay. Moreover, information noise increases since certain aspects of rail operations, such as shifting, track occupancy, or delays while awaiting connecting services, do not always require reporting to adjacent stations. These issues are evident on two-track, locally controlled lines, where each station often reserves one track for one direction and the second for the opposite, as shown in Figure 2. Additionally, unused time slots—denoting free capacity along the transport path—are frequently overlooked due to delays in information sharing and the need to provide detailed explanations to uninvolved service employees at secondary locally managed stations.

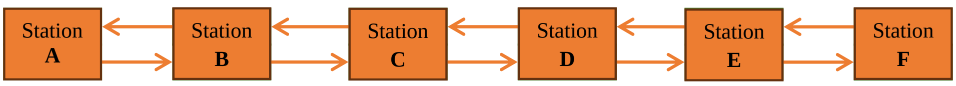

Figure 2. Simplified scheme of line operation via local control.

During remote control, as a rule, a relay room and a traffic office are in each transport hall with rail branching, enabling the operation of the interlocking system not only in the case of malfunctions, but also during standard interlocking system operations. The exact time positioning of trains, shown on the graphic–technology interface, track layout panel at the workplace, or large-scale display, provides a cohesive view of all non-standard situations in the control room. These elements become particularly evident on two-track, remotely controlled lines, where each transport facility uses both tracks' flexibly for each direction, as illustrated in Figure 3.

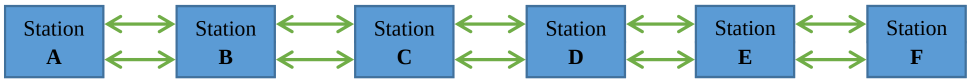

Figure 3. Simplified scheme of line operation via remote control.

The added value is found in the collaborative work within the monitored area at each control center, enabling immediate responses to situations and the flexible adjustment of control zone boundaries. Moreover, every dispatcher in a control room is engaged within a unified problem-solving approach, which supports effective resolutions through teamwork and agile responses. As a result, the extended process of relaying information and precisely describing traffic conditions to non-involved personnel in adjacent transport facilities becomes unnecessary.

A combination of exact train timing, shown on the graphic–technological interface or the track relief display at the workstation, along with monitoring one or more adjacent transport nodes (stations) at the entrance boundary of the controlled area, provides a full overview of any non-standard situations occurring in the controlled section. These elements manifest on two-track section-controlled lines such that each transport company within each controlled area utilizes both tracks at each direction. However, similar to local control, the same operational phenomena typically emerge at the edges of controlled areas, as illustrated in Figure 4.

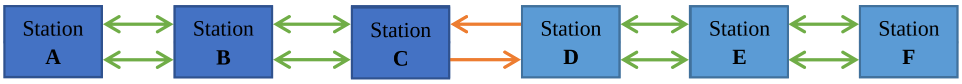

Figure 4. Simplified scheme of line operation via separated remote control.

Teamwork within the controlled area can add value, but it can never achieve as significant a synergistic effect as with remote control because the size of the controlled area is never as extensive and there are not as many track/section dispatchers. This aspect manifests itself in the inability to change the sizes of the managed areas operatively. Furthermore, a problem arises when transmitting information. This phenomenon occurs when communicating and explaining the problem to other dispatchers, as all dispatchers are not in one place, i.e., they are not part of the given problem and cannot effectively solve it as a team and react to it dynamically [25–28].

In ongoing research, which focuses on exploring the efficiency of human resources in railway transport operation, the insights provided in the conference paper named *A Conceptual Model of Human Behavior in Socio-Technical Systems* could be highly pertinent. The paper discusses the investigation of factors influencing failures due to human error, highlighting the development of human reliability analysis (HRA) methods to quantify the probabilities of human error. Particularly relevant is the emphasis on dynamic HRA methods, designed to address the shortcomings in modeling the dynamic nature of human performance. Given the interest in evaluating the effectiveness of different control methods in railway operations, understanding the factors influencing human performance within socio-technical systems becomes crucial. The system dynamics approach proposed in the abstract offers a valuable framework for elucidating the relationships among these factors, potentially informing our analysis of the impact of control methods on human resource efficiency in railway transport. By leveraging insights from the paper, the understanding of the complex interplay between human behavior and operational dynamics in railway systems can be enriched, contributing to more comprehensive and nuanced research outcomes [29].

In the current research endeavor, which is centered on examining the resilience and reliability of railway systems in the face of disruptions, the insights provided in the paper named *An Adaptive Resilience Approach for a High-Capacity Railway* are highly relevant. The paper discusses the analysis of events as systems, particularly focusing on complex systems and their qualitative and quantitative behavior. Given the focus on evaluating the efficiency and reliability of railway operations, understanding the concept of resilience, defined as a system's ability to resist, adapt, and recover from unpredictable events, is paramount. The study's emphasis on resilience within railway networks, known to be more vulnerable to disruptions compared to road systems, aligns closely with our research objectives. Specifically, the investigation of a high-capacity railway section in the event of a breakdown offers valuable insights into system recovery and operational reliability. The proposed methodology, which involves a simulation-based model to quantify system recovery and evaluate the resilience indicator (RI) across the entire railway line, holds significant promise for our research. By examining the impact of various decisions on system maintenance and comparing the results with acceptability thresholds, as outlined in the paper, the understanding of railway system resilience and reliability is enhanced. Leveraging the formalization methodology described in the paper, which utilizes fundamental knowledge of system functioning and malfunctioning, can enrich the analysis and contribute to more robust research outcomes [30].

There are also many manuscripts and publications that contain specific and unique information from the mentioned area and which can serve as inspiration for comparative analysis with our new research. In the paper [31], research was carried out in a transport system of an international transport company. An MCDM model was created for the purpose of human resource evaluation, on which the overall efficiency of the company depends. A total of 23 drivers were evaluated based on five crucial criteria in order to increase employee motivation through their periodic remuneration. The full consistency method (FUCOM) was applied to determine the significance of the criteria, while the evaluation of potential solutions was performed using Measurement Alternatives and Ranking according to Compromise Solution (MARCOS). After the results were obtained, the created model was validated through comparisons with seven other MCDM methods. The article [32] presents a methodical advancement which enables finding risk factors to transport companies in the HR field, and determines their significance and impact on the economic results of the company. Timely detection risk ability, importance assignment of individual risk factors and the subsequent division into risk groups will allow for determining appropriate measures that will help reduce the risk to a predetermined level or eliminate risk causes, and thus reduce the enterprise risk overall to enable flexible response to changing market conditions and increase company competitiveness. Very important and interesting outputs and progressive ideas are contained in the contributions [33,34]. These contributions were the motivation to move the issue of human resource efficiency to a higher professional–scientific level and, at the same time, apply it to the operation of railway transport. This is exactly what scientific research activities and their results in this contribution are aimed at.

3. Results

For the quantitative analysis, the section of railway line 330 Přerov–řeclav between Staré Město u Uherského Hradiště and Přerov was selected. The stations in this section are located on a double track, and an electrified line equipped with third-category line and station signaling systems, allowing for remote operation. This section comprises eight stations and spans a length of 43.7 km.

The input data for the quantitative analysis were gathered from the period between 24 May 2021 and 24 June 2021, always between 10:50 and 15:00. From the collected data, representative trains were identified which enter the "entry boundary". The entry boundary refers to the station where trains enter the analyzed section of the line. The entry stations are therefore Přerov přednádraží, Otrokovice (from the Zlín Malenovice station), Hulín (only from the Kroměříž station, as all trains from the Třebětice station either terminated at Hulín or continued to Kroměříž during the observed period; thus, this direction was not considered), and Staré Město u Uherského Hradiště. A section of the railway infrastructure map with a marked railway line is shown in Figure 5.

Figure 5. Analyzed section showed on the railway map.

The following principle was applied to all trains passing through the observed section. If a train entered (either departs or passes through) the station Přerov, Hulín, or Otrokovice, it continued to the station Staré Město u Uherského Hradiště. Conversely, if a train entered (either departed or passed through) the station Staré Město u Uherského Hradiště, Otrokovice, or Hulín, it continued to Přerov. This principle did not apply to passenger trains numbered 14256, 14225, 14260, and 14261, which run only between Otrokovice and Hulín, or in the reverse direction, and continue onto connecting lines. Furthermore, this principle did not apply to freight trains in specific operational situations.

Passenger trains were subject to the proposed one-phase analysis. This proposed analysis only examined the delay value the train had upon departure or passage through the given entry station. This is because passenger trains, apart from one service, maintained the same composition throughout the entire observed period. Background for the further analysis are data from the Table 1.

Table 1. List of the analyzed trains.

Train Number	Locomotive	Weight [t]	Length [m]	Speed [km·h^{-1}]	Notices
103	1216	400	152	160	
130	380	377	150	160	
131	380	400	150	160	
807	661	-	133	160	
808	661	-	133	160	
809	661	-	133	160	
810	661	-	133	160	
886	193 D	500	170	160	
887	193 D	385	170	160	
888	193 D	500	170	160	On Friday length 195 m
889	193 D	500	170	160	

Table 1. *Cont.*

Train Number	Locomotive	Weight [t]	Length [m]	Speed [km·h^{-1}]	Notices
1235	480	-	90	160	
1238	480	-	90	160	
4209	362	150	95	140	
4210	362	150	95	140	
4211	362	150	95	140	
4212	362	150	95	140	
4213	362	150	95	140	
4214	362	150	95	140	
4216	362	150	95	140	
4233	362	150	95	140	
14223	814	-	57	80	2 units
14254	814	-	57	80	2 units
14260	814	-	29	80	
14263	814	-	29	80	

Table 2 was created based on the data obtained from the analysis of passenger trains that regularly entered the monitored stations during the observed period. Each train was monitored daily at the entry station, and its delay was recorded. From the collected data, the median delay was calculated and this median was added to the scheduled entry time of the train at the entry station, resulting in a standardized entry time. This standardized entry time served as an independent input value for comparing the different control methods (remote and local).

Table 2. Overview of the trains and median inputs.

Train Number	Regular Input	Median	Typical Input
103	11:49:00	9	11:58:00
130	12:38:30	1.5	12:40:00
131	14:49:00	12	15:01:00
807	11:58:00	0	11:58:00
808	13:24:00	2	13:26:00
809	13:58:00	0	13:58:00
810	11:24:00	3.5	11:27:30
886	13:31:00	5	13:36:00
887	11:52:00	12	12:04:00
888	11:31:00	4	11:35:00
889	13:52:00	4.5	13:56:30
1235	12:25:00	1	12:26:00
1238	14:19:00	0	14:19:00
4209	11:25:00	3	11:28:00
4210	11:34:00	4.5	11:38:30
4211	13:25:00	3.5	13:28:30

Table 2. *Cont.*

Train Number	Regular Input	Median	Typical Input
4212	12:45:00	0.5	12:45:30
4213	14:25:00	6	14:31:00
4214	13:44:00	3	13:47:00
4216	14:39:00	5	14:44:00
4233	12:30:00	1.5	12:31:30
14223	12:20:00	3.5	12:23:30
14254	11:19:00	0	11:19:00
14260	13:12:00	2	13:14:00
14263	14:23:00	4.5	14:27:30

For freight trains, during the monitored period, the entry time into the station, and the type of train (Nex, Pn, Lv, and residual capacity trains), as well as train length, weight, maximum speed, and locomotive class were recorded. Based on these data, a two-phase analysis was conducted. In the first phase, the number of trains entering the selected stations at the monitored time was observed. From this part of the analysis, the average number of freight trains entering each entry station was calculated. Weekends were excluded from the calculation of the average due to the lower intensity of freight train traffic. This result was then rounded to whole numbers. Table 3 shows the outcome of the first phase of the freight train analysis.

Table 3. Background for the second-phase analysis.

Train Type	Average	Rounded	Direction	Notice
Pn	0.2	0	From Přerov přednádraží to Staré Město u Uherského Hradiště	cancelled
residual	3.9	4		
Nex	1.8	2		
Lv	0.5	1		Only to Otrokovice
Pn	0.4	0	From Staré Město u Uherského Hradiště to Přerov přednádraží	cancelled
residual	2	2		
Nex	2.5	3		
Lv	0.2	0		cancelled

In the second part of the analysis, so-called "typical trains" were created. There are trains of which the weight, speed, locomotive class, and length are based on the most frequently occurring parameters for each type of train and entry station. For the construction of these typical freight trains, basic parameters were assigned to each train. The basic parameters include weight, speed, length, locomotive class, and entry time, i.e., the time when the train passed through or departed from the monitored station. These basic parameters were determined based on the most frequent occurrences of each parameter for the different types of trains (Lv, Nex, Pn, and residual capacity trains). Table 4 presents the resulting typical trains.

Table 4. Background for the second-phase analysis.

Train Type	Typical Input	Weight [t]	Length [m]	Locomotive	Speed [km·h^{-1}]	Direction
Lv	11:09:00	87	17	91,547,363	120	From Přerov přednádraží to Otrokovice
Nex	10:58:30	1871	387	91,811,293	100	From Přerov přednádraží to Staré Město u Uherského Hradiště
Nex	12:16:00	2090	478	91,806,193	100	
Z	11:02:30	87	17	91,547,363	120	
Z	12:51:30	24	14	99,549,439	80	
Z	13:56:00	2282	608	91,547,383	100	
Z	14:07:00	1761	582	92,542,753	90	
Nex	12:22:00	638	485	91,515,370	100	From Staré Město u Uherského Hradiště to Přerov přednádraží
Nex	13:02:30	1099	567	91,811,293	100	
Nex	13:37:00	723	538	91,547,388	100	
Z	10:57:30	89	19	91,806,193	100	
Z	14:12:00	758	529	92,542,742	90	

Based on Table 2, which represents the typical entry times of passenger trains, and Table 4, it is possible to demonstrably prove the benefits of remote control through quantitative analysis. To illustrate the mechanism for evaluating the benefits of remote control, the following example was provided.

The first two columns of Table 5 are populated using data from Tables 2 and 4. Next, the exit times of the trains from the monitored boundaries must be determined. For the reference variant, these times were calculated by adding the travel time to the typical entry time of the train at the entry station. This resulted in a reference timetable. These are the train paths that were generated in the forecast (future) section of the timetable sheet (graph). Such paths are shown in Figure 2 in the red-framed section. The forecast timetable (graph) was then compiled according to the principles described in the article for remote control (highlighted in green in the figure) and local control (highlighted in blue in the figure). Once this timetable (graph) was completed, columns 6 and 7 were filled in. Column 8 set the point value for one minute of delay. This value was obtained through a pairwise method that reflects the train prioritization outlined in the infrastructure manager's internal regulations. Columns 9 and 10 were calculated by multiplying the times in columns 4, 5, and 8. Specifically, multiplying one row from column 4 with column 8 gives the value in column 9, and multiplying one row from column 5 with column 8 gives the value in column 10. The entire table is completed using this principle, and then all values calculated in columns 9 and 10 are summed.

Once the points were totaled, the initial results could be observed. The primary indicator was the points earned: the more points a particular control type receives, the less efficiently the timetable (graph) is being followed under that type of control. The next step in calculating the point score was to sum all the points for both remote and local control types. These total points represent the worst possible result we can achieve and simultaneously provide a reference value for converting the points into percentages assigned to each control type. After this step, where percentages were assigned to remote and local control, it became clear how much better remote control is than local control in percentage terms. The final percentages indicate how much more beneficial remote control is compared to local control. Figure 6 describes three separate situations based on the content above.

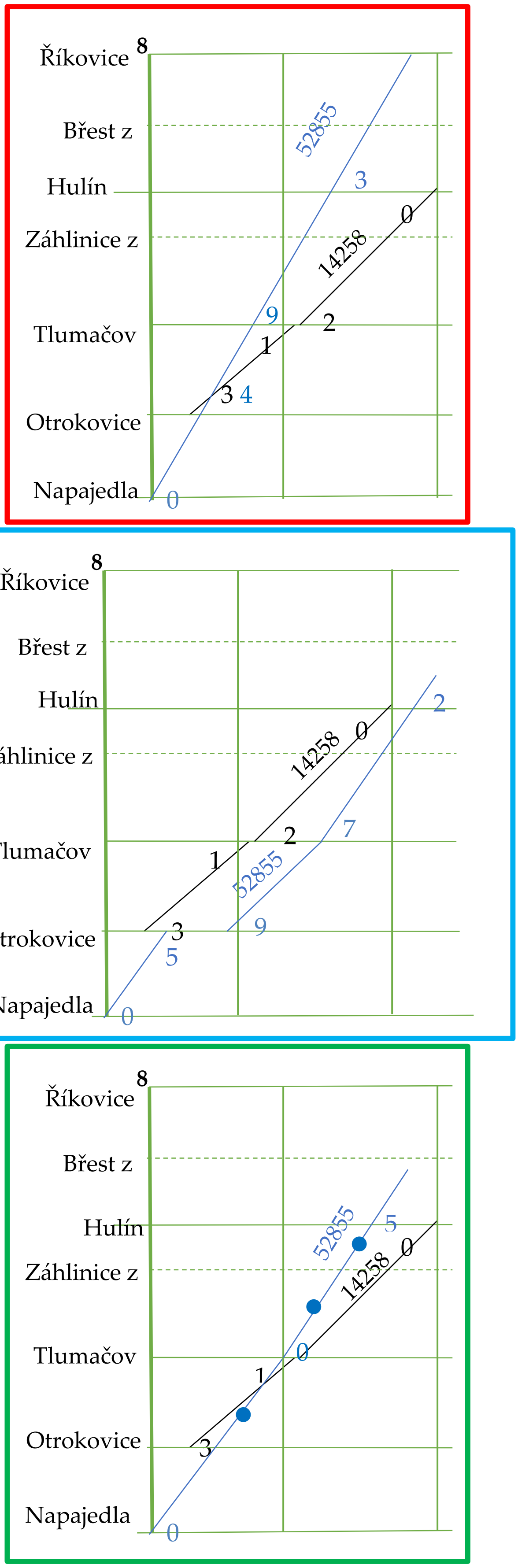

Figure 6. Graphic display of the trains in the train traffic diagram.

There is mentioned comparison of remote and local control in the Table 5.

Table 5. Comparison of remote and local control.

1	2	3	4	5	6	7	8	9	10
Train Type	**Train Number**	**Output Time**			**Difference between Origin and**		**One-Minute Value**	**Evaluation**	
		Origin	**Remote Control**	**Local Control**	**Remote Control**	**Local Control**		**Remote Control**	**Local Control**
Os	14258	8:20:00	8:20:00	8:20:00	0	0	5.24	0	0
Z	52855	8:13:30	8:15:00	8:22:00	1.5	8.5	0.48	0.72	4.08
							Sum	0.72	4.08
							Overall	4.80	
							Percentage	85%	15%
					Advantage of remote control			70%	

The required number of employees mainly depends on the following factors:

- The track configuration and the necessity of stopping trains in the desired position;
- The number of departing or regularly switching trains at each station;
- The size of the reporting district of the given station;
- Inspection of the evaluation device for diagnosing defects in moving vehicles;
- Assistance in accompanying persons with reduced mobility and orientation.

Table 6 displays the required staffing for one shift on a section of the line with strong local and transit work at the stations.

Table 6. Number of employees at stations with strong local and transit work.

<table>
<tr><th rowspan="3">Station</th><th colspan="3">Local Control (No. of Employees)</th><th colspan="4">Remote Control (No. of Employees)</th></tr>
<tr><th colspan="2">Station Dispatcher</th><th rowspan="2">Other</th><th rowspan="2">Station Disp.</th><th colspan="2">Remote Disp.</th><th rowspan="2">Other</th></tr>
<tr><th>Outside</th><th>Inside</th><th>Main</th><th>Section</th></tr>
<tr><td>Říkovice</td><td></td><td>1</td><td></td><td>-</td><td rowspan="5">1</td><td rowspan="5">1</td><td rowspan="7">1</td></tr>
<tr><td>Hulín</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Tlumačov</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>Otrokovice</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Napajedla</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>Huštěnovice</td><td></td><td>1</td><td></td><td>-</td><td rowspan="2">-</td><td rowspan="2">1</td></tr>
<tr><td>Staré Město</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>per shift</td><td colspan="2">10</td><td>3</td><td>3</td><td>1</td><td>2</td><td>1</td></tr>
<tr><td>overall</td><td colspan="2">55</td><td>17</td><td>17</td><td colspan="2">17</td><td>6</td></tr>
</table>

The reduction in the number of employees may be more pronounced on lines where the movement of passengers on the track is excluded. This exclusion of movement is ensured by means of island or external platforms. The appropriate placement of traffic signals eliminates the need to physically stop trains with the "Stop" signal in the required position to ensure the safety of passengers. This factor also contributes to lower station staffing. Another important aspect is the number of starting trains, which, if it is not a connecting or train-forming station, is usually lower. On such lines, the savings can be even higher (see Table 7).

Table 7. Number of employees at stations with low local and transit work.

<table>
<tr><th rowspan="3">Station</th><th colspan="3">Local Control (No. of Employees)</th><th colspan="4">Remote Control (No. of Employees)</th></tr>
<tr><th colspan="2">Station Dispatcher</th><th rowspan="2">Other</th><th rowspan="2">Station Disp.</th><th colspan="2">Remote Disp.</th><th rowspan="2">Other</th></tr>
<tr><th>Outside</th><th>Inside</th><th>Main</th><th>Section</th></tr>
<tr><td>Nedakonice</td><td></td><td>1</td><td></td><td>-</td><td rowspan="8">1</td><td rowspan="8">1</td><td rowspan="8">1</td></tr>
<tr><td>Mor. Písek</td><td>1</td><td>1</td><td>1</td><td>-</td></tr>
<tr><td>Bzenec-př.</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>Rohatec</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>Hodonín</td><td>1</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>Lužice</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>Mor. N. Ves</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>Hrušky</td><td></td><td>1</td><td></td><td>-</td></tr>
<tr><td>per shift</td><td colspan="2">11</td><td>2</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>overall</td><td colspan="2">61</td><td>11</td><td>6</td><td colspan="2">11</td><td>6</td></tr>
</table>

The issue of the required number of personnel is also reflected in economic indicators, specifically in wages. For comparison, Tables 1 and 2 are financially calculated which demonstrate the wage evaluation for more busy transport companies (see Tables 8 and 9). The values are written in Czech crowns (CZK).

Table 8. Wages comparison at stations with strong local and transit work.

<table>
<tr><th rowspan="2">Position</th><th colspan="2">Local Control</th><th colspan="3">Remote Control</th></tr>
<tr><th>Dispatchers</th><th>Others</th><th>St. Disp.</th><th>Re. Disp.</th><th>Others</th></tr>
<tr><td>Number of employees</td><td>55</td><td>17</td><td>17</td><td>17</td><td>6</td></tr>
<tr><td>Remote Dispatcher</td><td>-</td><td>-</td><td>-</td><td>9,048,272</td><td>-</td></tr>
<tr><td>Station Dispatcher</td><td>24,289,887</td><td>-</td><td>7,507,783</td><td>-</td><td>-</td></tr>
<tr><td>Others (at dispatching centre)</td><td>-</td><td>-</td><td>-</td><td>-</td><td>2,307,327</td></tr>
<tr><td>Others (at stations)</td><td>-</td><td>5,601,051</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Other positions</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Overall wage costs</td><td colspan="2">29,890,937</td><td colspan="3">18,863,382</td></tr>
<tr><td>Annual difference</td><td colspan="2">11,027,556 CZK</td><td colspan="2">Savings</td><td>36.89%</td></tr>
</table>

Table 9. Wages comparison at stations with low local and transit work.

<table>
<tr><th rowspan="2">Position</th><th colspan="2">Local Control</th><th colspan="3">Remote Control</th></tr>
<tr><th>Dispatchers</th><th>Others</th><th>Other Pos.</th><th>Re. Disp.</th><th>Others</th></tr>
<tr><td>Number of employees</td><td>61</td><td>11</td><td>6</td><td>11</td><td>6</td></tr>
<tr><td>Remote Dispatcher</td><td>-</td><td>-</td><td>-</td><td>5,854,764</td><td>-</td></tr>
<tr><td>Station Dispatcher</td><td>26,939,692</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Others (at dispatching centre)</td><td>-</td><td>-</td><td>-</td><td>-</td><td>2,307,327</td></tr>
<tr><td>Others (at stations)</td><td>-</td><td>3,624,209</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Other positions</td><td>-</td><td>-</td><td>1,976,842</td><td>-</td><td>-</td></tr>
<tr><td>Overall wage costs</td><td colspan="2">30,563,902</td><td colspan="3">10,138,932</td></tr>
<tr><td>Annual difference</td><td colspan="2">20,424,969 CZK</td><td colspan="2">Savings</td><td>66.83%</td></tr>
</table>

The following formulas describe the determination of average gross wages. Table 10 presents the gross wage components for individual job positions which are included in the hourly wage. Table 11 shows the average gross wages at individual job positions depending on the time.

$$average\ hourly\ wage = \left(M_h + O + P_{np} + \frac{P_n}{3} + \frac{P_{s+n}}{S} \cdot 2 \right) \cdot k_s \quad (1)$$

Table 10. Gross wage components for individual job positions.

In the Systemization for One Job Position in a Twelve-Hour Continuous Shift, the Norm Is 5.5 People	Hourly Wage [CZK]	Rewards	Surcharges for:		
			Continuous Traffic	Night	Saturdays + Sundays
Position		5.5 (%)	12	14 (%)	13 (%)
Remote Dispatcher	229.20	12.61	12.00	32.09	29.80
Station Dispatcher	188.40	10.36	12.00	26.38	24.49
Others (at dispatching centre)	162.70	8.95	12.00	22.78	21.15
Others (at stations)	137.90	7.58	12.00	19.31	17.93
Other positions	137.90	7.58	12.00	19.31	17.93

Table 11. Average gross wages in individual job positions.

Position	Average Hourly Wage [CZK]	Average Annual Salary [CZK]	Average Monthly Salary [CZK]
Remote Dispatcher	284.32	532,251	44,354
Others (at dispatching centre)	235.92	441,634	36,803
Station Dispatcher	205.42	384,554	32,046
Others (at dispatching centre)	176.00	329,474	27,456
Others (at stations)	176.00	329,474	27,456

- M_h = hourly wage;
- O = rewards;
- P_{np} = surcharge for continuous operation;
- P_n = night supplement;
- P_{s+n} = surcharge for Saturday and Sunday;
- S = systemization of the number of people per job position;
- K_s = public holiday coefficient;
- n_t = weekly hourly rate.

$$O = \frac{M_h}{100} \cdot 5.5 \quad (2)$$

$$P_n = \frac{M_h}{100} \cdot 14 \quad (3)$$

$$P_{s+n} = \frac{M_h}{100} \cdot 14 \quad (4)$$

$$k_s = \frac{n_t \cdot n\_f\ weeks\ in\ a\ year + \frac{n\_f\ public\ holidays\ per\ year\ *\ 24}{S}}{n_t\ .\ n\_f\ weeks\ in\ a\ year} \quad (5)$$

When comparing Tables 8 and 9, it is possible to observe significant wage savings brought about by remote control. If these wage savings are divided by the length of the controlled section, Table 12 is obtained. If the Přerov–Břeclav section was determined as a reference track, then a column expressing the conversion of savings per 1 km of remotely controlled track was added based on this section. Once this parameter is determined, it is enough to multiply it by the length of controlled double-track sections from the central dispatching workplace in Přerov.

Table 12. Wage quantification of the benefits of remote control.

Interval	Přerov–Staré Město u U.H.	Přerov–Břeclav	Conversion to 1 km Remote Controlled Track	Conversion to All Double-Track Lines Operated from CDP Přerov	All Double-Track Lines Operated from CDP Přerov and CDP Prague	Units
Minute	21	60	0.62	269	490	$CZK \cdot min^{-1}$
Hour	1259	3590	37.25	16,127	29,376	$CZK\ h^{-1}$
Day	30,212	86,171	893.89	387,056	705,014	$CZK \cdot day^{-1}$
Moon	918,963	2,621,044	27,189.25	11,772,945	21,444,162	$CZK \cdot mouth^{-1}$
Year	11,027,556	31,452,525	326,271.01	141,275,346	257,329,943	$CZK \cdot year^{-1}$

4. Discussion

The comparative analysis of local control and remote control in railway transport operation offers insights into their technological and economic implications. While local control presents advantages such as the prompt resolution of on-site situations through physical station occupation, it is accompanied by significant drawbacks. These include the need for a substantial number of professionally qualified employees and limitations in accessing real-time information, exacerbated by the inherent delay of 180 s in the Train Track Position application. Communication gaps and reliance on telephone-based interactions further hinder efficient decision-making during non-standard situations, impacting traffic flow adversely.

On the contrary, remote control is emerging as a technologically advanced alternative offering substantial economic benefits. The installation of relay rooms, traffic offices, and optical cables facilitates seamless real-time data transfer, enhancing operational efficiency and enabling immediate responses to dynamic situations. The discussion underscores the substantial wage savings achievable through remote control, particularly at stations with excluded passenger movement. The detailed economic indicators presented in Tables 3 and 4 highlight the financial advantages of remote control, providing a comprehensive breakdown of wage components and savings.

Moreover, this research contributes to the literature by offering insights into the operational dynamics and economic implications of both control methods. However, it is essential to acknowledge potential limitations and identify avenues for future research. Specifically, future studies could delve deeper into understanding the specificity of the studied region and explore the evolving nature of railway technologies. Additionally, there is a need to focus on addressing communication gaps and enhancing real-time information access in local control systems to improve operational efficiency. Furthermore, the integration of advanced technologies such as artificial intelligence (AI) and machine learning (ML) algorithms could offer novel approaches to optimize decision-making processes in railway transport management. Comparative studies across different geographical regions and railway networks could provide valuable insights into the applicability of remote-control systems and their economic implications in diverse contexts. Moreover, investigating the integration of remote-control systems with emerging technologies such as the Internet of Things (IoT) and Big Data analytics could offer innovative solutions to optimize railway transport operations and enhance the overall system resilience. By addressing these research gaps, future studies can significantly contribute to the advancement of railway transport management practices and enhance safety and efficiency in railway operations.

This research contributes to the sustainability of transport across four pillars:

- Social: By enhancing operational efficiency in rail transport, it reduces the demand for specialized employees (dispatchers) in challenging remote positions, thereby supporting workforce wellbeing and enabling a safer, stable employment in local areas.
- Economic: Increased automation and remote control deliver substantial cost savings on labor, maintenance, and infrastructure, making rail transport a more viable and competitive economic option.
- Environmental: Optimized scheduling and route management reduce energy consumption and emissions, thereby lowering the ecological impact of rail transport.
- Governance: The shift to advanced, centralized management strengthens compliance with regulatory standards and enhances resilience during crises, aligning with strategic governance goals for sustainable transport development.

5. Conclusions

In conclusion, this research yields significant insights into the comparative analysis of local control and remote control within railway transport operations, with a specific focus on technological and economic dimensions. Local control, while effective in swiftly resolving on-site challenges, confronts formidable hurdles, notably the demand for a considerable number of qualified personnel. Communication gaps and reliance on the Train Track Position application, characterized by a 180 s delay in train position data, contribute to operational inefficiencies. The application's limitations, coupled with the need for telephone communication between dispersed operating employees, result in delayed responses to non-standard situations.

Contrastingly, remote control is emerging as a technologically advanced and economically advantageous alternative. Real-time data transfer through optical cables and collaborative teamwork within controlled areas facilitates prompt responses and operational adaptability. The research underscores substantial wage savings through remote control, revealing a 36.89% reduction in wage costs for stations with strong local and transit work.

The research outcomes advocate for the adoption of remote-control systems to enhance operational efficiency, reduce personnel requirements, and achieve substantial cost savings in railway transport operations. Notably, the research highlights the potential for a 66.83% reduction in wage costs for stations with low local and transit work, further emphasizing the economic benefits of remote control. These findings underscore the significance of technology-driven solutions in addressing contemporary challenges within the railway transport sector. The research's implications extend beyond the immediate context, offering valuable recommendations for future research. Exploring regional variations, evolving technologies, and the broader applicability of the findings could deepen our understanding of operational dynamics in railway transport management.

In conclusion, this research provides compelling evidence for the efficacy of remote control, paving the way for the integration of advanced technologies to optimize safety, reduce costs, and enhance overall efficiency in railway transport.

While the general conclusions about the advantages of remote-control methods are known, a more detailed examination that distinguishes remote-controlled lines based on operational, technological, and technical reasons—where the physical staffing of railway stations is still required—has not been widely addressed. This research identifies the specific factors that influence the need for the physical presence of specialized personnel at railway stations under remote control not only at the central or regional dispatch centers, but also at the stations that, despite being remotely controlled, must be physically staffed for operational and technical reasons. The factors that determine the required number of staff are primarily based on the following (as the work concludes):

- The track configuration and the necessity to stop trains in specific positions;
- The number of departing or regularly transferring trains at each station;
- The size of the reporting zone of the given station;

- The need to monitor diagnostic equipment for faults in passing vehicles;
- Assistance provided to persons with reduced mobility and orientation.

The results of this research allow for a relevant validation of how to efficiently allocate traffic personnel once the system for informing train drivers of irregularities on the track is introduced across the network of the infrastructure manager. This will be facilitated by the new order system for briefing train drivers, which is already used by other infrastructure managers (replacing the current method of briefing train drivers with written orders). This replacement will be implemented in the Czech Republic within the 2025/2026 timetable. These findings can serve as a fundamental decision-making framework and a financial strategy for the more efficient use of professionally qualified personnel, who are currently in short supply and whose training is both time-consuming and costly.

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