The technology of non-stop passage of high-speed passenger and freight trains on double-track sections and its impact on operational performance

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Abstract. Currently, a mixed system of high-speed passenger and freight trains has been implemented on the railways of Uzbekistan. During the movement of high-speed passenger trains on double-track main line sections, the movement of freight trains at all stations and segments is temporarily suspended for a specific period. From this perspective, in the present time, the suspension of freight train traffic is leading to numerous technical and economic expenses. In this article, based on experimental runs using the technology of passing freight trains without stopping, train movement schedules have been drawn up, and train operations have been organized without unnecessary stops. This research paper provides a restructured overview of the introduction and practical implementation of non-stop train operation technology for double-track railway lines where both high-speed passenger and freight trains operate simultaneously. Using real operational schedules, comparative experimental charts were developed to evaluate the new approach. The outcomes of this analysis demonstrate how the proposed technology influences efficiency and key performance indicators of train movements. A regression-based analytical model was also constructed to determine the relation between freight train waiting time and average section speed, ensuring reliability through statistical verification. Furthermore, the application of innovative solutions and technologies mentioned in this article to sections of high-speed highways creates an opportunity to increase transport transit potential and improve economic indicators.

Keywords: high-speed trains, section speed, operational efficiency, freight transport, regression analysis, schedule optimization.

1. Introduction

Ensuring safe and efficient train crossings, particularly in conditions where both high-speed passenger and freight trains share double-track sections, is one of the major operational challenges of modern railways. Previous studies [1]-[6] have highlighted these concerns and recommended optimization methods. Building upon such findings, this study develops experimental movement charts aimed at assessing the influence of a non-stop passage technology for freight and passenger trains on railway performance. To achieve this, the Uzbekistan-Yangi Yangier double-track line was selected as a case study, with charts created and compared against normative schedules (Figs. 1-2). The effectiveness of the proposed method was measured through variations in section speed and average dwell time at intermediate stations.

In Figs. 1 and 2 I_{high-s} – the time interval between consecutive high-speed passenger trains, in minutes; $I_{pas\,sin\,arrival.}$ – the time interval for freight trains arriving at stations after high-speed passenger trains, in minutes; $I_{pas\,sin\,departure.}$ – the time interval for sequential dispatch of freight trains from stations following passenger trains, in minutes; τ_i – departure and arrival times at

stations for each category of trains, in minutes; Trains numbered 760, 762, 764 and 766 indicated in red on the schedule, represent high-speed passenger trains; Trains numbered 3117, 3119 and 3121 which are indicated in green, represent freight trains on the schedule.
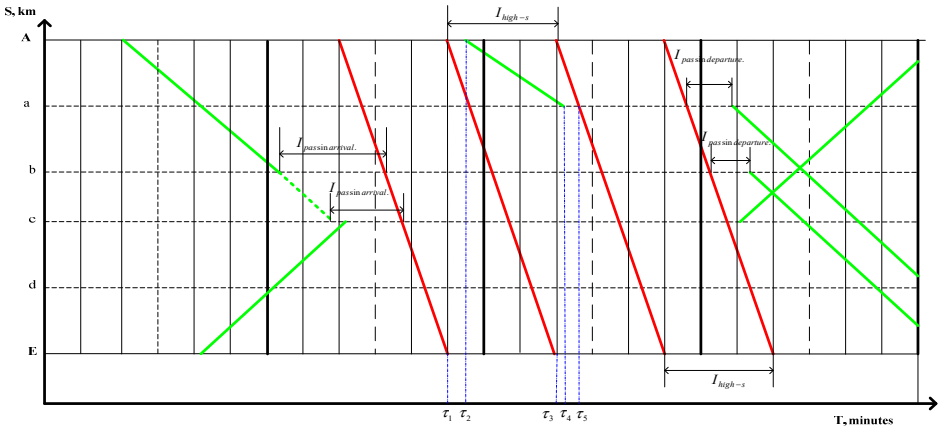

Fig. 1. Fragment of a typical train movement schedule for the year 2023
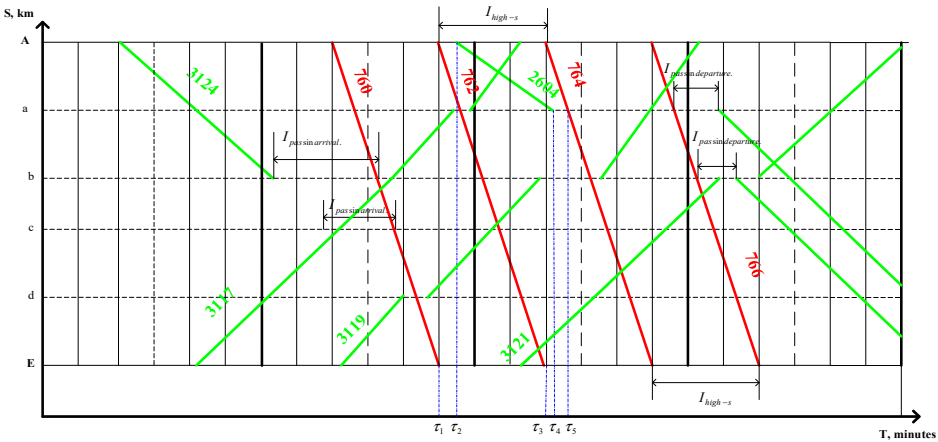in the joint-stock company "Uzbekistan temir yullari" (Uzbekistan Railways)

Fig. 2. Fragment of an experimental train chart developed based on the technology
of non-stop passage of high-speed passenger and freight trains

2. Analysis literature and methodology

Operational efficiency on railway sections is often expressed through parameters such as sectional speed, technical speed, pedestrian speed, and route speed. Additionally, various coefficients sectional speed coefficient, technical speed coefficient, and others are calculated based on these values [3], [6]. These factors are strongly influenced by variables such as train weight, length, locomotive traction power, aerodynamic resistance, and track gradient. Mathematical expressions for determining train speed and coefficients were applied Eq. (1-4), while both standard and experimental charts were prepared for analysis. Figs. 3-4 summarize the calculated values for the standard and revised tables:

$$\begin{cases} v_{travel\ speed} = f(Q_{gr}, L_{train}, W_{loc}, C_i, i, k) \rightarrow v_{max}, \\ v_{techn.-speed} = f(v_{travel\ speed}, t_{acc.}, t_{dec.}) \rightarrow v_{travel\ speed}, \\ v_{sec.-speed} = f(v_{techn.-speed}, t_{simp.}^{int\ ermed}, k_{stop.}) \rightarrow v_{techn.-speed}, \\ v_{route-speed} = f(v_{sec.-speed}, t_{simp.}^{total}) \rightarrow v_{sec.-speed}, \end{cases} \tag{1}$$

where $v_{travel\ speed}$, $v_{techn.-speed}$, $v_{sec.-speed}$, $v_{route-speed}$ − correspondingly, the pedestrian, technical, sectional, and route travel speeds, measured in km/h; Q_{gr} − the total mass of the train consist, in tons (t); L_{train} − the overall length of the train consist, in meters (m); W_{loc} − the traction power of the locomotive, in kilowatts (kW); C_i – the aerodynamic resistance coefficients affecting train motion; i – the gradient (profile) of the railway section, in ‰ (per mille); k – additional operational and technical parameters.

The conditions, algorithms, aerodynamic effects, and solutions for the safe intersection of high-speed passenger and freight trains on double-track high-speed main lines of Uzbekistan railways were described in detail in previous scientific studies [12]-[13]. Based on this and the experimental train movement charts have been developed for the Uzbekistan-Yangi Yangiyer section. The values of the normative and experimental charts were calculated using Figs. 3-4.

The average values of the parameters for the typical chart and the experimental train movement charts are presented in Table 1.

Train No.	Departure time from station U	Arrival time from station YY	Total travel time in hours	Including		Train-km	Train No.	Departure time from station YY	Arrival time from station U	Total travel time in hours	Including		Train-km
				Travel time hours	Stopover duration at intermediate station in hours						Travel time hours	Stopover duration at intermediate station in hours	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
3114	20-20	23-24	3.07	2.45	0.62	113	3403	00-32	09-58	9.43	3.05	6.38	113
3116	21-28	01-11	3.72	2.62	1.10	113	3009	21-46	00-04	2.30	2.30	0	113
3402	22-05	06-42	8.62	3.03	5.59	113	3011	00-29	02-47	2.30	2.30	0	113
3112	22-16	01-40	3.40	2.53	0.87	113	3115	01-27	03-57	2.50	2.38	0.12	113
3110	23-00	2-14	3.23	2.45	0.78	113	3013	01-59	04-17	2.30	2.30	0	113
3118	00-38	2-55	2.28	2.28	0	113	3015	03-34	07-29	3.92	2.55	1.37	113
3120	01-19	3-36	2.28	2.28	0	113	3117	05-07	10-14	5.12	2.55	2.57	113
2598	02-00	4-17	2.28	2.28	0	113	3119	06-17	10-32	4.53	2.55	1.98	113
2600	02-40	4-57	2.28	2.28	0	113	3121	07-32	11-59	4.45	2.47	1.98	113
3006	03-49	6-06	2.28	2.28	0	113	3019	08-25	11-28	3.05	2.47	0.58	113
3124	04-39	09-41	5.03	2.37	2.66	113	3101	09-15	11-45	2.50	2.38	0.12	113
2604	05-29	10-39	5.17	2.45	2.72	113	3103	10-26	13-46	3.33	2.47	0.86	113
3126	09-26	12-31	3.08	2.37	0.71	113	3105	11-16	14-13	2.95	2.47	0.48	113
2580	10-42	12-59	2.28	2.28	0	113	3001	13-17	15-35	2.30	2.30	0	113
3102	11-43	14-00	2.28	2.28	0	113	3003	14-08	16-26	2.30	2.30	0	113
3016	12-19	14-36	2.28	2.28	0	113	3107	14-59	17-20	2.30	2.30	0	113
3104	12-40	14-57	2.28	2.28	0	113	3109	15-46	20-17	4.52	2.38	2.14	113
2962	13-00	15-59	2.98	2.37	0.61	113	3111	16-09	20-51	4.70	2.38	2.32	113
3106	13-40	16-21	2.68	2.37	0.31	113	-	-	-	-	-	-	-
3020	14-35	16-52	2.28	2.28	0	113	-	-	-	-	-	-	-
3406	14-55	21-00	6.10	2.97	3.13	113	-	-	-	-	-	-	-
3022	15-12	19-54	4.70	2.70	2.00	113	-	-	-	-	-	-	-
1254	15-57	20-34	4.62	2.62	2.00	113	-	-	-	-	-	-	-
2588	19-59	22-16	2.28	2.28	0	113	-	-	-	-	-	-	-
Total:			81.49	58.39	23.10	2712				64.8	43.9	20.9	2034

Fig. 3. Parameters for establishing a standard train operation schedule
($N_{high-speed} = 6$ s.t., $V_{high-speed} = 160$ km/h, $V_{freight} = 60$ km/h, $N_{freight} = 21$ s.t.)

Through the application of regression modeling and the least squares method, a functional relationship was established between the movement speed of freight trains on a given section and the time spent at intermediate stations. This relationship is determined by the number of freight and passenger trains, the speeds of different train categories, as well as the section length within the range [7]-[11].

The data in the above figures and table are based on experimental train movement graphs drawn using the technology of continuous passing of freight and high-speed passenger trains on

In the general case, let the correlation function of multiple factors be of the following order:

$$V_{sec.speed} = a \cdot N_{high-speed} + b \cdot N_{freight} + c \cdot L_{sec.,} \tag{2}$$
$$T_{downtaime} = a_1 \cdot N_{high-speed} + b_1 \cdot N_{freight} + c_1 \cdot L1_{1_{sec.,}} \tag{3}$$

where $V_{sec.speed}$ – the sectional speed of freight trains, km/h; $T_{downtaime}$ – the dwell time of freight trains at intermediate stations, hours; a, b, c, d, e – the coefficients to be determined are obtained through the following equation; $N_{high-speed}$, $N_{freight}$ – the number of high-speed and freight trains, respectively, paired trains; $L_{sec.}$ – length of the section, km; Δ – the ratio of speeds between freight trains and high-speed passenger trains.

It is known that applying the least squares method to a regression model involves minimizing the quadratic deviations between the actual values of the function and their approximate (smoothed) analogues. Based on the results of experimental studies, train movement schemes were developed for operational sections (Uzbekistan-Yangi Yangiyer, post-block Jizzakh, Jizzakh-Samarkand), taking into account the speeds of freight and high-speed passenger trains, as well as the technical characteristics of each section. By applying the Cramer's method to solve the above equations, the following empirical universal formulas were obtained:

$$\begin{cases} V_{sec-speed}^{exis-tech} = -1.82 \cdot N_{high-speed} - 0.08 \cdot N_{freight} - 0.5482 \cdot L_{sec}, \\ V_{sec-speed}^{prop-tech} = -1.415 \cdot N_{high-speed} - 0.16 \cdot N_{freight} - 0.5529 \cdot L_{sec}. \end{cases} \tag{4}$$

4. Results and their discussion

The graphs of the generated multivariate functions can be seen in the following Figs. 5-6.
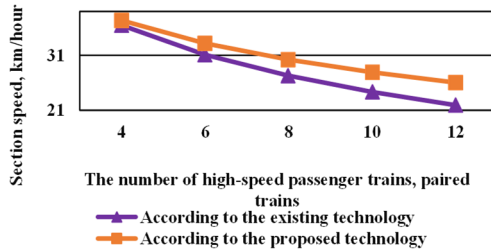
Fig. 5. The graph of the empirical function for the section speed can be observed on the normative and experimental train movement charts
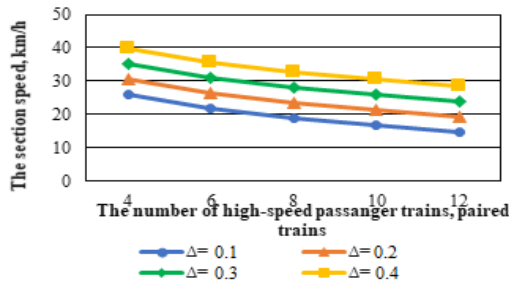

Fig. 6. The dependency of the section speed on the experimental train movement charts on the ratio and number of train speeds

Figs. 5-6 present the dependency graphs between sectional speed, freight dwell time, and the ratio of train types. The analysis showed an approximation error of only 2.5 %, with a correlation

coefficient of 0.9871 and $R^2 = 0.9744$. These results confirm the model's validity.

5. Conclusions

The findings suggest that implementing non-stop train crossing technology on the Uzbekistan-Yangi Yangier line leads to a 5.12 % (2.09 km/h) increase in freight train sectional speed. Furthermore, average dwell times decreased by 19.32 % (4.25 hours). When the number of high-speed trains increased from 4 to 12 pairs, the reduction in sectional speed was significantly lower with the proposed method (30.3 % instead of 39.91 %). An economic evaluation revealed that this reduction in dwell times translates into substantial financial benefits. Based on average operating costs per train-hour, the estimated annual efficiency gain amounts to 466 billion USD for freight operations under the new system. The study demonstrates that applying the technology of non-stop passage for freight trains alongside high-speed passenger services on double-track sections improves both speed performance and economic efficiency. The technology not only reduces freight train delays but also enhances the overall utilization of section capacity, ensuring sustainable development of railway operations in Uzbekistan. Its adoption could serve as a model for other railways facing similar mixed-traffic challenges.

Acknowledgements

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

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