Collective Intelligent Management of Freight Trains' Flow

Boris Davydov
Institute of Natural Science
Far Eastern State Transport University
Khabarovsk, Russian Federation
e-mail: dbi@rambler.ru

***Abstract*—The paper describes method and criteria for assessing the quality of freight trains' traffic dispatching. The main idea is to make the maximum profit for the rail operator through the compromising decisions between regional (commercial) and local traffic dispatchers. We use results of the game theory and the operations research method (AHP) to find optimal trains' traffic adjustments. The game model of joint decision making is used to overcome the internal conflict between dispatchers. It is helpful to use the increment of local profit as a criterion for assessing the quality of traffic controller's decisions. We also describe the modified AHP method oriented for the efficient on-line management. We present an example of the hierarchy model and results of the decisions efficiency assessment for the typical situation of freight trains traffic. Rational use of computing abilities of the decision support tools together with collective intelligence allow to increase quality of decisions on settlement difficult conflicts between trains.**

Keywords-Trains' traffic; real-time management; railway dispatching; optimal decision making; transportation economics

I. Introduction

The main function of the operative train traffic management is solving two problems. The first problem is how to organize the best transportation service for consumers (passengers, cargo owners). First of all, the management provides high passenger trains' punctuality. The second condition is meeting the requirements of railroad operator in getting profit from the transportation process realization. This is mainly attained by the rational organization of the freight trains stream passing.

The need for operational management arises owing to disturbances which are caused by repair breaks, technical failures and errors of operational personnel. Failures are characterized by a high variety of variants and there are many ways of their elimination. Besides, it is known that information about railroad situation is often incomplete. This leads to the adoption of the optimum decision whose result is overcoming of an arising problem..

The analysis of the researches and developments in the related field allows us to make the following conclusion: nowadays it is impossible to make the full automation in real time for train traffic. The effective way to solve the problem is to take the decision through the man-machine dialogue.

Numerous researches all over the world are devoted to the optimization problem and to effective management of railway traffic. The present work carries out the analysis of the joint passenger/freight traffic effective management with the use of intelligent computer support.

We formulate an optimization problem in which at least two agents – regional and section traffic manager – control trains movement. Regional dispatcher (RD) objective is to maximize the line productivity, sometimes without taking the local section effectiveness into account. Regional dispatcher is given the authority to control the trains set repositioning. Section dispatcher (SD) has the opportunity to improve the operations by prescribing the rational headways and by solving the local conflicts. There are many cases when infrastructure managers are involved into the decision making process.

The developed model of the interacting parties gives the opportunity to provide the cooperative way to resolve the working conflict between RD and SD and to take the optimal decisions by using the analytic hierarchy process (AHP).

The paper is structured as follows: Section II presents the specificity of trains' traffic operative management on the main railways. In Section III, we present the overview of the methods of conflicts resolution to the trains' movement in the railway section. Section IV describes the modes of operation and economic performance criteria of the railway. We also show the conflict solution algorithm that uses the game theoretic approach. In Section V, we present the trains' control model, based on the analytical hierarchy process (AHP-approach). Algorithm, based on AHP, delivers agreed decisions of rail managers. An example of using AHP-model are presented in Section VI, show the effectiveness of the proposed approach. The paper ends with conclusions, the main one being the following. The hierarchy model and man-machine dialogue promotes adoption of effective decisions and the subsequent fine adjustments.

II. Background

Many of conventional main railways (Russian, American, Chinese etc.) are characterized by intensive joint passenger and freight traffic with prevalence of a freight segment. The basis of freight traffic is heavy trains. Dense railway system with the intensive passenger flows, similar to European railroads, is available only in nearest areas of the large cities. All the above define the specificity of trains' traffic operative management on the main railways. There are many differences in the passenger and freight rail line traffic dispatching. First of all, passenger traffic requires high micro-punctuality. It is not true for the conventional freight

 ISBN: 978-1-61208-269-1

trains traffic. Railway operative planners often do not take these differences into consideration. Nonoptimal adjustments and economical losses are the consequences of this incomprehension.

III. Overview of the Related Literature

Many authors consider the problem of conflict resolution in real-time on the railroads [1-4]. Most of them use the determined modeling of the railway traffic. This approach allows accurate predicting of the future evolution of the traffic on the basis of the actual train positions and speeds, signaling and safety system constraints. Computerized supporting system operates with accurate input data. If input data is incomplete or indistinct, it is unlikely that the solutions provided by the DSS will be effective. It is known that the additional real-world constraints such as commercial interests and human behaviors are not taken into attention by the support tools. It is necessary to remove this fundamental disadvantage by the use of professionals' experience and intuition.

Criteria of a freight trains' traffic control is different from the passenger one. There are a few works devoted to this topic [5-8]. The works mentioned do not demonstrate the adequate formulation of economic quality indicator of dispatching. This paper gives a novel economic model and indicator which enables to make effective freight traffic adjustments.

There are many works in the field of collective decisions making [9, 10]. Most of them describe the approaches which demand much time for the problem analysis. Up to now, there a few works devoted to the collective decision-making whose purpose is intellectual support of real-time transportations management. These researches show that it is effective to resort to the possibilities of the analytical hierarchy process (AHP) for operative personnel viewpoints coordination. A wide range of AHP problems and applications has been described in edited volumes and books (e.g., [11-13]). Some of them [14-18] are devoted to aggregating individual judgments. But a fast coordination approach is not known to be effective in wide practice. This work contributes to fill the gap between theory and practice of train operative management by the human and machine intelligent interaction.

IV. Trains' Traffic Optimizing Criteria

Trains' traffic on conventional rail lines - from the point of view of operative management - is divided into two segments. Trains of the passenger segment are defined by the highest priority. Their passing through the railway section is carried out by using any resources (free ways, additional fuel, etc.) when failure occurs. Unlike passenger trains the stream of the freight trains can move more economically. Therefore the first stage of formulating the optimization problem for the traffic control area is to set the specific criteria: punctuality of trains' movement, section throughput or local economic efficiency.

The failures sharply change movement conditions of the rail section. In these cases the dispatching personnel ought to repair the schedule to provide minimum losses of the throughput and the expenses. Modified operative train schedule for a section movement is under construction in a real time. The choice of the best variant from a number of possible decisions is being represented as the optimization problem. The losses of the throughput and expenses may serve as the criteria for optimization.

The provision of rational modes of trains' traffic on a railway section is an important component of an operative management. On the one hand, the management should "construct" a chain of train-units to minimize conflicts between trains. This purpose is reached by transmitting commands to locomotives. These commands correspond to the developed dispatching plan. On the other hand, each train may be regarded as an independent unit and its movement should be optimal. Both degree of safety and power efficiency may be used here as criteria for a traffic optimality.

Cost-effective traffic management is the choice of adjusting actions that is aimed at providing the minimum economic losses caused by train delays. The optimization criterion is needed in order to solve the problem of searching the ways of effective process management. In this case the most efficient development of the process is expected. Economical indexes and reliability rate are usually used as criteria of the industrial processes flow and systems operating.

Fundamental criteria of the railway functioning quality are the following:

- operational safety;
- railway section capacity;
- economic effectiveness of handling trains along the section.

First of all, the capacity criterion is used in those sections which are characterized by the large volume of passenger and freight traffic. There are few possibilities for an operating cost saving under the heavy traffic.

The quality of movement of the passenger trains or group of trains is determined by the degree of correspondence of the real timetable (stations arrival and departure times) to the normative (scheduled) timetable. Assessment of passenger timetable is given by the train operating reliability index [17].

Punctuality as the requirement to the freight services movement recedes into the background. The main issue is prevention of unplanned stops, slowdowns of trains and therefore the loss of time and energy. The trains' trajectories on a railroad section can be chosen rather arbitrarily. This flexibility is particularly important in situations where you need to prevent future failure of movement or propagation of an already existing fault in the chain of trains. The optimization problem solution allows assigning such schedule to each train that will minimize the losses of time and energy on the entire packet of trains.

The following optimization criteria are appropriate for adjusting the timetable of freight traffic:

- best utilization of train operating productivity – ensuring maximum volume of freight and empty cars traffic;
- cost-effective operating in the period of weak traffic.

 ISBN: 978-1-61208-269-1

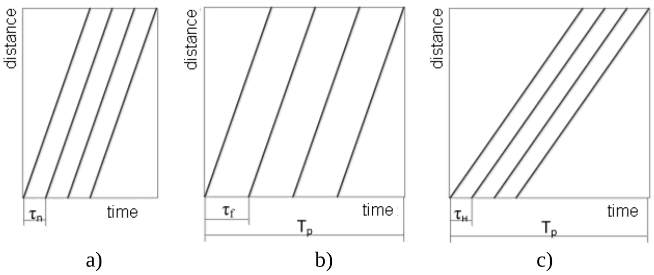

Figure 1. Schedule's fragments: a) normative; b) sparse timetable; c) enhanced travel times

The first criterion is used when traffic volume is approaching to the theoretical capacity of the railway as a limit. Cost minimization comes to the background during these periods. This operation mode of the railroad is called **extensive**.

Economical mode is established when the flow density of freight trains falls. During this period traffic controllers can use non-standard (decelerated) schedules for one or more trains which allow large energy savings. Variants of the train timing for the above mentioned section operations are shown on Figure 1. Regional traffic operator specifies one of these modes for every up-coming hour.

Regional traffic operator organizes and controls the functioning of extensive segment of trains' stream. Local dispatcher controls the efficient trains' movement. It is a basis for the collective management paradigm.

Best economic effect can be obtained using a rational combination of trains N^{ext} that represents an extensive segment and trains N^{econ} with economy movement. The train traffic separation into two segments can be viewed as a game problem the aim of which is to mitigate the conflict between the managers [18].

We suggest a new economic efficiency criterion, which is used to find a decision for trains' traffic regulation. It is helpful to use the increment of local profit ΔB as a criterion for assessing the quality of traffic controller's decisions who regulates the freight trains flow on the section [19]:

$$\Delta B = \Delta I - \Delta E \, ,$$

where ΔI is the change of an operator company's income because of the realized adjustment;

ΔE is the additional expenses for making the adjustment.

The optimal variant is chosen from the range of feasible decisions according to the maximum of efficiency function: $\Delta B \to max$.

The area of the solutions for the ratio choice of N^{ext} and N^{econ} in the flow of freight trains is shown on the Edgeworth-Bowley diagram (Figure 2). The diagram includes all possible combinations of the decisions in the game – i. e. shares of economical (N^{econ}) and fast (N^{ext}) freight trains in the aggregate flow. Coordinates (a_{10} , b_{10}) are valid for the strategy of the fast (extensive) segment.

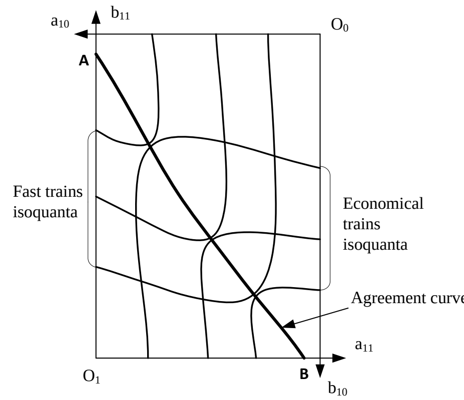

Figure 2. Edgeworth-Bowley diagram for the variants of the train traffic management strategy

The method of choosing a compromising decision which meets the condition of maximum corporation gain is given by Kolemaev [20]. It is shown that the optimal decisions according to Pareto principle are located on the contractual curve. This curve (*AB* line) is shown on the Edgeworth-Bowley diagram.

The choice of a decision lying on the *AB* is accompanied by severe competition between the parties. More mild interaction and cooperation between the players occur when the source point is chosen beyond this curve. The moving from this point along the line of equal output (isoquantum) provides way of increasing the second player gain without influence on the interests of the first player. Figure 2 shows the isoquanta which is corresponded with the game tactics of the each game participant.

We should note that this feature allows dispatchers to find the optimal decision without the players' participation. This means that the dispatchers elaborate compromising decision on defining the structure of the trains flow in the majority of typical situations.

The sizes of the extensive and economical segments obtained through the game analysis are used further as the local priorities of the second level when calculating the resultant vector of the optimizing problem.

V. MODEL OF THE FREIGHT TRAINS' MANAGEMENT

We formulate an optimization problem in which two agents control the trains' movement. The objective of one of them (regional traffic dispatcher - RD) is to maximize the line productivity, at the same time without taking the local section effectiveness into account. RD is given the authority to control the trains pool repositioning. Another one (section dispatcher - SD) has the possibility to improve the operations by the rational headways prescriptions and passing trains over a section. This means that trains can travel on less than maximum velocity to minimize fuel consumption. The suggested approach in comparison with the traditional dispatching approach is a potentially cost-effective technique for the control of trains' movement in a real environment.

Operation decisions on traffic management are often made under the conditions of shortage of information and time. In complicated and non-standard situations two or more dispatchers participate in the decision making. The majority of factors involved in the optimization task are defined indistinctly and there is a discrepancy in how different people evaluate their influence on the traffic.

Operation decisions on traffic management are often made under the conditions of shortage of information and time. In complicated and non-standard situations two or more dispatchers participate in the decision making. The majority of factors involved in the optimization task are defined indistinctly and there is a discrepancy in how different people evaluate their influence on the traffic.

The choice of priority resolution among a row of alternative variants given poorly formalized or insufficient information about the subject is made through employing the analytical hierarchy process (AHP by T. Saaty [12]). The basic framework is a benefit/cost analysis. The last mentioned is used as a priorities-determining method in relation to the operational constraints, specialties, actors and their preferences.

This paper presents an attempt to employ the AHP method in the problem of taking rational decisions on-line which are adopting in current conditions. The dispatcher who operates the freight trains traffic resolves several heterogeneous optimization tasks simultaneously. He has little time to think out each decision thoroughly. Therefore the algorithm of his dialogue with the computer system which prompts the variants of adjusting actions and evaluates their efficiency must be maximally simplified.

Analytical hierarchy process formulates a problem which should be decomposed into elements belonging to different hierarchical levels. Level I present the general goal (the choice of an optimal variant) and it is called the focus of the problem. Level II (the subgoal level) comprises the row of the scenarios which includes both extensive (fast) and economy segments of train movement. The lower level (the level of politics) – covers the variants of the resolutions which are compared with each other.

The hierarchy of the operating process of freight trains focuses either on volume of the traffic passed or on profits of shipping operations (Figure 3). The weights of the variants are defined on the basis of judgments of persons (or group of people) when using AHP method. They make a decision by the way of determination the mutual priorities of the elements of the hierarchy.

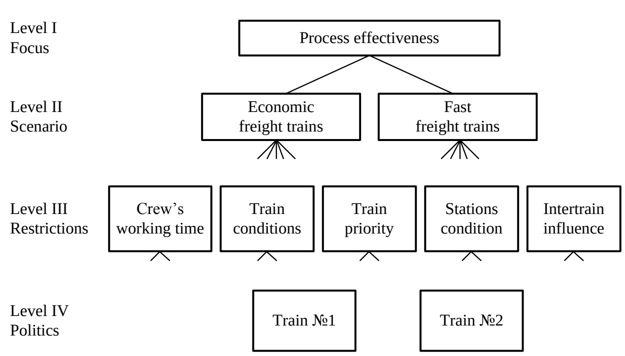

Figure 3. Hierarchy of the freight train traffic management

These people (experts) make use of their knowledge, experience and intuition to define the weights of the elements of the lower level with respect to the criteria of higher level. They employ the method of pair comparison which provides the numerical evaluations of the judgments.

The priority of each policy, i.e., choice of the decision variant, is determined through employing the procedure of synthesis of multiple judgments. This procedure is based on the weighing formula which gives relative weights Y_i of each variant:

$$Y_i = \sum_n \overline{x_{jk}} \cdot \overline{x_k} \ ,$$

where n – number of criteria;

$\overline{x_{ik}}$ - local priority of j policy (lower level);

$\overline{x_k}$ - local priority of k criterion (upper level).

Hierarchy analysis allows us to outline the ways of relieving of the internal conflict within the system. In order to achieve this, the degree of influence of each actor on the process is determined according to the AHP technique. The results of modeling and the outcomes of real situations are also compared. This helps to substantiate compromise resolutions of the problem.

When process deviates the standard condition there is a need of intervention of the dispatcher. These regulations may be an unplanned stopping of a freight train or its new scheduled departure from the station. It also may be a passing priority change of consecutive freight trains.

Selection of a specific train which would provide the best result is more complicated problem. It is reasonable to resolve this optimization problem with the help of modified hierarchy model.

The analysis shows that the hierarchy of the train traffic management coincides with the inverse AHP. Such process models the desirable future; this allows us to define the priorities of the policies – operations decisions which lead to the achievement of the desired resolution.

The type of criterion for the forthcoming period is set by the Chief (regional) dispatcher. This period may comprise 3 or 6 hours; in certain cases it may be diminished to 1 hour. The scenario of the train passing process (Level II) implies rational combination of freight trains which are let through at an accelerated pace and the trains of economic (standard, decelerated) movement. The schedule of the latter trains is established in the way to obtain maximum saving of electricity or fuel. It is obvious that the mode of economical passing is reasonable during the slump in the intensity of the traffic.

Revenues from shipping operations decrease due to little number of trains when the saving regime is employed. Nevertheless additional profit can be obtained at this period due to significant decrease in operational costs.

The trains, one of which requires such a regulation, are considered as the variants of decision (Level IV). Train dispatcher chooses the criterion for evaluation of the weight of each decision (Level III) in every specific situation. If the problem is connected with the need for stop at the station the

 ISBN: 978-1-61208-269-1

priority will be given to the train whose service is the most urgent. Dispatcher expresses his understanding through filling the table of pair comparison.

Standard AHP consider the structure of the hierarchy unchanged during the whole period of analysis. The number of criteria for each level of hierarchy is representative to cover all the variants of situations which can occur on the section. The size of pairwise matrix proves to be large which leads to substantial expenditures of experts' time and effort.

The suggested specialized model differs from the traditional model in the following way. The structure of the hierarchy is not fixed. It changes depending on the situation in the section under operation. These changes are caused by rapid and uncontrolled restrictions. The choice of the suitable criterion corresponding to a situation is made. Commercial priority may be of the most importance for one train and technical condition is suited to others. Dispatcher has the information about the restrictions which take place. Therefore it is reasonable to charge them with the selection of the type of problem (restriction) which is taken into consideration in each specific situation. The dispatcher makes the choice through entering the corresponding indication in the adviser-program. The chosen restriction is used then as a criterion for comparison of trains. This algorithm corresponds with the logic usually employed by dispatcher. The volume of man-computer interactions is minimal.

VI. EXAMPLE OF THE DISPATCHING HIERARCHY MODEL UTILIZATION

As an example of the modified AHP method, we show one of typical problems on decision-making on a overcome of an unplanned obstacle to movement of a stream of trains. The restriction makes the train dispatcher stop one of the freight trains at a station. Rational decision is to select the train whose stop will cause minimal losses.

The choice is made among three freight trains. Train 1 is a container train with low weight but an extremely large length (100 cars). Two other trains have small length; one of them is a heavy haul train (6,000 tones), the other is of medium weight. The restriction is the length of the tracks at the some stations. Station M is the only station where the length of the tracks allows stopping the long train.

Table 1 shows the source data used in decision making and the results of analysis for the situations with intensive and weak train traffic. The first rational decision (weak flow) is to stop the train №3; the opposite adjustment (intensive flow) is to stop the train №1.

TABLE I. SOURCE DATA AND RESULTS OF ANALYSIS FOR THE DECISION ABOUT AN UNPLANNED STOP OF THE FREIGHT TRAIN

Trains	**Commercial value**	**Length of train**	**Additional expenses for stop**	**Priority**	
				Intensive flow	***Weak flow***
№1	1.0	1.0	30	3	1
№2	0.5	0.7	100	2	3
№3	0.9	0.7	60	1	2

In the latter case the commercial interest to deliver containers in time will not be breached. Expenditures on passing the trains through will also be lower.

Real testing of the presented methodology was carrying out on the Transsiberian main rail line. It is shown the 10 percent reduction of unplanned freight trains stops and up to 8 percent energy economy.

CONCLUSIONS

We presented a new technique of realization of traffic control of freight trains' operative management which is based on economic basis. The criterion of economic efficiency to make optimum adjustments into trains' traffic was formulated.

We also offered game approach for selection of the compromise dispatching decision. It will be effective for the short time traffic planning. The hierarchy model and man-machine dialogue promote adoption of effective decisions and the subsequent fine adjustments.

The developed modification of AHP allows making a compromise decisions on regulation of a freight stream through dialogue between heads of control center. Dialogue is implemented rationally with attraction of computer abilities and hierarchy model.

The number of interactions of train dispatcher with the computerized "adviser" is minimized due to game approach. In ordinary cases dispatcher need to execute only two choice operations for each pair of trains: type of problem and local priority of trains.

Real testing of the economical supported dispatching on the Russian main rail lines show the 10 percent reduction of unplanned freight trains stops and great energy economy.

The reported study was partially supported by RFBR, research project № 12-08-98513-p_vostok_a.

REFERENCES

[1] A. D'Ariano, F. Corman, D. Pacciarelli, and M. Pranzo, Reordering and Local Rerouting Strategies to Manage Train Traffic in Real Time, Transportation Science, Vol. 42, No. 4, November 2008, pp. 405-419

[2] M. J. Dorfman and J. Medanic, Scheduling trains on a railway network using a discrete event model of railway traffic, Transportation Research, Part B, 2004, 38, pp. 81–98

[3] X. Delorme, Modelisation et resolution de problemes lies a lexploitation d'infrastructures ferroviaires, PhD thesis, University of Valenciennes et du Hainaut Cambresis, 2003

[4] V. A. Ivnitskiy and A. A. Poplavskiy, The problem of transition to the informational-managing regime in the system of the transportation process operational managment, Vestnik VNIIZhT, vol.1, 2007, pp. 15-21 (in russian).

[5] T. Richter, Systematic analysis of transit freight train Performance, / 4th Int. seminar on Railway Operations Modeling and Analysis, Book of abstracts, Rome, Feb. 2011, p. 35

[6] M. Carey, and I. Crawford, Scheduling trains on a network of busy complex stations, Transportation Research, Part B, 41 (2): 2007, pp.159–178

[7] B. D.Nikiforof, E. M.Tishkin, V. M.Makarov, and V. S.Klimanov, Trains' traffic management on the railway direction of transportation, Railway transport, vol.2, 1982, pp. 17-24 (in russian).

[8] V. A. Ivnitskiy, Speed outstanding risk of freight trains due to technical failures, Vestnik VNIIZhT, vol.1, 2012, pp.33-37 (in russian).

[9] O. Meixner, Fuzzy AHP Group Decision Analysis and its Application for the Evaluation of Energy Sources, Proceedings of the International Symposium on the Analytic Hierarchy Process, 2010, pp. 114-119.

[10] L. Mikhailov, Group prioritization in the AHP by fuzzy preference programming method, Computers & Operations Research, 31., 2004, pp. 293–301.

[11] G. S. Maltugueva and A.U. Yurin, The algorithm of collective choice on the basis of the generalized rankings for decision-making support,Modern technologies. System analysis. The simulation, vol.3, 2009, pp.57-62 (in russian).

[12] T. L. Saaty and L. Vargas, Models, Methods, Concepts and Applications of the Analytic Hierarchy Process, Kluwer, Boston, MA., 2000, 381 p.

[13] E. Forman and S. Gass, The analytic hierarchy process: an exposition, Operations Research, Vol. 49, 2001, pp. 469-486.

[14] E. Forman and K. Paniwati, Aggregating individual judgments and priorities with the analytical hierarchy process, European Journal of Operational Research, Vol. 108., 1998, pp. 165-169.

[15] A. Shahin and M. A. Mahbod, Prioritization of key performance indicators. An integration of analytical hierarchy process and goal setting, International Journal of Productivity and Performance Management, Vol. 56 No. 3, 2007, pp. 226-240.

[16] K. Suryadi, Empirical Experience on Combining AHP with Non-ANP Decision Models in Managing Cross Functional Conflict, Proceedings of the International Symposium on the Analytic Hierarchy Process, 2007. pp. 183-191.

[17] A. P. Kovalev, The timetable reliability and passenger trains speed volume estimation, Railway Transport, Russia, 2006, №5, pp. 42-45 (in russian).

[18] B. I. Davydov, V. I. Chebotarev, The gaming solving of the problem of trains' traffic dispatching, Transport Bulletin, Russia, 2007, №10, pp. 37-39 (in russian).

[19] B. I. Davydov, Economically effective trains traffic managment, Railway Economic, Russia, 2012, №3, pp. 28-37 (in russian).

[20] Mathematical methods and models of the operations research, ed. by V. Kolemaev, UNITI-DANA, Moscow, 2008, 350 p.