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DEVELOPMENT AND PRACTICAL APPLICATION OF THE HIGHEST TRAIN TRAFFIC DIAGRAM LEVEL IN RAILWAY PASSENGER TRANSPORT

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Abstract

The graphic form of the railway transport timetabling is a train traffic diagram, which represents a graphic representation of train movements. The process of its creation can be perceived as the result of the supply on the railway passenger transport market. However, it is not always possible to comprehensively respect passenger demand when creating it, since many different factors enter the construction process. The most important factors include the parameters of the railway infrastructure. The timetable is used mainly in the planning of railway transport, as well as in the implementation, management and control of transport. In recent years, the concept of a train timetable has undergone some development in several European countries, as well as in the Slovak Republic within long-distance and regional railway passenger transport. This contribution focuses on the analysis of the development of the train traffic diagram in railway passenger transport, describing the levels of its development. It focuses more closely on the description and characteristic of the highest fifth level of the train traffic diagram or timetable, while trying to modify this level and achieve the so-called "ideal" train traffic diagram. The contribution contains theoretical concepts as well as practical examples of the mentioned topic.

Keywords: train traffic diagram, railway transport, levels, timetabling

1 Introduction

Railway transport, due to its high capacity and environmental benefits, is suited to serve as the backbone of public passenger transport. Its potential is often limited by operational, managerial, infrastructural, and rolling stock constraints. Limited vehicle availability and lower-quality infrastructure hinder attractive services and influence timetable planning, which frequently remains supply-oriented rather than demand-driven. The train traffic diagram is a key tool for managing railway operations, ensuring safe, efficient, and cost-effective transport while maximizing rolling stock use and labour productivity. Its effective use requires service standards, sustainable mobility and regional transport plans, and systematic timetable evaluation based on passenger performance indicators [1].

In recent years, passenger transport needs have changed significantly, requiring adjustments and rationalization of existing services. The operating system of passenger rail has therefore evolved, highlighting the need to optimize timetables and service layers. Effective optimization depends on system regularity, coherence, and high-quality train operations, which are reflected in the train traffic diagram, including both regular and special services.

The mentioned issue is the subject of several significant scientific and research outputs. Previous scientific and professional contributions focused on technological and operational processes of railway passenger transport [2-4] concepts of compiling and optimizing timetables and optimizing train routes [5-7], the importance of coordinated transfer connections and the assessment of the connection's quality [8, 9]. A comprehensive overview of the development of railway timetable research is given in [10, 11].
Following these contributions and their scientific and research outputs, the proposals of the authors of this article are also presented. In the case of the creation and implementation of the proposals, the universal scientific method Delphi was used, as well as heuristic and metaheuristic methods. Simple methods of graph theory were also used.

2 Current concepts and levels of train traffic diagram

The process of train traffic diagram creation has evolved significantly in recent years, focusing on improved systematization, service frequency, operational concepts, and time-slot adjustments. Five development levels can be identified. The first level is the unsystematic timetable, characterized by irregular train timings, weak time coordination, and inefficient train circulation. The second level is the systematic timetable, where trips repeat in fixed intervals, travel times are symmetrical, and node-to-node times match the service interval. This widely used concept supports coordinated regional and long-distance connections. The third level introduces multiple service layers, typically combining slower and faster trains with coordinated transfers at hub stations. The fourth level expands this approach to three or more train categories and may include specialized service patterns, while maintaining systematic connections. The fifth level is the integrated clock-cycle timetable, used on selected lines in advanced European systems such as Switzerland and the Netherlands. It coordinates long-distance, regional, suburban, and urban transport into a unified network with regular intervals and synchronized transfers at hubs. This concept offers clear, memorable schedules, symmetrical connections, reduced travel times, efficient vehicle use, and transparent network organization. The basic principle of integrated clock cycle train traffic diagrams is mentioned in figure 1.

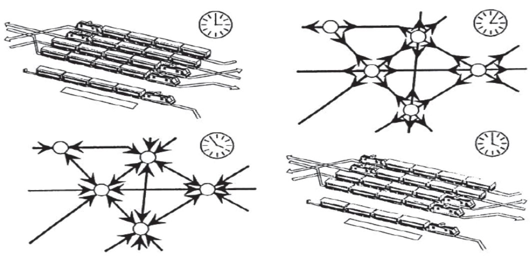

Figure 1 The basic principle of integrated clock cycle train traffic diagrams [5]

This level has been gradually developed and over time. Clock cycle operation was gradually introduced on several lines, transfer links in hub stations were optimized, and zone transport service has also been introduced in regional and long-distance transport. The scope of transport service has been sequentially changed on several lines. Significant systemic changes in Slovakia were also recorded in 2022, 2024 and 2025, when individual phases of the so-called "revolutionary" train traffic diagram were gradually introduced into practice.

3 The fifth level of train traffic diagram implementation

The third chapter describes the modification of the fifth level of the train traffic diagram to an “ideal” train traffic diagram.

3.1 Modification of the fifth train traffic diagram level

The highest possible level of the train traffic diagram is the higher-level principle of the integrated clock cycle train traffic diagram, which can be stated as the so-called ideal train traffic diagram or timetable. This type of timetable must also be applied to other transport modes (suburban and long-distance buses, urban public transport, use of progressive public passenger transport systems, etc.). Within the framework of railway passenger transport, the above level can be achieved by eliminating the bottlenecks and disadvantages. Specifically, this concerns:

- adjustment of travel speeds, and thus travel times, which requires adjustments to the railway infrastructure (modernization of the line, increase in throughput capacity, etc.)
- ensuring the crossing of long-distance trains at hub stations
- adjustment of travel times on regional lines so that it is possible to ensure transfer connections, especially to long-distance trains at hub stations, and also to ensure arrivals/departures from/to catchment areas on the lines according to the basic needs of passengers (commuting to schools, work, offices etc.)
- in long-distance and regional transport, the need to ensure maximum efficiency of train runs (no sharp turns, no long waiting times at turning stations)
- use of variability in planning individual lines and connections
- adjustment of infrastructure at hub railway stations (more boarding edges, more underpasses, larger spaces for passengers, etc.)
- efforts to eliminate problems of inefficient use of trains during peak transport periods (e.g. the possibility of using night train sets during the day)
- creation of a crisis plans for the possibility of introducing short-term changes and eliminating potential instability of the train transport schedule.

The specified level of timetable must be universal and practically applicable on any railway line. A brief example of the timetable proposal of the fourth level is shown on the fictitious railway line A – B3 in figure 2. On the specified line, the travel times of trains of individual categories are adjusted so that they are optimal for ensuring the smoothness of the timetable, the appropriate continuity of individual connections and, overall, for the travelling public, carriers and the infrastructure manager.

Km	Train	IC	R		EC	R		R		IC	R		R		EC	R
	from								Ax					Ax		
0	**A**	**10.08**	**10.17**	10.21	**11.08**	**11.17**	11.21	**11.47**		**12.08**	**12.17**	12.21	**12.47**		**13.08**	**13.17**
3	Aa			10.26			11.26					12.26				
6	**Ab**		**10.25**	10.31		**11.25**	11.31	**11.55**	12.01		**12.25**	12.31	**12.55**	13.01		**13.25**
8	Ac			10.34			11.34		12.04			12.34		13.04		
12	D1			10.38			11.38		12.08			12.38		13.08		
17	D2			10.42			11.42		12.12			12.42		13.12		
19	D3			10.44			11.44		12.14			12.44		13.14		
22	D4			10.47			11.47		12.17			12.47		13.17		
26	**B1**		**10.36**	10.51		**11.36**	11.51	**12.06**	12.21		**12.36**	12.51	**13.06**	13.21		**13.36**
26	**B1**		**10.38**	10.53		**11.38**	11.53	**12.08**			**12.38**	12.53	**13.08**			**13.38**
30	D5			10.57			11.57					12.57				
33	D6			11.00			12.00					13.00				
38	D7			11.04			12.04					13.04				
41	**B2**		**10.46**	11.07		**11.46**	12.07	**12.16**			**12.46**	13.07	**13.16**			**13.46**
41	**B2**		**10.47**	11.09		**11.47**	12.09	**12.18**			**12.47**	13.09	**13.18**			**13.47**
44	D8			11.13			12.13					13.13				
47	C1		**10.53**	11.17		**11.53**	12.17				**12.53**	13.17				**13.53**
51	D9			11.21			12.21					13.21				
56	B3a			11.25			12.25					13.25				
59	**B3**	**10.39**	**11.00**	11.27	**11.39**	**12.00**	12.27			**12.39**	**13.00**	13.27			**13.39**	**14.00**
	to							B5					B5			

Figure 2 Proposal of the fifth-level timetable on the A – B3 railway line from 10.00 a.m. to 2.00 p.m. [5]

3.2 Example of the fifth train traffic diagram level in international railway transport

A significant measure of the modified fifth level of the timetable is the need to optimize travel times, especially in international long-distance transport between major cities in individual countries. Ideally, it is appropriate to achieve that these travel times represent rounded “whole” hours, so that it is practical for passengers and carriers, as well as for the creation of the timetables themselves.

When constructing integrated clock cycle train traffic diagrams and creating timetables, it is also essential to use the principles of mathematics and geometry. Specifically, it is very important to be inspired by the principles of graph theory. The railway network problem can be represented as a simple graph, where the vertices represent the nodal stations (integrated clock cycle transport nodes) and the edges represent the optimal travel times between them. In this example the principles of graph theory were applied to a real railway network in the following steps. For the needs of international long-distance transport, 9 transport nodes have been selected (Paris, Munich, Zurich, Berlin, Prague, Vienna, Bratislava, Budapest, Warsaw). This is the initial first phase of implementing the integrated clock cycle train traffic diagram for international long-distance transport. It is then necessary to connect these nodes and assign a value to the edges that will represent the optimal travel times between them, suitable for the principles of integrated clock cycle timetables. Within the first phase of implementation, these values are approximately the same as the present travel times between them. These times are given in hours and are shown in figure 3.

Figure 3 Optimal travel times between integrated clock cycle transport nodes

A practical example of such a train timetable concept is its implementation on the Vienna/Bratislava – Prague railway line. However, at this moment, the stated travel times cannot be achieved. This is mainly due to low permitted speed on the Brno – Břeclav railway section in the Czech Republic and on the Kúty – Bratislava railway section in the Slovak Republic. The potential timetable is shown in figure 4 [4].

The speed increase to 160 km/h, and up to 200 km/h along 8 km long section of the Břeclav – Brno railway line, will be achieved by the comprehensive track modernisation. After the implementation of the infrastructure measures, it will be possible to implement the proposed timetable.

(Wien HBF) - Bratislava hl. st. - Praha hl. n.

km	Vlak	RailJet	RailJet	RailJet	EC	RailJet	RailJet	EC	RailJet	EC	RailJet	EC	RailJet
	Zo stanice							Budapest	Villach	Budapest	Villach	Miskolc	Zagreb
0	**Bratislava hl. st**			**5.20**	**6.20**		**7.20**	**8.20**		**10.20**		**12.20**	
64	Kúty			|	|		|	|		|		|	
-	**Wien Hbf**			(	(	**6.05**	(	(	**9.05**	(	**11.05**	(	**13.05**
82	Břeclav			**6.00**	**7.00**	**6.59**	**8.00**	**9.00**	**10.00**	**11.00**	**12.00**	**13.00**	**14.00**
82	Břeclav			**6.03**	***7.03***	**7.03**	**8.03**	**9.03**	**10.03**	**11.03**	**12.03**	**13.03**	**14.03**
141	**Brno hl. n.**			**6.28**		**7.28**	**8.28**	**9.28**	**10.28**	**11.28**	**12.28**	**13.28**	**14.28**
141	**Brno hl. n.**	**4.20**	**5.30**	**6.30**		**7.30**	**8.30**	**9.30**	**10.30**	**11.30**	**12.30**	**13.30**	**14.30**
232	Česká Třebová	**5.21**	|	|		|	|	|	|	|	|	|	|
292	Pardubice hl. n.	**5.56**	**7.01**	**8.01**		**9.01**	**10.01**	**11.01**	**12.01**	**13.01**	**14.01**	**15.01**	**16.01**
0	**Brno hl. n.**	(	(	(		(	(	(	(	(	(	(	(
88	Žďár nad Sázavou	(	(	(		(	(	(	(	(	(	(	(
121	**Havlíčkuv Brod**	(	(	(		(	(	(	(	(	(	(	(
184	Kutná Hora hl. n.	(	(	(		(	(	(	(	(	(	(	(
334	Kolín	**6.17**	|	|		|	|	|	|	|	|	|	|
	Praha - Libeň	**6.49**	|	|		|	|	|	|	|	|	|	|
396	**Praha hl. n.**	**6.55**	**7.55**	**8.55**		**9.55**	**10.55**	**11.55**	**12.55**	**13.55**	**14.55**	**15.55**	**16.55**
	Do stanice		Hamburg		Warszawa	Kobenhavn	Brussel	Hamburg	Rostock				Berlin

Figure 4 Proposal of the fifth-level timetable on the Vienna/Bratislava – Prague transport route [4]

3.3 Example of the fifth train traffic diagram level in national railway transport

The above-mentioned fifth level of train traffic diagram should also be applied to real national railway lines. As an example, the most frequent long-distance transport route in the Slovak Republic, the Bratislava – Žilina – Košice railway line, can be used. Figure 5 shows an example of a long-distance transport timetable with four train categories (Fast train – R, RailJet train – RJ, InterCity train – IC, Express train – EX). This example represents several principles of the fifth level of the train traffic diagram, but if we wanted to "upgrade" it to an "ideal" train traffic diagram, a few more measures would have to be implemented on the current railway infrastructure [5]. There are also measures to increase speed, in particular the completion of the modernization of the Bratislava - Žilina railway section and selected sections on the Žilina - Košice railway line to a speed of 160 km/h.

km	Vlak	R	R	EX	R	RJ	EX	R	R	EX	R	IC	R	R	R	EX	R	EX	R
	Zo stanice					Munchen						Wien							
0	**Bratislava hl. st.**	14.45	15.11	15.25	15.45		**16.30**	16.45	17.11	17.25	17.45	**18.25**		18.45	19.11	19.25	19.45	**20.21**	
4	Bratislava - Vinohrady	14.51	15.17	|	15.51		|	16.51	17.17	|	17.51	|		18.51	19.17	|	19.51	|	
46	Trnava	15.15	15.45	15.50	16.15	16.49	**16.55**	17.15	17.45	17.50	18.15	**18.50**		19.15	19.45	19.50	20.15	**20.46**	
63	Leopoldov	15.27	o15.55	|	16.27	|	|	17.27	o17.55	|	18.27	|		19.27	o19.55	|	20.27	|	
81	Piešťany	15.39		|	16.39	|	|	17.39		|	18.39	|		19.39		|	20.39	|	
99	Nové Mesto n/V	15.51		|	16.51	|	|	17.51		|	18.51	|		19.51		|	20.51	|	
124	Trenčín	16.06		16.26	17.06	|	**17.31**	18.06		18.26	19.06	|		20.06		20.26	21.06	**21.22**	
132	Trenčianska Teplá	|		|	17.14	|	|	|		|	19.14	|		|		|	21.14	|	
137	Dubnica nad Váhom	16.16		|	|	|	|	18.16		|	|	|		20.16		|	|	|	
159	Púchov	16.30		|	17.30	|	|	18.30		|	19.30	|		20.30		|	21.30	|	
171	Považská Bystrica	16.39		|	17.39	|	|	18.39		|	19.39	|		20.39		|	21.39	|	
203	**Žilina** o	16.57		17.06	17.57	18.01	**18.11**	18.57		19.06	19.57	**20.02**		20.57		21.06	21.57	**22.02**	
203	**Žilina**	17.09		17.13		18.04	**18.14**			19.09	↳	**20.04**	→20.09			21.09	↳	**22.05**	→22.09
224	Vrútky	17.27		|		|	**18.32**			19.27		|	20.27			21.27		|	22.27
242	Kraľovany	17.40				|	**18.45**			19.40		|	20.40			21.40			22.40
260	Ružomberok	17.55				|	**19.00**			19.55		|	20.55			21.55			22.55
286	Liptovský Mikuláš	18.14				|	**19.19**			20.14		|	21.14			22.14			23.14
325	Štrba	18.46				|	**19.48**			20.43		|	21.43			22.43			23.43
344	Poprad - Tatry	19.08				19.45	**20.10**			21.05		**21.45**	22.05			23.05			o 0.03
370	Spišská Nová Ves	19.27				|	**20.29**			21.24		|	22.24			23.24			
410	Margecany	19.54				|	**20.56**			21.51		|	22.51			23.51			
429	Kysak					20.39	**21.11**			22.06		**22.39**	23.06			0.06			
445	**Košice** o					20.51	**21.23**			22.18		**22.51**	23.18			0.18			
	Do stanice	Prešov	PD/NR	Martin	Ostrava				PD/NR						PD/NR			Martin	

Figure 5 Proposal of the fifth-level timetable on the Bratislava – Žilina – Košice transport route [5]

4 Conclusion

The contribution outlines the process of compiling a train traffic diagram and its individual levels using various scientific methods. It emphasizes practical results, briefly explaining each level and their differences. Special attention is given to the highest (fifth) level, described in greater detail, including a proposed modification illustrating an ideal timetable. A brief evaluation of the diagrams and their levels is presented in table 1. This table evaluates particular train traffic diagram levels (levels 1-5) in the context of selected indicators listed in the first column of the table. These are indicators that evaluate the quality and efficiency of the timetable as such, including the number of train categories, operating and transfer connections, technological processes, timetabling features etc. The characteristic features for the mentioned specific levels are marked in the corresponding box with an “X” symbol. Based on table 1, it can be concluded that the simplest type is the first train traffic diagram level and the most ideal is the fifth train traffic diagram level.

Table 1 Summary of train traffic diagram levels

Indicator/level of train traffic diagram	1	2	3	4	5
Regularity		x	x	x	x
Systematicity (interval or tact transport)		x	x	x	x
Only one train category	x	x			
Two train categories (slow and fast segment)			x		
At least 3 train categories				x	x
Simply transfer links		x	x		
High-quality transfer links				x	x
Integrated clock cycle features					x
Specially adjusted travel times					x
Optimal use of vehicles			x	x	x
Repetition of technological operations				x	x

As part of the quality assessment of individual levels of train traffic diagrams, it is also possible to compare the fifth modified level with the current level on a specific railway line. In this case, we can focus on the criteria of the average travel time and the average travel speed on the railway lines Bratislava - Košice and Bratislava - Prague. Table 2 shows a comparison of the criterion values and the difference in the monitored values according to the figures 4 and 5 with current real values.

Table 2 Summary of train traffic diagram levels

Criterion	Current timetable period	Ideal train traffic diagram	Δ
Average travel time (h) – figure 4	5.58	4.7	- 0.88
Average travel speed (km/h)- figure 4	79.39	94.26	+ 14.87
Average travel time (h) - figure 5	4.45	3.58	- 0.87
Average travel speed (km/h) - figure 5	88.99	110.61	+ 21.62

Table 2 shows that after the implementation of infrastructural measures on both railway lines, a significant increase in travel speed will be achieved, and thus a reduction in travel time. Evaluation of the proposed fifth level revealed persistent bottlenecks that prevent full compliance with established principles, highlighting the need for continued analysis and research. In practice, efforts should progressively approximate the ideal train traffic diagram within specific railway networks. A key medium-term objective is the creation of a pan-European fifth-level integrated timetable, first for long-distance and later for interregional, regional, suburban, and urban transport. The main societal benefit lies in more efficient distribution of transport work and the strengthening of rail through increased service provision, as demand is driven by supply. Improving long-distance, suburban, and regional services, eliminating missing node connections, and coordinating infrastructure measures with service plans are essential to enhance rail transport attractiveness.

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References

[1] Hansen, I.A., Pachl, J.: Railway Timetabling & Operations, Analysis – Modelling – Optimisation – Simulation – Performance Evaluation, DVV Media, Hamburg, 2014.

[2] Vojtek, M., Kendra, M., Zitrický, V., Široký, J.: Mathematical approaches for improving the efficiency of railway transport, Open Engineering, 10 (2020) 1, pp. 57–63

[3] Pribula, D., Zitrický, V., Kendra, M.: Micromobility as a feeder for railway passenger transport, Transportation Research Procedia, 77 (2024), pp. 18–25, DOI: 10.1016/j.trpro.2024.01.003

[4] Dedík, M., Gašparík, J., Bulková, Z., Kendra, M., Šulko, P.: Optimization of timetables on the Prague – Bratislava/Vienna rail transport route in the post-pandemic period, Logi: Scientific Journal on Transport and Logistics, 14 (2023) 1, pp. 110–121

[5] Dedík, M., Zitrický, V., Valla, M., Gašparík, J., Figlus, T.: Optimization of timetables on the Bratislava – Žilina – Košice route in the period after the end of the COVID-19 pandemic, Sustainability, 14 (2022) 9, 5031, DOI: https://doi.org/10.3390/su14095031

[6] Abramović, B., Šimunec, I.: Optimization of railway traffic on Varaždin – Golubovec railway line, International Symposium EURO – ŽEL 2012, Tribun EU Press, Brno, 2012.

[7] Gašparík, J., Abramović, B., Halás, M.: A new graphical approach to railway infrastructure capacity analysis, Promet, 27 (2015), pp. 283–290, DOI: 10.7307/ptt.v27i4.1701

[8] L'upták, V., Bartuška, L., Hanzl, J.: Assessment of connection quality on transport networks applying the empirical models in traffic planning: A case study, 22nd International Conference Transport Means, Lithuania, 3–5 October 2018.

[9] Peeters, L.W.P.: Cyclic railway timetable optimization, doctoral dissertation, Erasmus University Rotterdam, 2003.

[10] Caprara, A., Kroon, L., Monaci, M., Peeters, L., Toth, P.: Passenger railway optimization, Handbooks in Operations Research and Management Science, 14 (2007), pp. 129–187, DOI: 10.1016/S0927-0507(06)14003-7

[11] Duarte, P.J.C., de Sousa, J.P., Crainic, T.G.: Fifty years of operations research in railway timetabling and rolling stock planning, EURO Journal on Transportation and Logistics, 14 (2025), 100110, DOI: 10.1016/j.ejtl.2024.100110