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# Design of Simulators for Automated Information Systems of Engineers' Training

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**Abstract:** Training simulators help to increase the skills of engineers and operators in handling emergency situations. Their application in training contributes to a deeper understanding of the essence of production processes, the principles of the process equipment and developing the required level of practical skills to manage technical systems. The article states the problem of design of a training simulator and focuses on the elements of mathematical models of a human operator, who manages the technical system of chemical production in routine and emergency modes of operation. An algorithm for the development of a virtual simulator as a functional diagram in IDEF0 notation was described. The developed sets of production rules and sequences of actions formed the basis for the creation of software modules for a training simulatorin LabVIEW graphical programming environment.

**Key words:** Training simulator, information system, engineering staff, human operator, SCADA systems, mathematical model of activity

## INTRODUCTION

The problem of training professional engineering staff for hazardous industries has not lost its relevance. The reason is that accidents occur at certain intervals and cause environmental damage to the entire regions. This study show that human errors lead to more than half of the accidents. Today, it is impossible to completely remove the human factor from chemical production (Meel *et al.*, 2008; Zio *et al.*, 2009; Rigby, 1970; Despic and Simonovic, 2000). This study describes some modern methods of reducing the negative impact of human factor on the reliability of technical systems. The opportunities of training simulators and principles are shown in this study. Approaches to mathematical modeling that are used to describe the activity of a human operator enable to create training simulators that can fully simulate the work of an operator.

To date, technical systems of most chemical companies are managed by the Automated Process Control Systems (APCS). Their staff can monitor and influence the course of operation processes, for example, users can highlight object elements in the diagram, scan them and visualize additional parameters on the screen, display the graphs showing changes of parameters with a predetermined depth and time against the background of a technical system fragment, etc. The control over the process by APCS considerably simplifies the operator's job but only if the process runs in the normal mode. If some input disturbance occurs in many cases, the operator cannot take the necessary measures to eliminate it (Lee and Seong, 2009; Swain and Guttmann, 1983; Swain, 1963).

The main goal of training is to prepare an operator for an adequate perception of information and timely response to the occurrence of emergencies. The only way to achieve this is by applying a systematic approach. First, an operator must be familiar with the whole production cycle, i.e., manufacturing instructions, the location of equipment and pipelines in workshops, Emergency Response Plan (ERP). As a rule, getting acquainted with the standard documentation is not give sufficient as familiarization with ERPRule does not guarantee at the time of emergency then an operator will take the necessary steps to prevent it. Hence, operators have to develop the required skills and abilities for the timely and proper decision-making in routine and emergency modes of technical system management (Li *et al.*, 2011).

To solve this problem, it is proposed to use specialized training simulators designed for comprehensive training of an operator for various conditions of the production process.

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Modern APCS are based on SCADA-systems. Application of computer technology can significantly simplify the operator's job as modern data acquisition devices allow taking real-time readings from the whole system and transmitting them to the operator control panel. Therefore, SCADA-systems are ideal for the development of training simulators, as they enable to achieve almost full compliance of the simulator front panel with the operator panel control.

## STATEMENT OF THE PROBLEM OF A TRAINING SIMULATOR DESIGN

In this study, we consider the design of a training simulator in the LabVIEW graphical programming environment. Its application allows to achieving almost complete simulation of the operator panel control, create a network version of the simulator for TCP/IP and HTTP. It is a user-friendly programming environment compatible with modern programming languages; it can be operated on multiple platforms and has a convenient debugger interface.

The need to use network protocols appears when the technical system is run by several operators which causes a potential hazard in their interaction.

Therefore, a training simulator creates jobs for several operators working on different work stations and interacting in network protocols. Application of simulators with "Group of operators-Instructor" system helps to improve interaction between operators and reduce the effects of disturbing factors.

We formulate the statement of the problem of designing a training simulator for operators of Technical Systems (TS).

It is necessary to develop an operators' training simulator that comprises:

- A cluster of background materials [L]:

$$[L] = [\,[T_j], \bar{G}_j, [M_j], DB\,]$$

- A cluster of panel functional units of atraining simulator [F]:

$$[F]=\begin{bmatrix} \bar{S}_1 & \bar{W}_1 & \bar{Z}_1 & \bar{C}_1 & [Q_1] \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \bar{S}_n & \bar{W}_n & \bar{Z}_n & \bar{C}_n & [Q_n] \end{bmatrix}$$

- Methods and channels of network interaction between trainees and instructors [Net):

$$[Net] = [\bar{O}_1, \bar{E}_1, \bar{P}_1]$$

- Methods of teaching and training of operators [MT]:

$$[MT] = [\overline{SP}_j^M, \overline{AP}_j^M, \overline{MI}_j]$$

The simulator forms the desired composition and achieves the required level of skills to manage the technical system in routine and emergency situations, $\bar{U}_j^*$ in conformity with the information-analytical regulations of TS R including the models of system operation and failures, models of TS operator's actions:

$$R : \bar{U}_j \xrightarrow{[L],[F],\ [Net],[MT]} \bar{U}_j^*$$

The matrix of elements of the function block [Q] used in the statement of the problem is described as follows:

$$[Q]=\begin{bmatrix} r_1 & x_1 & y_1 & c_1 \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ r_K & x_K & y_K & c_K \end{bmatrix}$$

Cluster $[T_j]$ which determines the composition of text information and reference materials comprises:

$$[T_j] = [\overline{TP}_j, \overline{AO}_j, \overline{SP}_j^T, \overline{AP}_j^T, \overline{PO}_j, \overline{PI}_j, \overline{PP}_j, \overline{VP}_j]$$

Cluster $[M_j]$ which determines the composition of multimedia information and reference materials is described as follows:

$$[M_j] = [3D, \overline{OP}]$$

In the statement of the problem, we used the following notation.

$\bar{G}_j$ is vector determining the composition of graphical information and reference materials; j is serial number of the product created in the TS; DB is the database for storing information and reference materials; $\bar{S}i$ is vector of the functional block size; $\bar{Z}_i$ is coordinate vector of functional block; $\bar{C}_i$ is vector determining the color version of the function block; n is the number of functional blocks; $\bar{O}_1$ is vector of object interaction; $\bar{E}_1$ is vector of object relations; $\bar{P}_1$ is vector of networking technologies; l is serial number of the training simulator object; $\overline{SP}_j^M$ is training methodology in routine mode of operation; $\overline{AP}_j^M$ is training methodology in emergency mode of operation; $\overline{MI}_j$ is methodology of instructor's work; $r_i$ is element size; $x_i$, $y_i$ are coordinates of the function block; $c_i$ is color version of elements; K is the number of elements of the function block; $\overline{TP}_j$ is materials on the production technology; $\overline{AO}_j$ is materials for hardware design; $\overline{SP}_j^T$ is the description of routine mode of TS operation; $\overline{AP}_j^T$ is the description of emergency mode of TS operation; $\overline{PO}_j$ is operator's guide; $\overline{PI}_j$ is instructor's guide; $\overline{PP}_j$ is programmer's guide; $\overline{VP}_j$ is a set of screen tips; 3D is interactive 3D-model of production facility; $\overline{OP}$ is video tutorials.

It should be noted that it is necessary to achieve full compliance of virtual control panels of a training simulator with the real control panels of TS. Any deviations can induce operator skills that do not correspond to the actual production and can have a negative effect.

## MATHEMATICAL MODELING OF HUMAN OPERATOR

Models of operation and failures of TS and model of a human operator play an important role in the development of control panel and the entire training simulator; they must be created at the design stage of the technical system and included in the information-analytical regulations (Chang and Mosleh, 2007; Ostroukh *et al*., 2014; Ertugrul, 2008; Tron and Margaliot, 2004).

We propose the following approach to mathematical modeling of a human operator in the analysis of an operator's involvement in the production process. We used graph G(C, D) for modeling of the activity. Application of the graph illustrates the sequence of operator's actions.

We consider the formation of a mathematical model of a human operator in the following example. The production activity of a human operator is described by the graph (Fig. 1).

Each vertex of the graph (set C) is assigned a production rule.

IF condition then action 1, otherwise step 2 and each branch (set D) is a set of actions that are necessary for transition.

We divide a set of elements of the front panel into Data Display Facilities (DDF) $X_{stn}$ and controls $Y_{stn}$.

Where, s is stage number, t is type of panel element and n is panelelement number on the stage.

For notational convenience, we distinguish DDF and controls in the mathematical model of human operator by the following features:

**Data Display Facilities**

- LEDs
- Temperature sensors
- Flow sensors
- Pressure sensors
- Level sensors
- Pipe filling
- Timer

**Controls**

- Tumblers

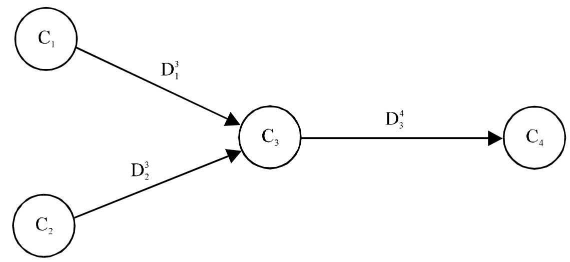


Fig. 1: Graph describing apart of production activity of human operator

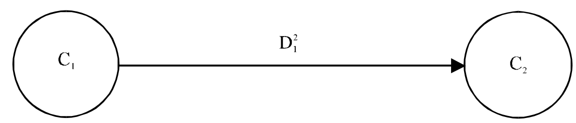


Fig. 2: Example of a graph illustrating the activities of human operator in an emergency situation

Table 1: Example of the table snippet of production rules corresponding to the vertices of the graph G (C, D)

| Vertex | Description |
|---|---|
| $C_9$ | If $X_{121}$<9 then $D_9^{10}$ |
| $C_{10}$ | If $_{153}$> 140 then $D_{10}^{11}$ |
| $C_{11}$ | If $X_{121}$<9 and $X_{151}$> 3140 then $D_{11}^{12}$ |

Table 2: Example of table snippet of a set of actions corresponding to the branches of the graph G (C, D)

| Branches | Description |
|---|---|
| $D_9^{10}$ | $Y_{138} = 1$; $X_{153} = (140; 150)$; $Y_{138} = 0$ |
| $D_{10}^{11}$ | $Y_{134} = 1$; $X_{153} = 0$; $\kappa T3 = 1$;$Y_{134} = 0$ |
| $D_{11}^{12}$ | $Y_{112} = 1$; $X_{111} = 1$; $X_{172} = (60; 65)$; $X_{111} = 0$; $\kappa T4 = 1$; $Y_{112} = 0$ |

Table 3: Example of table snippet of DDF values and positions of controls at time zero

| Element | Value |
|---|---|
| $X_{411}$ | 0 |
| $X_{421}$ | 25 |
| $X_{431}$ | 0 |
| $X_{432}$ | 0 |

- Regulators
- Button

In Table 1 and 2, snippets of production rules and set of actions corresponding to the vertices and branches are as follows.

To describe the initial state of the technical system, we used the table of DDF values as show in Table 3 and positions of controls at time zero.

When modeling operator activity in an emergency mode of TS operation, we use the machine like the one above to describe individual legends stipulated in the plan of emergency localization (index L). In general, the graph that describes the activities of human operator in any given emergency situationis as follows (Fig. 2).

Table 4: Compliance of emergency notification devices on the operator panel and notation for mathematical model elements

| Elements | Description | Elements | Description |
|---|---|---|---|
| $X_{L1}$ | Failure warning for mixer in machine 26 | $Y_{L1}$ | Callrepairteam |
| $X_{L2}$ | Failure warning for isolation valve κ12 | $Y_{L2}$ | Callemergency service |
| $X_{L4}$ | Warning for loss-of-piping integrity κ3 | $Y_{L3}$ | Switching to manual control mode |
| $X_{L7}$ | Excessive temperature in machine 26 | $Y_{L4}$ | Emergency shutdown of all workshop systems |
| $X_{L8}$ | APCS failure | $Y_{L5}$ | Callrescueservice |
| $X_{L10}$ | Smoke pollution in the workshop | | |

Table 5: Production rules and a set of actions

| Rules | Actions | Description |
|---|---|---|
| $C_1$ | If $X_{L1} = 1$ TO $D_1^2$ | Mixer engine failure |
| $D_1^2$ | $Y_{131} = 0$; $Y_{132} = 0$; $Y_{133} = 0$; $Y_{134} = 0$; $Y_{135} = 0$; $Y_{136} = 0$; $Y_{121} = Y_{121}+20\%$; $Y_{L1} = 1$ | |
| $C_2$ | Making decision on possibility of further operation of TS | |
| $C_1$ | If $X_{L8} = 1$ then $D_1^2$ | APCS failure |
| $D_1^2$ | $Y_{L3} = 1$; $Y_{L2} = 1$; $Y_{L1} = 1$ | |
| $C_2$ | Making decision on possibility of further operation of TS | |
| $C_1$ | If $X_{L10} = 1$ then $D_1^2$ | Smoke pollution in the workshop |
| $D_1^2$ | $Y_{L4} = 1$; $Y_{L5} = 1$; $Y_{L2} = 1$; $Y_{L1} = 1$ | |
| $C_2$ | Making decision on possibility of further operation of TS | |

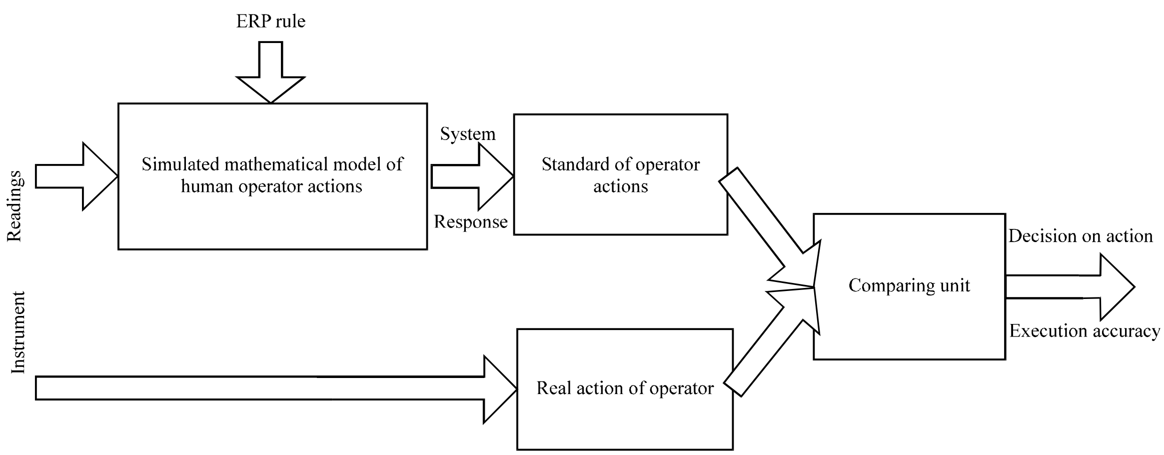


Fig. 3: Schematic diagram of a training simulator

Vertex $C_1$ of the graph is assigned a production rule allowing the operator to display the values of DDF of a virtual remote control to identify an emergency situation and make a decision on the necessary action to its localization. Branch $D_1^2$ of the graph is assigned a set of actions for the localization of an emergency situation in accordance with the ERS. Vertex $C_2$ of the graph corresponds to the location of the emergency situation which requires TS personnel to make a decision on further operation of the technical system in a real production process.

The fragment of the compliance table of emergency notification devices on the operator panel and notation for mathematical model elements is shown in Table 4.

The example of table snippet of production rules and a set of actions for emergency situations is given in Table 5.

We propose to use the presented models of operator's activities in routine and emergency operation modes in a training simulator, a schematic diagram of which is shown in Fig. 3.

Here, the input parameters for the application that processes simulation mathematical model of human operator are instrument readings of a training simulator. Based on these readings, the system generates "reference operator action", i.e., the action that the operator must perform. During operation on the simulator the operator actions are compared with the 'reference' ones and the decision on the correctness of these actions is made.

Training simulators can be actively used, not only for education or training of maintenance personnel of industrial enterprises but also in training of engineering students in the study of disciplines of specialization. Compliance of virtual simulators with industrial installations and technical systems can significantly increase the level of personnel skills; it can be used in educational institutions to train specialists skilled in management of industrial systems. This is particularly relevant for inflammable and explosive industries, where there is no possibility of training on "pilot" plants. Operator training in emergency situations on training simulators helps to acquire practical skills required for the localization of defects of the process equipment and the prevention of accidents and disasters.

## ALGORITHM FOR DESIGNING TRAINING SIMULATORS FOR OPERATORS OF TECHNICAL SYSTEMS

Algorithm for designing a training simulator is presented in a functional diagram in IDEF0 notation (Fig. 4) which includes the following processes (Krasnynskiy *et al*., 2012; Barinov *et al*., 2012; Ostroukh and Nikolaev, 2013a, b; Vladimirovich *et al*., 2012a, b; 2013a, b, 2014; Vladimirovich and Evgenievna, 2011; Vladimirovich and Vladimorov, 2012; Ismoilov *et al*., 2013).

**Development of the structure of a training simulator:** Initially, the input data for the first stage is the object of study.

The object of study is a technical system formed by the set of process steps required to manufacture products in the given quantities and assortments under control of a human operator. At this stage, the structure of the core modules of the simulator is determined; it is composed of training and maintenance categories. Training modules are those which used directly in training (training simulator, system of testing, information-reference module). Service modules are not involved directly into the training process; they perform the functions of storage, analysis, processing of information flows of a training simulator (preset module, database module, network interaction module).

It is desirable to start the development of a module with highlighting the main objectives of a training simulator. This study is performed by the analytical group. In general, the main objectives of a training simulator are teaching theoretical knowledge and developing practical skills as well as progress check. Further on, it is necessary to determine the composition of the modules and form the information flow structure that is expedient to create in MS VISIO editor. It should be taken into account that further development of the training simulator might lead to changes in the composition of modules and their relations.

**Analysis of regulatory documents:** The design of a training simulator is based on regulatory documents. Manufacturing instructions and emergency response plan are the main regulatory documents governing the production process, the sequence of process steps and the work of operators for chemical industry.

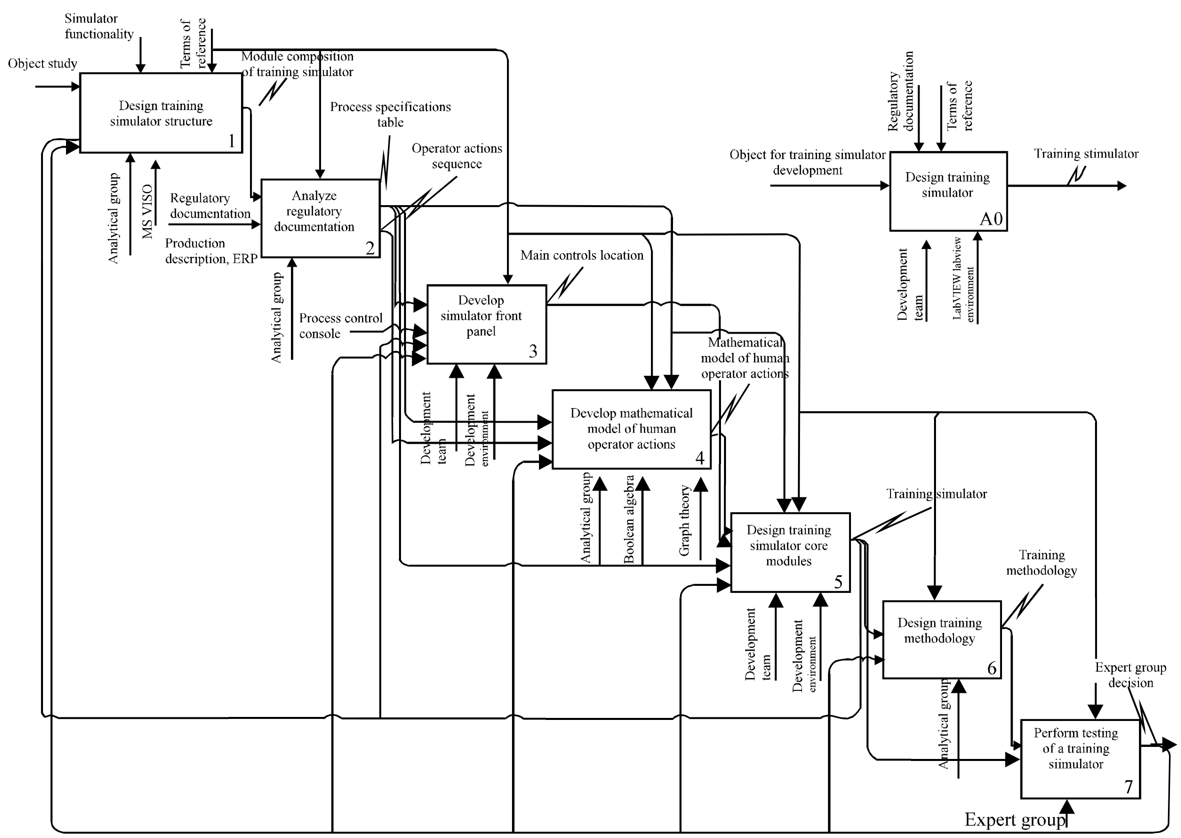


Fig. 4: Algorithm for design of a training simulator

In normal operation, when the Manufacturing Process (MP) goes in the routine mode, the operator is guided by manufacturing instructions. Therefore, the developer of a training simulator has to retrieve information for hardware composition of a technical system, material flows, time and material characteristics of production. Also, it is necessary to consider both main and auxiliary stages of the production process. All selected characteristics must be entered in the summary table.

ERP is the basis for the application of the simulator for training in emergency situations. The analysis and selection of the most common failures of process equipment, emergency situations which can lead to human casualties and environmental disasters are implemented on the basis of ERP in consultation with the heads of repair and rescue services of the company. This is necessary for the formation of legends of possible emergency situations that will be implemented in a training simulator. The ERP provides the necessary sequence of actions to be taken by an operator to minimize the consequences of failure development. Also, the analysis of regulatory documents is included in the theoretical part of operators' training which helps to become familiar with the most important parts of the production process.

**Design of the simulator front panel:** The front panel of the training simulator should be exactly the same as the control panel of TS. The front panel of the simulator is supposed to be equipped with the control board and the simulator controls. Thus, it is necessary to apply ergonomic design principles and position the elements in such a way so as to minimize the introduced changes. Since, modern training simulators are multiple user systems, it is necessary to provide work stations for all operators involved in the TS management as well as a work station for the instructor complemented with an additional tab including a list of legends of emergency situations.

It is advisable to start the development of a module with designing the structure of the TS control panel. It is necessary to determine on what basis, the controls are divided on the panel. This can be done by stages or by element type; it is also important to consider that certain electronic equipment can be installed on site. Next one needs to identify the main controls and data display facilities. This stage is performed by a group of developers. The position and type of controls as well as DDF are required to create a virtual console, similar to the TS control panel.

The background image of the simulator front panel simulates the static elements of the real control panel of TS. In some cases, when controls or DDF are installed on site, it is expedient to provide a schematic representation of their location in the background image. The last stage of the development of the front panel of the training simulator is the installation of controls and DDF on the front panel of the simulator.

**Development of the mathematical model of human operator:** It is advisable to begin this process by examining the sequence of operator actions, obtained at the analysis stage of regulatory documents. To describe a mathematical model of human operator actions, we propose to use a system of production rules and graph theory.

**Development of the core modules of the training simulator:** The composition of modules was determined at the design stage of the training simulator structure as represented in (Fig. 5). The core modules of the training simulator include:

- **Information-reference module:** It is advisable to begin software implementation of the training simulator modules with information-reference module. This is due to the primarily fact that the underlying data for the creation of information-reference module is taken from the standard documentation (manufacturing instructions, ERP)

The development of information-reference module requires determining the main stages of training. In general, they can be reduced to practical and theoretical stages. It is expedient to divide information-reference module into three main parts:

- Set of documentation for theoretical training
- Set of documentation for practical training
- Database for storing information

The process of creating a set of documents for theoretical training begins with sample materials from regulatory documents. When working with performance specification, it is necessary to allocate materials directly related to production technology and hardware design of TS. In the analysis of ERP, it is necessary to form groups of emergency situations by similar parameters.

The selected materials should be divided into groups and training sets should be created, on production technology, hardware design of TS, operator actions in regular and emergency modes of operation. When forming materials on production technology, the data is used from the manufacturing instructions. They must explicitly describe the process in general, the process steps and the operation of each of the machines.

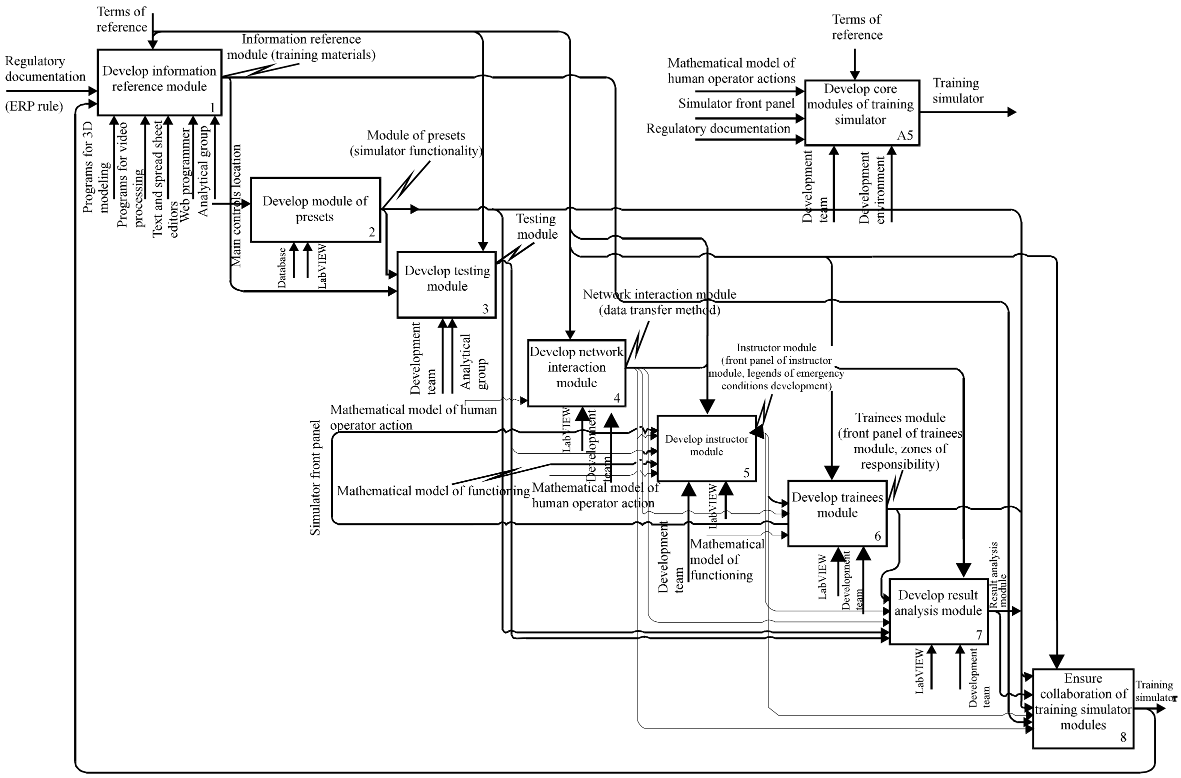


Fig. 5: Core modules of training simulator

When developing materials for hardware design of TS, it is necessary to give an idea of the basic and auxiliary equipment used in the system are type, quantity and modes. One must describe in detail the layout of controls and data display facilities located both on the control panel and on site. In the process of developing materials for actions in emergency situations, it is necessary to consult experts from repair teams and technicians. All possible emergency situations must be divided into groups according to the method of response or the mechanisms of occurrence and there are some common approaches to the actions to eliminate accidents. Another step in the creation of documents for theoretical training is to develop training videos as well as 3-D models. As part of this step, it is necessary to create training videos featuring operator working at the control panel in routine and emergency modes of operation. They focus on the most common failures and ways to address them. The development of 3-D visualization of the object can help trainees to get the prior knowledge of the technical system and production facility. The solution to this problem is proposed by creating interactive 3-D models using game "engines" that enable to move a simulated object, study its structure and location of certain nodes.

After all the necessary documents on theoretical training have been developed and they are combined in a single set.

The development of the set of documents for practical training consists of the following stages:

- Development of programmer's guide
- Development of trainee's guide
- Development of instructor's guide
- Development of screen tips set
- Collecting the set of documents for practical training

Based on the characteristics of chemical production involving frequent changes of the product range and consequently the minor changes of the process, it is necessary to provide the modular principle of creating a training simulator. The simulator, if required, should be easy to rebuild. Companies often have a staff of programmers who can upgrade the simulator. On this basis, the documents should include programmer's guide. It should describe the structure of the simulator, core modules, the principles of the simulator as well as the ways to change the simulator. Also, programmer's guide should describe how the simulator database is filled. Trainee's guide includes a description of the simulator opportunities, principles of its operation, the work of an operator in the routine and emergency modes of operation, the description of a real control panel, the differences between the real and virtual control panels as well as the main stages of training. Instructor's guide is a detailed description of the methodology of operators' training; trainee's guide should be integrated in full and supplemented with the features of the instructor's work, i.e., it must include a description of emergency situations, the rules of downloading and using the legends of emergency situations.

The development of a screen tips set is based on the analysis of the simulator front panel as well as regulatory documents. In the early stages of the training process, all the events displayed on the virtual console should be explainedin screen tips. For example, if the machine is overheated the light indicator signals danger and a screen tip describing the actions required to reduce the temperature of the medium in the machine is supposed to pop up.

When sets of documents for theoretical and practical training stages are formed, it is necessary to develop a database to store information and combine everything in a single module which can be easily accessed. When creating a database (DB), it should be remembered that information necessary for the development of the subsequent modules will be stored in the database.

- **Module of presets:** The next module which should be developed is the module of presets. It is responsible for the possibility of the initial choice of the basic parameters of training. The first step is to analyze the options for training that will be implemented in the simulator. For example, we can offer the following training options; theoretical training, initial training on the simulator (with popup messages), practical training on the simulator, testing, etc. All data on the progress of training must be recorded in the database

Further on, it is necessary to develop a software implementation of a simulator selection as well as that of an instructor who conducts the training. It is convenient to implement the system of selection through a web-based interface with a set of scripts to select the desired data from the database. This set of scripts is also convenient for the procedures of selecting a trainee, a simulator mode and the current task for the trainee. The development team fills in the table of simulator modes in the database since it is not changed in operation.

- **Testing module:** The development of testing module requires materials designed to create the information-reference module. The first step here is to develop a structure of tests. At this stage one must determine which test items and how many of them will be offered to trainees to check their progress. An instructional group performs this stage given the characteristics of production process as well as the recommendations of the department of technical training. The structure of the test items should include questions on all areas of expertise offered by the operator in training, production technology, hardware design of TS, work in emergency situations, etc. Testing of personnel involves assessment of skills gained in training, so the instructional group should develop a scale to assess the operator skills developed through theoretical stage of training

The final stage in the development of the module is the creation of testing system. It is designed by the development team with the use of web-programming (php, HTML). Testing module must be integrated into the simulator and combined with the database of test tasks.

- **Network interaction module:** This module is created by the development team and used to connect separate objects of the simulator; it is also used to organize work with the simulator via., the internet. It is advisable to begin the development of this module with the definition of network interaction objects. Based on the characteristics of each particular simulator, the list of the objects can vary but in general it consists of the following objects:
  - Instructor's workplace
  - Operators' workstations
  - Database server
  - WEB-server

Based on these network interaction objects, one can define the links between them as well as data sets and the direction of information flow which will be implemented in the training simulator. It is necessary to ensure that the number and direction of the subsequent modules can vary. After creating complete data flow diagrams in the simulator, it is necessary to determine data transfer technology. It ensures trouble-free operation of the simulator. After determining the network interaction technology, one can begin to develop software for the network interaction module. The data to be transmitted using the network interaction module should be stored in the database.

- **Instructor module:** There are two ways of constructing the training simulator:

- The module of instructor and trainees consists of the front panel with the network interaction module, i.e., when an operator or instructor takes an action the information on it is immediately transmitted to the server, where it is processed and server gives response to this action
- The instructor module and the server are combined; thus, the instructor's actions are processed immediately and the trainees' actions are also transmitted to the server for processing

The main difference between the front panels of the instructor module and the trainee module is an extra set of tabs with legends of emergency situations; the set is designed after determining the list of emergency situations. If, it is decided to combine the server part with the instructor module, it is necessary to create software that implements the mathematical model (the activities of a human operator, the model of emergency situations, the operation model). Software is created by the development team in the LabVIEW programming environment. When you create the instructor module, it is necessary to develop scripts to communicate with the database. It is advisable to store data on the current state of DDF and controls in the database. This will prevent further problems when combining modules in the simulator.

- **Trainee modules:** In practice, the technical system is often managed by a group of operators rather than a single one. Therefore, for collaborative training of groups of operators, it is necessary divide the training simulator into areas of responsibility. The areas of responsibility are usually divided into stages. The procedure is described in the manufacturing instructions. Collaborative training of groups of operators involves in the appropriate amount of workstations. Further, it is necessary to develop scripts to communicate with the database

The work of modules should be organized as follows. When an operator performs an action, it is forwarded to the server; then, using mathematical model of human operator, the correctness of this action is analyzed and the information is transmitted to the trainee module. If the trainee tries to take the control action on the object which is not within the area of his/her responsibility, the action is not performed and added to the error log entry.

- **Result analysis module:** The final stage in the training of operators is the analysis of results. Since the trainee receives the necessary theoretical knowledge and practical skills, the analysis of the degree of preparedness must be conducted in two directions. The evaluation system of theoretical knowledge must be developed on the basis of the testing system. Admission of an operator to work on the simulator is performed by the instructor only after the trainee completed the test tasks on the theoretical course of study. Further, it is necessary to develop the evaluation system of practical skills. This stage is implemented on the basis of the training simulator through the controlling passage on the simulator. The controlling passage includes options to work in routine and emergency situations

The final stage in training is a decision on the admission of the operator to work on the manufacturing facility. Thus, it is necessary to develop the evaluation criteria for admission of the operator to work. The required level of theoretical knowledge and practical skills of an operator to work on the TS must be specified.The system should make recommendations to the instructor for further training of an operator in case of erroneous actions. This stage is implemented by the analytical group. Further, the development team creates software for the result analysis module.

- **Ensuring collaboration of training simulator modules:** After the modules have been developed, it is necessary to combine them into a single training simulator. Combining is performed by the development team. However, the modules are subject to change and development over time. After they have been combined, it is necessary to test the training simulator on working capacity. At this stage, the adequacy of the mathematical model is checked by the analytical group. If the mathematical model is found to be adequate, it is necessary to supplement the technical documentation and the information-reference module

**Development of training techniques:** After the core modules of the simulator have been created and combined into a single unit it is necessary to develop the methods of teaching staff using the training simulator. This methodology should be included into the technical documentation file which is supplied together with the training simulator. It is logical to develop the methodology of trainingin collaboration with the experts in the field of vocational training and technical experts from the developer's company as well as customer representatives.

Before designing, the methodology of operators' traininga common approach to the training process must be developed. Training techniques should be divided into theoretical and practical training. Within the theoretical training, an operator uses the information-reference module which contains information on production technology, hardware design, actions in routine and emergency modes of operation, etc. As part of the practical training, the training procedures must be developed. Training is made for regular and emergency modes of operation. Therefore, the methodology should include the basic stages of training and instructor recommendations. The instructor working procedure is developed by the instructional group taking into account the features of production industry. The methodology should include assessment scale of knowledge and skills of an operator as well as recommendations on the admission of the operator to work on TS. All recommendations are to be combined into a single methodology and included in the technical documentation of the training simulator.

**Training simulator testing:** Testing of the training simulator is performed by a group of experts. This should include third-party experts in the given field and representatives of the client company. Testing of the training simulator should be conducted in the presence of production technologist, mechanics, operators and production management staff. This stage involves verification of the adequacy of the mathematical model, the degree of similarity of the operator panel and the simulator panel, the compliance of the simulator capabilities with the requirements specification. Validation of the mathematical model is as follows; the operator performs an operation on the simulator and monitors the system response to this action. If the response of the system complies with the requirements of regulatory documents, it is concluded that the mathematical model is adequate. This procedure is repeated for all possible actions of the operators.

The developed algorithm of the training simulator design was used to create the simulator for training of chemical technological production operators at JSC "Pigment". It enables to study the process and control systems, receive practical skills while working with the technical system in regular operating conditions, acquire practical skills of work on prevention, localization and elimination of emergency situations and reduce the human impact on the reliability of the technical system.

## CONCLUSIONS

The presented statement of the problem of the training simulator design helps to create the desired composition and achieve the level of technical skills of system management in routine and emergency modes of operation on the basis of information-analytical TS Regulations. The mathematical models of human operators, managing the technical system of chemical production in routine and emergency modes of operation, have been developed.

The set of production rules and sequences of actions inspired the creation of the training simulator software modules providing the visualization of the technical system functioning, management and processing of information about the actions of the operator. We developed an algorithm for creating the training simulator and functional diagrams, describing the main stages of creating the training simulator.

The application of the modular principle of the training simulator design made it possible to increase the functionality of the created training simulator and reduce the development time on its software by 35-60% with its subsequent replication for industries with minor differences in the technology of production.

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