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The Criterion for Optimal Rescheduling in Mixed Train Traffic

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Abstract

Rescheduling the train traffic to compensate deviations requires the use of an adequate criterion. The measures of punctuality are the optimality criteria in managing the flow of passenger trains. The quality of rescheduling the freight train traffic is reflected in amount of the operator company profits. Purpose of this study is to find such a criterion, which allows determining the optimal dispatching adjustments for rail section with mixed passenger and freight traffic.
In our paper, we consider the totality of problems that relate to meeting the demands both the passengers and the consignees. We offer the use of two types of models. The first model describes the formation of the result in the passenger transport segment. The optimality criterion is based on taking account the number of passengers who are late in reaching their destination points. Another criterion is constructed using the new micro-economic model proposed in the earlier study. This criterion reflects the economic results obtained by the freight trains passage. The paper describes a new complex criterion, which is designed to find optimal solutions for the operational management of mixed flow on the main line.
The proposed new criterion and the method of its on-line using, allow improving quality of the rescheduling decisions. These solutions reduce the number of passengers who get damage caused by delays. Also, are reduced cost losses up to 6 percent due to energy savings through optimal traffic adjustments.

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*Keywords:*train rescheduling; optimal decision; economic criterion; punctuality

1. Introduction

Passenger and freight trains both move in the mixed flow on the main rail line. Quality requirements for the passage of various types of trains are significantly different. The travel process of passenger trains assumes the satisfaction of punctuality requirements. Punctuality is considered as the consumer characteristic, that is, as a property that meets the needs of customers. Freight trains do not need of a detailed compliance of the schedule at all intermediate stations. The motion of each train on the railway sections and along the entire route should be cost-effective.

Ensuring a safe headway and the synchronicity of trains is the normal mode of the rail section operation. When trains run synchronously, there are no arrival delays and unplanned short stops at the open tracks. In the real

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situation, deviations from the schedule are inevitable. Deviations disrupt synchronism and cause the process of propagation the delays.

The appearance of multiple small deviations affects the economic results of the operator company in two ways. Firstly, additional energy and other resources are spent to overcome them. It is lead to overrun the operating cost. And secondly, it reduced the level of income of the company by reducing the volume of traffic. For example, during periods when there are larger disruptions, we have to reduce the number of trains and lose the part of the income. The same occurs when the passengers feel discomfort due to persistent delays and as a result they are moved to other modes of transport. This is a consequence of competition and leads to a deterioration of economic performance of the railway company in the longer term. Operational management of the traffic eliminates a significant number of delays, thus weakens influence of this factor.

The shippers practically do not feel small perturbations of train traffic because they are not interested in the appropriate information. Therefore, in the segment of freight traffic for local delays deferred reaction is not observed in the form of customer churn. The operator receives a loss of benefit due to increased operating costs, mainly on the unplanned stops.

That reference is enough to apprehend that the management of passenger train flow is a profitable part of the economic result. The expenditure part of the result is related to the loss of energy at unscheduled stops and has a lot of weight in the objective function, which is used in solving the rescheduling problem. This provision applies to both of passenger and the freight trains. Combining in one complex criterion of the quantities that characterize punctuality and operating costs is a difficult challenge. This problem is not solved enough in the prior researches.

In this paper we attempt to analyze the problem of economic evaluation, the quality of rail traffic and to formulate the complex criterion, which is used in the process of determining the optimal decisions when rescheduling. After carrying the analytical review of the known papers (sections 2 and 3), we give a more realistic economic assessment of the passenger train delays in the section 5. Then we formulate a complex optimization criterion of management quality in the mixed train flow traffic that is used for the on-line rescheduling (section 6). In the final part, we present the experimental results and the theoretical estimates, which show the potential benefits from optimal rescheduling.

2. Literature review

Many researches devoted to the algorithms that optimally adjust the schedule. The well-known papers Törnquist (2006), Cacchiani et al. (2014) provide an extensive survey of recovery models and algorithms for real-time railway rescheduling. It should be emphasized that the vast majority of authors investigate the problem of rescheduling the passenger trains flow. A very few studies are devoted to solving the problem of optimal on-line management of freight trains. Early works Kraay et al. (1991), Dong (1997) have explored the deterministic macro-models of train traffic on the single-track line. It was later developed the theory of micro-models of freight trains flow, Caprara et al. (2002).

A significant number of studies devoted to the development of criteria for determining the optimal solutions for the train traffic management. Top-level rail experts created the set of railway efficiency performance indicators that measure efficiency from the government, passenger/client, infrastructure manager and train operating company perspectives, Beck et al. (2013). The ideas of this fundamental work are reflected in many developments.

Most studies on the rescheduling problem use the total cumulated delay of trains at all stations or at the final station of the site as the measure of punctuality. In the suburban areas of megacities transfer of passengers presents a mass phenomenon. Many papers consider a violation of the quality of service as a problem that arises when appears the transfer of passengers at the connections. The cumulative volume of delays due to problem of the passenger interchange, Schobel (2009), or the number of modified (or canceled) scheduled stops, Chiu et al. (2002), are usually considered as the quality criteria.

It is suggested to use the total delay both during the direct trips and in the breaches of connections as the optimality criterion, Wüst and Steiner (2012). The delay is weighed in this case with the amount of passengers M who got lateness:

$$Q = \sum M_i \tau_i + \sum M_k \tau_k \, , \tag{1}$$

where τ_i, τ_k are the delays respectively on direct routes and on connections.

The second component of this expression appears when passengers are not able to carry out to change trains due to arised delay. In some studies (see, for example, Corman et al. (2010)) punctuality is estimated by the value, which is share of all delayed trains.

Neglect of important features that are inherent to passengers, is a major disadvantage of the criterion which uses cumulative delay. One of the features is the distinction of interests of different groups of passengers. Another characteristic reflects the situation at different stations and in different times of day. The timing criterion in the classical treatment does not allow estimating the economic consequences of delays and the effect from removing process of them.

The separate group consists of papers, which explores the process of elimination the large failure in the movement of trains. In this case, the quality of dispatching is evaluated by the level of losses that are caused by a decrease the number of passengers and by the cost of unscheduled work with the rolling stock, Cacchiani et al. (2014), Nielsen et al. (2012).

A literature review on costs of delays to freight railroad, causes, measures, impacts on different types of trains has been presented by Johnson and Fowkes (2008). Major causes of freight congestion delays has been extensively studied and statistically analyzed by Gorman (2009).

The paper of Higgins et al. (1996) first described the cost objective function that takes into account the delay trains and operating expenses during their running. This idea was developed in the research of many authors (see, for example, Goverde (2005), Lindfeldt (2010)). Mes et al. (2006) consider the complex criterion, which includes the train travel expense and penalty loss due to lateness of the train.

Several authors (Chang et al. (2000), Shi et al. (2004), Ghoseiri et al. (2004)) have developed a multi objective programming models for the optimal trains management. By contrast, Fan et al. (2011) estimate the each train delay by the penalty, which is determined by the category of the train. They are used the criterion, which is a weighted sum of train delays, when searching for the optimal solution for the mixed flow of trains. It is believed that the weight of each delay has some monetary penalty.

The analysis of published studies shows the lack of a clear economic criterion hinders to optimal solution of rescheduling problem both of passenger and freight train traffic.

3. Economic evaluation of the traffic quality on the railway section

Operational management on the railway section where there is traffic of passenger and freight trains require availability of a comprehensive quality criterion. This criterion is used for formulating the optimal solutions in the process of rescheduling. Formation of such a criterion for the mixed flow is a complicated problem. This measure should be taken into account at the same time as the temporal characteristics and the operational cost.

In the majority of papers the economic objective function for the optimal rescheduling focuses on size of the arrival train delay at the station. The sum of the weighted delays for all trains has been considered as a criterion of the operative management. So, the authors of Bo Fan et al. (2011) and Bocharnikov et al. (2007) estimate the value of each delay by the penalty, which is determined by such a category of train as intercity, commuter or freight ones. Thus the objective function is as follows:

$$Q(\Theta) = \sum_i \tau_{on\,i} P_i \,, \tag{2}$$

where P_i is the penalty for 1 minute delay.

The quantity *F* characterizes a scenario that provides a minimum value of the objective function:

$$\hat{\Theta} = arg\ min\ Q(\Theta). \tag{3}$$

Necessary to specify the shortcomings of the specified approach:

- lack of differentiation the penalties by time of day;
- neglect of number the passengers who are experiencing discomfort due to delays or the connections breakdown;
- neglect of the additional costs, which are necessary for the traffic control.

Here we note the local delays of freight trains are not subject to penalty fees, although themselves unplanned stop brings great economic losses due to the additional energy consumption.

In the above papers used an approach that is based on the Pareto-optimality when looking for a solution of the two-factor scheduling problem. Fitness functions for energy consumption $\mu(E_i)$ and for delay-time $\mu(\tau_{p\,i})$ are weighted to yield a generalized cost function for the train *i*. In that paper each delay are weighted for the certain train type by the use of the value of penalty per minute in UK Pounds:

$$Q_i = w_E \mu(E_i) + w_{pen} \mu(\tau_{p\,i}). \tag{4}$$

The delay weight of the intercity train is the extremely high, commuter train is lower than intercity train and freight train is very low. As we can see the weight w_{pen} is assigned subjectively, and its size is quite approximate. This may result to incorrect management decisions.

There is a study Boland et al. (2012), in which each arrival delay of the train at the final station is weighted by the amount of alight passengers. Every minute of the delay of one passenger assessed by the penalty equal to 0.31 AUS dollars. The authors of paper Crevier et al. (2010) has attempted to use the monetary criterion in solving the optimization problem for control of the freight traffic. The authors introduce the freight cost rate ***c*** per one car, which includes the existing tariff e_f and monetary estimation ρ of the level of service:

$$c = e_f + \rho\,. \tag{5}$$

With the help of assessment ρ they propose to take into account perception of the level of service by the customer, i.e. the transportation duration *T* and the service quality *Q*. Obviously, the definition of the component ρ is a difficult methodological task. Here we can refer to Crainic (1998), who argue: «The customers' expectations have traditionally been expressed in terms of «getting there» at the lowest cost possible».

To overcome these difficulties, we must to change the approach to the evaluation of the quality of regulation the mixed freight and passenger traffic. Let us make two main assumptions:

- no the length of delays inflicts damage to passengers (and not the total value of all delays on trains), but the number of delays;
- high quality of the freight train management involves the creation of conditions necessary to ensure punctuality in the passenger segment with minimal loss in operating costs (i.e., in power consumption).

Indeed, the magnitude of damages to be considered proportional to the number of passengers in delayed trains, in the case of ordinary tardiness with duration of the order the several minutes. Such the late arrivals are in majority. But this value depends on the number n_d^{Pass} of train delays at the arrivals.

The full economic losses are to be minimized in the process of adjustment the timetable, determined by the number of delays the passenger and freight trains. After all, the presence of regular delays leads to a reduction the number of passengers and to decrease in revenue of the operator company. In themselves the delays in the arrival of freight trains at the intermediate stations is very little impact on economic performance. The exception is the trains that followed on the hard lines of the schedule, as well as the greatly delayed freight trains with a high risk of a penalty. Therefore, the number of delays of freight trains n_d^{Fr} should be treated as a technological measure that is different from n_d^{Pass} what is an index of quality the passenger service. The primary delays of freight trains causes two type of troubles such as the emergence of delays of passenger trains and the fuel (energy) overrun on each of lateness.

The pass of passenger trains in the mixed flow in many cases is carried out due to deterioration of freight trains' paths, what leads to further delays of the freight services. Thus, the search for the optimal variant of correcting the schedule includes ensuring the accuracy of the passenger trains arrival at the station and minimizing the number of unplanned delays the all kinds of trains.

4. New quality measure of the passenger train traffic

Punctuality in the passenger traffic segment is an important component of the quality of rail service. The high level of punctuality increases the number of users of transport services and, consequently, income of the carrier and operator company. We understand punctuality is the timetable accuracy in detail, i.e. for each intermediate point of the train route.

Most studies on optimal traffic management have used the total cumulated delay of trains on all stations or on the final station as a measure of punctuality. This indicator allows in solving a number of problems for constructing an optimal timetable adjustments. However, this approach is not fully reflect the situation how completely satisfying demands of passengers.

The first property of a person which should be observed by the operator when he organizes the traffic control is as follows. The passenger begins to perceive the late arrival of the train as a significant delay only for sufficiently large values of delay. This measure has the uniqueness for every station and for different times of day. For example, a person perceives the delay more acutely during peak hours. Therefore, for the *i*-th situation in this period the threshold of perception $\Delta T_{p\,i}^{lim}$ is smaller. Therefore the measure of quality the service should not contain all the delays, except that lateness which exceed a specified threshold. It is observed that in the assessment of the punctuality-loss many railways take into account the delays, exceeding a definite value, for example, 3 minutes, Goverde et al. (2008).

Another circumstance that must be taken into account in the assessment of quality is the damage caused by delays for the different groups of passengers. Obviously, the approach is most appropriate when the priority service is given to groups which are more numerous. One example is the management of traffic on the suburban train line. Most attention during rush hours manager devotes to stations where is carried the mass boarding and alighting of passengers. He instinctively tries to make such adjustments to reduce the delays of trains at these stations. Therefore, if the delay of the train exceeds the threshold value, it is advisable to assess the damage by the number of passengers $M_{d\,j}$ who fell under the delay.

We formulate the following criterion for the quality of traffic the heavy passenger train flow, using the approach just described. *The scenario is considered the best, if its implementation gives delayed arrival at all the stations of the minimum number of passengers*. In this case, are taken into account the delays that exceed certain defined thresholds:

$$\sum M_{d\,ij} \to min\,, \qquad \tau_{ij} \ge \Delta T_{d\,ij}^{lim}\,, \qquad i = 1, 2,\ldots, m, \qquad j = 1, 2,\ldots, n, \tag{6}$$

where the index *(ij)* denotes the value of describing events occurring in the *i*-th interval the time of day at the *j*-th station. Obviously the value of specified thresholds for different types of trains such as high-speed, intercity or commuter must be different.

Frequently there are situations when we need to plan a priority pass of the delayed train or the train with a valuable cargo. The priority of the train must be done by toughening the requirements for the threshold ΔT_p^{lim}. This is carried by assigning the weighting coefficient a^{pr}, which is reflected by the following equation:

$$\Delta T_p^{lim\;pr} = a^{pr} \Delta T_p^{lim}\,. \tag{7}$$

We offer the flexible (adaptive) rule for the classification of certain deviations to the set of significant delays. It is necessary if to take into account the "worth" (priority) of the train when selecting the optimal sequence of passes moving units. According to this rule, we consider a significant value such a delay whose duration exceeds the certain allowable threshold $\tau_{all\,k}$. This threshold interval depends on how much delays are tolerable for the particular train or for trains' category. The values of $\tau_{all\,k}$ are kept lower for trains which have a high price of delay. Obviously, in this case, the number of delays to be factored in the calculations is increased.

For example, the threshold value of delay commuter trains during rush hours can be set to 1 minute, in other periods of the day to 2 minutes. For those of local passenger trains that have to deliver passengers on time to the connection station, this interval should be shortened to 0.5 minutes or less. The lateness is considered significant for the long-distance trains, if exceeds the value of 3 minutes.

Using this rule it enables the separation of any delays into the groups, each of which is characterized by the following relationship:

$$\tau_d \geq \tau_{all\,k} . \tag{8}$$

A similar classification procedure is carried out and for the freight train traffic. This procedure consists of establishing the various limits of delays for which the deviation from the schedule is believed significant, and included in the calculation.

Factors affecting the value of the allowable freight train delay $\tau_{all\,f}$ are the weight of the train and unacceptably high delay regarding the timetable. This carries the risk to pay of the penalty for late delivery of goods or the use of heavy acceleration to compensate the delay.

"Freight" component of the objective function as well as "passenger" component is included to the sum of quantities, each corresponding to a different gradation of delays. The most rigid boundary is set for those freight trains following to the solid timetable. For example, it can be made the limiting delay value of these trains, equal to 10 minutes.

5. Outlying economic result due regulating the passenger train flow

The economic result from the activities of the railway operator is the difference of income I and operational expenses C:

$$B = I - C . \tag{9}$$

The revenues are decreased to a value I_d and the cost increased to C_d when the traffic process takes place in a disturbed environment. We can restore a certain amount of lost income ΔI and reduce the cost of ΔC , if to make the operational adjustments that are aimed at delay reducing. The resulting benefit is a measure of the efficiency of performed adjustments, Davydov et al. (2014). Therefore, the specified quantity we will use hereinafter as the objective function in the search for the optimal solutions: $\Delta B \rightarrow max$.

Income from operations is determined by the amount of transported passengers. The passenger flow volume may be reduced if some of them will choose other mean of transportation or other rail carrier. This can happen if delays of trains regularly occur on a given rail line. However, the process of outflow the passengers take place for a long time. Therefore, a decrease in income, which is caused by this factor, should be considered as deferred (outlying) losses.

The sensitivity of economic indicator to a certain impact factor usually reflected of the coefficient of elasticity E. This indicator shows how income decreases while reducing the number of passengers on the value of $\delta M = \Delta M / M$. These passengers are dissatisfied due lateness of trains. The value of this change is the following:

$$\Delta I = \delta M \cdot I_0 \cdot E , \quad E \leq 0 . \tag{10}$$

We can express the cost savings that result from dispatching adjustments as a share of the full expenditure: $\Delta C = \delta C \cdot C_0$. The value is determined mainly by the amount of energy saved. Overspending of energy, which is caused by deviations from the schedule, cannot be completely eliminated at the optimal regulation. Also one cannot ignore the proper amount of expenses $\delta C'$. Assume that the real economy of the excessive costs $\delta C''$ is a result of the rescheduling, in this case, the expenditure component of the final economic result will be:

$$\Delta C = \delta C' \cdot \delta C'' \cdot C_0 . \tag{11}$$

We now estimate how large the contribution into the result ΔB of both the considered component that occurs on the railway line with the real movement of trains. This takes into account the share of passengers who fall under the delays is really small, less than 1 percent. If to carry out the rational adjustments it can remove only a portion of delays, which is estimated to be about 0.1. One can reasonably assume that the elasticity of demand for transport services is low. This is due to the fact that the passenger traffics are categorized as services of first necessity and characteristics of the various transport options are identical, Beuthe et al. (2014). In this case, the coefficient of elasticity is close to zero ($|E| << 1$). If we accept E to be (0.1), then the value of the revenue will not exceed the following magnitude: $\Delta I = 1 \cdot 10^{-4} I_0$.

Many studies show the energy saving potential for the train traction is estimated at 10-20 percent of the total consumption A_0. With the effective dispatching is possible to realize part of the excess consumption, at least 1 percent of the volume A_0. Then we obtain the following estimate of the change in expenditure, which is caused by dispatching:

$$\Delta C = 1 \cdot 10^{-2} C_0 .$$

Assume that the profitability in the passenger segment is small and does not exceed 10 percent. Then the values of income and expense for the train flow can be considered similar in magnitude when performed the estimations: $I_0 \approx C_0$. Therefore, we can conclude that the change of the economic result, which is due to the optimal dispatching, mainly caused by the expenditure component ΔC. This component exceeds the magnitude of revenue increment ΔI not less than on two orders.

6. New integrated criterion of quality the operational management

Now we will try to solve the problem of combining the requirements of local punctuality and economic efficiency in the development of criterion to be used for selection the optimal rescheduling solutions. Obviously, the first group of requirements is valid for passenger trains and freight trains with the inflexible schedule. The second group of the requirements will be applicable to all types of trains. Let us present the requirement that the desired criterion must have the form of the economic quantity.

The adjustments are aimed for the elimination of delays and allow reduction of losses to the railway operator. The first part of benefit occurs due to the weakening the outflow of passengers and it is equal to restored part of income ΔI_p (see section 5). The second part is a reduction of operating expenses, which arises as a result of elimination the unscheduled delays. This economy occurs mainly due to a decrease in energy consumption. If we use an approach that is based on the Pareto-optimality, we can offer complex criterion, which represents the weighted sum of these components:

$$Q = \left(w_p \Delta I_p + w_A \Delta C_A \right), \quad w_p + w_A = 1 . \tag{12}$$

The advantage of the proposed cost function over the similar function, which is used in previous papers, is a dimensionless character of weighting coefficients. Weighing of components the criterion is necessary because there are the various character of the flow of trains and various rescheduling problems at different times. If the mixed flow is dominated by passenger trains and traffic is rather intensive, it is expedient to choose the weight $w_p \to 1$. In this case, we arrive essentially to the temporary criterion that brings to the fore the delays of passengers (see section 3).

In cases where the intensity of passenger and freight trains in a mixed flow is comparable, the weight of the energy component increases. The similar situation occurs when operative stop is required to the one group of trains, and accelerates other trains for the purpose of optimal rescheduling. In this case, there is a great of energy overruns; hence, there is a need in the power flow optimization. Obviously, right now it is expedient to take $w_A \to 1$. In this latter case it is necessary to take into account the energy overruns at that sections where higher speed and unplanned stops are observed. In this model, which describes the process of forming the energy loss at the site, it is sufficient to account of number of deviations from the schedule n_p and n_f respectively, for passenger and freight trains. Thus the objective function takes the following form:

$$\left(n_p \Delta A_p + n_f \Delta A_f\right) \rightarrow min\,, \tag{13}$$

where ΔA_p, ΔA_f are the means of energy overrun at single deviation, respectively for passenger and freight trains.

7. Real delays of trains and economic benefits of their elimination

The process of the emergence the unscheduled delays was studied experimentally at several sites of the busy Trans-Siberian railway main line (Russia), Beuthe et al. (2014), Davydov et al. (2014). The intensive mixed flow of trains moves on this line. The passenger segment of the flow makes up the share less than 20 percent. The schedule is constructed in such a way that the passenger trains are moving by packets at certain periods of the day.

We obtained experimental data on the duration of primary unscheduled stops of freight trains and energy losses that occur at every short stop. Research has shown that the distribution function of the length the stop is an exponential with the parameter $\lambda = 0.26 \;\; 1/\text{min}$. Was plotted dependence the initial headway *T* of the number of expected unscheduled delays *m*. The graph is built for various probabilities *p* of the knock-on delays on the basis of experimental data and the stochastic model of propagation the delays (see Fig. 1, Davydov and Chebotarev (2015)).

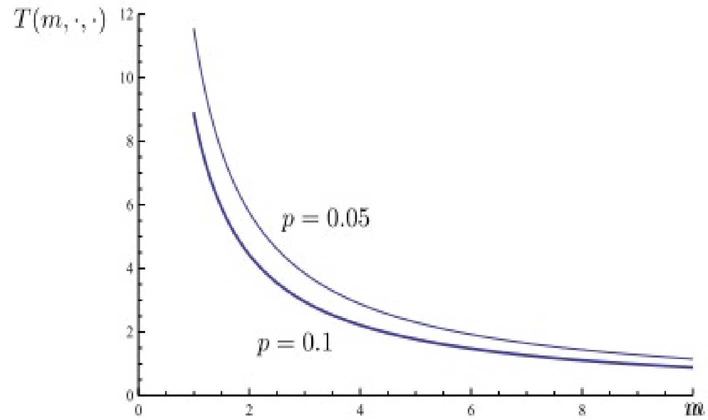

Figure 1: Dependence of initial headway of the number of expected unscheduled delays in the presence of their various probabilities *p*

Here we define the minimum interval of departure the trains T_{dep} , wherein the number of secondary stops m_{knock} does not exceed *m* with probability $\alpha = 1 - p$. The calculation takes into account that initial headway at the departure T_{dep} is the sum of the quantity *T* and a fixed amount of the safe interval t_0 : $T_{dep} = T + t_0$.

Observations show that the trains depart from the starting station with an average interval of 9.5 minutes in the peak hours of the traffic on the main line. Taking into account that the safe headway while moving of heavy trains is equal 5 minutes we conclude that the value of the variable *T* has an average size of 4.5 minutes. As follows from the graph in Fig. 1, in this case there are two unscheduled stop with probability of 0.9.

According to the statistics, which is obtained on the investigated mainline, there is one of the unplanned stop the freight train every 3 hours (on average). During this time, the train runs along a site of about 200 KM. The average number of stops on this section makes 1.8, which is consistent with the results of the calculation.

The average loss of power during unscheduled stop of intercity train is equal to 140 kWh. The loss of heavy freight train with the weight of 6-8 tons is reached 300 kWh. Additional energy consumption which arises from the accelerated run of the passenger unit to compensate for the delay is equal to 60 kWh. Specified values of energy consumption confirmed by the numerous calculations and experimental research. Usually one takes readings of the energy meter on the locomotive at the certain points before and after the investigated site when carrying out the practical measurements.

The calculation shows that inefficient power consumption due to unscheduled stops is about 6% of the total volume of this resource throughout the entire site. The daily amount of traffic on the Trans-Siberian Railway makes up to 70 pairs of trains. Reducing the number of stops at least by half, and the use of energy-efficient modes of driving the trains provide the annual energy savings exceeding 8 million kilowatt-hours. This gain is achieved at every dispatching site with the stretch of 200 KM.

8. Conclusions and future work

1. Compliance of the punctuality of the passenger train traffic can be purely motivated economically, if we consider the position of dispatching personnel. The purpose of precise compliance the schedule is to ensure the "local" quality of life, namely, passenger satisfaction levels of the transport service.

2. The number of passengers that are affected by the delay of trains is an adequate measure of reducing the level of service. The thresholds, by which the unacceptable delays determined, are assigned to each station taking into account the specific requests of passengers (i.e. Stakeholders). This indicator is an effective criterion for the optimal rescheduling.

3. The disturbances of traffic cause significant energy losses, leading to increased operating costs. Using energy-saving technologies for efficient management gives a big economic benefit while moving the flow of trains.

4. When searching for optimal solutions we need to use the criterion of operating costs when there is a relatively stable traffic and no cancellation of trains.

5. The weight of the revenue part the economic criterion increases in period of strong failures, when the schedule changes greatly and some trains are canceled.

In the future, we plan to study the problem of changes in the number of passengers depending on the quality of movement the trains as well as due to effective rescheduling during periods of mass delays.

References

Beck, A., Bente, H., Schilling, M., 2013. Railway Efficiency – An Overview and a Look at Opportunities for Improvement / The International Transport Forum, Discussion paper No. 2013-12, May (2013), 44 p.

Beuthe, M., Jourquin, B., Urbain, N., 2014. Estimating Freight Transport Price Elasticity in Multi-mode Studies: A Review and Additional Results from a Multimodal Network Model / Transport Reviews: A Transnational Transdisciplinary Journal, Volume 34, Issue 5, pp. 626-644.

Bocharnikov, Y.V., Tobias, A.M., Roberts, C., Hillmansen, S., Goodman, C.J., 2007. Optimal driving strategy for traction energy saving on DC suburban railways / IET Electr. Power Appl., 1, (5), pp. 675-682.

Boland, N., Evans, I., Mears, C., Niven, T., Pattison, M., Wallace, M., Waterer, H., 2012. Rail disruption: passenger focused recovery / Computers in Railways XIII, pp. 543-553.

Cacchiani, V., Huisman, D., Kidd, M., Kroon, L., Toth, P., Veelenturf, L., Wagenaar, J., 2014. Overview of recovery models and algorithms for real-time railway rescheduling. Transportation Research, Part B, 63, pp. 15-37.

Caprara, A., Fischetti, M., Toth, P., 2002. Modeling and solving the train timetabling problem / Operations Research, v. 50, iss. 5, pp. 851-862.

Chang, Y., Yen, C., Shen, C., 2000. A multiobjective model for passenger train services planning application to Taiwan’s high speed rail line / Transportation research, Part B, vol. 34, № 2, pp. 91-106.

Chebotarev, V., Davydov, B., Dynkin, B., Kablukova, K., 2014. Prediction of the Train Traffic when Random Failures Occur / The 6th International Conference on Railway Operations Modelling and Analysis RailTokyo-2015.

Chiu, C. K., Chou, C. M., Lee, J. H. M., Leung, H., Leung, Y. W., 2002. A constraint-based interactive train rescheduling tool / Constraints, 7 (2), pp. 167-198.

Corman, F., D’Ariano, A., Longo, G., Medeossi, G., 2010. Robustness and Delay Reduction of Advanced Tran Dispatching Solutions under Disturbances / 12th World Congress of Transport Research, July 11-15, 2010.

Crainic, T., 1998. A Survey of Optimization Models for LongHaul Freight Transportation / CRT-98-67, 81 p.

Crevier, B., Cordeau, J.-F., Savard, G., 2010. Integrated Operations Planning and Revenue Management for Rail Freight Transportation.

Davydov, B., Dynkin, B., Chebotarev, V., 2014. Optimal rescheduling for the mixed passenger and freight line / 14th International Conference on Railway Engineering Design and Optimization, pp. 649-661.

Dong, Y., 1997. Modeling rail freight operations under different operating strategies / PhD Thesis, Massachusetts Institute of Technology, AAT 0599098.

Fan, B., Roberts, C., Weston, P., 2011. A hybrid algorithm for optimal junction traffic control / 4th International Seminar on Railway Operations Modelling and Analysis, Rome, Feb. 2011.

Ghoseiri, K., Szidarobszke, F., Asgharpour, M., 2004. A multi-objective train scheduling model and solution / Transportation research, Part B, vol. 38, no. 10, pp. 927-952.

Gorman, M., 2009. Statistical estimation of railroad congestion delay / Transportation Research, Part E, Logistics and Transportation Review, 45(3), pp. 446-456.

Goverde, R., 2005. Punctuality of Railway Operations and Timetable Stability Analysis / PhD Thesis, Technische Universiteit Delft, 310 p.

Goverde, R. M. P., Daamen, W., Hansen, I. A., 2008. Automatic identification of route conflict occurrences and their consequences / Computers in Railways XI, pp. 473-482.

Higgins, A., Kozan, E., Ferreira, L., 1996. Optimal scheduling of trains on a single line track / Transportation Research, Part B, vol. 30, № 2, pp. 147-161.

Johnson, D., Fowkes, T., 2008. A literature review in Determining the Costs of Delay to Different Types of Train / Institute for Transport Studies, University of Leeds, 36 p.

Kraay, D., Harker, P. T., Chen, B., 1991. Optimal Pacing of Trains in Freight Railroads: Model Formulation and Solution / Operations Research, vol. 39, iss. 1, pp. 82-100.

Lindfeldt, O., 2010. Evaluation of punctuality on a heavily utilised railway line with mixed traffic / Computers in Railways XI, pp. 545-553.

Mes, M., van der Heijden, M., Schuur, P., 2006. Opportunity costs calculation in agent-based vehicle routing and scheduling / Report, Univercity of Twente, Netherlands, 35 p.

Nielsen, L., Kroon, L., Maroti, G., 2012. A rolling horizon approach for disruption management of railway rolling stock / European Journal of Operational Research, 220, pp. 496-509.

Schobel, A., 2009. Capacity constraints in delay management / Public Transport, 1 (2), pp. 135-154.

Shi, F., Deng, L., Li, X., Fang, Q., 2004. Research on passenger train plans for dedicated passenger traffic lines / Journal of the China Railway Society, vol. 26, № 2, pp. 16-20.

Törnquist, J., 2006. Computer-based decision support for railway traffic scheduling and dispatching: a review of models and algorithms. In: Proceedings of 5th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems.

Wüst, R., Steiner, A., 2012. A multi-component closed-loop control framework for rail traffic networks / 12th Swiss Transport Research Conference, May 2-4, pp. 1-34.

Давыдов, Б. И., Чеботарев, В. И., 2015. Оптимальные режимы движения потока грузовых поездов / Транспорт: наука, техника, управление, №1, с. 65-67.