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Technological Triangle—Making Public Transport Sustainable and More Accessible

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Abstract

The technological triangle is a non-mathematical representation of the relationship between the characteristics of transport infrastructure, modes of transport, and the operational concept in a specific region. It is only through the synergistic effect of these three vertices that the railway undertaking, infrastructure manager, and authority can achieve optimal resource utilisation. Concurrently, it is imperative to exert pressure on the authorities to implement conceptual, systematic, and predictable measures. The process of implementing changes to transport infrastructure is a protracted one, typically spanning several years from the initial stages of preparation through to the project's execution. The application of the technological triangle is possible on various parts of the infrastructure. Based on previous research, the authors prepared this Article to address intermediate stations, which were identified as the key focus of this article. Therefore, the authors in this article answer the question of what typical solutions exist for intermediate station configurations in relation to the operational concept and financial costs. Twenty different configurations were selected, and each was examined from the perspectives of financial, operational, planning, automation, and user pillars. The weights of the individual pillars were then assessed from the perspective of the infrastructure manager, the carrier, and the customer. The result is a comprehensive assessment of all wayside station configurations from different perspectives. Each user of this workflow can determine the weights of the individual pillars according to their needs and financial capabilities. This also gives the article a general use. The final part of the article presents specific examples of existing structures in the Czech Republic, which were not built with the perspective of this article in mind. The authors point out that if our method were applied, not only would large platform stations be built, which is the case for many intermediate stations in the Czech Republic; instead, more efficient solutions would be developed and adapted to the specific case.

Keywords: public service obligation; technological triangle; operational concept; railway infrastructure; intermediate station; sustainability

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1. Introduction

A properly functioning transport system is a combination of many factors. All of these can be gradually combined until three remain, which the authors refer to as the technological triangle. This is a non-mathematical, or rather qualitative, expression of the relationship between transport infrastructure, vehicles, and timetables [1].

One of the main pillars of liberalising the European railway market was to provide as open a market as possible, where access would be granted to all without discrimination [2]. At the same time, however, this led to the economic separation of the individual vertices of the triangle. All three entities located at the vertices of the triangle thus gradually began to have different interests and priorities. This has led and continues to lead, for example, to temporal discontinuity in the modernisation of transport infrastructure, the purchase of vehicles, and the client's requirements for the timetable concept [3]. This results in a reduction in the overall attractiveness of public transport [4–6].

A significant limitation in the application of dynamic parameters in newly deployed vehicles is the adherence to the periodic timetable, which constitutes a fundamental planning instrument for many regional public transport authorities [7]. This timetable is based on the principle of coordinated and regular departures from interchange nodes [8]. While enhanced dynamic properties of vehicles contribute to shorter travel times, such improvements are not effectively integrated beyond the structural framework of the timetable [9]. The advantage of earlier arrivals is therefore primarily manifested in the increased capacity of vehicles to compensate for operational delays, which in turn contributes to the robustness of the timetable and enhances the overall stability of the public transport system.

The provision of public passenger rail services by the competent authority (state, region, or municipality) in categories such as Os (local—this category is under the obligation of regions, and the stopping policy is that this train stops at every station or stop) and Sp (fast local—this category is like the Os one. However, the stopping policy is slightly different. These trains stop at main stations, or they are used for zone service. The train runs the first part of the line straight from the origin station and then stops at every stop.) Trains are guided by the objective of maximising daily vehicle utilisation while simultaneously reducing travel times. This approach reflects an effort to employ both infrastructure and rolling stock at their full potential. From a transport systems perspective, travel time is defined as the interval between two operational points specified in the timetable. It is determined by three key factors: infrastructure, transport technology, and vehicles. Exploiting the upper limits of these parameters—namely, the maximum permissible line speed, the vehicle speed corresponding to line constraints, optimal acceleration rates, and minimal headways—creates a synergistic effect that ensures the efficient use of available resources. Nevertheless, the rigidity of such a system means that even minor delays cannot be absorbed, which compromises its stability. This phenomenon is particularly evident on heavily used single-track lines. As a result, the intended synergistic effect is disrupted, potentially leading to the perception that an older vehicle fleet operating punctually may, in practice, yield greater overall benefits [6,10,11].

Travel times, technological intervals, and headways represent decisive factors in ensuring the delay-free operation of train services. In practice, however, discrepancies often arise when the technological interval does not fully align with regulatory requirements, primarily due to the need to maintain buffer times and exact interval spacing. This highlights the potential for adapting infrastructure to meet the needs of the intended operational concept. Ideally, infrastructure should be aligned with the dynamic and technical characteristics of the rolling stock, thereby enabling the development of an operational framework founded on optimal travel times that minimise the occurrence of delays. The key scientific task in this context is to determine the appropriate value of supplementary time within the scheduled travel period [12].

Alongside the modernisation of rolling stock, substantial upgrades are also being carried out on the railway infrastructure. In selected locations, local realignments are introduced, accompanied by increases in curve radii and cant, which collectively enable higher line speeds. Additionally, new speed profiles are being implemented, expanding the

operational possibilities beyond those previously available on the given line. The benefits of such speed enhancements are most apparent when applied consistently across longer sections of the system. However, to achieve tangible time savings on a system-wide level, equal attention must be devoted to the operational concept. In cases where a timetable or integrated timetable (ITT) governs the line, this particularly concerns timetable nodes and passing loops, where overtaking and train crossings take place. Anticipating future developments, it is therefore essential to adapt the infrastructure in such a way that the interval times between timetable nodes remain achievable, while also strengthening overall traffic stability [13].

Infrastructure modernisation can be realised through various measures [14,15]. These include extending existing station tracks or constructing additional sections, which brings advantages both for freight transport—by allowing the operation of longer trains—and for passenger services, where shifting the conflict point significantly reduces operational intervals. Furthermore, the implementation of modern signalling systems, particularly in the context of the European Train Control System (ETCS), which is a part of the European Rail Traffic Management System (ERTMS). It is a set of rules that establishes the European Train Protection standard. For more information, see https://www.ertms.net/), necessitates the establishment of an appropriate track configuration to ensure the effective operation of the upgraded network.

Source [16] (p. 46) provides research conducted for regional lines, which included standard legislative elements for station design, primarily on single-track lines of lesser importance. The evaluation mainly encompassed factors present within the designated location.

Public service obligations (PSO) in the railway sector are regulated by Regulation (EC) No. 1370/2007 of the European Parliament and of the Council, as amended by Regulation (EU) 2016/2338 [17]. This legislation defines the framework under which competent authorities may award public service contracts to guarantee the provision of passenger rail services deemed essential in the public interest but unlikely to be offered under purely commercial conditions. In accordance with the regulation, railway PSO contracts must be awarded through competitive tendering, except in cases where conditions for direct award are explicitly met. Where the annual service volume exceeds 500,000 train-kilometres, competitive tendering is mandatory [18]. The standard duration of such contracts is limited to ten years. However, this period may be extended (up to fifteen years) if justified by substantial investment in rolling stock or infrastructure. Given the long service life of vehicles, transferring rolling stock to a successor operator at the end of the contractual period is considered a prudent approach [1,19].

Before launching a competitive procedure, authorities are required to assess whether operators have fair access to suitable rolling stock. Where access is restricted, authorities may intervene by purchasing vehicles and leasing them to operators, offering procurement guarantees, or committing to buy the rolling stock after contract expiry. These measures, however, must comply with State aid regulations. To ensure transparency, competent authorities must publish a notice at least one year before the commencement of the award procedure. This notice, which must be published in the Official Journal of the European Union, must specify the award procedure (competitive or direct), the scope and duration of the contract, and the services covered. Experience from the Czech Republic and Slovakia demonstrates that these obligations are often not met, particularly regarding non-discriminatory access to rolling stock [20]. As a result, railway undertakings are frequently forced to acquire rolling stock independently, which can lead to suboptimal vehicle utilisation, especially where the authority shows little interest in the type and quality of vehicles used.

Financial compensation for PSO contracts must reflect only the net economic effect of fulfilling the obligation. This is defined as the costs incurred in providing the service, minus revenues earned (e.g., ticket sales, ancillary income), plus a reasonable profit corresponding to market conditions and risks. To prevent cross-subsidisation or overcompensation, operators providing both commercial and PSO services must maintain separate accounts. The award of a PSO contract also involves binding legal, financial, and technological commitments, with the timetable serving as the central planning instrument. The timetable establishes service frequency, departure and arrival times, and connections, and forms the basis for the rolling stock circulation plan. This plan determines the number of trainsets required, their daily rotation between services, and their turnaround operations. Efficient circulation planning reduces idle time, minimises fleet requirements, and ensures balanced kilometrage distribution, an essential factor in maintenance planning.

Rolling stock maintenance, scheduled according to kilometres travelled or elapsed service time, is critical for safety and reliability. Accordingly, circulation plans must also account for technical servicing, refuelling, cleaning, and sanitation operations. Various infrastructure parameters, including platform length, line speed, signalling systems, track capacity, station locations, and depot availability, influence operational efficiency. From an economic perspective, efficiency is further shaped by infrastructure access charges, depreciation or leasing costs of rolling stock, energy consumption, and maintenance expenditures.

Overall, the PSO framework provides the legal and economic foundation for regional passenger rail transport. Its success, however, depends not only on compliance with legislation but also on the effective integration of timetable planning, rolling stock utilisation, and cost management. Properly designed trainset circulation, including adequate turnaround and maintenance slots, can reduce the required fleet size and thereby ease pressure on public finances while improving the operational efficiency of services.

Finally, the transport order (or operational concept) must be consistent with the available infrastructure and rolling stock, and it must reflect long-term development objectives. If any part of this system fails to meet the required parameters, the entire operating model is compromised. From a traffic management perspective, this results in timetable instability and insufficient freight capacity; from the passenger perspective, it manifests in persistent delays that cannot be mitigated due to inadequate infrastructure or vehicle performance.

A case from the Czech Republic demonstrates the consequences of inadequate coordination. The lift bridge, which is located on the line between Vraňany and Lužec nad Vltavou, was constructed in 2020/2021. Furthermore, upgrades were made to the line's safety equipment. However, shortly after its induction into service, passenger transport operations were terminated on this line, with only sporadic tourist traffic remaining. Currently, due to the line's underutilization, its official closure is being considered. The bridge was funded by the waterway's authority, which utilises the lift for boats; however, the investment of CZK 250 million (approximately EUR 10.25 million) was deemed a failure following the termination of regular passenger train services. However, the official closure of the railway line would result in the complete loss of the investment, as the costs of inspecting and operating the bridge for ships would remain [21,22].

The issue of synergy between the three vertices of the technological triangle can then be applied to various parts of the railway infrastructure. This may include:

- Interstation sections. This issue is discussed in the literature13–14.
- Most essential railway stations, where regional lines start/end and where the long-distance segment also stops. These stations are typically too complex in scope, and their reconstruction requires a significant amount of time (the preparation and construction horizon are approximately 5–10 years) and substantial financial resources.

- Intermediate stations are intended, namely, for the dispatching of train sequences (order of trains) and the crossing of trains on single-track lines. The authors chose this type of station for their further research because it is relatively less time- and financially intensive. These stations are also the most common, which is discussed further in the following section.
- Technical support for railway operators and the Service Facilities. This is a self-issue that should be addressed separately, as it is a task for the carrier rather than other entities.

The authors analyzed multi-track lines in the Czech Republic, with a primary focus on the category of stations. The data for the analysis were derived from [23]. The study, involving 263 stations, presented in Table 1, distinguished three categories:

- Nodes—the largest stations characteristically possess multiple lines connected to them.
- Connecting stations—stations of a more substantial size which are interconnected with one or more additional routes.
- Intermediate stations—stations, which are generally of a more compact nature and primarily employed for traffic management in both routine operations and during periods of disruption and restrictions.

Table 1. Analysis of station categories on multiple-track lines.

Line	Nodes	Connecting Stations	Intermediate Stations	Number of Stations
Kolín (excl.) - H. Brod - Brno-Maloměřice (excl.)	1	7	12	20
Děčín (incl.) - Kralupy n. V. - Praha hl. n. (excl.)	4	4	9	17
Děčín východ (incl.) – Kolín (excl.)	4	5	12	21
Praha hl. n.(incl.) – Přerov (excl.)	7	11	18	36
Praha hl. n. (excl.) - Lysá n. L. (excl.)	0	2	2	4
Praha hl. n. (excl.) – Ševětín (incl.)	3	5	11	19
Zliv (incl.) – Číčenice (incl.)	0	2	1	3
Horažďovice př. (incl.) – Nepomuk (incl.)	0	2	1	3
Praha hl. n. (excl.) – Přovany (incl.) + Plzeň-Koterov	3	6	9	18
Lipová u Ch. (incl.) - Ústí nad Labem západ (incl.)	5	9	14	28
Chabařovice (incl.) – Bílina (excl.)	0	2	3	5
Obrnice (incl.) – Počerady (incl.)	0	1	1	2
Pardubice (excl.) - Opatovice-pohřeb. (incl.)	0	2	1	3
Česká Třebová (excl.) – Lanžhot (incl.)	3	6	10	19
Zastávka u B. (incl.) - Veselí n. M. (incl.)	1	3	11	15
Břeclav (excl.) - Petrovice u K. (incl.)	8	7	15	30
Hranice na M. (excl.) - Horní L. (incl.)	1	2	5	8
Ostrava-Vítkovice (incl.) - Mosty u J. (incl.) + Karviná, Louky n. O.	2	2	8	12
Together	**42**	**78**	**143**	**263**
Percentage	**15.97%**	**29.66%**	**54.37%**	**100%**

As is apparent in Figure 1, intermediate stations predominate, accounting for more than 54%. It is possible to assess the viability of implementing configuration adjustments

that could result in a comprehensive enhancement of the prevailing conditions at 49% of all stations.

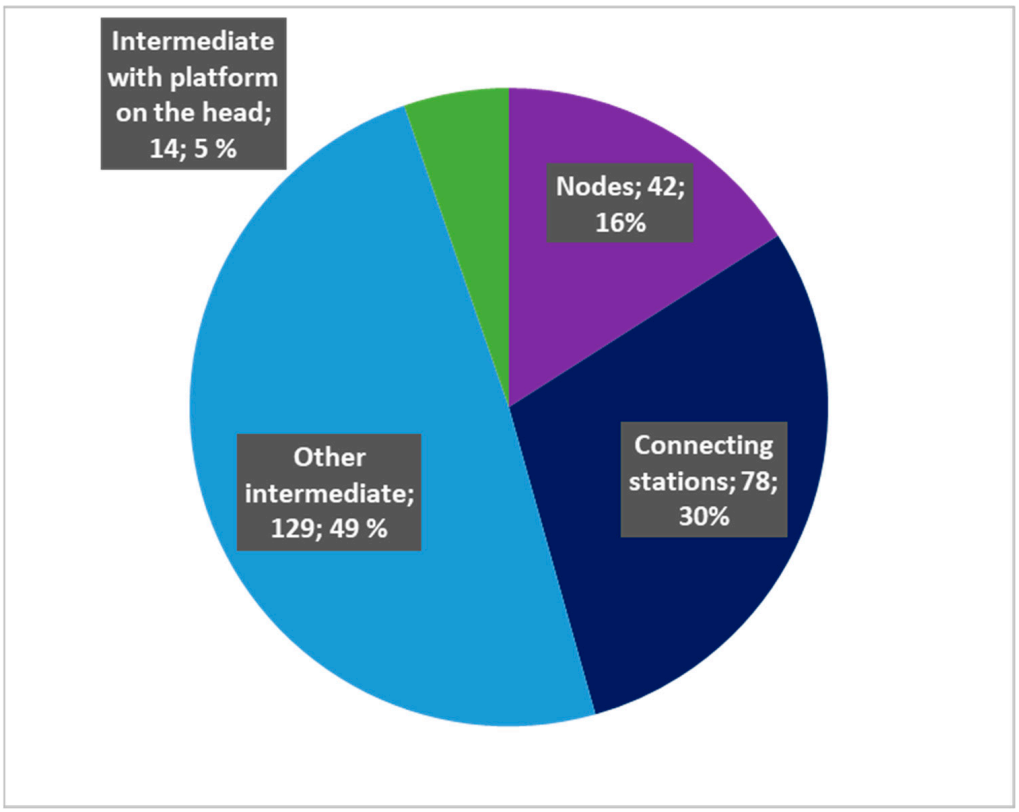


Figure 1. Percentages of station categories.

The article presents a selection of intermediate stations and introduces a mathematical apparatus for evaluating these stations based on their typology. The concept of the technological triangle is examined not only as a theoretical framework but also through its practical implications in transport systems [24].

Utilising cases to illustrate this point, the article demonstrates how optimally designed stations can generate benefits that extend beyond the individual interests of stakeholders. The utilisation of mathematical formulation enables the quantification of these stakeholders' interests, thereby facilitating a more accurate evaluation. High-quality stations are characterised by the absence of physical barriers between platforms and the surrounding infrastructure, a feature that enhances passenger comfort, expedites the exchange process, and optimises accessibility. These elements correspond to the priorities of both the PSO authority and the railway undertaking. From the perspective of the infrastructure manager, such stations support automation, meet timetable requirements, and enable efficient traffic management, thereby meeting the needs of all users of the technological triangle.

The objective is to develop a methodology that facilitates the decision-making process between station configurations and engages additional stakeholders, thereby achieving synergy within the technological triangle.

2. Materials and Methods

One of the vertices of the technology triangle is the infrastructure vertex. To ensure a synergistic effect between the individual sides of the technological triangle, it is necessary to accurately evaluate the benefits of buildings, related timetables, and, ultimately, the type of vehicle, which is reflected in travel times. These should be reflected in the track solution of

the stations [23]. A key step is to create a multi-criteria analysis tool that will help optimise decision-making when assessing which type of station to choose for reconstruction. Five pillars were selected as the leading indicators because modern rail transport is a complex system. The stability and efficiency of which depend on the mutual interconnection of those pillars. These pillars characterise the financial, operational, planning, automation, and user framework in which everyday operations take place. Their balance is necessary to achieve a synergistic effect that exceeds the benefits of individual components. To achieve systemic time savings, these adjustments must be carried out consistently and in accordance with the operating concept, particularly at tact nodes and stations where trains regularly or frequently overtake and cross each other. It is anticipated that the implementation of adjustments will be less urgent in locations where such operations are expected to occur with comparatively low frequency. This multi-criteria analysis also contributes to achieving the scientific task of determining the optimal value of additional time in the planned travel time, which will ensure stability of operation even with minor deviations, by indirectly preferring non-level access to the platform and thus standardizing stations and thereby contributing to finding a better median, or eliminating fluctuations in the maximum values of additional time to the planned travel time. The Fuller method and the WSA method were selected as multi-criteria analysis methods. The Fuller method is used to compare individual types within pillars, and the WSA method is then used to evaluate each pillar individually.

The Fuller method, also known as the pairwise comparison method, consists of evaluating each pair of elements and selecting the more important one. The total number of these comparisons can be determined using Formula (1).

$$\binom{n}{2} = \frac{n \cdot (n-1)}{2}, \tag{1}$$

This approach is often employed in decision-making models to evaluate different options systematically, and the results of these comparisons are then used to determine the relative importance of individual elements. The basic structure of the method is the so-called Fuller triangle, which ensures that each criterion is compared with every other criterion exactly once. Its principle is shown in Table 2 [25].

Table 2. Fuller triangle.

Station type 1	Station type 1	...	Station type 1	Station type 1
Station type 2	Station type 3	...	Station type $n-1$	Station type n
Station type 2	Station type 2	...	Station type 2	
Station type 3	Station type 4	...	Station type n	
...				
...				
Station type $n-2$	Station type $n-2$			
Station type $n-1$	Station type n			
Station type $n-1$				
Station type n				

For a more straightforward mathematical calculation, Table 3 has been compiled, which, instead of circling the variants in the Fuller triangle, assigns priority by assigning either one or zero to the variants. The green and red undercolourcaptures this principle.

Table 3. Modified Fuller triangle.

Station Type	1	2	3	...	n	∑ Preference	Scale
1	x	1	1	...	1	f_1	s_1
2	0	x	1	...	1	f_2	s_2
3	0	0	x	...	1	f_3	s_3
...	...	...	...	x	...	...	...
n	0	0	0	...	x	f_n	s_n

Calculation of weights of importance according to Formula (2).

$$s_i = \frac{2 \cdot f_i}{n \cdot (n-1)}, \quad (2)$$

where:

s_i—station importance scale [-]
f_i—preference of stations [-]
n—total number of stations [-]

To differentiate between various types of stations, it is necessary to evaluate them based on several key criteria. These types will subsequently be categorised, the categorisation being instrumental in establishing their suitability for specific applications. Based on the modified Fuller's triangle, it is possible to evaluate individual types of stations, as shown in Table 4. The stations are divided into twenty types based on specific criteria, which are:

- Number of line tracks,
- Platform layout,
- Crossover between main tracks,
- Platform access,
- Platform location.

Supplementary Materials Figure S1 provides an illustration of the typology of stations using a tree structure based on Table 4, including images representing all 20 station types.

The primary criterion under consideration is the number of line tracks. For this paper, a distinction is made only between single-track and double-track lines. This is primarily because such lines are the most common, and because lines with a higher number of tracks would only be combinations of solutions for single-track and double-track lines.

The arrangement (layout) of platforms constitutes a pivotal criterion that exerts a substantial influence on two primary domains: the operational aspect, i.e., the feasibility and modalities of inter-train transfers at the station, and the financial dimension, given that an augmented number of platform edges entails augmented financial expenditures. We divide platform locations into three types. The first of these is the classic layout, in which the platforms are located directly in the track group in the middle of the station. The second group consists of platforms located at the head of the station, positioned at one of the heads, outside the main track group. In this instance, no distinction is made between the location of crossovers, which is governed by an additional criterion. The third type is categorised as mixed and is exclusively considered for single-track lines. It refers to a situation where the track group is divided into several parts by a central head, with the platform located in both parts of the track group. Figure 2 illustrates the three types of station layout. Blue color depicts a platform.

Table 4. Typology of stations.

Type	Number of Line Tracks	Platform Layout	Crossover Between Main Tracks	Platform Access	Platform Location
1	2	classical	both	level	-
2	2	classical	both	mixed	-
3	2	classical	both	tunnel	-
4	2	classical	single each	level	-
5	2	classical	single each	mixed	-
6	2	classical	single each	tunnel	-
7	2	classical	one head	level	-
8	2	classical	one head	mixed	-
9	2	classical	one head	tunnel	-
10	2	head	Type A	tunnel	middle
11	2	head	Type A	tunnel	sides
12	2	head	Type B	tunnel	middle
13	2	head	Type B	tunnel	sides
14	2	head	Type C	tunnel	middle
15	2	head	Type C	tunnel	sides
16	1	classical	-	level	-
17	1	classical	-	mixed	-
18	1	classical	-	tunnel	-
19	1	head	-	tunnel	-
20	1	mixed	-	mixed	-

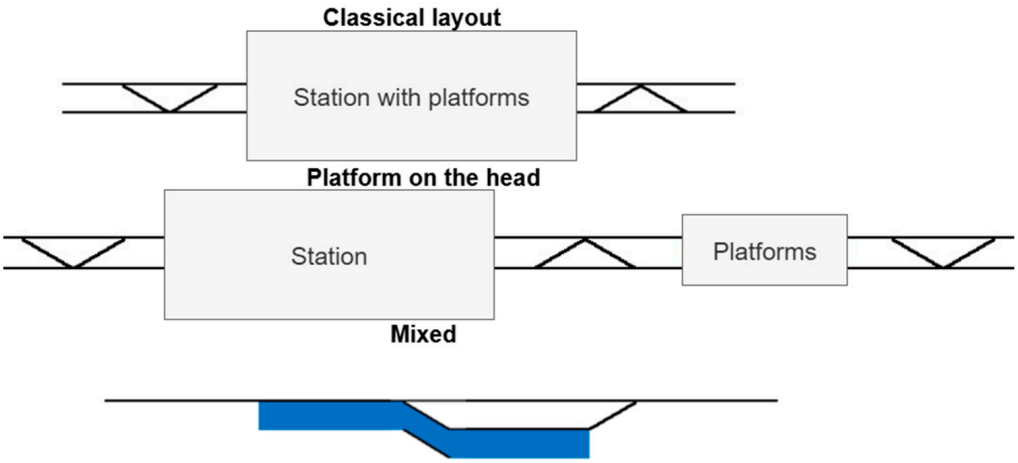


Figure 2. Types of platform layouts.

Access to the platform is a relatively important parameter that directly affects transport technology and operating intervals. Nevertheless, it also exerts a direct influence on the levels of comfort and safety experienced by passengers. The first option is level access. The second option is an overpass or underpass (station tunnel), which should be selected in

accordance with the topography of the surrounding area. The third option is a combination of the access options. Figure 3 shows the options for accessing the platform. Brown colour indicates an overpass or underpass used for accessing given platform. The grey colour marks level access via neighbouring tracks.

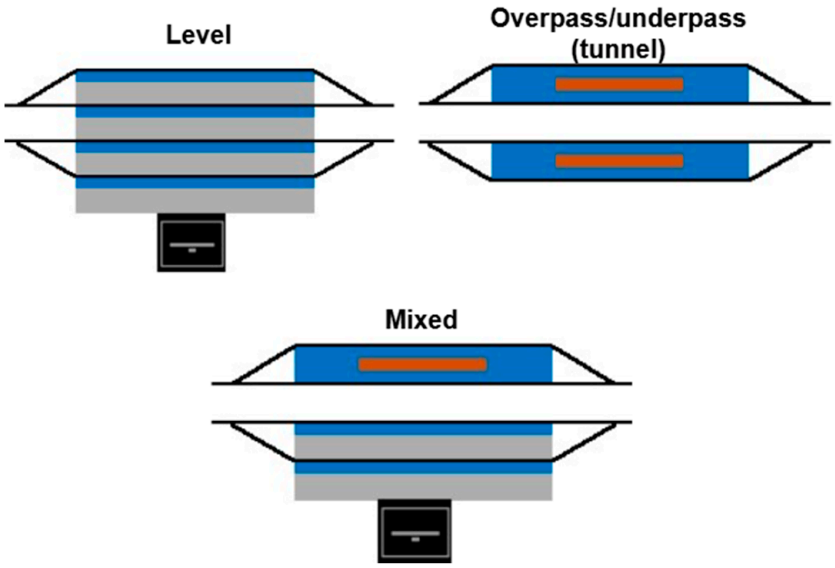


Figure 3. Platform access options.

The location of crossovers between main tracks has a direct impact on the feasibility of overtaking trains and the overall usability of station tracks. Crossovers are a crucial component of railway infrastructure, facilitating the movement of trains between distinct line tracks. In conjunction with track closures (TCRs), these mechanisms play an instrumental role in ensuring the seamless operation of the railway network. The initial option involves configuring double crossovers on both heads of the station. The second option under consideration is a double crossover on one of the station's heads. The third option involves implementing a single crossover on both heads of the station. Figure 4 illustrates the various types and numbers of crossovers at station heads.

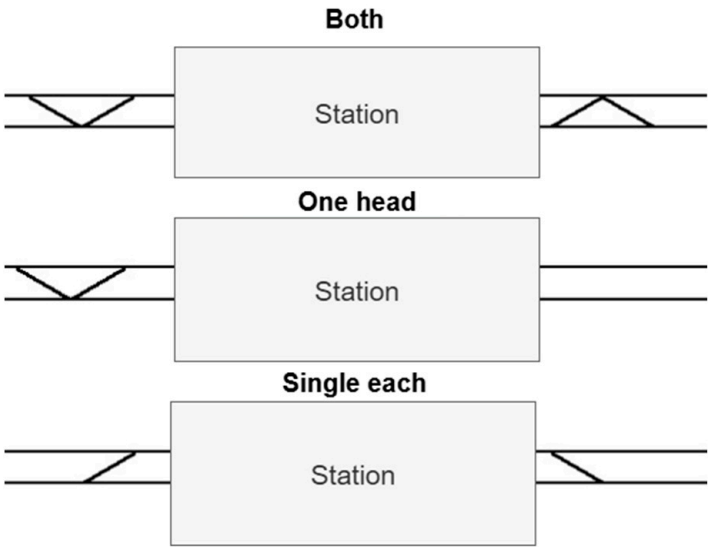


Figure 4. Location of crossover.

For stations with platforms positioned at the head of the station, types A, B, and C are distinguished in Figure 5. This distinction is based on the position of crossovers relative to the platform.

The location of the platform is a criterion that is only used at double-tracked line stations with platforms at the head of the station. A distinction is made between platforms located in the middle of the main tracks and those located on the sides of the main tracks. In the case of a platform in the middle (intermediate platform), it can be used to facilitate the transfer of passengers between two trains. The distinction between these two types is illustrated in Figure 6.

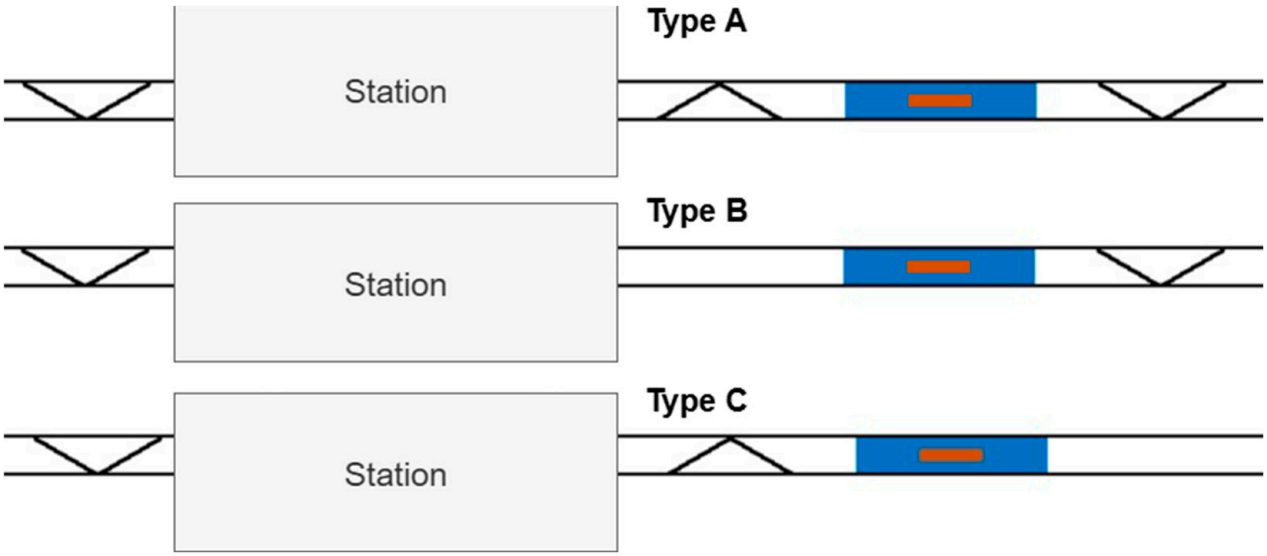


Figure 5. Crossover positions in stations with a platform at the station head.

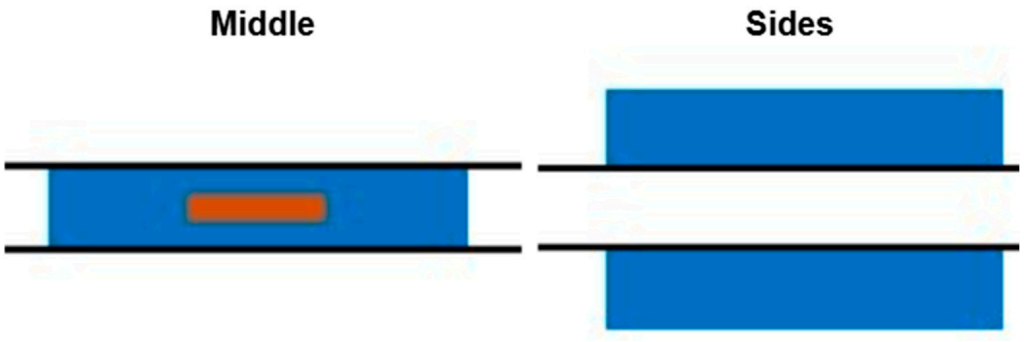


Figure 6. Platform location in stations with a platform at the station head.

2.1. Financial Pillar (Only the Tracks)

The financial stability of the railway system is closely linked to the efficient use of infrastructure. Investments in the tracks—such as extending station tracks, building switches, and modernising line tracks—bring not only higher capacity but also operational flexibility. Efficient infrastructure reduces operating, maintenance and energy costs, thereby relieving public expenditures. Tables 5 and 6 show the financial demands of individual station types; that is, the higher the preference for a given station type, the lower the cost of building it.

Table 5. Evaluation of the Financial Pillar for Double-Track Lines.

Station Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	∑ Preference	Scale
1	x	0	1	0	1	1	1	1	1	1	1	1	1	1	1	12	0.11
2	0	x	1	0	0	1	0	0	1	1	0	1	0	1	0	6	0.06
3	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
4	1	0	1	x	1	1	1	1	1	1	1	1	1	1	1	13	0.12
5	0	0	1	0	x	1	1	0	1	1	0	1	0	1	0	7	0.07
6	0	0	1	0	0	x	0	0	0	0	0	0	0	0	0	1	0.01
7	1	1	1	1	1	1	x	1	1	1	1	1	1	1	1	14	0.13
8	0	0	1	0	1	1	1	x	1	1	0	1	0	1	0	8	0.08
9	0	0	1	0	0	1	0	0	x	0	0	0	0	0	0	2	0.02
10	0	0	1	0	0	1	0	0	1	x	0	0	0	0	0	3	0.03
11	0	0	1	0	1	1	1	1	1	1	x	1	0	1	0	9	0.09
12	0	0	1	0	0	1	0	0	1	1	0	x	0	0	0	4	0.04
13	0	0	1	0	1	1	1	1	1	1	1	1	x	1	0	10	0.10
14	0	0	1	0	0	1	0	0	1	1	0	1	0	x	0	5	0.05
15	0	0	1	0	1	1	1	1	1	1	1	1	1	1	x	11	0.10

Table 6. Evaluation of the Financial Pillar for Single-Track Lines.

Station Type	16	17	18	19	20	∑ Preference	Scale
16	x	0	0	1	1	2	0.20
17	1	x	0	1	1	3	0.30
18	1	1	x	1	1	4	0.40
19	0	0	0	x	0	0	0.00
20	0	0	0	1	x	1	0.10

2.2. Operative Pillar (Technology)—"Not Every Train Runs on Time"

From an operational management perspective, it is crucial that the system can absorb operational deviations. Rigid cyclic timetables often fail to utilise the dynamic properties of modern vehicles. As a result, even minor delays can destabilise the entire operational model, especially on single-track lines. The technological triangle—comprising infrastructure, vehicles, and timetable—fails here if the individual elements are not correctly aligned. Paradoxically, older vehicles with higher punctuality can bring greater operational stability than modern units without system support.

Tables 7 and 8 illustrate the advantages of individual stations in mitigating delays, irregular overtaking, and closures. Specifically, the higher the preference for a given type of station, the better it can accommodate operational traffic management.

Table 7. Evaluation of the Operative Pillar for Double-Track Lines.

Station Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	∑ Preference	Scale
1	x	0	0	1	0	0	1	1	1	0	0	0	0	0	0	4	0.04
2	1	x	0	1	1	1	1	1	1	0	0	1	1	1	1	11	0.10
3	1	1	x	1	1	1	1	1	1	0	0	1	1	1	1	12	0.11
4	0	0	0	x	0	0	1	1	0	0	0	0	0	0	0	2	0.02
5	1	0	0	1	x	0	1	1	1	0	0	0	0	0	0	5	0.05
6	1	0	0	1	1	x	1	1	1	0	0	0	0	0	0	6	0.06
7	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0	0	0.00
8	0	0	0	0	0	0	1	x	0	0	0	0	0	0	0	1	0.01
9	0	0	0	1	0	0	1	1	x	0	0	0	0	0	0	3	0.03
10	1	1	1	1	1	1	1	1	1	x	1	1	1	1	1	14	0.13
11	1	1	1	1	1	1	1	1	1	0	x	1	1	1	1	13	0.12
12	1	0	0	1	1	1	1	1	1	0	0	x	1	1	1	10	0.10
13	1	0	0	1	1	1	1	1	1	0	0	0	x	1	1	9	0.09
14	1	0	0	1	1	1	1	1	1	0	0	0	0	x	1	8	0.08
15	1	0	0	1	1	1	1	1	1	0	0	0	0	0	x	7	0.07

Table 8. Evaluation of the Operative Pillar for Single-Track Lines.

Station Type	16	17	18	19	20	∑ Preference	Scale
16	x	0	0	1	1	2	0.20
17	1	x	0	1	1	3	0.30
18	1	1	x	1	1	4	0.40
19	0	0	0	x	0	0	0.00
20	0	0	0	1	x	1	0.10

2.3. Planning Pillar (Timetable)—"All Trains Run on Time"

The planning pillar represents the ideal state where the timetable is fully adhered to. This requires aligning the route parameters with the technical characteristics of the vehicles and the operational concept. Optimal driving times and precisely defined technological intervals form the basis of a robust timetable. A turnaround plan that considers maintenance, turnover and mileage is key to the efficient use of the fleet. The full potential of the synergistic effect of the technological triangle is manifested in this pillar.

Tables 9 and 10 show the impact of individual station types on their suitability for use in timetable planning, i.e., the higher the preference for a given station type, the more suitable it is for timetable planning.

Table 9. Evaluation of the Planning Pillar for Double-Track Lines.

Station Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	∑ Preference	Scale
1	x	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2	0.02
2	1	x	0	1	1	1	1	1	1	1	1	1	1	1	1	13	0.12
3	1	1	x	1	1	1	1	1	1	1	1	1	1	1	1	14	0.13
4	0	0	0	x	0	0	1	0	0	0	0	0	0	0	0	1	0.01
5	1	0	0	1	x	0	1	1	1	0	0	0	0	1	1	7	0.07
6	1	0	0	1	1	x	1	1	1	0	0	0	0	1	1	8	0.08
7	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0	0	0.00
8	1	0	0	1	0	0	1	x	0	0	0	0	0	1	1	5	0.05
9	1	0	0	1	0	0	1	1	x	0	0	0	0	1	1	6	0.06
10	1	0	0	1	1	1	1	1	1	x	1	1	1	1	1	12	0.11
11	1	0	0	1	1	1	1	1	1	0	x	1	1	1	1	11	0.10
12	1	0	0	1	1	1	1	1	1	0	0	x	1	1	1	10	0.10
13	1	0	0	1	1	1	1	1	1	0	0	0	x	1	1	9	0.09
14	1	0	0	1	0	0	1	0	0	0	0	0	0	x	1	4	0.04
15	1	0	0	1	0	0	1	0	0	0	0	0	0	0	x	3	0.03

Table 10. Evaluation of the Planning Pillar for Single-Track Lines.

Station Type	16	17	18	19	20	∑ Preference	Scale
16	x	0	0	1	0	1	0.10
17	1	x	0	1	1	3	0.30
18	1	1	x	1	1	4	0.40
19	0	0	0	x	0	0	0.00
20	1	0	0	1	x	2	0.20

2.4. Automation Pillar

Automation of decision-making processes, deployment of ARS (Automatic Route Settings) systems and integration with dispatching tools represent a fundamental step towards modern traffic management. Predictive models based on current data enable dynamic prioritisation of trains, thereby increasing the system's ability to respond to operational challenges. Automation also supports timetable stability and allows efficient use of infrastructure and vehicles.

Tables 11 and 12 show the suitability or unsuitability of stations for ARS deployment. The preferences shown can also be divided into three bands: station type is entirely suitable for ARS deployment, station type is partially ideal for ARS deployment, and station type is unsuitable for ARS deployment. This preference threshold is individual for different infrastructure managers in various countries. However, the hierarchy presented above applies everywhere. The preferences in Tables 11 and 12 determine that the higher the preference for a given station type, the more suitable it is for automation or ARS.

Table 11. Evaluation of the Automation Pillar for Double-Track Lines.

Station Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	∑ Preference	Scale
1	x	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2	0.02
2	1	x	0	1	1	0	1	1	0	0	0	0	0	0	0	5	0.05
3	1	1	x	1	1	1	1	1	1	1	1	1	1	1	1	14	0.13
4	0	0	0	x	0	0	1	0	0	0	0	0	0	0	0	1	0.01
5	1	0	0	1	x	0	1	1	0	0	0	0	0	0	0	4	0.04
6	1	1	0	1	1	x	1	1	1	0	0	0	0	0	0	7	0.07
7	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0	0	0.00
8	1	0	0	1	0	0	1	x	0	0	0	0	0	0	0	3	0.03
9	1	1	0	1	1	0	1	1	x	0	0	0	0	0	0	6	0.06
10	1	1	0	1	1	1	1	1	1	x	1	1	1	1	1	13	0.12
11	1	1	0	1	1	1	1	1	1	0	x	1	1	1	1	12	0.11
12	1	1	0	1	1	1	1	1	1	0	0	x	1	1	1	11	0.10
13	1	1	0	1	1	1	1	1	1	0	0	0	x	1	1	10	0.10
14	1	1	0	1	1	1	1	1	1	0	0	0	0	x	1	9	0.09
15	1	1	0	1	1	1	1	1	1	0	0	0	0	0	x	8	0.08

Table 12. Evaluation of the Automation Pillar for Single-Track Lines.

Station Type	16	17	18	19	20	∑ Preference	Scale
16	x	0	0	0	0	0	0.00
17	1	x	0	0	0	1	0.10
18	1	1	x	1	1	4	0.40
19	1	1	0	x	0	2	0.20
20	1	1	0	1	x	3	0.30

2.5. Users Pillar (Passengers)

From the passenger's perspective, reliability, punctuality and comfort are key factors. Insufficient coordination between infrastructure, vehicles and timetables leads to permanent delays that cannot be compensated for. This reduces the attractiveness of public transport and user confidence. Effective planning, modernisation, and automation must always focus on the user experience, which is the ultimate measure of the system's success.

Tables 13 and 14 form a comprehensive part of the overall view of station reconstruction. This is a view that is sometimes overlooked and sometimes subject to enormous pressure, even at the cost of non-compliance with the pillars mentioned above. In this article, the passenger's perspective, or the user pillar, was constructed with an emphasis on walking distance from the natural centres of the given municipalities. In Central Europe, especially in the Czech Republic and Slovakia, during construction and reconstruction, emphasis has been placed in some cases on platforms only on the tracks at the station, i.e., the classic layout of platforms, and thus the layout of head platforms has been forgotten or not implemented.

Table 13. Evaluation of the Users Pillar for Double-Track Lines.

Station Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	∑ Preference	Scale
1	x	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2	0.02
2	1	x	0	1	1	0	1	1	0	0	0	0	0	0	0	5	0.05
3	1	1	x	1	1	1	1	1	1	0	1	0	1	0	1	11	0.10
4	0	0	0	x	0	0	1	0	0	0	0	0	0	0	0	1	0.01
5	1	0	0	1	x	0	1	1	0	0	0	0	0	0	0	4	0.04
6	1	1	0	1	1	x	1	1	1	0	1	0	1	0	1	10	0.10
7	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0	0	0.00
8	1	0	0	1	0	0	1	x	0	0	0	0	0	0	0	3	0.03
9	1	1	0	1	1	0	1	1	x	0	1	0	1	0	1	9	0.09
10	1	1	1	1	1	1	1	1	1	x	1	0	1	0	1	12	0.11
11	1	1	0	1	1	0	1	1	0	0	x	0	0	0	0	6	0.06
12	1	1	1	1	1	1	1	1	1	1	1	x	1	0	1	13	0.12
13	1	1	0	1	1	0	1	1	0	0	1	0	x	0	0	7	0.07
14	1	1	1	1	1	1	1	1	1	1	1	1	1	x	1	14	0.13
15	1	1	0	1	1	0	1	1	0	0	1	0	1	0	x	8	0.08

Table 14. Evaluation of the Users Pillar for Single-Track Lines.

Station Type	16	17	18	19	20	∑ Preference	Scale
16	x	0	0	0	0	0	0.00
17	1	x	0	0	0	1	0.10
18	1	1	x	0	0	2	0.20
19	1	1	1	x	1	4	0.40
20	1	1	1	0	x	3	0.30

In instances where a settlement is situated in proximity to the station head, platforms located at the station's head are particularly well-suited. In consideration of the trend towards increasing station length in response to the proliferation of longer trains, in conjunction with the imposition of restrictions on safety equipment (e.g., overlap distances, ETCS braking curves), access to the town may become comparatively protracted and convoluted in a conventional layout. It is also important to note that in many classical layout cases, the construction of intermediate platforms with grade-separated access is necessary. This results in the station group being wider and possessing a reduced number of tracks. The advantage of head platforms is generally better walking distance, which is combined with lower investment costs. This should therefore be a new trend in the reconstruction of simple (intermediate) stations.

Platforms situated at the head of railway stations have been shown to optimise passenger access to railway infrastructure within the served area. The incorporation of a stop at the head of a railway station has been demonstrated to enhance the accessibility of the line, thereby reducing the distances that passengers must walk. The configuration of such a stop should be informed by the transport and technological conditions of the line, as well as the requirements for integration with other modes of transport.

The distance that can be traversed on foot is a fundamental parameter for evaluating the accessibility of railway stops from the perspective of end users. For assessment, the catchment area of a stop is generally defined as a 5–10-min walk, which corresponds to

approximately 500–1000 metres, depending on the nature of the environment. The analysis of walking accessibility is conducted through the utilisation of circular polygons or, more precisely, isochrones derived from the actual network of pedestrian routes. This analysis facilitates the quantification of the proportion of residents or employment opportunities located within walking distance of the railway infrastructure, thereby enabling an objective evaluation of the benefits associated with new or relocated stations.

When constructing such a station, it is necessary to carefully consider the future transport technology, especially when selecting the location of the platform and the boundaries of the tracks with signals. These elements assume significance in terms of capacity, in addition to the termination and departure of trains.

In conclusion, a successful train prioritisation strategy must be built on the synergistic effect between infrastructure, vehicles and operational technology. Only their coordinated integration will create a robust, efficient, and attractive railway system that can respond to the challenges of modern transportation.

The Weighted Superposition Attraction (WSA), sometimes referred to as the weighted partial ranking method, is based on the principle of maximising utility using a linear function. When using it, a normalised criteria matrix is first created, where the values are transformed into the interval <0, 1>, with the ideal option receiving the value zero and the baseline option receiving the value 1. Based on these adjusted values, the total utility of the individual options is then calculated. The best option is the one with the highest utility value; projects can also be ranked according to the results achieved. The WSA method can therefore be performed according to the following five steps [26]:

1. Convert minimisation criteria to maximisation criteria;
2. Determine the ideal alternative (H) and the basal alternative (D);
3. Transform the criterion matrix Y into a normalised criterion matrix R using Formula (3);

$$v_{ij} = \frac{y_{ij} - D_j}{H - D_j}, \tag{3}$$

4. Determine the weighted relative utility of individual alternatives. The utility of alternative a_i is equal to Formula (4);

$$u(a_i) = \sum_{j=1}^{n} v_j \cdot r_{ij}, \tag{4}$$

5. The alternative that achieves the maximum utility value is evaluated by the method as the best.

2.6. Point Allocation Method to Assign Preferences

It is worth noting that the final step of the method is optional. The decision to utilise this model was motivated by its widespread adoption by the Czech infrastructure administrator for evaluating transport structures. The criteria are assigned weights that reflect their importance in the decision-making process. The calculation of the weighting coefficients is conducted in accordance with Formula (5). The scoring method allows for the individual evaluation of each criterion. The authors allocated 10 points to the most significant criterion and 2 points to the least important criterion [26].

$$v_i = \frac{b_i}{\sum_{i \epsilon I} b_i} \tag{5}$$

where:

v_i—weight of criteria *i*
b_i—points assigned to the criteria *i*
I—a set of criteria

3. Results and Discussion

An entity represents each vertex of the technological triangle. In the context of network infrastructure, the designated entity responsible for managing transport routes is the infrastructure manager. In the context of vehicle operators, the designated entity responsible for managing vehicle operations is the railway undertaking. The PSO authority is the designated entity accountable for managing ordering processes. Table 15 devised utilising the Formula (5), reflects three perspectives, i.e., the three vertices of the technological triangle.

Table 15. Preferences.

Pillar	Preferences of					
	Infrastructure Manager		PSO Authority		Railway Undertaking	
financial	10	0.33	4	0.13	2	0.07
operational	6	0.20	6	0.20	8	0.27
planning	4	0.13	8	0.27	6	0.20
automation	8	0.27	2	0.07	4	0.13
user	2	0.07	10	0.33	10	0.33

From the infrastructure manager's standpoint, finance is considered a pivotal component of any construction project. Furthermore, emphasis is placed on automation as a crucial element in reducing operating costs, given its capacity to minimise the number of employees directly engaged in rail transport management. Finally, the significance of operational management in eliminating delays is emphasised. These weights were determined based on discussions with IM experts who oversee the preparation and financing of construction projects.

The PSO authority places the most significant emphasis on passengers, i.e., users of the station infrastructure. The authority also emphasises the importance of the planning pillar in enabling the effective fulfilment of the needs of transport hubs in each area. Furthermore, the authority has identified the operational management element as being significant, given its overarching objective of ensuring minimal delays in train operations.

From the perspective of railway undertakings, users (passengers) are a pivotal asset; therefore, an appropriate location, i.e., one with a short walking distance, is deemed essential. Furthermore, emphasis is placed on the operational and planning pillars to eliminate delays and ensure the optimal design of train paths. Finally, automation is a vital aspect to consider, as increased automation is imperative in achieving cost reductions, specifically leading to lower fees for the utilisation of railway infrastructure.

As illustrated in Table 16, the total score for each pillar on double-track lines is summarised accordingly.

Table 16. Score of each pillar for double-track lines.

Station Type	Pillar				
	Financial	**Operational**	**Planning**	**Automation**	**User**
1	0.11	0.04	0.02	0.02	0.02
2	0.06	0.10	0.12	0.05	0.05
3	0.00	0.11	0.13	0.13	0.10
4	0.12	0.02	0.01	0.01	0.01
5	0.07	0.05	0.07	0.04	0.04
6	0.01	0.06	0.08	0.07	0.10
7	0.13	0.00	0.00	0.00	0.00
8	0.08	0.01	0.05	0.03	0.03
9	0.02	0.03	0.06	0.06	0.09
10	0.03	0.13	0.11	0.12	0.11
11	0.09	0.12	0.10	0.11	0.06
12	0.04	0.10	0.10	0.10	0.12
13	0.10	0.09	0.09	0.10	0.07
14	0.05	0.08	0.04	0.09	0.13
15	0.10	0.07	0.03	0.08	0.08

The following section presents a synopsis of the global score assigned to each pillar for single-track lines, as illustrated in Table 17.

Table 17. Score of each pillar for single-track lines.

Station Type	Pillar				
	Financial	**Operational**	**Planning**	**Automation**	**User**
16	0.20	0.20	0.10	0.00	0.00
17	0.10	0.30	0.30	0.10	0.10
18	0.00	0.40	0.40	0.40	0.20
19	0.40	0.00	0.00	0.20	0.40
20	0.30	0.10	0.20	0.30	0.30

Tables 18 and 19 present the evaluation's findings, including both the results for individual stakeholders and the overall results for single-track and double-track lines, respectively.

The findings indicate that stations with platforms positioned at the head of the train (types 10–15) achieved a top-half ranking when stakeholder perspectives were considered, thereby demonstrating their overall effectiveness. Types 3 and 2 have been demonstrated to be effective due to their enhanced crossing options and operational flexibility. In terms of ranking, Type 3 is elevated primarily due to the comprehensive provision of grade-separated passenger access.

Table 18. Results of the WSA method for the double-track lines.

Station Type	Preferences of						Sum of Ranking	Order
	Infrastructure Manager		PSO Authority		Railway Undertaking			
	Overall Result	Ranking	Overall Result	Ranking	Overall Result	Ranking		
10	0.092	2	0.107	1	0.115	1	4	1
3	0.083	4	0.102	2	0.110	2	8	2
11	0.102	1	0.091	4	0.094	4	9	3
12	0.081	5	0.098	3	0.102	3	11	4
13	0.090	3	0.081	6	0.081	6	15	5
14	0.068	8	0.082	5	0.087	5	18	6
2	0.072	7	0.081	7	0.079	7	21	7
15	0.077	6	0.065	9	0.066	9	24	8
6	0.049	12	0.069	8	0.072	8	28	9
5	0.053	10	0.051	11	0.048	11	32	10
1	0.055	9	0.036	13	0.030	12	34	11
9	0.041	15	0.056	10	0.057	10	35	12
4	0.050	11	0.027	14	0.020	14	39	13
8	0.043	14	0.036	12	0.030	13	39	14
7	0.044	13	0.018	15	0.009	15	43	15

Table 19. Results of the WSA method for the single-track lines.

Station Type	Preferences of						Sum of Ranking	Order
	Infrastructure Manager		PSO authority		Railway Undertaking			
	Overall Result	Ranking	Overall Result	Ranking	Overall Result	Ranking		
18	0.253	1	0.280	1	0.307	1	3	1
20	0.247	2	0.233	5	0.227	2	9	2
17	0.167	4	0.193	3	0.193	3	10	3
19	0.213	3	0.200	4	0.187	4	11	4
16	0.120	5	0.093	2	0.087	5	12	5

The following three illustrations (Figures 7–9) demonstrate the three most highly regarded solutions for double-track stations, of which the first and third feature a platform situated at the station's head. These are suitable for stations where train turnarounds are not expected. Still, it is possible to perform them, especially from/towards the direction where the platform is located, so that the train can be accommodated in the passing track group during the turnaround. The second option is sufficiently versatile; however, it is also more space-intensive and costly in terms of investment, given the number of platforms involved.

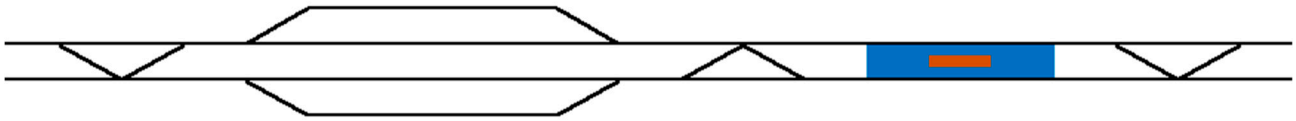


Figure 7. Best station topology for the double-track lines (Type 10).



Figure 8. Second-best station topology for the double-track lines (Type 3).

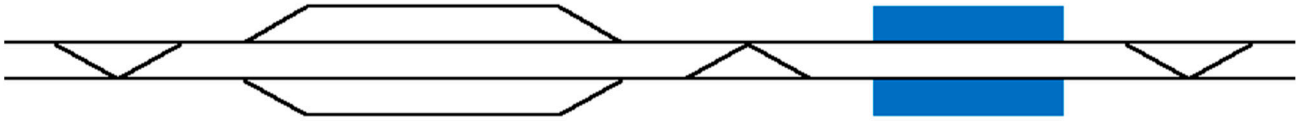


Figure 9. Third-best station topology for the double-track lines (Type 11).

Figures 10 and 11 illustrate the two solutions that have received the highest ratings for single-track stations. The first solution incorporates intermediate platforms, whereas the second solution features a platform divided into two tracks. This solution is particularly relevant for stations where passenger trains do not regularly cross paths, as improper sequencing of these trains can result in longer operating intervals. However, the advantage of this solution lies in the simple access to the platform, which is located only in front of the station building, and in the possibility of using both parts of the platform together during occasional long passenger train operations. In the Czech Republic, this solution is implemented at the Mikulov station.



Figure 10. Best station topology for the single-track lines (Type 18).



Figure 11. Second-best station topology for the single-track lines (Type 20).

The primary solution is analogous to type 3, but for single-track lines, which may prove advantageous, for instance, in stations where double tracking is anticipated in the medium term. However, if double-tracking is planned, consider the station types suitable for double-track lines at the earliest stage of planning.

A common feature of all the best station topologies, whether for double-track or single-track lines, is grade-separated access to platforms. From the perspective of passengers, the benefits of this system include enhanced comfort, expedited access to trains, and optimised passenger exchange processes both during boarding and alighting. Additionally, the system offers advantages for individuals with reduced mobility and orientation. These characteristics are indicative of the priorities established by the PSO authority and the railway undertaking. From the perspective of the infrastructure manager, such infrastructure reflects the intention of automation, because ARS (e.g., ASVC) can be implemented in such station configurations. It is noteworthy that a further commonality among all station topologies is the integration of timetable planning requirements, also referred to as the planning pillar. Moreover, this station topology facilitates high-quality operational management of train traffic, which is the operational pillar. This requirement is entirely in line with the needs of all users of the technological triangle.

The emphasis placed on the user and operational pillars may vary among railway undertakings depending on the type of PSO—whether it is a gross or net contract, which differ in terms of whether the PSO authority or the railway undertaking takes fare revenue. Regarding the issue of gross contracts, it would seem logical for these interests to be transferred more to the authority, although, regrettably, this does not occur very frequently. In this case, however, preferences were divided according to net contracts, as this order type is commonplace in the Czech Republic.

As presented in Table 20, the numerical data and percentage values pertaining to intermediate stations and stations with platforms on the head have been enumerated by the authors of the research study. It was conducted on a comprehensive array of continuous multiple-track lines within the Czech Republic, encompassing the infrastructure of Správa železnic. The determination of values was based on the analysis of source [23], and the colours are according to the three-colour scale.

The results of the line analysis demonstrate that intermediate stations account for more than 50% of most double-track and multi-track lines. A mere 14 stations feature platforms at the head of the station, accounting for a mere 9.79% of the total number of intermediate stations. That equates to just 5.32% of all stations on multi-track lines. On many lines, the incidence of stations with head platforms per 10 stations on the line is very low, and on some lines, it is even zero. This offers considerable scope and potential for the future development of such types of stations.

The exception to this is the Prague–Ševětín line, which forms part of the connection to České Budějovice, where this solution is adopted in three cases (one of which is Dynín, which will be presented in more detail in the following section), resulting in an incidence of 1.58 stations with a platform on the head per 10 stations. It is evident that other cases exhibiting a higher incidence are attributable to the fact that the lines are shorter and consequently possess a reduced number of stations (Chabařovice—Bílina, Pardubice—Opatovice-Pohřebačka).

The construction of the stations with platforms on the head was primarily driven by the necessity of track relocations and comprehensive reconstructions of long sections. This, in turn, presents an opportunity to reposition the platform at the head of the station, thereby enhancing passenger accessibility.

The methodology is suitable for intermediate stations, determining the basic layout, which can, however, be further adapted, especially in terms of spatial possibilities. Platforms at the head of the station are suitable for bringing the station closer to the built-up area, thus making rail transport more attractive.

Platforms located at the midpoint of the main tracks are well-suited for stations where passengers may transfer between trains. Such platforms may be advantageous in intermediate stations connected to a junction with a branch line, or those situated next to a station with a branch line where, given the size of the surrounding settlement, it is not economically viable for long-distance trains to stop.

This section presents a series of real-life projects for platforms located at the station's head. The literature [27] is used to demonstrate 10-min walking distances on a map. Blue is used to indicate distances from the original platform location, while orange shows isochrones from the new location. The northern direction is indicated with an arrow.

The current platforms at the head of the station in Krasíkov have been in operation for over 15 years. As demonstrated in Figure 12, there has been a substantial enhancement in the proximity of rail transportation to residential areas. The strategic positioning of the structure in proximity to the road underpass has been demonstrated to engender a synergistic effect, thereby obviating the necessity for the construction of an underpass.

Table 20. Intermediate stations and platforms on the head-on double-track lines in the Czech Republic.

Line	Intermediate Stations	Percentage from All Stations on the Given Line	Number of Stations	Stations with Platform on the Head (Included in Intermediate)	Incidence of Stations with a Platform on the Head—Per 10 Stations	Stations with Platform on the Head
Kolín (excl.) - H. Brod - Brno-Maloměřice (excl.)	12	60%	20	1	0.50	*Vlkov u Tišnova*
Děčín (incl.) - Kralupy n. V. - Praha hl. n. (excl.)	9	52.94%	17	1	0.59	*Praha-Podbaba*
Děčín východ (incl.) – Kolín (excl.)	12	57.14%	21	1	0.48	*Litoměřice město + Litoměřice d. n.*
Praha hl. n. (incl.) - Přerov (excl.)	18	50%	36	3	0.83	*Brandýs n. O.; Krasíkov; Hoštejn*
Praha hl. n. (excl.) - Lysá n. L. (excl.)	2	50%	4	0	0	
Praha hl. n. (excl.) - Ševětín (incl.)	11	57.89%	19	3	1.58	*Votice; Červený Újezd; Dynín*
Zliv (incl.) – Číčenice (incl.)	1	33.33%	3	0	0	
Horažďovice př. (incl.) - Nepomuk (incl.)	1	33.33%	3	0	0	
Praha hl. n. (excl.) - Přovany (incl.) + Plzeň-Koterov	9	50%	18	1	0.56	*Plzeň-Slovany + Plzeň-Koterov*
Lipová u Ch. (incl.) - Ústí nad Labem západ (incl.)	14	50%	28	0	0	
Chabařovice (incl.) - Bílina (excl.)	3	60%	5	2	4	*Krupka-Bohosudov; Jeníkov-Oldřichov*
Obrnice (incl.) - Počerady (incl.)	1	50%	2	0	0	
Pardubice (excl.) - Opatovice-pohřeb. (incl.)	1	33.33%	3	1	3.33	*Stéblová*
Česká Třebová (excl.) – Lanžhot (incl.)	10	52.63%	19	0	0	
Zastávka u B.(incl.) - Veselí n. M. (incl.)	11	73.33%	15	1	0.67	*Tetčice + Tetčice-Bobrava*
Břeclav (excl.) - Petrovice u K. (incl.)	15	50%	30	0	0	
Hranice na M. (excl.) - Horní L.(incl.)	5	62.50%	8	0	0	
Ostrava-Vítkovice (incl.) - Mosty u J. (incl.) + Karviná, Louky n. O.	8	66.67%	12	0	0	
Together	**143**	**54.37%**	**263**	**14**	**0.53**	

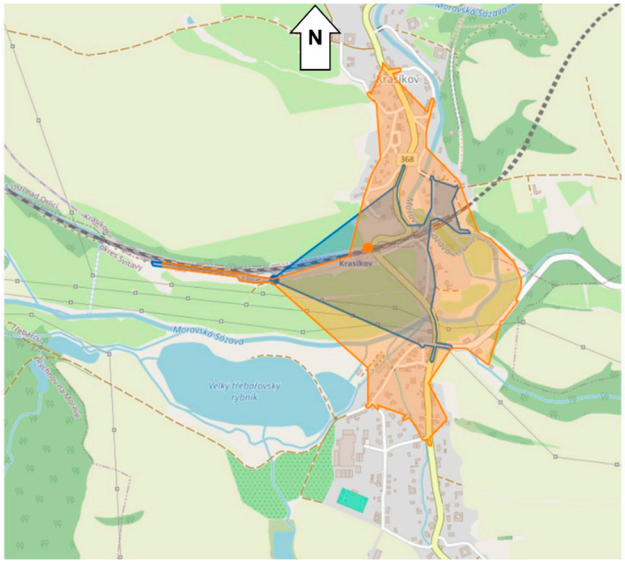


Figure 12. Isochrones of old and new platform locations in Krasíkov.

A new halt in Dynín has also been in operation for several years, replacing the original platform at the passing tracks (see Figure 13). As with Krasíkov, it is near the built-up area and is accessible via a road underpass that provides pedestrian access to the platforms.

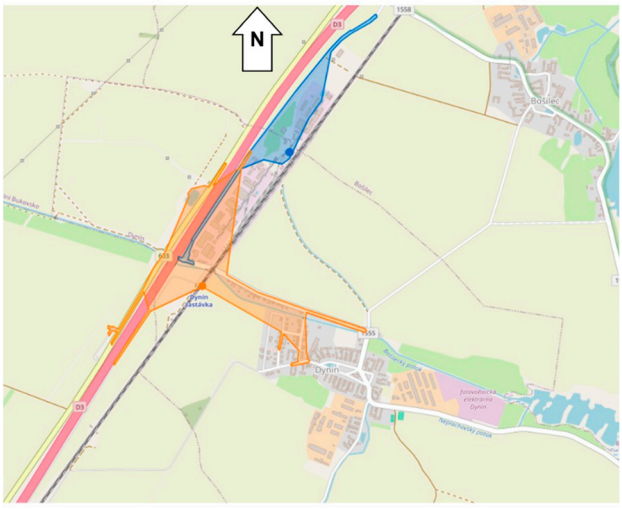


Figure 13. Isochrones of old and new platform locations in Dynín.

As demonstrated by Figure 14, recent developments in the Vlkov u Tišnova area have involved platforms positioned at the head of the station, with a notable degree of residential density in the surrounding area. As in previous cases, a shared road underpass with a sidewalk is used to access the platform. In contrast to earlier instances, the tracks at the platforms are fenced off with signals. This configuration facilitates the efficient reversal of passenger trains at this station without significant impediments.

Stations with platforms at the head of the station can be used effectively for overtaking trains on less-frequented double-track lines. In favourable conditions, trains can stop at the arrival head on the opposite track and then enter the overtaking track group. In the interim, the overtaking train is permitted to pass along its primary track. In the most favourable circumstances, the length of the station and the time allotted for passengers to disembark and board will preclude the necessity to extend the station's stay due to traffic reasons.

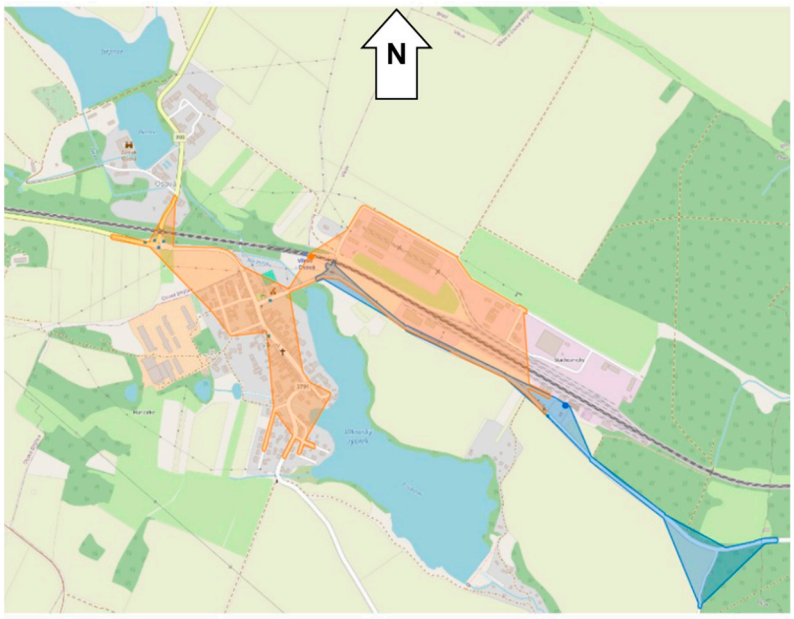


Figure 14. Isochrones of old and new platform locations in Vlkov u Tišnova.

The present research focuses on intermediate stations with simple designs, as these do not involve the more complicated technological processes that occur, for example, in train turnaround stations or stations with intensive siding service. In the case of stations where trains turn around, it is appropriate to focus on a zero-track group solution (a track group positioned centrally between the main tracks), as there is no conflict between the train paths when these trains enter and depart, with trains travelling in the opposite direction. However, such stations are demanding in terms of width and length due to the safety equipment, especially the design of the turnout tracks and overlap distances (ERTMS).

In the future, the addition of further solutions and conducting related research for different categories of stations is recommended. These may include connected stations, stations used for passenger train turnarounds, stations with heavily used sidings or stations designated for freight transport.

4. Conclusions

The sustainability of the transport system is a highly complex and multi-layered task that requires a coordinated approach across all levels of management, planning and implementation of transport processes. The entire transport sector—from strategic planning to infrastructure development and daily operational practice—must function in harmony with one another, considering environmental, economic, and social aspects.

The issue of Public Service Obligation (PSO) must be addressed within the technological triangle, which links technology, human resources, and organisational processes. It is only through the integration of these elements that sustainable transport development can be achieved, one which meets the societal and economic requirements of the region.

A notable characteristic of high-quality stations, whether situated on single or double-track lines, is the provision of grade-separated access to platforms. The implementation of this system has been shown to have several benefits, including enhanced passenger comfort, reduced boarding and alighting times, and improved accessibility for individuals with reduced mobility. These features are indicative of the priorities of both the PSO authority and the railway undertaking.

From the infrastructure manager's perspective, such station design supports automation, particularly including automatic route setting. The system enables efficient traffic management. In this way, it aligns with the needs of all users within the technological triangle.

Stations need to be constructed in a sufficiently robust manner to meet the operational concept's requirements. However, it is equally crucial to consider potential reserves, whether for freight transport or the possible development of transport infrastructure. Furthermore, it is imperative to ensure the operational capacity of the railway during closures (TCRs), a consideration that assumes particular significance on double-track lines.

Infrastructure, particularly railway stations and passing loops, constitutes a significant component of the triangle. This is primarily because they facilitate the processes of crossing and overtaking. In the context of single-track lines, the act of crossing assumes a heightened significance, given its role in shaping the operational concept. In the context of double-track lines, the process of overtaking becomes imperative, as it enables trains of varying velocities to utilise the track's capacity collectively. It is essential to emphasise the significance of crossing on double-track lines in the event of temporary capacity restrictions (TCRs).

This methodology is conducive to the systematisation and involvement of all stakeholders in decision-making processes concerning future station configurations. In the future, it would be appropriate to expand the range of station types and modify the methodology for connecting stations, which are also considerable in number. In the context of nodes, it is imperative to emphasise that a substantial degree of individualisation in solutions is inevitable.

This approach to the sustainability of the transport system not only enables the quality of public transport to be improved but also strengthens its competitiveness against individual transport, helping to achieve broader sustainable development goals set at both national and international levels. However, it is worth noting that versatile solutions tend to be more expensive. Nevertheless, with knowledge of the future operating concept, it is possible to optimise the infrastructure to suit the specific needs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su18020670/s1, Figure S1: Tree of possible solutions.

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