Automation of Business Processes of the Trains Movement Control on Moscow Underground

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Abstract. Constant traffic growth requires higher levels of safety and traffic management. Passenger transport control covers many business processes that can be split into several groups: planning, supervision, control, analysis, paperflow management, workforce management. The paper deals with modeling and automation analysis of the Moscow metro traffic, which covers 56% of passenger throughput in one of the world's largest cities.

Keywords: computational modeling, control systems, process control, traffic control.

1 Introduction

Constant traffic growth demands for higher levels of safety and traffic management quality. The unified automated information control system of planning and management of transportation process (AICS TP) copes with the challenge. The system forms unified information space and uses modern processing know-how. The paper contains authors' experience in modeling and automation of Moscow metro business processes.

2 Background

Moscow metro covers 56% of passenger throughput in one of the world's largest cities. Traffic management is carried out by the Dispatch Service (DS). In the eighties of the last century there were attempts to create automated planning tools for traffic management purposes [1,2,3]. The appropriate mathematical methods and software were developed. Unfortunately they were not implemented due to the lack of suitable hardware and interface. However experience gained in the course of the studies was used in the further research.

Until 1998 the DS implemented both in-house (developed by employees of the information-computing center of the Moscow underground) and outsourced automated systems. These were systems for the remote management of objects on the metro lines and means for information visualization.

In 1998 Moscow government supported the start of the metro traffic complex automation. The initial target was to automate DS operating staff training process. Training consists of games that test the ability to manage traffic in case of failure and to mitigate any failure effect according to existing job descriptions.

Until that time training games were carried out as follows. The coach and the learner took part in a training game. Everyone had the same sheet of planned schedule. The coach specified situations and violations, simulated messages from workers lines, accepted commands from the learner, wrote all information incoming and outgoing from him on the sheet of planned schedule and drew current position of trains in real time. The learner took simulated messages and responded to them, giving a voice command, wrote accepted messages and commands specifying the time on his sheet of planned schedule and also drew current position of trains. According to the results of the game, the coach estimated the actions of the learner due to its completeness and timeliness of management.

In 2000 the task was set to automate train movement planning. Until then trains were scheduled manually. At the same time as a result of gained data and analysis, the goal was set to automate passenger trains control process. These related tasks can be efficiently solved within the single AICS TP.

3 Task

First of all we defined a set of system users and their tasks [4]. The users of the AICS are Moscow metro Dispatch Service employees. To define the tasks and solution scenarios we identified traffic planning and control business processes using two approaches [5]:

- “the inside attitude”, based on the institutional regulatory papers and interview both with DS employees and IT personnel and top management;
- “the outside attitude”, based on the entity strategic goal set by parties concerned (federal and municipal authorities, passengers) - to satisfy existing transportation needs.

We were looking to establish a set of processes for the unit that directly exercises control over transport movement. Each business process corresponds to a set of separate functions. Normally these functions are executed by the unit as a whole. Table 1contains this information.

Fig. 1 shows upper level hierarchy of the planning and control related business processes. Process identification allowed us to single out AICS TP main components, which will be responsible for process automation:

Table 1. Business Processes List of Organisational Unit Transport Company Directly Exercising Control over Passenger Transport Movement

Business process	Detailed description
Planning processes	• drafting the schedule of passenger vehicles (hereinafter, the schedule); • planning adjusted to the schedule technical maintenance works of the transport company,; • planning technical means to reinforce schedule (scheduled and operative, in case of deviations from planned).
The processes of operative management	• reinforcing the schedule; • providing traffic safety; • assuring movement control when there are deviations from the schedule; • adopting operational measures to restore the traffic on schedule in the shortest possible time; • adopting operational measures to ensure passenger transportation in case of considerable passenger traffic increase; • using to the utmost existing infrastructure to provide for the specified amount of traffic.
Control processes	Control over the work of other departments
The analysis processes	• analyzing the schedule; • estimating actions of employees, connected with movement of vehicles; • calculating technical and economic indices of the operational work of the entity.
Provision of information resources	• providing information on the schedule; • registering schedule deviations; • providing information on schedule deviations; • exchanging operational information with other units' employees.
The processes of organization of activities of all personnel involved in the management of traffic	• providing human resources; • improving professional skills and personnel training; • providing labor protection items; • carrying out measures on civil defense plan.
Support processes	Other functions determined by internal documentation of the company and instructions of the company management.

- the automated system of the planned schedule construction;
- simulator of a train dispatcher;
- the automated system of operative dispatch management;
- automated system of the objects on the subway lines remote management;
- means to visualize objects status and current trains position information.

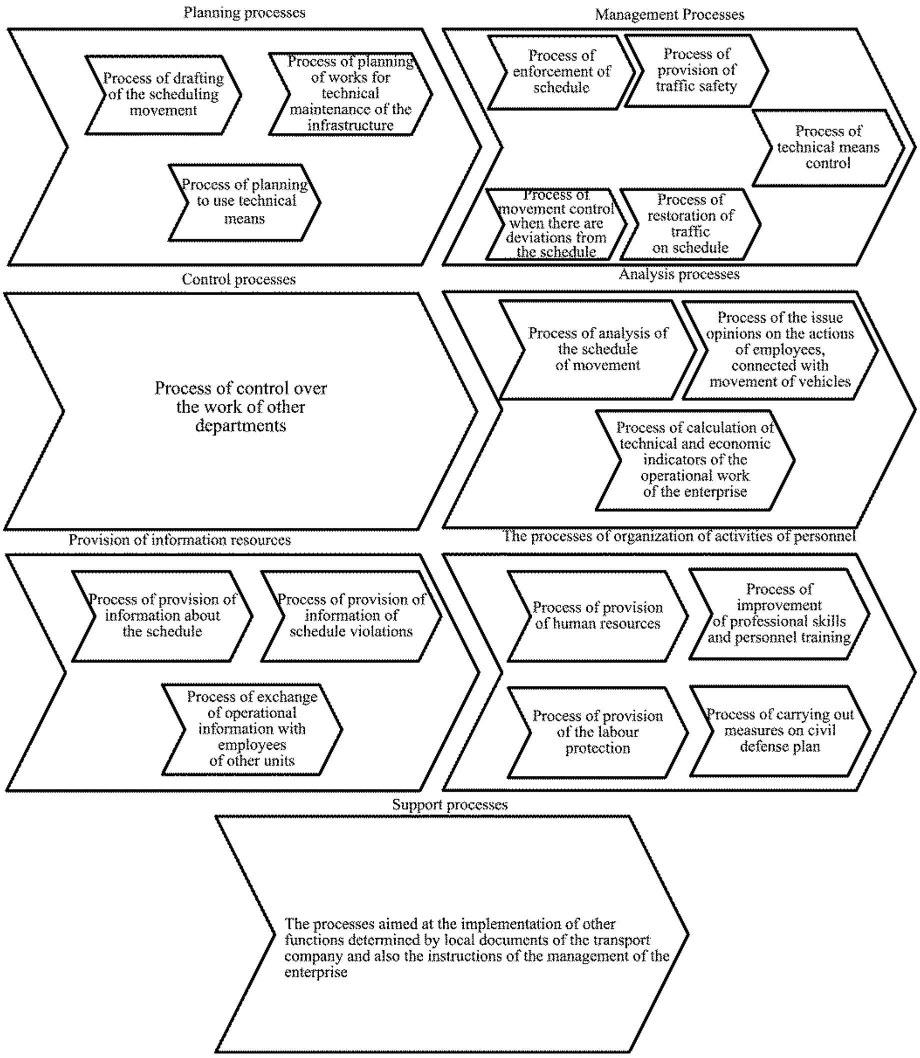

Fig. 1. Model of top level business processes

4 Approach

4.1 Multifunctional Model of Subway Line

One of the main components of the AICS software is the multifunctional model of subway line developed with the participation of the authors [6]. It makes good sense to check the operation of automated train control tools using underground line model. The underground line model is core of the simulator. It allows to simulate the movement of the whole set of trains moving on the subway lines, the operation of the major subsystems of the line associated with the movement of trains, the external environment and the reactions of workers and technical means for control commands of train dispatcher. The simulator implements the most detailed models of train control, control system of turnouts and signals, systems of the interval regulation of the traffic and passenger traffic level.

The model includes the following main components:

- the line model;
- train traffic control model;
- trains model;
- energy supply systems model;
- turnouts and signals control system model;
- traffic interval regulation model;
- passenger traffic model;
- tasks management model;
- results evaluation model;
- simulation results visualization model.

Separate technical facilities models include:

- algorithm of the proper object functioning;
- description of failures which may arise during the object operation;
- description of the failures' impact on the state of the object.

This provides the modeling of standard and non-standard technological situations. Depending on the purposes for which multifunctional model is used, the level of detail and construction type of individual model can be customized.

4.2 Business Processes Modeling

Next we constructed solving tasks scenarios with detailed automated business processes. As an example of the detailed top level business process we will look at the technical means control process. This process is employed primarily to maximize the use of existing infrastructure to support the specified traffic level.

This is one of the main activities for managing the movement of passenger vehicles. Fig. 2 presents the model of such business process constructed with regard to the underground Dispatch Service. DS employees as well as employees of other services directly managing technical means (persons on duty of centralization posts, stations, depot, train drivers) who report operationally to train dispatcher, are users of this process.

Let us consider how the actions performed by the Dispatcher-centralizer in the process of operation of turnouts and signals with automated working places (AWP) affect the operation of technical means. As a rule, dispatcher-centralizer implements process control with the set of relays, turnouts or signals. The management process of control of individual relays, turnouts, signals is implemented within the control process of set of relays, turnouts or signals, or, in case of deviations from the schedule of movement, functional disorders of technical means, diagnosing their functioning.

The basic process of control of set of relays, turnouts or signals is the route of route-relay interlocking (hereinafter, the route) management process. The route is called the pre-prepared way with turnouts, translated and secured in the correct position for the intended train movement or shunting composition [7]. In this paper we present two possible formalization of description of route management process.

The route has multiple states, in each of which some actions are performed. The transition from one state to another is carried out under certain conditions. Formaliza-

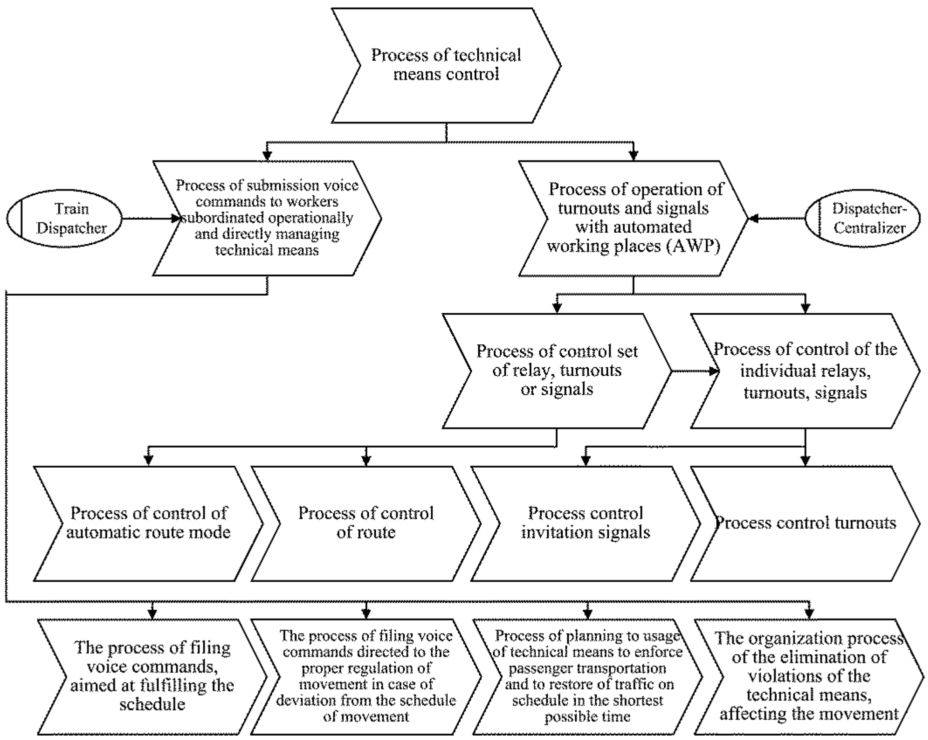

Fig. 2. Model of process of control of the technical means, affecting the movement

tion of description of the functioning of such systems is done conveniently using Petri nets [7]. The transition of a route from one state to another can take some time. This time is a random value that depends on the initial state of the turnouts, signals and other objects on the line. In this case Petri nets are temporary stochastic networks.

Then each state corresponds to the place of Petri network. Each transition of a system from one state to another corresponds to the Petri net transition, which is the fulfillment of certain conditions. Also the advantage of this formalization is a marking that uniquely identifies the network status. The vertices of the graph are divided into two sets and connected so that each arc is directed away from the element of one set to the element of another set. This allows us to clearly describe the features of functioning of routes. Fig. 3 shows a network in which places correspond to route states:

p_0^m – the route is inactive;

p_1^m – the route is specified;

p_2^m –route is assembled – turnouts were translated to the correct position;

p_3^m – the route is preliminarily locked – section before the route is free and indication of the route is turned on;

p_4^m – the route is finally locked – section before the route is busy;

p_5^m – artificial route cutting.

Fig. 4 presents the formalization of the same process, carried out using the EPC notation used to describe business processes.

The choice of the particular description form depends on the purpose for which this description is used. If the primary object is technical means and, for example, the task of modelling of its functioning is solved, then the first form is more convenient. Using Petri nets approach for modelling the process of route control presented in this paper, has shown its effectiveness when functioning of various modifications routes and their associations (automatic route mode) needs to be taken into account. One of the goals for constructing train dispatcher simulator is to train infrastructure control process. Therefore these questions were specifically addressed when train dispatcher simulator was created. At the same time Petri net proved its effectiveness in the model of train traffic control [8].

If processes are being depicted in employees' job description or for training purposes (shaping learning scenarios), the second form is more convenient.

4.2 Using Uniformity Principle

AICS software automates scheduling and subway trains control. Regularity of the intervals of motion is one of the key principles to be implemented for the purpose of these tasks. It's essential from the point of view of quality of passenger services. If number of trains on the line is unchanged then all traffic intervals should be equal. When the number of trains on the line is changed in accordance with passenger traffic

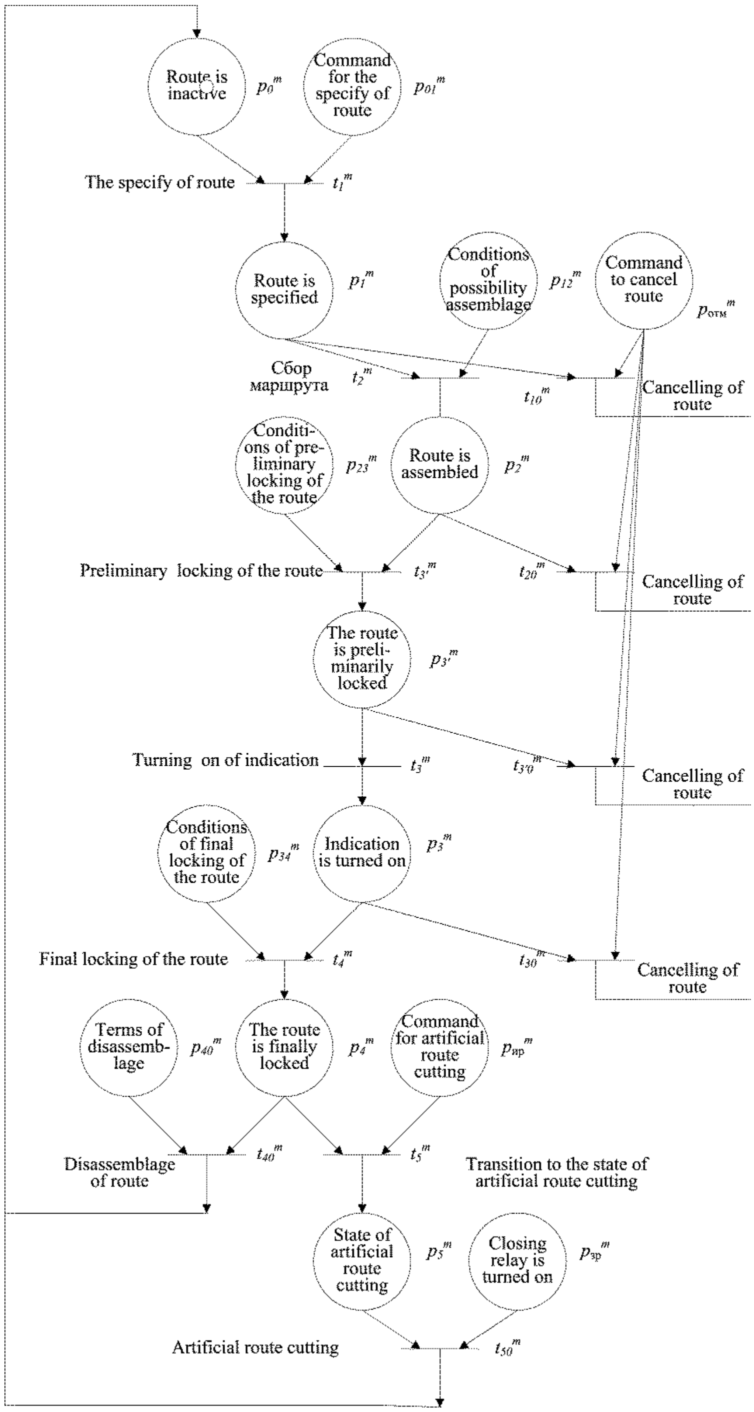

Fig. 3. Network of functioning of route

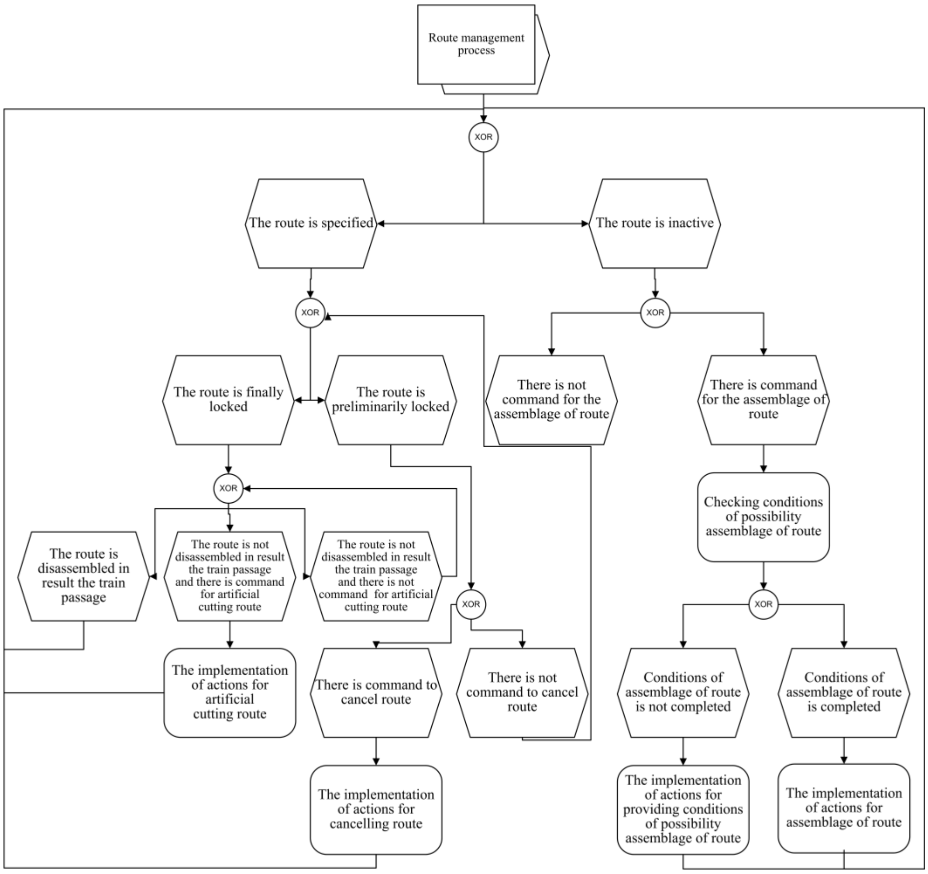

Fig. 4. Model of route management process

fluctuations, traffic intervals are not equal. Irregular intervals cause inconvenience for passengers. The degree of discomfort is estimated duration of the transition process alignment intervals. The decline of such discomfort can be achieved by a uniform entry/removal of trains. It provides the minimum duration of the transition process for subsequent alignment intervals [9].

5 Transformation Results

Let us consider results of AICS TP components and others automation tools implementation, developed by the Department of "Management and information Security" of the Moscow State University of Railways Engineering (MIIT) and for many years used in the Moscow metro.

The simulator train dispatcher [10] is intended to automate personnel functions training process, which include the processes of operational management, control and analysis. The means of entering commands to control technical means and visualization of the results of functioning of the simulator replicate the facilities represented on the true-life Moscow metro lines. The simulator train dispatcher operates successfully since 2000. In 2004, the development of train dispatchers training and knowledge control automated system has started. This system is designed not only to equip the operating DS personnel with practical skills of train control, but also to receive and verify theoretical knowledge (for technical studies). Technical studies are aimed at the assessment of theoretical knowledge, they provide for knowledge periodic update in accordance with employees' job descriptions with subsequent verification of this knowledge. The system implements two technologies of training and knowledge control: theoretical classes by testing the learner on the chosen topic of normative-technical documentation, and conducting training games.

The planned schedule construction automated system is used for automation of planning traffic processes, providing information about the timetable, calculation of technical and economic indicators of the operational work of the company [9]. In the framework of the system the following procedures are implemented: step-by-step automated construction of planned schedule of passenger trains (PS PT), automated correction of PS PT, check PS PT for compliance with the initial requirements, display and print of the system functioning results in the agreed with the Moscow metro format. Implementing a recursive step-by-step procedure for automated construction of PS PT we get a wide set of variants. Selecting a schedule from this set is a multi-criteria task. Recursive multilevel nature of the construction procedure and wide possibilities of variation of control actions determine the existence of a large number of options for building PS PT (over a million). The analysis of the results showed that the portion of successfully implemented options is about 1% of the number examined. While choosing appropriate variant it is possible to improve the value of the selected quality criterion without deterioration of values in comparison with planned schedule, which was built by qualified specialists. The system has been successfully used since 2004. The effect of the introduction of this system is very much evident: group planning the movement of passenger trains successfully copes with scheduling of movement for constantly developing subway lines without changing the numerical composition of the group.

The automated system of operative dispatch management can be used for automation of management processes movement in case of deviation from the planned schedule, restoration movement on planned schedule, calculation of technical and economic indicators of the operational work of the company, performance analysis of the planned schedule and information on schedule deviations [11]. On the basis of data from the metro line, the system analyzes the current situation on line, specifies the deviation type from a given list, selects the operational management algorithm for the metro line from the algorithms' set for data processing and decision, and makes decision how to further operate the metro line, in case of failure and need to restore the traffic on the planned schedule after failure eliminated.

Multifunctional model of subway line can be also applied for other business processes (technological processes) modeling tools in the Moscow metro, such as:

- optimal energy consumption calculation automated system is used to automate the process of technical means planning [12];
- electricity system calculation complex program for rolling stock with recuperation [13] is also used to automate the process of technical means planning.

Presented in the case-study paper the automated systems are applied to the conditions of all lines of the Moscow metro, use a common database and include subsystems for data conversion, which allow to organize automatic information exchange. All applied systems are constantly updated to reflect the new demands of the Moscow metro caused by its development and growing requirements for quality and volume of services.

Comprehensive approach to the modelling of business-processes allows to automate many processes of movement control with minimal labor and financial costs while making maximum use of existing data and knowledge databases.

6 Reflection

Developed in the beginning of XXI century software and purchased at the same time hardware are outdated morally and physically and require reengineering based on accumulated experience.

High rates of development of the Moscow metro urge to automate the process of creating and editing model elements, determine the relationships between objects, develop graphical forms display, write games scenarios. This enables to speculate on the need to create automated model designing system or specialized CASE-tools.

Within automated planning and trains movement management, the choice of the control decisions sequence is performed using recursive procedures. This approach helps to obtain a wide set of variants of planned and operative schedules. The formation of this set and selection of a rational solution can be speeded up with the use of parallel programming methods. These challenges and radical changes in system software require the development of new application software in modern programming environments.

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