CURRENT PROBLEMS IN RAIL VEHICLES

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MODERN ROLLING STOCK AS A PILLAR OF THE TECHNOLOGICAL TRIANGLE

MODERNÍ VOZIDLA JAKO PILÍŘ TECHNOLOGICKÉHO TROJÚHELNÍKU

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Abstract

This conference is an established forum for presenting novel insights and current technological advances in rolling stock. Both practical and scientific evidence underscores the significance of this sector, with its innovations contributing to the growing popularity of rail transport. This article, however, offers a cautionary perspective. It serves as a warning for those responsible for ordering these vehicles under public service obligations, as well as those who build and manage the supporting infrastructure. While many innovations are undoubtedly beneficial, some can complicate technological integration and pose significant challenges for transport technologists. The pivotal element in this regard is the uniformity among the transport infrastructure, the vehicles used, and the customer's operational concept along a specified route. Collectively, these are referred to as the technological triangle. This article presents practical examples of effective solutions and their real-world impact, focusing on the synergistic effect of modernizing rolling stock and railway infrastructure and linking these aspects with the timetable and operational concept.

Keywords

public service obligation, rolling stock, technological period, operational concept, railway infrastructure

Abstrakt

Tato konference pravidelně přináší nové poznatky a aktuální technologický posun v oblasti kolejových vozidel. Jak praktická řešení, tak vědecké přístupy ukazují, že tento segment je velmi významný a jeho inovace přispívají k vyšší oblibě kolejové dopravy. Tento článek ukazuje trochu jiný pohled a nastavuje zrcadlo těch, kteří následně tato vozidla objednávají v závazku veřejné služby nebo pro ně tvoří a spravují infrastrukturu. Řada inovací je velmi pozitivních, ale najdou se i takové, které prodlužují technologické časy a komplikují tak práci dopravním technologům. Klíčovým aspektem tak je soulad dopravní infrastruktury, použitých vozidel a také provozního konceptu objednatele na dané trati. Souhrnně se tyto aspekty označují jako technologický trojúhelník. V tomto článku jsou představeny některé takové případy dobré praxe a jejich reálné dopady. Jedná se zejména

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o synergický efekt modernizace vozového parku, železniční infrastruktury a propojení těchto aspektů s jízdním řádem a provozním konceptem.

Klíčová slova

závazek veřejné služby, kolejové vozidlo, technologický čas, provozní koncept, železniční infrastruktura

1 INTRODUCTION

The means of transport, specifically rolling stock, constitute a pivotal element in determining the mode of public transport selection. The utilisation of modern vehicles is perceived as a favourable development by both customers and railway undertakings. This is because it enhances the attractiveness and competitiveness of public rail transport. However, it is essential to note that enhanced vehicle specifications do not inherently translate into reduced journey or travel times. A comprehensive system approach, incorporating the vehicle, the infrastructure, and the timetable, is imperative to create synergies and elevate the entire transport system to higher efficiency. This phenomenon is referred to as the technological triangle [1, 2]. Another analogous instance of technological advancement is the transition from conventional to high-speed rail. As is evidenced by numerous scientific studies, the implementation of a high-speed rail system has been demonstrated to positively impact economic development and regional accessibility [3, 4]. In the Czech Republic, this issue is addressed, for example, in [1, 5, 6].

Although the new vehicles, particularly in conventional operation, can lead to savings in some sense (for example, through push-pull mode options, which can reduce turnaround times and therefore the number of vehicles needed), there are also drawbacks that these vehicles entail, such as higher cost of transport performance. Due to prevailing political and social circumstances, it is not feasible to pass on the entire increase in price to the customer. This increases the financial burden of the transport chapter on the municipality finances, and not all municipalities are willing to accept this increase.

A further constraint on utilising dynamic parameters in new vehicles is the periodic timetable, heavily relied upon by many regional public transport organisers. The underlying principle of this timetable is the regular departure of connections from interchange stations. The enhanced dynamic characteristics of the vehicles, which result in reduced journey times, are not reflected beyond this passing loop. The positive effect of earlier arrivals can be seen in the increased ability of the vehicle to eliminate delays, leading to greater stability of the timetable and, by extension, of the entire public transport system. In principle, this can entail the act of reaching a tact node or the relocation of a crossing. Conversely, it has the capacity to augment the freight segment's capacity, thereby facilitating the availability of optimal train paths characterised by reduced stoppages and enhanced smoothness in operation. This, in turn, results in a reduction in the traction energy consumption of freight trains.

2 VEHICLES

One of the supporting pillars of the technological triangle is the vehicle. Its traction characteristics and other technical parameters influence the length of the travelling time and the vehicle's dwell time at a stop. From a technological perspective, it is possible to utilise the principles of request stops or departures at the arrival time.

2.1 Travelling time

The public service obligator (state, region, municipality), as the guarantor of transport services for Os (local), Sp (fast local) and R (fast) train categories, aims to structure the order in such a way that their daily utilisation is maximised, and travel times are minimised. This can be characterised as utilising infrastructure and vehicles to their maximum capacity. From a transportation perspective, travelling time is the time period between two traffic points listed in the tabular timetable. This travelling time depends on the following factors: infrastructure, transport technology, and vehicles. If we utilise the maximum limits of all these factors – meaning maximum line speed, maximum vehicle speed (depending on the maximum line speed), maximum acceleration, and minimum dwell times – we will achieve a synergistic effect in utilising allocated resources. However, with any delay, the system cannot eliminate it, and thus, the system becomes unstable. This case can be observed on busy single-track lines. Consequently, the critical aspect of the synergistic effect is lost, which creates the impression that a system with older vehicles running on time is more beneficial [7, 8, 9].

Travelling time, technological intervals and headways greatly influence this aspect of running trains without delays. Thus, it is not exceptional that the technological interval does not correspond to the regulatory reality due to the need to ensure edge time and a precise interval. Here, then, the possibility of adapting the infrastructure to the needs of the operational concept is offered. Ideally, the infrastructure will be modified to match the operational characteristics of the rolling stock. In this way, it will be possible to construct an operational concept based on the optimum travelling time that will eliminate possible delays. The scientific challenge is determining the ideal supplement time value for the travelling time.

Supplement time to the travelling time

For this research, the OpenTrack simulation software was used. The research team has many years of experience with this SW and has fine-tuned the SW settings so that its fidelity to real operation is very high [10]. Research has been conducted in previous years [2, 11, 12] to investigate the interplay between train requirements in a public service obligation (PSO) and infrastructure possibilities. The simulated infrastructure contained one intermediate section (27 km long, track speed 100 km·h^{-1}) bounded by stations with train development. Travel time, vehicle performance and energy consumption were monitored. The parameterised variable was vehicle power, which was varied between 50% and 100% for the simulation. This then resulted in different travel times and the consumption of traction energy. The consumption is only addressed to the consumption of the electric traction. The results are presented in Tab. 1. The complete simulation data is then available from the authors.

Tab. 1 Selected simulation parameters

Vehicle performance [%]	Travelling time [mm:ss]	Energy consumption [MJ]
100	16:59	795
90	18:01	665
80	19:19	547
70	21:01	432
60	23:20	338
50	26:33	244

Tab. 1 shows how to set up the supplement time for the fastest journey time. This creates a time margin that can be used to reduce the vehicle's consumption during standard conditions or to reduce the delay. Tab. 1 shows that the size of this margin is 9 minutes and 34 seconds at the 50% vehicle power output. That is 56% more travelling time than in the ideal case. In terms of traction energy consumption, this is a 70% saving. However, this extreme case allows for a dramatic reduction in delay, but the actual travelling time is exceptionally high. The search for the optimal setting between consumption and travel time has been addressed in [13]. From the traction energy consumption (ε) waveform knowledge, the traction energy saving can be derived from equation 1.

$$\varepsilon = \frac{E}{E_{\max}} \ (1, \mathrm{MJ}, \mathrm{MJ}) \tag{1}$$

where:

- E – energy consumption with specific vehicle performance [MJ]
- $E_{\max}$ – energy consumption with maximum vehicle performance [MJ]

A similar situation is in equation 2 with the travelling time (τ).

$$\tau = \frac{T}{T_{\max}}\ (1, \min, \min) \tag{2}$$

where:

- T – travelling time with specific vehicle performance [MJ]
- T_{max} – travelling time with maximum vehicle performance [MJ]

The energy-optimal travelling time is the driving time for which equation 3 holds. Then the differential coefficient of the consumption function with respect to time is equal to -1.

$$\frac{\mathrm{d}\varepsilon}{\mathrm{d}\tau} = -1 \tag{3}$$

In this research, the consumption function is represented by the regression equation in Fig. 1.

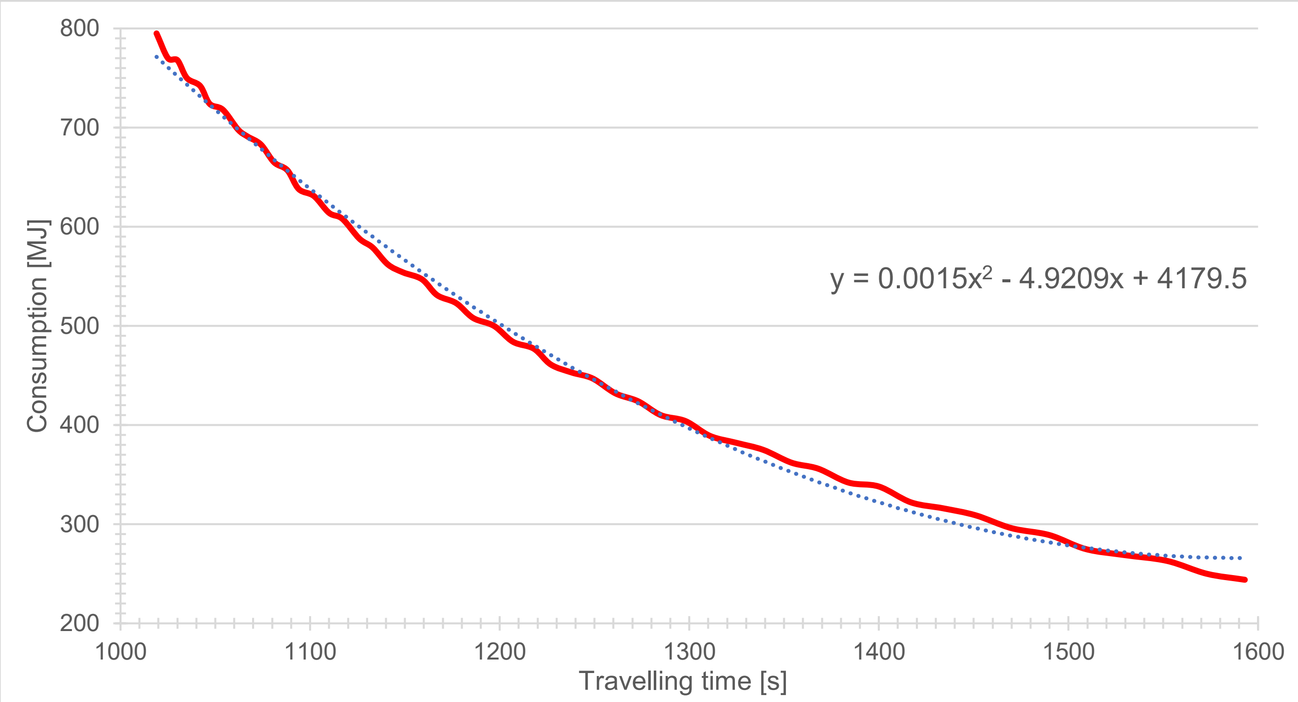

Fig. 1 Consumption concerning travelling time

The regression equation is expressed in formula 4. The correlation coefficient R^2 is equal to 0.9964.

$$\varepsilon = 0.0015 \cdot \tau^2 - 4.9209 \cdot \tau + 4\,179.5 \tag{4}$$

The differential coefficient of equation 4, according to equation 3, leads to the optimal consumption of the traction energy in formula 5.

$$\begin{aligned} 0.003 \cdot \tau - 4.9209 &= -1 \\ 0.003 \cdot \tau &= 3.9209 \\ \tau &= 1\,306 \end{aligned} \tag{5}$$

Tab. 2 The optimum vehicle performance

Vehicle performance [%]	Travelling time [mm:ss]	Travelling time [s]	Consumption [MJ]	Potential delay decrease [s]
68	21:25	1 285	410	266
67	21:38	1 298	404	279
66	21:51	1 311	389	292
65	22:05	1 325	382	306
64	22:19	1 339	375	320

The optimal travelling time should be 1 306 seconds, corresponding to 21:46 minutes. In the selection of source data in Tab. 2, this value corresponds to a vehicle performance of 66% to 67% (grey values). This corresponds to a potential delay reduction of between 279 and 292 seconds (about 4.5 minutes). This is 28.2% longer than the ideal travelling time.

Furthermore, the percentage of cases in which this value eliminates the delay from the absolute value of time that can be eliminated in the intermediate section can be obtained. To obtain such a number, it is necessary to ascertain the input delay of trains at the input edge, i.e. the point at which trains enter the monitored area. Based on formula 6, the proportion of delayed trains can be calculated based on the frequency of occurrence of a given delay value. Fig. 2 shows the delay values obtained from the continuous monthly measurements; the authors' complete data is then available.

$$P_{\mathrm{ZV}} = \frac{f_i}{\sum_{i=0}^{n} f_i} \tag{6}$$

where:

- P_{ZV} – share of delayed trains [-]
- f – frequency of the delay value [-]

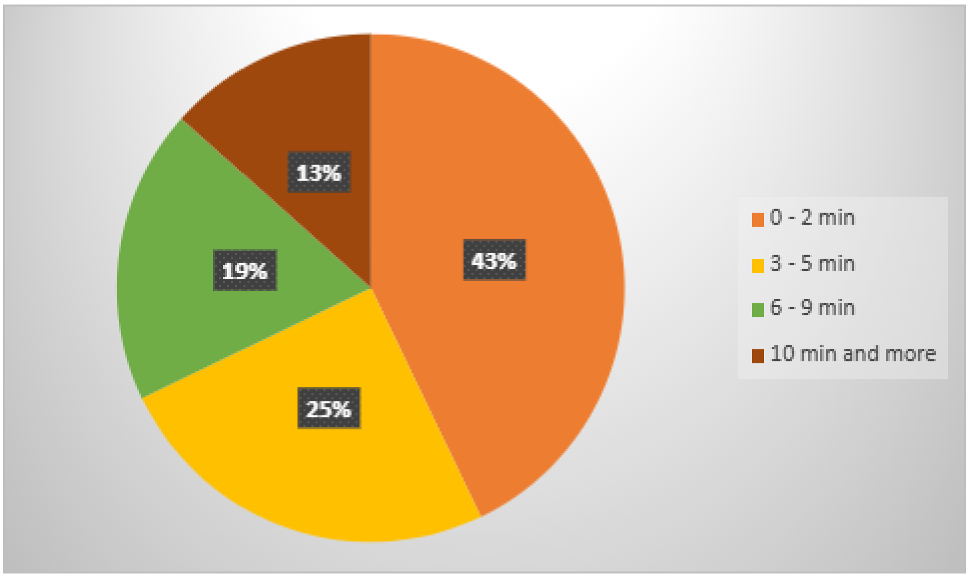

Fig. 2 Share of delayed trains; source: authors based [14]

Simulation of the input delay, based on an exponential probability distribution with parameter λ, was conducted. Valid data is needed to calculate the parameter λ, which accurately reflects the nature of the train delay in an input edge. This data is then used to construct a table of frequencies and proportions of delayed trains for a particular level of delay (see Fig. 2). This data is then used to calculate the mean value of the random variable (see Equations 7–9).

$$P_{\mathrm{ZV}} = P_{(x_i)} \tag{7}$$

$$E(X) = \sum_{i=1}^{n} x_i \cdot P_{(x_i)} \tag{8}$$

$$\lambda = \frac{1}{E(X)} \tag{9}$$

where:

- $P_{(x\_i)}$ – a function of probability
- $E(X)$ – mean value of the random variable
- λ – parameter of the function

After obtaining the parameter λ, the waveform of the measured values (blue curve in Fig. 3) and the waveform of the exponential function that characterises the measured values by the exponential function (orange curve in Fig. 3) can be plotted.

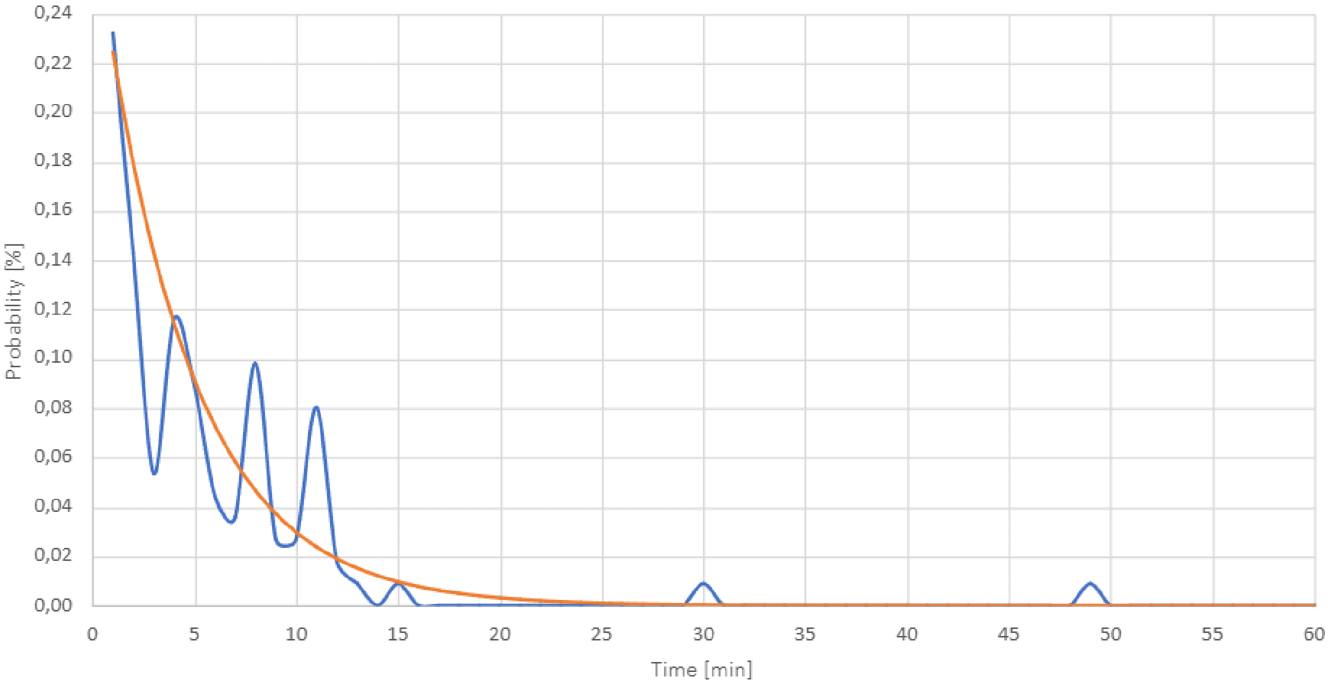

Fig. 3 Averages of measured values of delay; source: authors based [14]

Fig. 3 was set up according to the realised timetable of passenger trains. The results reflect the Directive SŽ SM124. Therefore, it is said that 65% of delayed trans can be eliminated by setting journey times to 67% of vehicle performance. The longer the stretch between major stations, the higher the value of the possible reduction in the absolute value of delay.

Some delays are caused by the connections between trains or buses inside the system. However, with a wider range of connections (an hourly timetable and a denser service), it is possible to set strict rules (short waiting times) and fully use the railway's capacity, even on single-track lines with minimal freight traffic.

2.2 Dwell times

The dwell times of passenger trains can be viewed in two distinct ways [15]. Firstly, the function of transport is to facilitate the exchange of passengers on the train. The process mentioned above pertains to the act of boarding and alighting. The length of this component is influenced by several factors, including the number of passengers getting on and off the train, the vehicle parameters (length of the train, number of doors, distance between doors, width of doors, time required to open doors), and possibly also the infrastructure (width of platform, length of platform, type of platform, access to platform). Furthermore, it should be noted that transfer links may also significantly impact this component.

Additionally, it possesses a traffic function, which facilitates the management of traffic operations, such as overtaking and crossing. The determination of the time for executing this traffic action is typically influenced by two primary factors: the imminent train, with which the monitored train is scheduled to interact, and the infrastructure, particularly the configuration of the designated transport station and the signalling apparatus (interlocking). These elements contribute to establishing operating intervals, which delineate the shortest permissible time for executing the traffic operation at a specific location. These intervals are the foundation for establishing the timetable, with the shortest permissible time determining the time allocation for executing the traffic operation at a given location.

The combination of these two functions constitutes the total length of stay. Ideally, there should be overlap between them, which is to be desired.

The positive effect of pre-selection on the speed of door opening is well-documented. In this system, passengers press the opening button before the train stops, pre-selecting the door. In some vehicles, the door on the correct side of the platform must be selected. In others, however, it is sufficient to press the button on any side, and the door will open only on the side unlocked by the train driver.

However, a disadvantage of modern vehicles is the relatively protracted time required to extend the door step, which increases both the time to open the door and the time to close it. Moreover, the device exhibits a range of malfunctions, particularly during the winter months, thus negatively impacting its functionality. Consequently, this results in an increase in the dwell times for passenger changes.

3 INFRASTRUCTURE

In addition to the renewal of vehicles, the railway infrastructure is undergoing significant upgrades. Local realignments are being implemented in certain instances, and the radius of curves and cant is also increasing. This facilitates the line speed enhancement. Furthermore, new speed profiles are being introduced which were not previously available on the line (*V*130, *V*150). It is imperative to acknowledge the significance of modifications to level crossings to effectively mitigate or eliminate the occurrence of speed reductions in their immediate vicinity. It is possible to achieve this in two ways. Firstly, the sight conditions around the crossing can be improved. Secondly, and most importantly, crossing protection can be installed or the level crossing can be completely removed and replaced with an off-grade crossing.

The impact of these speed increases can be favourable when speeds are elevated in coherent sections. However, to achieve system-wide time savings in the overall context, it is also necessary to focus on the operational concept, or, if a timetable or integrated timetable (ITT) is applied on the line, on its timetable nodes and passing loops where overtaking and crossing occur. To accommodate future developments, it is imperative to adapt the infrastructure to ensure system times between tact nodes can be achieved following these adaptations, whilst concomitantly enhancing traffic stability. It is imperative that infrastructure systems maintain sufficient reserves and are adequately prepared for the potential growth in traffic volume and subsequent expansion of associated infrastructure.

In the context of infrastructure development, various strategies can be employed. Existing services can be modified by extending station tracks or by adding new parts to the station, which has a positive effect on freight transport, where trains can be lengthened, but also on passenger transport, as the collision point can be shifted, resulting in a substantial reduction of operating intervals. This is further compounded by the deployment of advanced signalling equipment, a practice that, when considered within the broader context of ETCS, necessitates the establishment of an appropriate track configuration.

Construction of a new passing loop in Bartoušov

Should the travel speed of passenger trains be increased, whether due to an increase in line speed or the deployment of vehicles with superior dynamic characteristics (or a combination of both), the time saved may be rendered futile by the presence of protracted intermediate sections and the impracticability of movement, particularly regarding tact crossing of trains. Consequently, in such instances, it is recommended to establish a new station or passing loop that aligns with the requisite operational concept.

The passing loop in Bartoušov, situated on the regional line between Nymburk and Jičín stations, is a pertinent example. Following the establishment of this passing loop, a substantial reduction in journey times was achieved by the relocation of the train crossing from Kopidlno station. This was particularly evident in the direction of Jičín station, prior to the construction of the passing loop. Trains in this direction experienced a prolonged dwell time while waiting to cross at Kopidlno station. This can be seen in Fig. 4.

As shown in Tab. 3, there has been a reduction of over 20% in journey times on specific routes, despite the use of the same rolling stock (Class 814). A further comparable case is the recently constructed station Sedlec u Mikulova, which is situated on the line between Znojmo and Břeclav. In this instance, the tact crossing has been relocated to this station, reducing the journey times. Preparations are underway for additional comparable projects, including the Kuks passing loop in the vicinity of Jaroměř station and the Slavibоř station near Telč station.

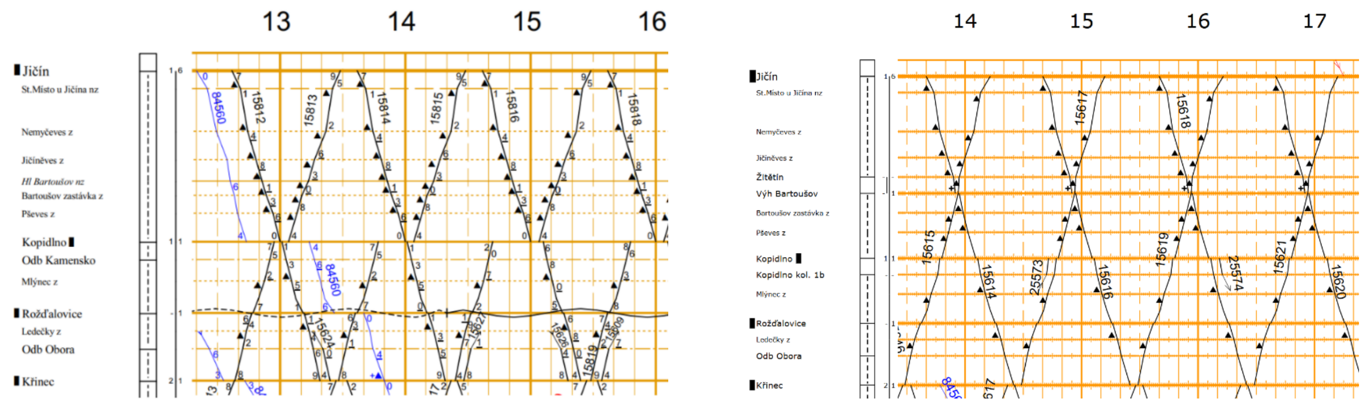

Fig. 4 Comparison of train traffic diagrams (2019 and 2025); source: Správa železnic, s.o.

Tab. 3 The change in journey times after the construction of a new passing loop; source: authors based on data of Správa železnic, s.o.

Route	Journey time[min]			
	Former (2019)	Current (2025)	**Difference**	
Nymburk – Jičín	80	63	**-17**	**-21.25 %**
Jičín – Nymburk	74	64	**-10**	**-13.51 %**
Křinec – Jičín	60	44	**-16**	**-26.67 %**
Jičín – Křinec	47	45	**-2**	**-4.26 %**

4 PUBLIC SERVICE OBLIGATION

Public service obligations (PSOs) in the railway sector are governed by Regulation No. 1370/2007 of the European Parliament and of the Council. This regulation establishes the conditions under which competent authorities may award public service contracts to ensure the provision of rail passenger services in the general interest. PSOs address situations where certain transport services, although socially necessary, would not be provided under purely commercial conditions. The regulation mandates that public service contracts, particularly in railway transport, must be competitively tendered unless specific conditions for direct award are met. Contracts must be competitively awarded for rail passenger transport services if the annual volume exceeds 500 000 train-kilometres (train-km). The maximum duration of competitively awarded contracts is 10 years, extendable under defined conditions (e.g. up to 15 years in case of significant investment in rolling stock or infrastructure). Nonetheless, considering the service life of rolling stock, it is deemed suitable for the vehicles to be transferred to a successor railway undertaking after the contractual period.

Before launching a competitive procedure, the competent authority must assess whether operators have fair access to rolling stock. If access is limited, authorities may implement facilitative measures such as purchasing rolling stock and leasing it to operators, offering guarantees for procurement, or committing to purchase the stock after contract termination. These interventions must comply with State aid rules.

Transparency is a legal obligation: the authority must publish a notice at least one year before launching a public service contract award. The notice must include the intended procedure (competitive or direct), the scope and duration of the contract, and the services concerned. The publication must be made in the Official Journal of the European Union, ensuring market visibility. Based on experience from the Czech Republic and Slovakia, competent authorities often fail to fulfil their obligation to ensure non-discriminatory access to rolling stock for railway undertakings, as required. As a result, railway undertakings are frequently compelled to procure suitable rolling stock independently, which often leads to suboptimal vehicle deployment on many routes, particularly where the competent authority shows little or no interest in the type and quality of vehicles used to operate the awarded services.

In the Czech Republic, the process of selecting railway passenger transport operators has revealed numerous shortcomings, particularly in ensuring transparency, non-discrimination, and adequate preparation time. For example, in the case of the Pardubice–Liberec–Ústí nad Labem route, the Ministry of Transport relied on a direct award and delayed the decision until only two months before the start of operations, which meant the operator had just three days to sign the contract. This clearly disadvantaged any potential new entrants. A similar issue occurred on the Kolín–Mělník–Ústí nad Labem route. Although the Ministry had an extra year for preparation, the contract was still signed only three months before the service was due to begin, which is still insufficient. This was especially problematic because new vehicles were required, and the Ministry introduced a three-year transitional period to allow their procurement. However, this solution significantly increased costs since the operator had to provide both interim and future rolling stock. In Královéhradecký Region, the regional authority also failed to engage with operators in a timely or substantive way and eventually awarded the contract to the existing provider, undermining the intended goal of market liberalization. Meanwhile, the situation in Slovakia is even more concerning. On the Bratislava–Banská Bystrica route, unrealistic tender conditions such as requiring rolling stock for Sunday-only services led to increased costs and an ultimately unsuccessful tender. The Žilina–Rajec tender failed twice because the technical requirements set by the Ministry were unachievable, and although three operators initially showed interest, only the national operator submitted a bid, which did not meet the criteria. On the Bratislava–Komárno line, the Ministry's repeated inability to set realistic and practical tender conditions resulted in no bids at all, even from the national carrier. This forced last-minute negotiations with the existing operator, who no longer had the necessary rolling stock under lease, leading to the use of trains from abroad. Despite the route's growing passenger numbers, infrastructure upgrades such as electrification and double-tracking have been ignored. These repeated failures suggest either a lack of genuine political will to liberalize the rail market or a lack of competence among the officials preparing the tenders, both of which contradict EU regulations and ultimately harm the public interest.

The financial compensation granted under PSO contracts must strictly reflect the net financial effect of fulfilling the obligation. This is defined as: Costs incurred by the operator in fulfilling the PSO, Minus the revenues generated (e.g. ticket sales, other commercial income), plus a reasonable profit, calculated concerning market conditions and associated risks. Operators providing commercial and PSO-covered services must keep separate accounts, ensuring no cross-subsidisation or overcompensation occurs. The awarding of a public service contract entails legal and financial commitments and detailed technological planning, rooted in the train timetable. The timetable forms the backbone of passenger service provision, specifying departure and arrival times at each station. It is developed based on passenger demand, required service frequency, peak and off-peak periods, and connections with other services. From the timetable, the railway undertaking derives the trainset circulation plan, which determines how rolling stock is deployed across services. The circulation plan defines how many trainsets are needed, how they rotate between services during the day, and where they are turned or coupled/uncoupled. A well-designed circulation plan minimises idle time, reduces the required fleet size, and ensures balanced distribution of trainset kilometrage – a key metric for maintenance planning. Rolling stock maintenance is essential to ensure safe and reliable operation. Maintenance schedules are based on kilometres travelled or time in service. The circulation plan must therefore be crafted to ensure even distribution of workload among trainsets, and to integrate necessary downtimes for technical servicing, refuelling, interior/exterior cleaning, and sanitation (e.g. tank emptying, water refills).

Operational and economic efficiency depend heavily on factors such as platform lengths (which determine maximum train length), line speed limits, track capacity, signalling and interlocking systems, number of stations, depot locations, and the availability of technical infrastructure. From an economic standpoint, trainset operations are influenced by infrastructure access charges, rolling stock depreciation or leasing costs, energy consumption, and maintenance expenses. In conclusion, the public service obligation framework forms regional railway service provision's legal and economic foundation. However, the success of a PSO contract in practice is equally dependent on the efficient integration of timetable planning, rolling stock deployment, and cost management. This interplay ensures compliance with contractual and legislative requirements and the delivery of reliable, high-quality passenger transport services in the public interest. When the contracting authority incorporates trainset circulations into the timetable planning, ensuring sufficient technological turnaround times at terminal stations and allocating appropriate windows for maintenance and repairs, it can minimise the required fleet size. This optimisation directly reduces the financial burden on public budgets while proportionally enhancing the operational efficiency of rail services.

The transport order, in other words, the operational concept, should correspond with the available infrastructure and vehicles and incorporate a long-term development plan. However, the target operating concept cannot be implemented if even one part of the chain does not meet the required parameters. Unfortunately, this sometimes happens, with negative consequences. From a traffic management point of view, this can lead to an unstable timetable and insufficient capacity for freight traffic. From a passenger's point of view, delays often occur that cannot be reduced due to insufficient line or vehicle parameters.

5 CONCLUSION

The aforementioned factors of vehicles, infrastructure and operational concept of the public service obligations are the vertices of the technological triangle. These vertices signify the necessity for meticulous coordination of the constituent steps. Effective coordination of these peaks in practice engenders synergies, resulting in reduced travel times and a potential reduction in the number of rolling stock required. Evidently, these measures result in a more appealing travel experience, consequently enhancing the return on investment. Nonetheless, it is imperative to acknowledge that infrastructure is not directly returnable. Given its extensive lifespan, it should be meticulously equipped to accommodate prospective development. The coordination of the sub-steps is a very complex and procedurally unsolved task. This task must be addressed by a body covering and linking the needs of all sides of the technological triangle. Alternatively, the said body must lead negotiations with the representatives of the companies concerned. This would facilitate the efficient management of investments. The coordinator must function as a non-interested party, ensuring that all vertices of the triangle are accorded equal weight. It was proposed that only the interested representatives of the companies would express their views in a proper, substantive and binding manner.

In conclusion, the efficiency of rail passenger services under public service obligations hinges not only on compliance with regulatory and financial frameworks but crucially on the contracting authority's proactive integration of timetable and trainset circulation planning. By designing schedules that incorporate adequate turnaround times, maintenance windows, and realistic rolling stock deployment, the authority can minimise the required fleet size, reduce idle time, and optimise resource utilisation. This approach not only lowers the financial burden on public budgets but also enhances the operational reliability and overall quality of services delivered to passengers, demonstrating that thoughtful planning at the procurement stage is key to sustainable and cost-effective railway operations.

In the Czech Republic, the long-term problem lies in the number of entities ordering transport and contractual relations and in the lack of a binding nature of future operational concepts based on unitary railway principles. A significant proportion of the challenges are rooted in the initiative to transition from a direct current (DC) network to a 25 kV 50 Hz alternating current (AC) system. This change is particularly pertinent because the 471 "City Elefant" series, which is predominantly operational in Prague and the wider area, is equipped with single-system DC technology. A further problem arises with the introduction of exclusive operation of ETCS-equipped vehicles on selected sections. A solution would be to reduce ordering entities and create a long-term, binding plan for operational concepts, according to which the infrastructure can be developed and modified. In the Czech Republic, contracting authorities typically fail to fulfil their obligations under European legislation, such as ensuring non-discriminatory access to rolling stock for operators. This discrepancy can be attributed to the regulatory framework governing the sector. National railway undertakings are obligated to adhere to procurement legislation in order to secure a contract with a vehicle manufacturer, whereas private railway undertakings are at liberty to award such contracts directly. This distinction is also reflected in the protracted nature of the process for national carriers.

In the case of the future of the Prague Railway Node, significant coordination took place between the ordering party and the infrastructure manager. The study involved initial preparations for infrastructure development projects to accommodate future traffic volumes and the new vehicles that will be in operation. In this paper, the focus was intentionally directed away from the Prague node, given its substantial scope, which encompasses an extensive examination of the demographic characteristics and all aspects of the triangle.

The present study has concentrated on smaller projects on regional lines, where such mismatches have been known to occur. The focus of the present discussion is one of the triangular edges, specifically the domain of infrastructure enhancement. In the Prague node, this will entail a substantial infrastructure modification, including introducing new lines.

Finally, it is necessary to consider the travel time reserves, whether the objective is to reduce delays as soon as possible or during the entire route. Furthermore, delays must be minimised by meticulously constructing the timetable, if not entirely prevented.

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