Methodology for Optimal Solution Search during the Freight Train Schedule Creation

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Abstract. Punctuality and the energy efficiency are the most significant criteria of immediate activity of every transport system. The problem of improving these characteristics is unfolded in this paper. The task of optimization the punctuality and energy efficiency is solved by adjusting departure headways and running times. Methodology of schedule parameters search is based on the statistical analysis of historical data. The study reveals a number of regularities that are characterizing the freight train flow at the main railway line. First of all, we note the important dependences between the punctuality characteristics and the chain position of the train.

1. Introduction
The timetable is a master document for managing the freight train traffic. Coordinated governance of all the local JSC “Russian railways” divisions is based on the normative schedule [1]. Nowadays, the train schedule is created on the basis of traction equation approach [2] with insertion an additional time margins. These additional times are allocated based on prior experience possessed by the scheduler.

According to the traction approach, the freight train considered as a local mass point. At the same time this model has a significant flaw – the model does not consider parameters of trains flow such the intensity and the density. More badly, this model does not take into account the random factors that cause significant delays. Punctuality of freight train arrivals depends on weather conditions, day period, season of year, temporary infrastructure limits and on other factors.

There are low degree of punctuality and insufficient level of use the infrastructure productivity at the railway system. Economic losses as well reputational risks are result of the traditional schedule creating approach based on the traction equation calculations [3]. So it is necessary to develop the methodology for determining the train schedule taking real conditions into account [4].

The robustness of timetable is provided by including additional time to running and dwelling intervals [5]. In this work we investigate the problem of train traffic planning with keeping criteria of
punctuality and expenses economy in mind. First of all we propose the method of group adjusting the train flow travelling at the rail site. The schedule parameters we determine on the basis of analysis the real statistics of freight train traffic at the main railway line.

We believe, probability model of train traffic is a basic of effective way to allocate the schedule parameters [6]. The possibility of accounting the statistics of trains travelling and the station activity is the main feature of our model. It requires the collection and study of historical data. This information uses for modeling the delay appearance process and forecasting the intertrain conflicts in future periods.

The main purpose of the present study is to find the correlation between basic parameters of the schedule such as train travel time and departure headways at the initial station of the railway section. The paper confirms, operational management allows decreasing the intertrain conflicts quantity by adjusting the mean value of headway. The result of our study will be used for long-term planning of the freight train traffic.

2. Literature review
Traffic stability and regularity of train flow are the most theoretically grounded criteria uses for creating the master schedule [7-9]. These criteria set rationale and economical efficient benchmarks while providing the railroad productivity, carrying capacity of a line and a stations as well. The stability implies forming approximately equal departure headway from the initial technical station for daily train flow. The regularity of flow implies economical grounded activity of infrastructure objects and stream-lining of production. Mentioned principles forms efficient model for a train traffic which provides minimization of energy losses arise due to train unscheduled interaction and train stops before the intermediate forbidding block signals and entrance signals. Unplanned decrease of train speed or stopping causes loss of time and electrical power [10].

The main parameters of pattern timetable such as travel time and headway are formed as the result of the traction equation accounts. However, in the present reality it is not enough to count the main parameters by the traditional approach. The traction accounts do not reflect the random factors for the single train followed on the line without external interference as maintenance "windows", infrastructure failures and other negative factors as well [11, 12].

The process of schedule creating does not include train interactions in the flow which has the periods of ups and downs daily [13]. According to this, the probability of happening the inter train conflicts increases in the times of intense traffic existence. In this case the primary delay provides the row of propagation delays. The minimization of delays is fulfilled by operational management. In case of the train flow decreasing intensity the dynamical interaction of trains become insignificant and provides the minimization of intertrain conflict [14].

There is a methodology of creating the master schedule on the base of accounting the main indexes in consider of train flow cyclicality in this paper.

3. The methodology of analysis the historical data
Introduction of schedule parameters are traditionally fulfilled by use of travel times obtained from traction equation calculations with adding time margins. The timetable is often violated because of insufficiency to taking real-world disturbances into account.

In particular, there is no considering the specific features of forming traffic such as traffic ups are defined by big volume of freight train transfer to neighboring regions. This intensive oncoming exchange increase strongly in approaching to the end of reporting period, i.e. to 6 a.m. and 6 p.m. So, there is a low level of punctuality of arriving trains on the destinations or to marshaling yards. Absence of the proper flow parameters during the procedure of creating the schedule has additional consequences in shape of unplanned stops for providing the punctuality of passenger trains, inadmissible increasing the working time for the train drivers, decreasing the quality of using the infrastructure and ineffective energy losses as well.
When intertrain conflict arises, the reaction of train driver would be unpredictable and depends on the qualification, work experience and other personal features. There is a significant influence on the train traffic of different factors such as current condition of infrastructure, the type of rolling stock composition and the weather condition.

There is an analysis of fulfilled schedule for the same period of time. The analysis includes study of travel time and headway statistics for the previous year as the first part of methodology. We select from the performed traffic data the packages of freight trains whose first train is moving unhindered. Let’s call this kind of train path as “the eigenmotion trip”.

The trains at the second, third and further positions in the package are caught up the previous train in one or other moments. This situation depends on the departure headway from the initial station. The following train is moved with minimal accepted intertrain interval behind the front train after the happened conflict.

The methodology has a proposal to determine the main parameters of timetable on the base of statistical analysis the historical data for different scenario of the train traffic, e.g. dense undisturbed traffic, infrastructure maintenance scenario, congested traffic when rolling stock failure occur, and so on. It is necessary to underline that guiding trains in dense flow is just one of scenario could happens in real practice of adjusting train traffic.

So in January, 2018 it was the period of less infrastructure maintenance on the segment of main line “O-Kp” (360 km long). We were selected data on traffic of the 25 trains packages of odd direction with 2-7 trains in one package. Also we selected the 13 trains packages of even direction with 2-10 trains in the package.

There were the obliged conditions for selection:
- the train on the first position of the package had the eigenmotion trip;
- the packages had been run through the whole segment of line;
- the second and further trains had reached the front train at the same point of the site.

We discovered, no one train had run the section O-Kp within the confirmed limit of time. So it means that no one train had reached the destination on time. We consider the limit of delay time of 5 minutes for define the punctuality.

There were fulfilled the factor analysis of the gathered experimental data in purpose to select the influences which are reasons of delays. The trains were grouped by different features which characterize the main kinds of influences. In particular, the trains were split by directions of travelling (odd and even).

The statistical analysis of historical data allows defining the margins to the travel time for different scenario. This is the base to create the method for conduct an operational adjusting the train traffic in the future. It has immediate practice significance in creating the robust schedule.

At the same time the historical data allows us to prove the dependence between the main parameters of timetable and the sequence position of the train in the package as well. It is possible by correlation analysis. It is very important focus for long-term planning because the dense flow does not allow to realize line productive and economy efficiency on the 100 percents. So, we need to scale pluses and minuses in the process of planning the freight volume and traffic flow.

4. Characteristics of the freight traffic in a dense flow

There are two main parameters of schedule such as section time to running and dwelling intervals. On the one hand, traditionally the analysis of the train traffic suggests the absence of dependence between these parameters. In theory, there are no influences of position in the package on them as well. On the other hand, there are real disturbance provides the appearance of this dependence (Figure 1). There is a research of the influences from the train position in the package on the parameters of section time to running and dwelling intervals in this paper. As the result of the analysis of historical data we can identify the clear mutual dependence. In our investigation trains were split to directions – even (mostly the cargo trains from west to south) and odd (mostly the empty trains from south to west). The character of the influence the departure headways and running time in obliged conditions when the...
first train has a eigenmotion trip and disturbs other trains in the package is submitted on the charts fulfilled on the base of mathematical figures for each train package.

![Figure 1](enum.png)

**Figure 1.** The models of intertrain conflicts: (a) in the flow with a big departure headways; (b) with a small departure headways.

![Figure 2](enum.png)

**Figure 2.** Dependence of the train position in the package on section running time and departure headways in even direction.

![Figure 3](enum.png)

**Figure 3.** Dependence of the train position in the package on section running time and departure headways in odd direction.

As we can notice the position of train in the package, running time and departure headways have mutual dependence (Figure 1, 2, 3). Real statistic data approve this statement. Compare the right and left graphs (Figure 2, 3) we can notice reverse dependence between departure headways and running time in package traffic. We can explain it by random factors in the process of managing the train traffic.
The package traffic is one of possible scenarios of operational management. In this scenario the train on the first position of the package has influence to the second and further trains and the departure headways define the intertrain conflicts.

The correlation analysis of the data provides the conclusion about dependence between departure headways and section running time. The results submitted on the chart (Table 1).

**Table 1.** The results of correlation analysis between departure headways and running time.

| Section | train position in the package | 2  | 3  |
|---------|------------------------------|----|----|
| Kh-O    | -0.26                        | -0.23 |

On the rail site “Kh-O” match to odd direction the coefficient of correlation decreases and have negative meaning. So, we can conclude that the second and further trains in the package have a fluent travel in condition of forming big departure headways and have a lot of intertrain conflicts in condition of forming little departure headways. The correlation analysis shows that the influence between departure headways and section running time decreases from the second train’s position to last train’s position in the package.

5. Conclusions and future work

In the article submitted the main items to form the multi train model of creating the pattern timetable in condition of absence daily steadiness of train traffic and grounded mutual dependence of main schedule parameters – the section running time and departure headways. Hence, adjusting the headways helps to manage the intertrain conflicts. There is confirmed the necessary of using the stochastic model for creation the timetable in case of different possible scenarios.

We proved the dependence between the main characteristics of the timetable and the train’s position in the package as well. Increasing the headway follows decreasing the intertrain conflict and vice versa. Correlation analysis of the real data about traffic on the main segment of JSC “Russian railways” shows it. This dependence is very important for creation long-term schedule. So, we need to consider this conclusion in the process of planning the train traffic.

Further work will investigate other scenarios of traffic flow in conditions of infrastructure maintenance, congested traffic when rolling stock and infrastructure failure occur, and so on. These failures happen frequent enough. So, we need to have scientific base and methods for creation correct timetable in consider of possible accidents.

References

[1] Pravila tekhnicheskoy ekspлуatации zheleznыh dorog Rossijskoy Federatsii Utverzhdeny Prikazom Mintransa Rossi ot 21.12.2010 286
[2] Pravila tyagovoy raschetov dlya poezdnoy raboty Utverzhdeny rasporyazheniem OAO «Rossiyskie zheleznys dorogi» ot 12.05.2016 867
[3] Al-Ibrahim A Dynamic 2010 Delay Management at Railways. A Semi-Markovian Decision Approach : PhD thesis (Al-Ibrahim Ali - Universiteit van Amsterdam) p 335
[4] Badhrudeen M and Ramesh V at al 2016 Headway Analysis using Automated Sensor Data under Indian Traffic Conditions Transportation Research Procedia 17 pp 331–339
[5] Berger A and Gebhardt A et al 2011 Stochastic Delay Prediction in Large Train Networks 11th Workshop on Algorithmic Approaches for Transportation Modelling Optimization and Systems (ATMOS 2011) OpenAccess Series in Informatics (OASIcs) vol 20 ed A Caprara S Kontogiannis p100–111
[6] E S Ventcel' and L A Ovcharov 2000 Teoriya veroyatnostej I ee inzhenernye prilozheniya (Moscow: Vysshaya shkola) p 480
[7] Kochnev F P and Sotnikov I B 1990 Upravlenie ekspluataционnoy rabotoy zheleznys dorog
[8] Carey M and Kwiecinski A 1994 Stochastic approximation to the effects of headways on knock-on delays of trains *Transportation Research* Part B 28(4) pp 251–267

[9] Goverde R M 2005 Punctuality of Railway Operations and Time-table Stability Analysis PhD thesis (Goverde Rob - Technical University of Delft) p 165

[10] Meester L E and Muns S 2007 Stochastic delay propagation in railway networks and phase-type distributions *Transportation Research* Part B 41 pp 218–230

[11] Riccardo R and Massimiliano G 2012 An empirical analysis of vehicle time headways on rural two-lane two-way road *Procedia Social and Behavioral Sciences* 54 pp 865–874

[12] Salido M A 2008 Robustness in Railway Transportation Scheduling, 7th World Congress on Intelligent Control and Automation (WCICA ‘08) ed M A Salido and F Barber et al (Chongqing China) p 2833-2837

[13] Levin D Yu 2008 Teoriya operativnogo upravleniya pervovozochnym processom: monografiya (Moscow: GOU «Uchebno-metodicheskij centr po obrazovaniyu na zhelezodorozhnom tr-te» p 625

[14] Yanfeng L I Jun L I 2017 Multy-class dynamic network traffic flow propagation model with physical queues *Front Eng Manag* 4(4) pp 399–407