Automated traffic control system in railways

S. A. Branishtov, D. A. Tumchenok, A. M. Shirvanyan
Institute of Control Sciences, Russian Academy of Sciences
Moscow, Russia
artshirvanyan@mail.ru

Y.A. Vershinin
Coventry University
Coventry, UK
o292j@gmx.com

***Abstract* — the article deals with the problem of traffic control at a large railroad station. We offer the approach and solutions to automate several tasks of operational control at the station. Methods: We studied the problem of planning the shunting work, the design of daily process schedule of station, selection and assembling the routes. Results: The algorithmic solution for design of daily process schedule of the station was developed. Through this, the design process is user friendly and easy, as well as a decision on the handling of trains in complex situations and exceptions is flexible and efficient. Practical implications: Algorithmic solution and results of research were implemented in software for train dispatcher's workstation. This software makes the control work simple, reduces the human errors and improves the safety of control.**

Keywords — train control, decision-support system, daily schedule, routing, shunting work.

I. Introduction

Traffic management and ensuring security are always important and difficult tasks on the railroad. Every year we watch an increase in delivery orders and traffic, but infrastructure capabilities are retained without changes. The effective scheduling and traffic control strategy in real time play a key role to improve the quality of service on the railroad. Much attention is paid to the problem of designing schedules. Creating a schedule is a long process involving intensive discussions between stakeholders and based on the available railway resources. At the same time, almost no attention is paid to decision support system in the control of real-time traffic. Meanwhile, automated systems allow us to find the best solutions and make better use of rail infrastructure. The difficulty in creating such systems is to implement a large number of interdependent operations in real time, with frequent occurrence of deviations from the schedule, and a limited time for a decision. The organization of train movement at the station is a complex process, the result of which depends on the reliability of technical devices, qualification of employees and even random events of the environment.

II. Automation systems for train operations

In order to organize train movement and shunting work the daily schedule of the station is developed. It includes an arrival and departure of trains, routes, pushing work, loading, repair, etc. The schedule describes time and place of all moving trains through the station, as well as reservation of tracks. At present, the functions of traffic management, responsibility for the execution of the schedule and ensuring the security entrusted to train dispatcher [1].

The work of train dispatcher requires precision of independent control actions and the accuracy giving instructions to the staff, the maximum concentration and monitoring of all processes, in-depth analysis of the situation and the ability to predict its evolution. During periods of high traffic, it is required to have a fast decision-making.

In practice, 80% of all violations of traffic safety are happen due to train dispatcher's faults. There are cases when he acts wrong or does not act at all instead of the required control action. There are errors due to violation of perception, fatigue, forgetfulness, distraction, failure to perform the requested action because of severe confusion, torpor, fright; there is too fast or too slow action, failure to comply with the required sequence of actions [2].

Modern computer systems of traffic control became to replace old hardware facilities based on relays and logic controllers with hard logic. There are dispatching centers with automated work places for train dispatcher in some countries [3].

Union Pacific Railways Company (USA) implemented the remotely-controlled signal and interlocking system, automation switchyard system and centralized traffic control. Traffic control center has a high level of automatic. This system improves the average train speed, traffic safety, and productivity of staff [4].

The Canadian Transportation Management Center works since 1991. They use a big screen showing a map and detailed information on all trains that are on the railway network at the moment. The trains are marked in four different colors depending on the value of the deviation from the schedule; the trains carrying dangerous goods are marked specially. They can perform the simulation of schedule changing and train delays, which allows adjusting the schedule to make it more stable. Additionally, they use train operation planning system which helps to plan locomotive turnovers and assignment its to the trains. Dispatcher can watch the current status of trains, archive of previous events for the last 24 hours and the forecast operations up to 48 hours [5].

Before 1995 year, Japan used the traffic control system COMTRAC and information system SMIS [6] but its cannot cope with the loads of operations in emergency situations. In 1995, the JR EAST Company implemented a new information and control system COSMOS. Integrated system COSMOS consists of seven subsystems, including the traffic management, train maintenance and energy control. Train control subsystem performs the presentation of information about the location of trains and delays, the management of routes, and support in emergency. Based on the data of schedule performance, COSMOS system allows creating a forecast of train movement and calculates the time of arrival and departure [7].

The automated control center in Italy operates in two modes. The first is the hard mode programming; the system selects the train routes in strict accordance with the schedule. The second is consulting mode, in which the system proposes several solutions for each situation and dispatcher can select the any of them. The system displays the schedule of trains, calculated by the computer. Information module provides the following real-time data: location, speed and delay of trains; routes established for passes through the station; state of traffic lights, track switch, road crossing over. There are forecasting utilities, decision support and statistical analysis [8].

There are many information systems in Russia for management of railway process (for example GID UralVNIIZhT [10] Dispark, Discon et al.) based on analytical and forecasting models. Its helps for following problems [9]:

- forecasting, planning, monitoring, recording and analysis of the traffic;
- real-time control of train traffic and shunting work;
- assignment the locomotives, crews and carriages to the train;
- planning of repair and maintenance of technical resources and facilities.

Most of the automated systems are informative, that is its provide comprehensive information about situation on railway net, available infrastructure and transport resources, but have no intelligent functions for direct control – the decision making and control actions are executed by human in the same volume.

III. ROUTE MANAGEMENT PROBLEM

The problem of choosing a route for one train is based on that you should take into account the other following train in schedule and its routes. These routes can be variant by themselves. The chosen route should occupy the tracks of the station so as not to block the movement of other trains. During high traffic time the control is not easy, there may be situations where the occupation of the tracks is such that there is no available path for the other trains. In such a case it should be applied other ways to control the trains, such as: manipulation of departure time or entry time (in allowed limits), planning the shunting movements, change arriving platform (it is violation of the schedule), use of composite routes with the change of direction of run, and others. [11].

Effective route management requires to solve the following problems simultaneously: forecast the occupation track in time; check for compliance the type of train and specialization receive path; take into account the dependence of switches and signals, speed limits on sections and switches and allowed direction of run on tracks; provide security intervals between trains.

IV. SELECTION THE ROUTES

The large railroad stations are characterized by extensive net of tracks and usually there are several possible routes between two points of the station. A modern control signaling system offers only one (main) route to train dispatcher. System helps to check the route for the intersection with used routes and then it forms this route by setting the railroad switches and traffic signals. Moreover, train dispatcher can control the switches manually to create alternative route if it is necessary. Train dispatcher makes decision on the basis of the current situation and on his experience. As mentioned above, it is hard and responsible work, which is not protected from mistakes. To automate this process, the authors of this paper have developed the routing algorithms and implemented of its in the software. The following paper presents the peculiarities of traffic management at the train station, which had been studied and implemented in software.

To represent the size of track network, for example, we can show the feature of one examined large railway station. It has 108 parking tracks including the platforms (starting and destination points in the network), 14 outgoing tracks (same), 222 track switches (21 are double). The spread of track network is defined by a number of switches together with number of all possible routes. It was found about two thousand routes between two parking tracks only on opposite station sides. There 148 840 routes were found in the railway station. The exhaustive search is time-consuming at this amount. To avoid the exhaustive search, it is accepted to use the following principle to select the best route. Firstly, the desired route should not intersect with existing routes that was selected at previous steps. Secondly, we need to consider the effect from this train to subsequent train by the schedule. Then we have to take a route that will have the least number of intersections in all its parts with possible future routes during the life time of desired route. Thus, the found route will have the minimal chance for intersection with subsequent trains.

The algorithm is implemented as follows. At first step we are searching all alternative routes for the given train and calculating run time for each route, taking into account the velocity profile along the route (Δt_{dr}). We take the maximal time to see the impact of this train to all possible subsequent trains.

Let's find the run time. Let t – is the start time of the run. For departing trains, this time coincides with the departure time that is specified in the schedule t_{dep}. For arriving trains, it is the moment of entrance to railroad station area (control area). This moment can be found if take in mind the train must arrive at the platform not later than the scheduled time t_{arr}. Thus, the maximal run time is $[t, t+\Delta t_{dr}]$, where $t = t_{dep}$ - for departing trains, $t = (t_{arr} - \Delta t_{dr})$ - for arriving trains.

On the second step we discard those routes that intersect with already prepared routes for previous trains. The remaining routes get the weight coefficient of influence to subsequent trains. The weight coefficient is calculated as the sum of used elements of route by all trains in run time interval. We choose the route with minimal weight coefficient. For example, in the studied railway station we detected the time interval with 7 running trains simultaneously. You can see it in Table 1. These trains are marked within bold rectangles. Time scale are shown in Fig. 1. Route 252 is already set for the train 7116 in time interval [7:45; 7:53], and the train is running. At this step we are searching the route for train 6207. There are 23 alternate routes for train 6207, and we need to choose only one of them. Its maximal running time is 7 minutes (from 7:46 to 7:53). There are few trains 6809, 6610, 5552, 6703, 6611 that will begin the run during this interval. The best route for 6207 should not intersect with train 7116 route and it is to the least impact on other trains. What is more, it must be at least one unblocked route for each subsequent train.

TABLE I. TIME TABLE

Train №	Main way	Arrival time	Parking way	Departure station	Train turnover	Train №	Main way	Departure time	Parking way	Destination station
					from 6403	6004	IV	7:34	10	Pushkino
6607	I	7:37	13	Monino						
6205	III	7:38	11	Sergiev Pasad	to 6308					
					from 6007	6504	II	7:42	11	Bolshevo
7201	III	7:43	6	Fryazino						
6609	I	7:43	12	Aleksandrov	to 6006					
					from 7109	7116	IV	7:45	13	Sergiev Pasad
					from 6203	6610	II	7:48	14	Monino
7111	III	7:48	7	Pushkino	to 7118					
					from 7107	5552	IV	7:49	4	Fryazino
6609	I	7:49	15	Fryazevo						
6207	III	7:53	8	Sergiev Pasad	to 6210					
6809	I	7:55	14	Monino	to 6818					
					from 6009	6006	II	7:58	12	Fryazevo
6703	III	7:58	10	Bolshevo	to 6706					
					from 6711	7118	IV	8:00	15	Aleksandrov
6611	I	8:00	13	Sofrino						
7113	III	8:03	11	Fryazion	to 7120					
					from 6807	6208	IV	8:05	7	Sergiev Pasad
6011	I	8:06	12	Sergiev Pasad	to 6008					
					from 6205	6308	II	8:06	11	Sofrino

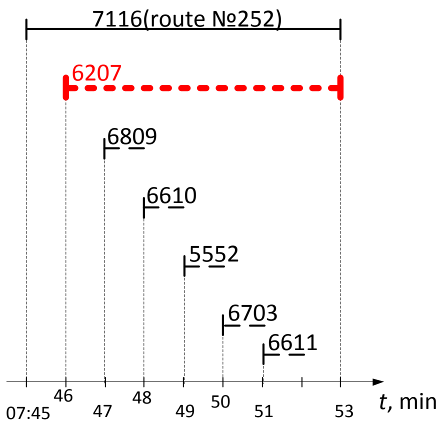

Fig. 1. Train diagram

This approach, when we take a route with the least influence on the other trains, it can guarantee a route for each train in highload station. It is provided under the condition that the schedule meets the service capabilities of the station infrastructure.

V. TIME MANIPULATION

Train schedule is the main regulatory and guiding document for all service work and train traffic control. It defines the technology of use railroad and transport infrastructure, integrates and organizes the work of all railroad departments and branches in a jointed transport system [12].

Schedule execution is the priority requirement for train dispatcher activity. Exact execution of schedule is quite difficult work, especially when abnormal or emergency situation is happened. At these moments, capabilities of the station infrastructure and available routes may be greatly limited. However, if we assume a slight shift of traveling time for some train, it will greatly simplify the problem of searching free route and will resolve a difficult situation. In accordance with the requirements [13] the delay of train arrival (or departure) for 5 minutes is not a flagrant violation of the schedule. This assumption may be used in route management algorithm as described below.

Firstly, we should consider all variants routes. Then, if we cannot find a free route then we are testing the ability to manipulate of travelling time of one or few trains in station area or at inlet. Thus, we calculate the delay of one train that allows to resolve the problem and to find the free route. If the delay value exceeds the allowable limit (defined by an expert) then you need to make a time correction of the next train schedules. If this value exceeds the allowable limit, we need to make a correction of travel time for nearest trains in schedule. The following parameters affect on the final decision: maximal delay, total amount of corrections and the number of trains that have been changed.

If this way is not leads to success then there are other ways to resolve difficult situations, such as: we can set different arrival track or set compose route through the intermediate parking place. In each case, we propose several solutions; the responsible person chooses the best of them.

VI. Shunting works planning

Train dispatcher must plan in advance all processes at station (train operation, shunting work, loading operations, maintenance etc.) to avoid possible difficult or emergency situations. In most cases, he can anticipate all operations the day-ahead and write it in the daily schedule of the station. But sometime the day with intensive activity at station is happened, when he has to make new decisions in real time quickly and accurately. Train dispatcher must seek all available resources: locomotives, infrastructure, staff, time, facilities and other to guarantee the schedule.

For example, train departs at time t_{dep}. In accordance with requirements of technological process, the train must arrive at a platform for passenger boarding in advance for t_m minutes (for long-distance trains – 40 min, for commuter trains – 25 min). Thus, the time interval during which the shunting work may be performed is $[t_{rel}; t_{dep} - t_m]$, where t_{rel} – time when the preceding train leaves this platform.

Available shunting run range for the trains departing to the parking or depot is $[t_{arr} + t_n; t_{next}]$, where t_{arr} – arrival time to the platform; t_n – time required to unload passengers cars and service; t_{next} – arrival time of the next train to this platform.

The complexity of the decision making here arises when you want to set priorities and determine the order of operations. Some shunting operation must be performed in the nearest time, while others operations may be delayed and be moved to free time window in a future. But it is necessary to consider how these actions will affect the tasks in these windows. In addition, the algorithms for automatic scheduling of train operation and shunting work must take into account the following parameters:

- Available execution window for train operation;
- Operation priority (guided by schedule);
- Resource efficiency;
- Current situation at the station (plan the shunting work in low traffic time).

It is necessary to pay attention to the dependence of the railroad switches, because some of its affect each other. Active route sets used switches to ON position and dependent switches in free tracks will be set in OFF position, so it is impossible to use these tracks for other routes. When the software calculates the train route, in most cases it provides one free section between trains and security time interval. The route may be built both from start to destination point (parking track, exit track) and from start to intermediate point (shunting or routing stoplight).

Stop time period of passenger trains can be reduced to compensate the lag in the schedule. The software has a function for pass-through station type and for combined station type which allows to reduce the stop time period for trains when it is late. Here it is important to consider the sequence and type of trains on tracks to the next station. Train type determines the velocity and priority. The function can increase the stop time for some trains to skip forward high-speed train.

VII. Assistance in emergency case

Software interface presents detail information about all trains at every track in station area, moreover, it show the traffic lights status and switch states. It manages the train operation and shunting work in accordance with the schedule. New events, delays, any changes in a schedule require making new decision in real time. System calculates the optimal route for each train in advance and offers it to confirm by train dispatcher. Then system gives commands to the control hardware. Train dispatcher has possibility to set a route manually. Moreover, system estimates a new arrival time and uploading-downloading operation, shunting work and other until it coincide with the schedule. Thus, the train operation is performed automatically, it is reduces the manual work of dispatcher. In rescheduling mode the system takes into account the priorities and categories of trains, selects an optimal routes and predicts situation evolution.

The following cases was simulated:

- switch, traffic light, track malfunction;
- train stop in yard neck at 10, 30, 60 min;
- break the power supply for electric trains;
- long-distance train delays at 20, 40, 90 min in different time periods during the day;
- commuter train delays at 10, 20 min in rush hour.

Rescheduling process is always carried out in a reasonable time and no more than 55 seconds.

VIII. Journals

In addition to the management work, train dispatcher has a duty to provide documentation, such as journal of traffic control, journal of control messages, journal of train telephone messages, journal of switch inspection etc. In Russian Federation, he is guided by the "The instruction on train movement and shunting work for Russian railways" [11]. Train dispatcher makes a record about all arriving, departing and passing trains. Then, this data is transmitted to neighbor stations. To simplify the dispatcher’s work and improve his effectiveness, we have developed a function in software that fills the journal of trains in accordance with real time events. This journal can be exported to Excel or Word document.

Log action journal was developed for quality control. When dispatcher does not confirm the proposed automated solution, he can set an alternative route, and his decision will be recorded in the log.

IX. Conclusion

Automated decision support system for train management and shunting work will significantly reduce the burden and improve safety management in routine and emergency situations. It is very useful in following: analysis of station layout with the aim of available routes search when the infrastructure is limited (malfunctions); automate the process of route setting; real time control of schedule implementation and compliance; rescheduling train and shunting work for the upcoming events in order to minimize the train delay in the case of traffic disruption.

Train management software has following features:

- Interface for design station layout. This interface allows to create station layout from library interactive elements: track sections, the parking tracks (receiving and departure tracks, deadlocks), shunting and routing stoplights, switches, etc.;

- A module for calculating the daily schedule station. Input data: station layout and train schedules. The module automatically builds the routes to satisfy the security requirements (disjoint intervals of routes, velocity) and accuracy of schedules execution based on the input data.

- Module for the dynamic change the routes and schedule. Train dispatcher can perform the changing at any given time to fix the schedule violation or to resolve complex or emergency problem. Note, the schedule-calculating algorithm allows to make analysis of the quality of schedule and effectiveness of infrastructure resources using.

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