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DEVELOPMENT OF MODELS AND IMPROVEMENT OF METHODS FOR FORMALIZATION OF DESIGN PROBLEMS AND AUTOMATING TECHNICAL AND OPERATIONAL WORKS OF RAILWAY STATIONS

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The object of research is the processes of automation of the technical and operational assessment of railway stations (RWS).

Research solves the problem of developing models, methods and information technologies to automate the process of technical and operational assessment of the work of RWS.

As a result of the study, the following results were obtained: Analysis of scientific papers on the problem of automating the work of RWS. Development of new method and mathematical models to automate the task. Development of new descriptions for the technological processes (TechP) of the RWS based on visual programming methods. Development of simulation models for the automation of railway infrastructure management task.

The UML diagrams of state and activity have been adapted in order to represent the RWS operation technology. When formalizing the description of the RWS, the state diagrams are submitted taking into account the specifics of the description of the change in the phases of servicing objects in the process of TechP of individual objects maintenance.

It is shown that the state diagram for the RWS is a state machine (SM) that models the sequence of changing the states of an object. The detalization of the behavior of objects serviced at the RWS has been completed. Detalization is performed using diagrams of activity. The diagrams of activity are used to formally describe the technical support with objects and executors of work on the railway.

The scientific results obtained in the article, as well as new and improved models and methods, can be used in the development, improvement and formalization of the TechP of the RWS, research methods for informatization and automation objects on the railways of the Republic of Kazakhstan

Keywords: design automation, railway station, technical and operational assessment, technological processes, automated control system

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1. Introduction

The planning of technical support, an automated control system (ACS), the development of technologies for the operation of objects of the corresponding subject area (SbAr) are usually based on modeling methods. At the same time, design engineers need to have a holistic, systematic understanding of the models that describe the object of research. In turn, these models should reflect all aspects of the operation of future technical systems. By the models of the corresponding SbAr (and, in particular, railway stations, hereinafter referred to as RWS), let's mean a system that is capable of simulating the structure or main aspects of the operation of the research object. Assessment aspects of SbAr modeling are associated with determining the effectiveness of the implementation of automated processes at the object [1, 2].

It is advisable to create modern graphic models using specialized software on a computer.

Reproduction of existing production processes in the form of simple diagrams and brief descriptions helps to achieve a common understanding of the current norms and operational procedures between the executor and the customer of the RWS development projects.

Analysis of scientific works devoted to the problem of technical and operational assessment (TOA) of the work of RWS showed that today they mainly consider the issue of developing effective functional models based on the widespread use of computers ECM. At the same time, the issues of identifying these models, their parameterization, determining the conditions for conducting simulation experiments not enough attention is paid in specially oriented programming environments. Errors in the identification of station models and incorrectly chosen modeling conditions can significantly distort their technical and operational assessment. In this regard, these issues require additional research. Carrying out such studies entails the need to analyze the potential of using the UML language to formalize TechP of RWS, and creates conditions for increasing the efficiency of the work of technologists.

This circumstance, which presupposes the development of new and development of existing models and methods for constructing an automated system (AS) for the TOA of the RWS, which is an actual topic.

2. Literature review and problem statement

RWS are multi-phase, multi-channel queuing systems. The assessment of their technical and technological indicators is a complex task and is usually performed using analytical, graphical and simulation modeling. The experience of the practical use of the above models showed high efficiency, at the same time, the shortcomings of the model were also identified, associated with significant time spent on describing the technology of the RWS [3].

In the course of scientific research, to assess the technical and operational performance of RWS, the method of simulating their functioning on a computer began to be used. Until now, such models find their practical implementation in the form of various software systems that allow to simulate long periods of operation of RWS.

The disadvantages of this approach are related to the fact that the performance of RWS significantly depends on the order in which the rolling stock is processed. The choice of this sequence is carried out by the operational and dispatching personnel. The solution of the problems of automatic modeling of the functioning of RWS and, in particular, the solution of the problem of automatic control of their work, has not yet been solved. It is necessary to change the paradigm of automated traffic management; this determines changing the paradigm in railway operation management [4].

For the study, a characteristic feature was the accumulation of materials on the problem of developing transport CAD. The works were dominated by methodical works in the context of the development of mathematical methods, which formally described the structure of the development of RWS. Combinatorial, topological, matrix, graph models were used, which displayed essential features. The researchers emphasized the importance of a correct graphical representation of the technical equipment of RWS. All this together made it possible to formulate a number of canonical requirements that are usually imposed on mathematical analogues of real schemes of RWS. The proposed distributed cooperative control method [5] requires no information of the system parameters and adjusts the control parameters adaptively online.

A formal representation of the technology of operation of RWS, with the possibility of taking into account various options for its implementation, is provided by finite automata and Petri nets. These models represent the TechP in the form of discrete transitions between states [6].

To take into account the human impact on RWS operation is suggested to use ergatic models [7]. In conformity with concept of RWS ergatic models a person is directly involved into the simulation process and manages the station technological processes.

In the following model [8], the place is intended as block similar to railway and to show that block is busy by train, it is used the arc to each place. The supervisory control is designed to supervise train input and output to yards and stations, safety and non-blocking requirements in such a way that not only proposed railway network is not blocked but also safety is guaranteed.

However, they determine only the order of the technical inspection. For such an application as RWS, performing a technical inspection and linking them together in the form of finite state machines or Petri nets will require the synthesis of specialized software [9].

Functional models of RWS, together with the infrastructure management model of railway stations, can be used to analyze changes in the structures, technical equipment and technologies of RWS. And besides, these models can be used to assess the compliance of the technical and technological equipment of RWS with both existing and prospective volumes of work at the station [10].

The analysis of the conducted research and modern publications on the subject of the article showed that the trend of scientific research related to the computerization of TechP in railway transport and the procedures for making operational decisions in the tasks of technical and operational assessment of the work of RWS has become generally recognized in the world today.

The creation of new models of computerization of the processes of technical and operational assessment of the work of RWS, methods and hardware – oriented algorithms for the intellectualization of these processes, provides for scientific research in the field of organizing modern information technologies for the synthesis of automated systems for technical and operational evaluation of the work of RWS.

It can be concluded that a significant increase in the efficiency of using modern computer technologies is possible only by studying the general properties of mathematical modeling, methods for constructing intelligent systems, algorithms used in control tasks, features of modern and promising intelligent technologies for railway transport, as well as architectural features of automation systems for technical and operational assessment of the work of RWS.

In the scientific papers, insufficient attention is paid to the identification of these models and their parameterization. Errors in the identification of station models can significantly distort their technical and operational estimates. In this regard, these issues require additional research.

3. The aim and objectives of the study

The aim of the study is to develop models and methods for automating the process of technical and operational assessment of RWS.

To achieve this aim, the following objectives are accomplished:

– to improve of the method for formalizing the description of the TechP of the RWS based on the methods of visual programming;

– to develop of a methods for constructing RWS models as hierarchical finite state machines.

4. Materials and methods

4. 1. Creation of a model of the technological process of the railway station operation using unified modeling language

The Unified Modeling Language (UML) is a standard tool that allows to create diagrams of software and business processes. UML can be used to implement such operations as visualization, specification, construction and documentation of software system artifacts. The constructive use of the UML is based on general principles used in modeling of complex objects and systems. And besides, using the UML, it is possible to take into account many of the features of the processes of object – oriented analysis and planning of such systems and objects. The use of UML will allow solving the problems associated with documenting the system architecture, taking into account important details of technological processes (TechP) at the RWS. The UML toolkit offers its own language for formulating instructions for the RWS systems and provides tools for modeling of work during the planning and versioning phase of the RWS project.

The organizational structure of the RWS is a set of links (employees, structural division) and connections between them. A common method for representing the structure of the RWS is an organizational chart.

The initial stage of planning is the synthesis of a use case diagram (hereinafter UCD).

UCD in UML is used to graphically describe the general features of the actions of objects and systems. However, at this stage, the modeling does not consider its internal structure. For example, UCD can be useful for describing the reception of a train at the RWS, obtaining information about the clients' solvency for a freight RWS, displaying data on the arrival of a train on information boards of the station, etc [11].

As previously shown in works, the creation of UML of UCD for the RWS systems is necessary for:

– (at the initial stages of the RWS planning) defining the general boundaries and a context of a specific project (taking into account its features);

– (at the initial stages of the RWS planning) the formulation of general instructions for the algorithms of actions at specific RWS, depending on its features – freight, passenger, etc.;

– creation of the initial conceptual model of the RWS. At the subsequent stages, detalization is required in the form of logical, physical and software models;

– preparation of initial design documentation for the interaction of the RWS designers with its customers and executors of specific types of work.

Modeling the graphical representation of the TechP at the RWS by means of the UML visual language is achieved by creating diagrams of state (hereinafter DIS) and activities of various degrees of detalization.

In order to achieve a clear understanding of the TechP at the RWS, it is necessary to highlight its main components: objects requiring the actions of the executor; set of works; persons performing work.

A certain number of operations (works) provided for by the TechP are performed by each object at the RWS, and the execution of technological operations (hereinafter referred to as TechO) at the station is provided by executors (shunting locomotives, marshalling yard, etc.). Each TechO should be carried out by executors of a strictly defined specialization (for example, a technical inspection team (TIT) performs an inspection of wagons, the formation of a train – a shunting locomotive and a marshalling yard, etc.). At the same time, the executor of a particular specialization can perform several different operations (for example, the signalman performs the fastening of the train and the cleaning of brake shoes) [12].

Modeling of the TechP at the RWS is achieved by synthesizing UML diagrams of state and activity, respectively, DIS and DIA.

DIS in UML describes the process of changing the states (completed works of TechP) of only one object. In this case, a change in the state of an object (train, group of wagons) can be caused both by internal processes and due to the action of external pathogens. The main purpose of this UML diagram in the formalization of the TechP at the RWS is to describe all possible sequences of work, which together will form the options for the actions of objects during their stay at the RWS.

DIS in UML notation is essentially a graph of a special kind. This graph can be represented as a certain automate. The vertices of the graph will be the work performed at the RWS. Besides, such a graph contains some other types of automaton elements. These elements will be rendered as adequate graphical notations (conventions) in a specific modeling environment. The arcs of the graph are designed to represent transitions from state to state. The corresponding states describe the completion of the work and the transmission of the necessary signal to the executors of the next work in the diagram. DIS can be nested within each other.

The diagram of activity in the UML language (hereinafter referred to as DIA) reflects the TechP typical for the RWS. The diagram of activity is also a graph that represents a certain automate, but it has the following differences:

– on DIA, both states can be distinguished, and actions can be shown, and actions, in turn, can be represented as a new DIS or DIA, receiving nested diagrams;

– DIA has the operator of «choice» in the set of tools for presentation;

– on DIA, it is possible to show the parallelism of the processes performed at the RWS;

– on DIA there is a possibility of presenting the processes of synchronization at the RWS.

The graphical – analytical representation of TechP is visual for the development, understanding and subsequent creation of new functional blocks of TechP at the RWS and reduces the time spent for its study. It is also possible to present TechP of various degrees of detalization. After receiving a schematic representation of the TechP in the IBM Rational Rose environment, the user receives a text file describing the process. The file can be used in the analysis of TechP and to perform calculations of the formalization indicators of the TechP at the RWS.

Thus, the use of graph theory methods and the method of object – oriented analysis makes it possible to implement a graphical representation of the TechP of RWS using UML.

This approach makes it possible to reduce the time spent on creating a model of the RWS operation and to present a specific TechP for each station, as well as to specify, design, document and formalize the technical process, to develop work sequence diagrams of various degrees of detalization.

4. 2. Description of the railway station operation as a system of interacting state machines and a connected acyclic graph

The considered diagrams of states and activities prescribe the rules for the functioning of the RWS model. A station is a collection of automate interacting with each other in discrete time. Some automate exist all the time the model is running (permanent), and some are created and destroyed in the process of operation (temporary).

Permanent automates correspond to the RWS resources (shunting locomotives, paths, a technical inspection team, etc.). Trains correspond to temporary automate.

In a relationship with a temporary automate, a permanent automate accepts their requests for resource allocation or satisfies the request if it has a sufficient number of resource units at its disposal. At the end of the work of the temporary automate, the resource that was used to perform the work is returned to the permanent automate.

A temporary automate is created upon activation of a node or vertex of the type UCD function. In this case, the request to perform the following activities, which are described by the corresponding diagram of state, can be initiated multiple times. The state of the automate is set by the active vertex of DIS. Upon completion of the work corresponding to this vertex, the automate moves along the edge from this vertex to a new active one.

If several edges come from one vertex, then the transition occurs along one of them. The rule for selecting an edge is a vertex attribute. The work of the automate ends and the temporary automate is destroyed upon reaching the final state.

An ambiguous task is to simulate the operation of the RWS when the temporary automate is at one of the vertices of the diagram of state. DIA is assigned to this vertex, the vertices of which describe groups of works, and some works can be performed in parallel.

The internal model should be the basis for the development of effective methods of functional modeling of the RWS operation. An internal model is created automatically based on the input model using the models developed in the article.

Creation of a technology description used at the RWS can be performed in separate editors that are suitable for the RWS technologist. This can, for example, be AutoCAD, KOMPAS, etc. Moreover, the list of works can be easily imported from UML diagrams files, for example, below there is a fragment of the listing of the list of works at the RWS, imported from a *.mdl file describing the UML diagram for the TechP of the state machine for unloading wagons with different cargos:

(list States
(object ActivityState «Unloading wagons with coal (10 wagons)»
(object ActivityState «Unloading wagons with ore (15 wagons)»
(object ActivityState «Unloading wagons with mineral fertilizers (15 wagons)»
(object ActivityState «Unloading wagons with containers (10 wagons)»
(object ActivityState «Unloading wagons with grain (15 wagons)»
object ActivityState «Arrangement of empty wagons in the arrival park»)
(object ActivityState «Train on the path of arrival»)
(object ActivityState «Weighing»)
(object ActivityState «Weighted group of wagons on the path for settling»)

5. Results of the study of methods and models of the automation system technical and operational assessment of the work of railway stations

5. 1. Method of formalizing the description of the technological processes of railway stations

Let's consider on a specific example using UML diagrams the organization of the Zhetysu railway station. The Zhetysu railway station is located on the 1667$^{\text{th}}$ kilometer of the single-track section Almaty-Saryozek of the Almaty Department of Freight Transportation. According to the purpose and nature of the work performed, it belongs to intermediate RWS. Also in terms of the volume of cargo and technical operations and the complexity of work – to the second class. The RWS has 7 station tracks and 5 receiving and departure tracks. Shunting work is carried out by two locomotives.

One of the methods for obtaining primary information that was used during the pre-project survey of the plant is a production excursion (PE). During the PE, the list of the main performers of work at the RWS was studied. TechP of handling cargoes of various types, etc., were also studied. Observations were also made on the unloading of wagons at railway stations, interviews were conducted with the performers of the work of the relevant works. The production tour showed that unloading of goods is carried out in specialized areas. The occupancy of the unloading zones is reflected in the daily schedule of the RWS. In addition, specialized equipment and a shunting locomotive are actively involved in the TechP.

The design of the TechP at the RWS and the creation of their input model is characterized by a high level of interaction between the design engineer and the computer. This stage is characterized by the creation of an effective graphical representation focused on the visualization and formalization of the TechP at the RWS.

At this stage, a set of formalization diagrams of the TechP at the RWS is represented as a set of graphic objects Q_{en}. The following types of objects are highlighted: D_p – use case diagram; D_{Sch} – DIS; D_{act} – DIA.

Each of the given diagrams is associated with a set of tools for their graphical display.

Use – Case Diagram (UCD) for Zhetysu stations is presented as a directed graph, where the vertices of the graph are: tracks of railway stations; shunting locomotive; technical means of automation of loading and unloading operations; brigades of maintenance points, etc. Upon completion of the work corresponding to this vertex, it moves along the edge from this vertex to a new active vertex.

The graph is described by the following set:

$$D_p = \left\{ I_d^p, V, E, f_b, f_e, vt \right\}, \tag{1}$$

where I_d^p – use case diagram identifier; V – list of vertices of the graph; E – list of transitions; f_b – initial vertex of transition; f_e – final vertex of transition; vt – transition type function.

The initial and final vertices of the transition are defined as:

$$f_b : E \to V, f_e : E \to V, \tag{2}$$

$$vt: V \to VT, \quad (3)$$

$$VT = \{actor, entity, function\}. \quad (4)$$

Information about the diagram is contained in the file that describes the resulting model and contains:

– list of vertices of actors – V_a. Here V_a describes the vertex that its identifier defines, the field quid and stereotype are defined by the function VT. Each actor can have a list of parameters. The list of parameters is defined as class_attribute_list and each attribute is defined as ClassAtribute;

– list of vertices – functions V_f that are defined by identifier, name, by the field quid and additional urgent information;

– list of edges E. An edge is determined by the link type Association, identifier, name, by the field quid, field roles, a list of two objects Role. For each edge, there is a list of two vertices, final and initial.

The State Chart Diagram is described by the following set:

$$D_{Sch} = \{I_d^{Sch}, V, E, V_{start}, V_{stop}, f, f_b, f_e\}, \quad (5)$$

where I_d^{Sch} – state chart diagram identifier; V – set of vertices (states); E – list of transitions; V_{start} – vertices of the initial state of the diagram; V_{stop} – vertices of the final state of the diagram; f_b – initial vertex of transition; f_e – final vertex of transition; f – runtime function.

The initial and final vertices of the transition are defined as:

$$f: V \to R. \quad (6)$$

Information about a diagram, which is displayed in an identical file, consists of structures:

– list of vertices – names of works (V). The parameter (V) describes the vertex, which is defined by its identifier – fields quid and type containing a line «StartState». The attributes are presented in the field actions in the form of a list, each element of this list is an attribute of the vertex, the name of which is indicated in the field ActionTime. The field ActionTime contains the attribute of the operation execution at the top of the graph of values of the set W;

– list of edges (E). The list of edges (E) is defined by a field transitions and a service word list transition_list, each edge is defined by a structure objet State_Transition. Each edge is identified by an edge identifier, by the field label. The final vertex of the edge is defined by the service word supllier and supplier_quidi – the identifier of the final vertex. The initial vertex of the edge is determined by the service word client and client_quidu – the identifier of the initial vertex. The edge is characterized by the execution of the transition action and is determined by the field *Event*. The field Event is described by the name of the line type, by the identifier and the service message defined by the field *sendEvent*. The message has its own identifier;

– vertices of the initial state of the diagram are presented in the file by the field object State and are indicated by the line «$UNNAMED$ 0». The vertex is defined by the field type «StartState» as the initial state for the graph;

– the vertices of the final state of the diagram are presented in the file by the field object State and are indicated by the line «$UNNAMED$ 1». The vertex is defined by the field type «EndState» as the initial state for the graph.

DIA is described by the following structure:

$$D_{act} = \{I_d^{act}, V, E, V_{start}, V_{stop}, f, f_b, f_e, S\}, \quad (7)$$

where I_d^{act} – DIA identifier; V – set of vertices (states); S – list of parallel t existing actors; E – list of transitions; V_{start} – vertices of the initial state of the diagram; V_{stop} – vertices of the final state of the diagram; f_b – initial vertex of transition; f_e – final vertex of transition; f – runtime function,

$$V = VA \cup VC \cup VD \cup VG, \quad (8)$$

where VA – set of vertices of the diagram transition; VC – set of vertices of the conditional transition; VD – set of vertices of separation point transition; VG – set of vertices of connection point transition.

The sets VA, VC, VD, VG are pairwise disjoint. The set VD can have only one entry to the edge, and it takes the following form:

$$(\forall v \in VD)\, Card\,\{e \in E, f_b(e) = v\} = 1, \quad (9)$$

$$(\forall v \in VG)\, Card\,\{e \in E, f_e(e) = v\} = 1, \quad (10)$$

$$s: V \to S. \quad (11)$$

Information about the diagram that is displayed in the model file consists of such structures:

– a list of vertices – the names of works or transitions of a special type (transition type State; conditional transition; the transition of a separation point of a type SynchronizationState is determined by an identifier – the field quid. A separation point is characterized by a list of separation edges. The list is defined by the field transitions (list transitions_list and a list of edges with a field object State_Transitions). Each vertex is defined by the field quid, by the edge identifier and a list of edges of the initial state and final states. The initial edges are described by the field supplier and contain links to the initial state of the graph and the final states described by the field *client*. All transitions have their identifiers and data transfer events during transitions;

– the transition of the connection point of the type SynchronizationState is determined by the identifier – the field quid. A connection point is characterized by a list of connection edges. The list is defined by the field transitions (list transitions_list and a list of edges with a field object State_Transitions). Each vertex is defined by the field quid, by the edge identifier and a list of edges of the initial state and final edges. The initial edges are described by the field supplier and contain links to the initial state of the graph and the final states described by the field client. All transitions have their own identifiers and a data transfer event occurs when transitions are made;

– identifier V – describes the vertex that the list of edges E defines. The list of edges is determined by the field label, the final vertex of the edge is determined by the service word supplier and supplier_quidu – the identifier of the final vertex, the initial vertex of the edge is determined by the service word client and client_quidu – the identifier of the initial vertex. The edge is characterized by the execution of an action during the transition and is determined by the field *Event*. The field *Event* is characterized by the name of the line type, by the identifier and a service message, which is defined by the field *sendEvent*, and the message has its own identifier;

– vertices of the initial state of the diagram are presented in the file by the field object State and are indicated by the line «$UNNAMED$ 0». The vertex is defined by the field type «StartState» as the initial state for the graph;

– the vertices of the final state of the diagram are presented in the file by the field object State and are indicated by the line «$UNNAMED$ 1» by the field type «EndState». The vertex is defined as the initial state for the graph;

– the list of executors S is defined in the diagram as a section partitions (list Partitions, the list of executors is initiated by the field object Partitions, the identifier S is determined by the field quid, the field class contains data on the link of belonging to the UCD entity, the field persistence defines the type of entity.

In general, the presented model Q_{en} is a list of graphical objects that are written in a specific order.

Therefore, in the input model, there is proposed a description of the graphical – analytical representation of the RWS technological process, while the description is made in the IBM Rational Rose environment, which allows at the next stage to proceed to the stage of designing interfaces for the ACS or IS of RWS.

5. 2. State machines and a connected acyclic graph

Based on the UCD, there are formed lists of executors E and object templates D, each element of which is described by the following data structure:

– executor $e_r \in E$:

$$e_r = \{i_e, P_e\}, \tag{12}$$

where i_e – executor identifier; P_e – list of executor parameters; object template;

– $d_y \in D$:

$$d_y = \{i_d, P_c, E_d, A\}, \tag{13}$$

where i_d – object template identifier; P_c – set of object properties with default values; E_d – list of executors required for object maintenance; A – state machines, describing the procedure for performing technological operations (TechO) with an object.

The formation of the SM describing the procedure for performing TechO with an object is based on the DIS. To describe the automate, there is used an approximate parametric graph whose vertices correspond to the states of the SM, and the arcs correspond to transitions. Vertex incidence lists are used to describe the structure of the graph. Moreover, each state of the automate is described by the structure:

$$s_a = \{i_a, R, X\}, \tag{14}$$

where i_a – automate state identifier; R – TechO of the object in this phase of TechP; X – list of transitions.

Each element of the list of transitions is described by the structure:

$$x_q = \{z, i_a, f_p\}, \tag{15}$$

where z – input signal; f_p – transition function.

The technology for object maintenance in certain phases of TechP is formed on the basis of the DIA. The technology model is a directed graph $T=\{O, G\}$. TechO corresponds to the vertices of the graph $o_j \in O$, as well as the points at the beginning and at the end of the technological process, branching, merging, and decision making.

In particular, TechOs are represented by structures:

$$q_i = \{i_q, i_{qn}, f_s, f_d, f_e, E_q\}, \tag{16}$$

where i_q – vertex identifier; i_{qn} – next vertex identifier; $f_s f_e$ – functions performed respectively at the beginning and at the end of the operation; f_d – function that determines the duration of the operation; E_q – list of executors.

Each element of the list of executors is determined by the specialization of the executor required to start the work and by a parameter that indicates the order in which it is released from the operation.

As noted earlier, at the upper levels, the RWS models are collections of interrelated states. Each of these states can be represented as a sub – automate. Accordingly, the work of such sub – automate as part of the RWS will be conducted in parallel. The states that characterize the RWS operation will correspond to the various technological resources at the RWS. And in addition, the RWS scheme is supplemented by such objects as a dispatcher (the main function is the appointment of TechO executors) and an incoming flow generator (IFG) of service requests.

The work of the dispatcher and the IFG can be described using external algorithms.

From the point of view of representing the model of the RWS functioning as a finite – automaton model, both the dispatcher and the IFG can be represented as an automate with a single state. That is, the dispatcher and IFG will generate signals that will control the RWS operation. The interaction of the SM with each other is realized by means of signals automates generated during the operation.

For a typical structure, a SM of the RWS will respond to the following signals:

1) «Perform (object, type of work)». Such a signal is received by the dispatcher, processed by it, and then the executors are appointed.

2) «Execution (object, type of work, executors)». Executors (or executor) are SMs. The SM data will correspond to some units of technological resources of the RWS.

3) «Completion (object, type of work)». This signal serves to synchronize messages from executors about the completion of work.

4) «Time». A signal t that is needed to measure the time intervals that are allocated for the execution of work.

As an example, let's consider the diagram of changes of the SM states for a shunting locomotive, which is assigned to arriving trains, Fig. 1.

The operations shown in Fig. 1 can be represented as a graph describing the operation of a state machine, where a representation in the form of a graph for an automate (shunting locomotive), which transports wagons during their unloading.

In the course of modeling the operation of such a state machine, the task of obtaining information on the duration of the execution of specific TechOs is of paramount importance.

From the point of view of the description of the SM, it is necessary to assess the possibility of transition from the state A for which the objects can perform TechO with duration t into a certain state B. If the ultimate task is to automate the object control processes at the RWS, then obviously it is necessary to receive a signal that actually initiates the transition.

Next, it is necessary to decide on the place where it is possible to store information about the transition time. Within the framework of modeling with UML diagrams of the TechP at the RWS, let's assume that all incoming signals will be external in relation to the initial state of the object.

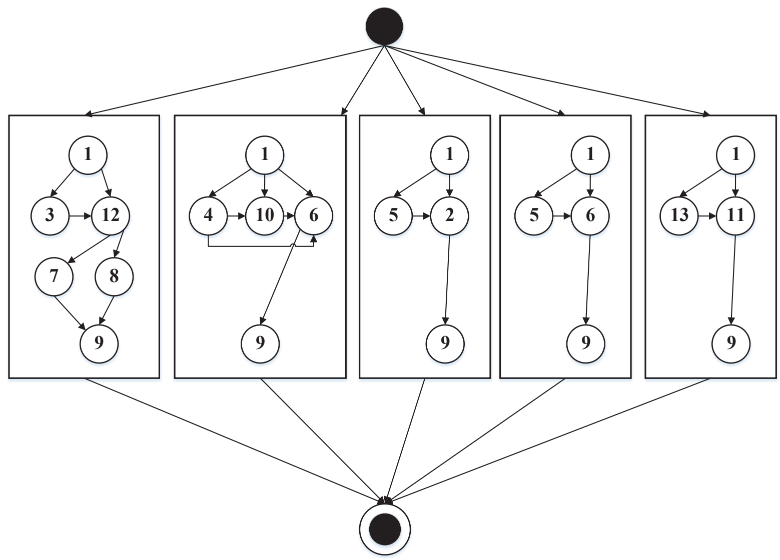

Fig. 1. SM state change diagram for a shunting locomotive assigned to arriving trains:
1 – Arrival of the locomotive; 2 – Setting for unloading a group of wagons (GW) on line – 1;
3 – Putting GW on the path of the grain park; 4 – Putting GW on the path of the coal park; 5 – Putting GW on the path of the ore park; 6 – Setting GrVag for unloading on line – 2; 7 – Setting GW for unloading at the station for unloading wagons No. 1; 8 – Setting GW for unloading at the station for unloading wagons No. 2; 9 – Placement of empty wagons on the way of the receiving and departure park; 10 – Setting GW for defrosting; 11 – Setting GW for unloading containers; 12 – Performing laboratory analysis of cargo; 13 – Putting GW on the path

Tracking the time of work performed by a shunting locomotive can be applied using two approaches:

– the first approach involves processing the SM states for each moment of event processing t;

– the second approach assumes the need to process SM events, which is characterized by a complex structure.

When using each of the above approaches, let's mean that it is necessary to create SM based on its rules for transitions between the states.

Therefore, if to take the rules for creating SM as a basis, applying the first approach, then it is necessary to process its states at every moment t. In this case, it is necessary to store in the ACS or IS time arrays describing the change in the states of the SM and the signals generated at the moment t. It is also necessary to check the transitions to the following states of the SM. Consequently, the SM operation will continue until at a certain moment in time t the SM state will correspond to the position («Train sent»).

The second approach is also generated on the basis of SM states. But in this case, it is more important to create SM based on the general principles of deduction – from general provisions to detailed ones. In addition, the SM is controlled through external signals. It is also typical for the second approach that transitions from one state to another will be accompanied by quantitative data.

Using these considerations, there was created a UML diagram for the SM, which shows the TechP for unloading wagons with different cargos, Fig. 2.

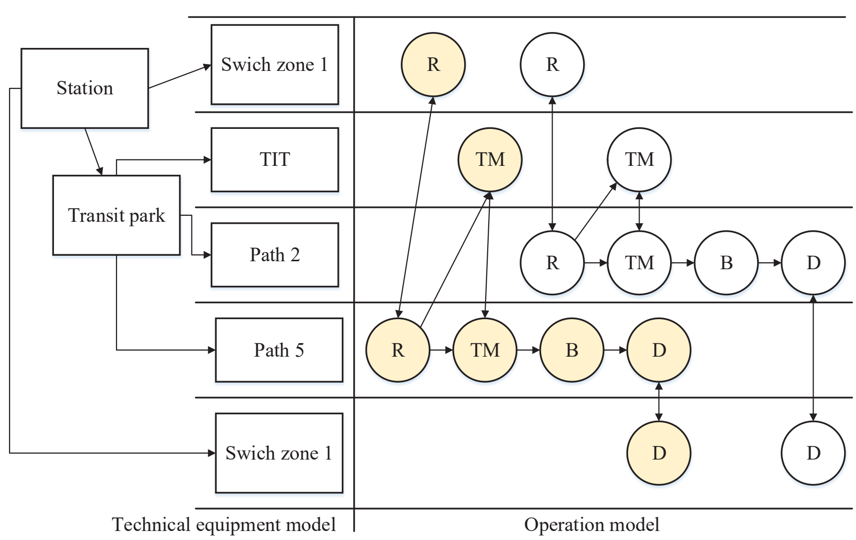

Fig. 2. Representation of the technical equipment of the RWS in the form of a graph (transit trains maintenance at the RWS):
R – Receiving train; TM – technical maintenance of the train; B – brakes inspection; D – departure;
Vertices colored – object 1; Vertices uncolored – object 2

Thus, this SM describes the model of the TechP at the RWS in UML notations and, in fact, is a set of hierarchical automates. In this case, each SM will correspond to a unit of the RWS technological resource (for example, for the resources shown in Fig. 2: path, shunting locomotive, etc.). Separate elements of the SM will be required to simulate the activities of the dispatcher and to develop an ACS or IS for the RWS.

Let's also note that the strategies of action of these elements will be described by a set of parameters, which at the next stages of designing an ACS or IS for the RWS can be considered as variables for the multi – criteria optimization task of the RWS operation. At first approximation, it is better to describe the activities of the dispatcher using the simplest strategy of the SM operation. With this supply, the wagons undergoing processing will correspond to the parameters of the SM state.

In addition to SM using as a tool for modeling the technical equipment of the RWS, it is also possible to use the theory of graphs, since for a number of cases, for example, when it is about modeling a special technical equipment of the RWS, this approach will be less laborious than developing a state machine. In this case, individual technical means (TechM) used at the RWS to automate TechP and the corresponding executors will be positioned as the vertexes of a tree (graph). The arcs of the graph will correspond to connections. Then the set of tree vertices (V) can be divided into such subsets (V_r, V_g, V_s). The vertexes V_r will represent the leaves of the tree to which the TechM, as well as the executors, will correspond to. As in the case of using the notations of UML diagrams or SM, the executors mean separate paths, shunting locomotives, TechM for automation of loading and unloading operations, technical inspection teams, commercial inspection team, etc.). The parameter V_s will correspond to the root of the tree, which forms the RWS. The nodes V_g will correspond to the TechM group used at the RWS. Moreover, the nodes V_g will be associated with the TechM groups, which are grouped according to certain principles (cargo handling points, a park of shunting locomotives, a laboratory, etc.). With this formulation of the problem, each vertex must be associated with its own list of parameters. For example, the vertex type (line, line group, RWS) will determine the parameter t_b. In order to determine the structure of the tree as a whole, it is necessary to assign a vertex v for each of the vertices u_b, i.e. $u_b \to v$. The rest of the parameters will be determined by the type of the vertex.

Then, the vertices $v_r \in V_r$ in the computer memory can be represented as follows:

$$v_r = \{t_b, u_b, s_r, n_r, y_r, h_r, z_r\}, \tag{17}$$

where s_r – vector of specialization of the executor (for example, TechM), which correspond to the types of operations performed; n_r – executor name (TechM); y_r, h_r, z_r – respectively ordinate, height and visibility of lines in daily plans – schedules of the RWS operation.

The vertices $v_g \in V_g$ in the computer memory can be represented as follows:

$$v_g = \{t_b, u_b, n_r, w_g\}, \tag{18}$$

where n_r – the name of the groups of executors (TechM); w_g – width of a specific group (TechM) on daily plans – schedules.

The vertex v_s is represented by the structure:

$$v_s = \{t_b, u_b, p_s, s_s, w_s\}, \tag{19}$$

where p_s – period for which the simulation is performed; s_s horizontal graph scale; w_s – column width for line title.

The RWS functioning can be represented as a process of station objects maintenance by individual executors. Such objects can include: a train, a wagon, a group of wagons, a locomotive, etc. Then, the object maintenance model will be a directed graph of the form $G(O, L)$. The vertices of the graph will correspond to individual TechOs, which the executors perform during the maintenance. The arcs of the graph will correspond to the cause – and – effect relationship between TechOs. The structure of such a graph can be represented as incidence lists. Then, each vertex (o) is associated with a list (or lists) of previous (p_o), as well as subsequent (n_o) vertices.

The implementation of individual TechOs in some cases requires the involvement of several executors (several TechMs).

For example, when using a marshalling yard, it is necessary to use the following TechMs: arrivals paths, thrust paths, shunting locomotive, signalman.Then, the vertices (a) and (c) have the form in which let's consider ($a \to c$) and ($c \to a$) as the simultaneous involvement of several executors (TechMs) to perform one TechO.

Then, each memory operation in a computer can be represented as follows:

$$o = \{p_0, n_0, t_0, p_0, b_0, v_0, w_0, l_0, d_0\}, \tag{20}$$

where t_0 – TechO type; b_0 – identifier of the object for which this TechO is implemented; v_0 – identifier of a specific TechO executor; x_0, w_0 – respectively, the beginning and duration of TechO; l_0 – pointer to a modeled point on the graph; d_0 – vector of additional parameters (this vector depends on the specifics of TechO).

Additional parameters that determine the specifics of TechO may be as follows: train number; the number of wagons, etc. Constants can be used as parameters of operations. It is also possible to also use a parameter b_0. The duration of a TechO can be represented as a constant, or it is possible to apply special functional dependencies that were obtained for different TechOs.

The technical equipment of railway stations can be represented as a graph for the case when it is necessary to simulate the service of transit trains at railway stations, Fig. 2.

Individual operations on the graph are displayed as corresponding icons. Combining operations imported, for example, from a *.mdl Rational Rose file into appropriate groups, is implemented using the lists p_0, n_0. Then the TechO group can be assigned to the object b. This is done by specifying its identifier b_0. Each of the objects can be associated with a list of parameters d_b.

By changing the parameters of objects, it is possible to provide a synchronous change of the corresponding parameters of all TechOs related to the object. Then the TechO of objects at the RWS can be formalized using a directed graph of the form $H(T, L)$.

A graph $H(T, L)$ is like a graph $G(O, L)$. In the graph $H(T, L)$, it is assumed that T – the graph of vertices or templates of TechO, and L – arcs (connections) between the vertices.

Individual operations can then be represented as follows:

$$t=\{p_t,n_t,t_o,s_t,x_t,w_t,l_o,d_t\}, \tag{21}$$

where s_t – specialization of the executor who performs TechO; x_t – conditional start point of TechO; w_t – duration of TechO; d_t – vector of default values of additional parameters that depend on the TechO type.

Executors' identifiers (v_0) are replaced by their specializations from the list (s_r).

If new objects are added to the UML diagrams, then the computer will select the executor, guided by their specialization. This will ultimately allow minimizing the duration of work on specific TechO.

Taking into account the fact that maintenance at the RWS is performed using standard technologies, the formalization of the TechP description can have a positive effect, which consists in reducing the time for developing and modifying maintenance schedules of TechOs. The developed graphic – analytical model, implemented, for example, in AutoCAD, makes it possible to automatically determine part of the indicators of the RWS functioning.

Considering that the development of schedule plans is usually performed by a RWS technologist, the use of a schedule plan, as well as tools for design automation packages such as AutoCAD, should not cause any particular difficulties [13]. In fact, in this case, the development of a plan – schedule resembles the usual process associated mainly with adding, removing and modifying icons on the plan. At the same time, the developed interface in any computer – aided design environment, for example, AutoCAD, will be intuitive for RWS technologists and will not require additional training, unlike the skills of designing UML diagrams. Let's note that formalization of the process of drawing up schedules, based on the models described in the chapter, will significantly reduce the time for creating such schedules. Also, this approach, in conjunction with the possibilities of combining the Rational Rose and AutoCAD package tools, increases the capabilities of both technologists and programmers of ACS and IS of RWS to make adjustments to already existing diagrams and plans – schedules of TechP, depending on the specific circumstances at the RWS, as well as coordination of modifications of operations with objects. The presence of models makes it possible to automate the processes of calculating the main indicators of the RWS operation, to visualize the results of calculations on the loading of TechM, downtime, etc.

Formal representation of the processes of the RWS functioning will also allow to automatically generate files with the initial data for the simulation of processes at the RWS.

The railway model builder software could be written using different tools, for example by selecting a general programming language C, Java, etc., or by a simulation language. The first solution needs great efforts; the last is good, but not flexible enough [14].

6. Discussion of experimental results on model development and improvement of formalization methods

Considering the relevance of the issues of studying the TechP of the RWS, the method of formalizing the description of TechP of RWS was improved on the basis of visual programming methods for simulating the operation of RWS. According to formulas (5), (7), the UML state and activity diagrams were adapted to represent the RWS technology.

A technique for constructing RWS models as hierarchical SM has been developed. The interaction of SM with each other is realized by means of signals generated by automata in the process of operation (Fig. 1).

When formalizing the work processes of RWS DIS, they describe the change in the phases of servicing objects in the course of performing TechP and work with individual objects. At the same time, changes in the states of objects can be caused both by internal processes and due to the action of external factors. DIAs are used to describe technological operations performed with objects within individual states.

The models of the technological process described using UML diagrams, and the methods for creating RWS models as hierarchical SMs are well suited for the development of object – oriented applications for ACS and IS of the RWS (Fig. 2).

The use of the UML language for the formalization of TechP of RWS potentially creates sufficient prerequisites for improving the efficiency of the work of technologists, in addition, the cost of developing visual design tools will decrease in parallel.

One of the priority ways to formalize the presentation of TechP is a linear Gantt chart (LGC). LGC reflects the duration of the technical inspection with the object, their relationship between themselves and the performers participating in the inspection.

The common disadvantages of LGC are that they require a strict list of works. The procedure for performing these works is also unchanged. At the same time, the actual technology of servicing trains on railways may differ in relation to specific conditions. So, when processing transit trains, various technology options arise depending on the need to change the locomotive, the presence of wagons that require repair, the serviceability of automation devices during reception and dispatch, etc.

The method of formalizing the description of the TechP of RWS using UML differs from existing solutions, for example, from LGC, by adapting state diagrams and UML activities to represent the technology of RWS and formalizing the description of RWS, taking into account the change in the phases of servicing objects in the process of executing the TechP, also the method of constructing models of the RWS as hierarchical SM differs from other methods in that, taking into account the features of the RWS, it is proposed to visualize the SM in the form of Harel diagrams, which made it possible to improve the methods of functional modeling of the RWS based on the use of hierarchical SM.

The article discusses the SM that simulates the work of RWS Zhetysu, which was implemented by means of the UML language in the Rational Rose environment. This significantly reduced the complexity of the work on the synthesis of the corresponding RWS models.

The developed methods and models are used to create software systems to support decision-making for managing and predicting the development of RWS, and are also used in simulation modeling to automate the technical and operational assessment of RWS.

However, there are limitations; in some cases, it is expedient to perform development automation and analysis of technological processes formalization technology using simpler modeling methods. It is also advisable to do this if it is not about the design and implementation of object-oriented software products, but about the need to perform the work documentation stage based on traditional design automation tools, for example, using the AutoCAD package.

In many cases, the RWS survey requires business trips and has a significant limitation in terms of the duration of execution, allocated human and material resources. Therefore, the effectiveness of the inspection of the technical and operational characteristics of RWS essentially depends on the correct organization of the work and the establishment of interaction between the representatives of the developer and the railroad personnel.

7. Conclusions

1. The method of formalizing the description of the TechP of RWS based on visual programming methods for the management of the infrastructure of RWS, based on the integrated implementation of decision support systems in the problems of forecasting the development and current assessment of the efficiency of the RWS, has been improved. The proposed solutions differ from the existing ones in the ability to automate the procedure for generating options for control actions using UML diagrams. The method described in the article allows, on the basis of DIS and DIA, to solve the problems associated with the technical and operational assessment of RWS, including taking into account various interval estimates of the degree of development of RWS and metrics that assess the degree of effectiveness of various TechPs on a particular RWS.

The formalization method has been developed and tested in real operating conditions on the Zhetysu freight RWS. The introduction of the method of formalizations in the RWS makes it possible to increase the efficiency of the applied organizational and technical measures to improve the efficiency of RWS and optimize its infrastructure.

2. It is shown that in the course of the development of effective automated systems for analyzing the technologies of the RWS operation, it is required to increase the efficiency of man – machine interaction when creating models of RWS processes. It has been established that the structure of the model of the RWS functioning should ensure the implementation of possibilities for the automatic analysis of RWS processes based on the minimum human participation in the process of entering information. The achievement of the solution to this problem is facilitated by graphical – analytical models of the RWS.

It has been established that the graphical – analytical models of the RWS operation are capable of providing a high speed of human – machine interaction and reducing the barriers between the cognitive perception by the engineer of the graphic models of TechP at the RWS and the UML notations, which are designed for programmers. There has been developed a model of graphic – analytical description of the RWS, in which, in contrast to the existing ones, there was added the ability to automatically correct the list of objects and technologies, as well as additional links between TechOs, which will reduce the load on designers during the development and analysis of technologies of the RWS functioning. Moreover, the list of objects and technologies can be automatically imported from UML diagram files.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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