The Methodology of Distributed Technological Complex System Simulation

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Abstract: The simulation of technological process in the oil pipelines system is considered in the paper. The solution of the task meets a number of difficulties originating during control and operation of distributed technological complexes (TC). One of main features is the taking into consideration numerous disturbances of objective and subjective character. The structure of system simulation model of distributed complex of oil production activity, waste-handling and haul is proposed. The detailed representation of structure and processes taking place in the TC, and also external environment that intensifies model adequacy and enables to obtain objective enough and authentic results close to reality.

1 Introduction

The analysis of the approaches and methods of compound technological complex (CTC) designing reveals that CTC belongs to the class of systems which analysis and synthesis requires the modern methodologies of designing and simulation based on system approach and the theory of complex multilevel systems [MM93, IY87]. The main features of such systems to be taken into account in their creation and maintenance are:
- spatial and temporal distribution;
- multiregularity caused by large number of units and links between them;
- multiconnectivity, i.e. availability of large number of system channels with material streams flows joining separate units of the system;
- hierarchical multilevel representation character;
- multipurpose operation character;
- many aspects (stratification) of representation;
- probability character of system operation and behavior connected to the complex interaction with varying external environment.

An example of the system belonging to this class can be the technological complex of oil production activity, waste-handling and haul (TCOPAWHH). The analysis of this domain has revealed a set of essential features complicating the tasks of its control:
- the territorial distribution;
- the large number of the tasks of planning, inspection and control rising in the

operation of each composing unit and TCOPAWHH as a whole;
- the continuous operation and engineering service cycle;
- high operational requirements to the process equipment;
- high energy consumption etc.

TCOPAWHH represents a compound technological distributed system consisting of the following main objects [GK97]: fields as cluster wells; complexes of fundamental oil refining; plants of oil pre-selling processing; tank batteries; oil pumping-over stations; bulk pump servers; main sites of pipelines.

The task of control an oil pump-over mechanism with the ramified extent pipeline system is complicated by the constant threat of failure of its programmed operation rhythm because of its sensitivity to numerous disturbances of objective and subjective character. An effective tool of the system behavior dynamics analysis is the system simulation modeling allowing taking into account the influence various fail and emergency situations. The modeling analysis method proposes the creation of the formalized CTC description, containing descriptions of elementary system objects and the principles of operation, properties and links of these objects. For the formalized description of the domain knowledges the framework based representation apparatus is effectively applied [K86].

From the positions of modern simulation modeling the program CTC model respecting the separate units structure and characteristics, principles of development and the course of the operation processing in time is created [EY98]. During the simulation process all the main moment (events, states) of compound system operation, including the strict registration and sequence of actions are reproduced. As well as any formalized approach, simulation modeling has its concepts and attributes. In this sense the dynamic processes are considered as the interaction of a number of system components, such as transactions, events, devices, queues, time etc.

The creation of the simulation model is preceded by the stage of compound system pilot survey, when the research purposes, characteristics, changed variable description, CTC operation algorithms are formed.

The compound system is represented in its simulation model as an aggregate of structural units (nodes) and links between them, where each unit has a corresponding program unit simulating its operation. After the definition of units the system links setting transitions between separate units, simulating the system flows, are described. The main purpose of the simulation is the modeling of dynamics, i.e. changing of CTC state in time.

2 Setting of the simulation task

The paper is related to the questions connected with creation of the system knowledge-oriented simulation model including CTC analysis, forecasting and control by means of oil complex as an example. The main tasks and requirements to guarantee an effective operation of the oil complex control system are:
- forecasting of the main planned indices of oil production activity, haul and sale, taking into consideration possible stoppages and breakdowns of oil deliveries (an insufficient, in comparison with the planned indices, oil delivery from the supplier; an insufficient, in comparison with planned indices, oil reception be the consumer);

- the controlling of oil stocks and free capacitances of tank batteries (the absence of oil in reservoirs or poor, in comparison with the planned indices, input of oil into the tank battery or poor, in comparison with planned indices, pumpdown of oil from the tank battery);
- the consideration of TCOPAWHH in short-term and long-term aspects (forecasting of the oil presence and deliveries taking into account the variation of field performances (oil field exclusion from production activity, new oil field inclusion, oil reserve depletion etc.));
- the consideration of primary emergencies (disturbations) influence: leaks and breaks of oil pipelines; primary equipment failure of pumping-over and bulk stations; equipment failure of tank batteries; energy supply failure; planned precautionary operations.

The sizes of pipeline transport system service are always planned in a long-term way, and availability of own mobile (insurance) oil stores in cascade system of tank batteries placed along the ramified pipeline increases its readiness to execute an order in strictly planned terms. It is explained by the possibility of TCOPAWHH to satisfy consumer's requirements in a concrete moment of time by oil sizes from its own stores and not only by incoming material flow.

Taking into account the necessity of rational control of oil stock and free capacitances in tank batteries, the task of control pump-over process can not be reduced to an aggregate of the individual tasks for the separate parts of TCOPAWHH. For any separate tank the current oil stores are determined both by pumping-in and by pumping-out sizes. Thus, in order to define the rational oil store size for all the tanks of the system it is necessary to set the balance limitations for both pumping-in and pumping-out sizes for every separate tank battery, and these limitations concern all the parts of TCOPAWHH.

For pipeline oil transportation it is important to solve the task of quality of oil sold to consumers. The solution of this task in case of long transport operations meets a number of difficulties. The importance of its solution is caused by the fact that the raw oil arrives from numerous sources and differs in its structure. A tank battery providing oil directly to consumers can receive oil that does not meet the requirements of contractual conditions. It could be impossible to return it to the suppliers because of the absence of the reverse material flows or roundabout lines. Such consignments of natural raw materials can only be brought to the standard conditions by additional technological operations requiring the special equipment and significant quantities of free capacitances. Maintenance of such engineering structures requires additional costs. Besides, storing the significant sub-standard oil sizes is unprofitable economically because of loosing the free-capacitance control efficiency and, as the consequence, infringing the planned oil transportation schedule. Such situations can break the execution of oil delivery program for a long time.

In connection with the possible oil demand vacillation the oil delivery control center keeps the right of changing delivery program (introducing) corrected command (directive) solutions. The achievement of a new purpose requires the revising of solved task results and adjustments of oil transport mechanism. It can also be considered as a disturbance which source is in the external environment. It can have a significant influence on the execution of main planned oil complex operation indices.

3 Creation of the TC system simulation model

TCOPAWHH system simulation model is formed on the basis of the distributed and ramified oil complex structure analysis.

Five main standard structural units are selected in the system simulation model. That is quite enough as they are universal and form the basis for creation of more complex group units including two or several simples. Every structural unit has its determined properties and characteristics set before. The interaction of the structural blocks is guaranteed by arcs with arrows that represent physically the parts of main pipeline.

Here is the more detailed consideration of TCOPAWHH objects and their characteristics to be represented in the system simulation model:

1. Oil field (further source) is characterized first of all by the intensity of natural raw arrival into the fundamental oil refining complex. The first task in the construction of a simulation model is the definition of concept of the transaction. In this system the transactions are the portions of the natural raw produced by the oil fields. Mostly the oil production activity is carried out by cluster method, therefore the natural raw proceeded from numerous sources can differ on its compound. So, the transaction gets the quality performance. From the standpoint of simulation technique the source represents the transactions (barrels of oil) generator, and its specified intensity (number of barrels per time unit) allows the simulation of transaction current beginning and movement with required simulation accuracy. The distinguishing feature of oil production activity, waste-handling and haul is their continuous character. The internal simulation mechanism is based on the discretely event principle that allows to represent the continuous flow as the discrete transaction (barrels of oil) flow.

2. Tank battery (TB) is intended for the creation of the insurance stores able to ensure an uninterrupted operation of main pipelines and also for storage of oil transmitted to the consumers. TB is represented as a set of tanks (capacitances), which amount changes from several up to several tens and even of hundreds units. The main parameters are: total capacity; amount of tanks; size of oil stored in tanks according to its quality; insurance store (minimum and maximum levels). The simulation system controls the achievement of minimum and maximum levels of tank battery insurance store. The filling of tanks occurs either consistently (according the oil quality) or according to the scheme specified by the dispatcher. Taking into account everything said above about the storekeeping in the system it is necessary to mark the expediency of spending some time in the beginning of given scheduled period (when simulating the dynamics of oil complex behavior in this period) for the creation of some oil stores and free capacitances in the system tank batteries. That will allow to weaken the influence of disturbations in some system blocks on the functioning of another blocks. The size of these stores is given separately for each tank battery. Originally in the model, the existing oil stores and free capacitances in the whole complex tank batteries reflecting real situation in TCOPAWHH by the beginning of simulation can be determined (on customer's request). From the point of view the system simulation modeling the TB is represented as a complex device with the determined amount of queues.

3. Pumping over station (POS) (represented in the model as a device) is an essential element of the oil complex equipped with pumps and providing the oil movement on the pipeline. By the character of the oil movement the pipelines can be divided into those with pumping-over stations without capacitances, i.e. tank batteries (the pumping-over is

carried "from pump to pump") and those having pumping -over stations with capacitances. According to that the intensity of oil proceeding to the next part is connected with the intensity of oil transfer through the previous part or the own station pump units intensity.

The simulation of POS operation reliability characteristics (partial or total failure of the capital station equipment) provides the possibility of the smooth intensity lowering from maximum value down to 0 (interpreted as an emergency station stoppage).

For the simulation of POS operation it is necessary to consider the main algorithms (service strategies) of its functioning. Figure 1 shows a theoretical scheme of the POS relations to another structure units of the model.
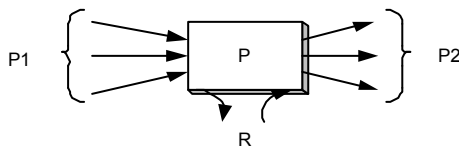

Fig. 1

- $P1$ - the set of POS included in the station P;
- $P2$ - the set of POS departing from the station P;
- R - the tank battery of the POS P.

The first feature is connected to the description of the storekeeping strategy it the station is supplied with an intermediate tank battery. When creating an insurance store the necessity of dividing the material flow entering a POS between the tank battery and the following site is rising. The several possible situations of oil flow control are selected here: to a linear site only; to a tank battery only; combined (in a parallel way (with the percentage parity of flow branching indicated); sequentially (with an alternation occurring by the transaction number indication)). The following feature is connected to the description of controlling mechanisms carrying out the simulation of pumping-over station functioning if the station has several outputs. Here are the principles of the material flow control:

- parallel (every output has its percentage parity of flow branching indicated);
- sequential (with the order of departing linear sites detour indicated);
- casual (with the probability distribution indicated; by default, the even law ensuring the equiprobable output choice is used);
- the expendable dispatching strategies: stations with a failure of the oil delivery to the consumers; stations with the insurance store infringed; stations with the greatest amount of consumers etc.

The last group of strategies is used by the system when taking an administrative decision about the mitigation or elimination of arisen conflict situations (disturbances) influence.

The next group of strategies connected to the use of accumulated insurance stores completes the creation of the full pump -over station operation algorithm. As it was said before, the insurance stores availability allows to ensure TCOPAWHH functioning (in partial or full size of the normal mode of its operation) in the case of deliveries schedule faults and failures, emergencies in a prior linear site pipeline site (or sites) or the failure of the base equipment in intermediate pumping-over stations. Here are two variants of the pumping-over station output flow organization of its own stores and the material flow incoming from the station input: parallel (with the percentage parity of flows

branching indicated); sequential (the alternation of two flows occurring by the transaction number indication).

4.   Bulk server, is connected to the tank battery immediately and intended for the dispatching of oil to the consumers. The server is characterized by its dispatching ports amount and the intensity of oil intake in each of them. In the simu lation model the server is represented as a complex device with the queue of consumers to each dispatching port. The principle of the queue functioning is, by default, FIFO (first input, first served) or the priority services (if the priorities are set).   The commutation of tank battery capacitances to the oil dispatching ports is carried out in the set order.

5.   Consumer is connected to one or several oil intake ports, for each of which the intake intensity is indicated. The consumer is represented as a transaction generator operating on the cyclic law with probability dispersion or on the schedule with intake time and size of taken oil indicated. By the beginning of the simulation modeling period every consumer is characterized by the set oil delivery schedule. The whole scheduled period is divided into the intervals for each of which the purchase size and natural raw quality is indicated. Executing the delivery schedule, the consumer has to concede the capacitances for oil pumping-in and further transportation (tanks, tankers etc.) for each scheduled interval. In the simulation the faults and failures in oil deliveries to the consumers are imitated. It is necessary to consider two situations: insufficient (in comparison with the planned indices) oil sizes delivery (supplier fault); insufficient (in comparison with the planned indices) oil sizes reception (consumer fault).

There is a necessity of operating control and the solving of the dispatching tasks at this stage. On the one hand, the oil short-delivery to the consumer can cause, first, the fines for delivery failures. Secondly, the possible situation of the supplier's request for increasing the consumer's oil reception (in comparison with the planned index) during a period of time (e.g. with the purposes of undelivered oil sizes compensation). On the other hand, the failure of the planned indices of oil reception be the consumer entails the increasing number of oil stores of a certain quality that can not be returned to the supplier because of the absence of reverse material flows. In both cases the decision is taken on the basis of the whole delivery program analysis and the analysis of the simulation at oil delivery terminals and the positions of the supplier and the consumer (the possibility of delivery (reception) terms changing, the possibility and possible terms of delivery (reception) restoring etc.).

For the solution of the set tasks the purposed simulation system suggests the following strategies:
-   the requirements of suppliers and consumers will not be taken into account in the course of simulation;
-   the requirements of suppliers and consumers will be satisfied compromisely to avoid the disturbance of oil complex operation efficiency;
-   the directive changing of delivery program will be based on the basis of the consumer's and supplier's requirements.

6.   The linear site of the main pipeline is one of most expensive oil complex components, since the total extent of the pipeline can amount to hundred and even thousands kilometers. The pipeline diameter and linear site length enable to estimate the volume of oil in it and its huge extent underlines the importance of controlling the emerging leaks and pipeline breaks. Technologically the linear site of the pipeline can be represent in the system simulation as one or several parallel pipelines. The linear site of

the main pipeline can be represented in the system simulation model as a complex device with input and output queues. The simulation of the oil movement in the pipeline is done as a temporal delay between the transaction moving from the input queue to the output queue. The length of the input queue characterizes the oil quantity in the pipeline.

The compound group objects of the model derived from the elementary objects defined above and inheriting their corresponding characteristics are selected here:

1. The main pumping station including the tank battery, the pumping station and the bulk server is intended for the receiving of oil from its production sources and fundamental refining plants.
2. The terminal points of the main pipeline generally are tank batteries with bulk servers (the tank battery can belong to an oil refining plant or to the main pumping station of the next pipeline system).
3. The pumping station with a capacitance (tank battery).
4. The pumping station with a bulk server (that means the presence of the TB).

The proposed set of model elements offers the possibility of describing the structure of any oil pipelines system.

The generators of leaks and failures represent the separate class of the model elements. The presence of built-in statistical functions allows simulating the probability processes connected to the occurrence of various emergencies. The operator can place them in the model both manually and selecting the automatic placement mode.

The leak generator operation causes the appearance of corresponding event that edges its way between the event of linear site connection and its disconnection (interrupting the movement of transaction from an input queue to the output queue). Then the place of leak is fixed. The leak intensity (the "side transaction" amount in the case of partial oil pipeline breaking) is determined by the set leak generator parameters. In the case of total pipeline breaking the amount of the "side transaction" depends on the velocity of their movement to the break place with possible summation of the transaction amount as a result of reverse oil movement from the site after its breaking. The additional parameters are the mode (permitting the leak elimination or not) and the time of the pipeline restoration (leak elimination).

The operation of the failure generator imitates both the full emergency failure of the technological equipment and the partial failure which degree is set by the smooth changing of the generated transaction parameters (e.g. falling of the oil pumping intensity). For each failure generator the following parameters are indicated: the time of transaction arrival to the system (set by the probability distribution); the degree of influence; the mode (allowing the restoring of the equipment or not) and the time of passage to the normal operation.

The following step to the creation of the system simulation model consists in the selection of main dynamics moments – the events. In the considered system two main selected events are connected to the devices: E_{Hj} - j device connection, E_{kj} - j device disconnection. Considering the tank battery it is necessary to take into account two operation modes: filling of capacitances and emptying of capacitances.

The transaction (oil barrels) controlled by the discrete events simulation mechanisms, are generated by transaction generators (sources, consumers) and then pass through the structural units of the model being processed by them and accumulating statistics on each step of modeling. The transaction passing through the system require

the service: in the main points of the system (pumping stations, bulk servers etc.); in the links of the system (main pipelines linear sites); in the auxiliary units where the transaction can be kept (TB).

4 Knowledge-oriented structure of the simulation model

The internal structure of the model is a knowledge-oriented framework tree-type structure formed automatically in the constructing of the visual images distributed technological complex system. For the visual images constructing the framework models of main events and simulation system units (devices, queues etc.) are determined. The framework is a knowledge structure that characterizes the specified sides and properties of the represented event or system unit. The proper interaction of the operator with the offered software package allows an easy filling the knowledge-oriented framework structures of the system simulation model with data.

The approach to construction of simulation models of TCOPAWHH that is based on frame structures consists of three main stages. At the first of them the object - a compound oil complex system - is analyzed, therefore the formalized descriptions - the frame model of main system events and objects - are defined. At the second - the algorithms of the operation are defined, therefore the frame models of the system behavior dynamics are received, and in the third - the typical system elements are defined.

An important stage that reveals novelty, universality and value of the offered model is the stage of the visual model conversion to the internal framework simulation structure F_R. With this purpose the following simulation frameworks are constructed:

- the transaction framework (F_{RT});
- the transaction generators framework (F_{RG});
- the future events framework (F_{RE});
- the devices framework (F_{RD});
- the queues framework (F_{RQ}).

The interaction and coordination of the frameworks in the simulation course is carried out with the simulation monitor that organizes the list of events considering the frameworks of system behavior dynamics and the system time.

According to the selected concept, the knowledge base for TCOPAWHH simulation consists of the three levels (fig. 2). At the first level the structural representations of the system objects are contained. At the second level the tasks of control and operation are represented as the situational and role frames. At last, at the third level there are the standard units of the system simulation model internal structure.

The base of rules is created together with the role frames at the second stage. In the base of rules the knowledges of concrete situations, operations and strategies are accumulated. These knowledges have mostly the procedural and intentional character and are described with the help of predicate logic.

The use of the base of rules and the logical interpreter constructed on its basis for the realizing of inference algorithm, is supposed for the solution of the several tasks:
- processing of knowledges about data domain and creation of input data for internal

simulation structures;
- decision making and output of help information in simulation course;
- interpretation of results of simulation.

For want of it the creation of several bases of rules describing the oil complex operation in various conditions (for example, in occurrence of emergencies) is possible. The use of the concept of knowledge bases allows the contributor to make "setup" of a model in an interactive mode to a concrete mode or situation and to make a simulation.

Framework of TCOPAWHH

Pumping over station No.1
Pump aggregate No.1
Pump aggregate No.2
Pump aggregate No.3
. . .

Tank battery No.1
Cap. No.1 Cap. No.2 Cap. No.3
Cap. No.4 Cap. No.5 Cap. No.6
Cap. No.7 Cap. No.8 Cap. No.9

Role frameworks

Base of rules

POS No.1
Rule Nr.1
Rule Nr.2
. . .
Rule Nr.K

TB No.1
Rule Nr.1
Rule Nr.2
. . .
Rule Nr.K

If
$(X1=A1)$
$(X2=A2)$
. . .
$(XK=AK)$
then
(action 1)
(action 2)
. . .
(action M)

The frameworks of standard units of internal structure

Transactions

Generators
Generator 1
. . .
Generator L

Devices
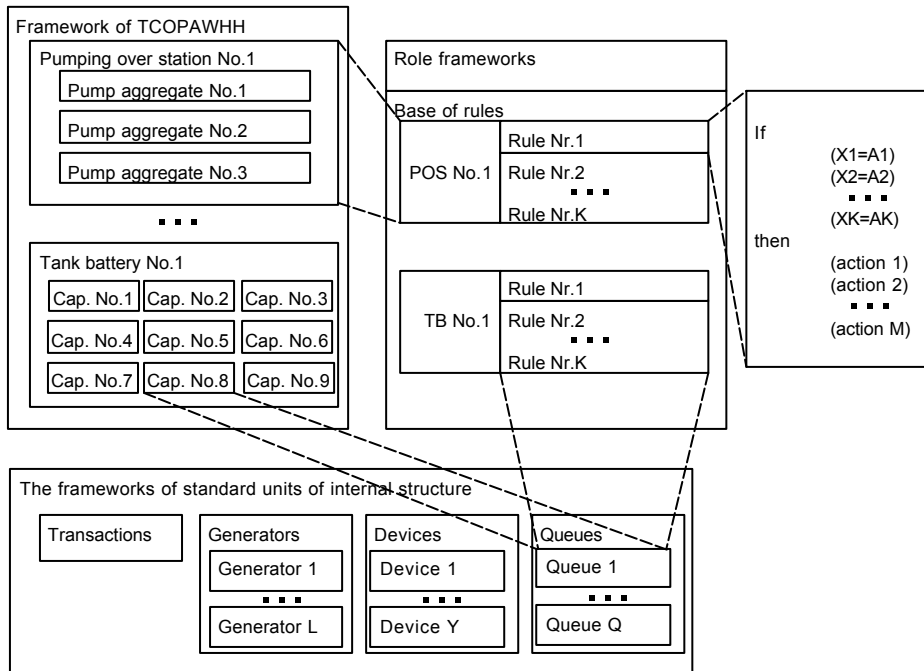Device 1
. . .
Device Y

Queues
Queue 1
. . .
Queue Q

Fig. 2.

In the development of the TCOPAWHH analysis program simulation model the main methods of the modern object-oriented modular programming technology were applied [SK90]. The general structure of the system model is represented in the Figure 3.

The main feature of the offered method is the simulation process visualization where the model has a visual character clear for the experts. The operator constantly has before his eyes the image of the separate units and the whole distributed oil complex structure. In the interface window of the program the structural units of the TC the library of which is present in the main program – are formed. The interrelations between the units are established. The operator has to enter the requested variables and additional dependencies. After that, the model is practically ready for testing. The system has the possibilities of attaching the TC structure to the electronic map of the district. Besides, there is a possibility of the indication of potential (most probable or already existing) places of oil leaks and the pipeline breaks.
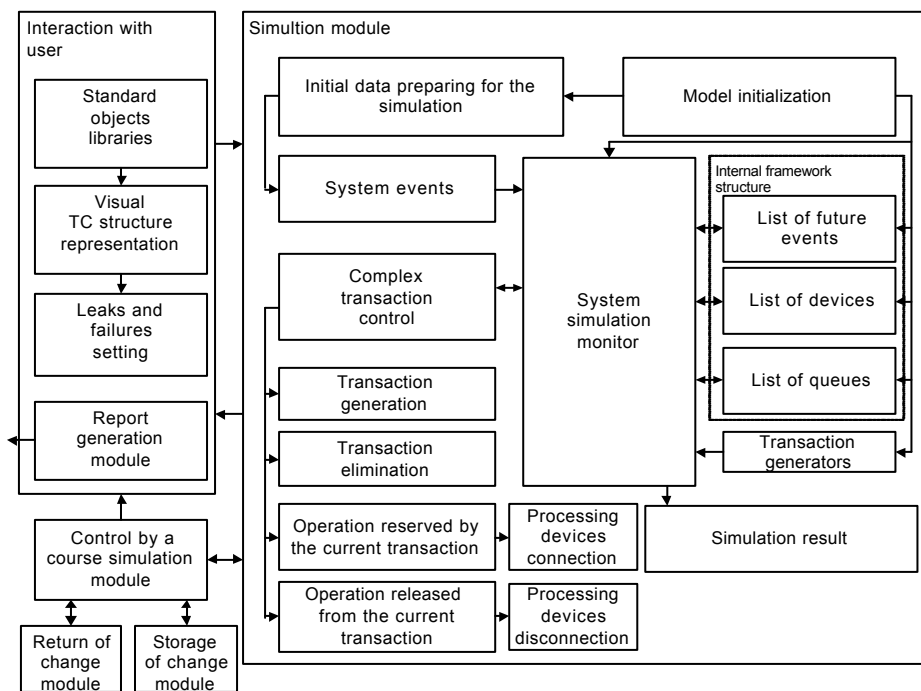
Interaction with user

- Standard objects libraries
- Visual TC structure representation
- Leaks and failures setting
- Report generation module

Control by a course simulation module

- Return of change module
- Storage of change module

Simultion module

- Initial data preparing for the simulation
- Model initialization
- System events
- Complex transaction control
- Transaction generation
- Transaction elimination
- Operation reserved by the current transaction
- Operation released from the current transaction
- Processing devices connection
- Processing devices disconnection

System simulation monitor

Internal framework structure

- List of future events
- List of devices
- List of queues
- Transaction generators

Simulation result

Fig. 3.

5 Results of TC system simulation

The system and the tool complex forming its basis, provide a wide spectrum of the information representation forms to observe the simulation course. Therefore the expert has the possibility of the immediate monitoring of the oil transport (considering the oil quality) between the TC units (in the model and diagrams) and of the corresponding resource objects occupation and vacation. The processes can be illustrated by the special "counters" outputting the separate parameter value in the definite place of the window. "The gauges" as the graphs and tables can be "cut" into any point of the model. Due to this feature the operator can control parameters of any fragment or structural block. It helps much the testing of the model and facilitates its modification during the simulation, providing the system with dispatching functions and tools.

As a result, the distributed TC system simulation allows establishing the following:

- the forecast of the fulfillment of oil production and its sale to the consumers planned parameters: expected actual sizes of oil deliveries to the consumers (totally and for the points of oil taking); expected amount of the oil taking capacitances delivered by the consumer (totally and for the points of oil taking); schedule fulfillment percentage(totally and for the points of oil taking);

- oil losses for the leaks and the oil pipeline breaks (totally and for every leak): the loss sizes; the costs;

- oil stores state and free capacitances availability in the tank batteries: oil sizes in the tanks of each park (considering oil quality); free capacitances; the disturbances connected with insurance store level;
- the state of consumer queues by the oil taking terminals: maximum, average queue length; the value of queue length in the end of the simulation;
- the sizes of the sold and transferred oil considering its quality: the oil sizes available in the system (in each site, intermediate points, tanks);
- the reliability metrics of the structural oil complex units operation: the total of refusals in the system; an amount of refusals of each unit of the system; probabilities of refusals;
- a number of auxiliary parameters: daily average cost of the spent electric power; daily average productivity of oil pumping out of the tank; daily average productivity of oil pumping into the tank; daily average productivity of oil pumping out of the source; daily average productivity of oil pumping to the consumer.

Summary: The complexity of the soluble tasks during the control of a technological complex of oil production, processing and transportation has stipulated the use of a simulation modeling method for the research of dynamics of its behavior. During the operation the following tasks were solved: the theoretical-set representation of the trunk oil pipelines system architecture is considered; the TCOPAWHH system simulation model is generated; the main moments connected to the simulation of the strategies of rational oil storekeeping and free capacities of the oil complex bulk stations are defined; the technique of the simulation of the structural oil complex units operation reliability characteristics is developed; the internal knowledge-oriented structure of the simulation model is developed; the common script of the simulation of the oil transportation process and the structure of resulting parameters is indicated.

The offered method can be spread to the system simulation of compound distributed technological complexes (as the railway, sea, automobile etc. transportation).

Bibliography

[MM93]   Marka, D.A.; Mc Gowen, K.: Methodology of structured analysis and design. 1993.

[IY87]   Ivahnenko, A.G.; Yrachkovsky, Y.P.: Modeling of compound system based on experimental data. Moscow, Radio and Communication, 1987.

[GK77]   Gaevskiy A.F., Konovalov G.T.: Optimization of technological processes of oil pumping-over in ACS of oil-trunk pipelines. 1977.

[K86]   Kess Y.Y.: The analysis and synthesis framework models of ACS. 1986.

[EY98]   Emelyanov, V.V.; Yasinovsky, S.I.: Introduction to intellectual simulation of complex discrete systems and processes. The language RAO. 1998.

[SK90]   Scurihin, V.I.; Kvachev, V.G.: Information technologies in trials of complex objects: methods and tools. 1990.