Simulation Environment for detailed simulation of Coal Mining in various types of Coal Seam

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***Abstract*—**One of a future developments of simulation is to create very detailed simulation models with wide application "from the box", with minimum involvement of simulationists and maximum involvement of field engineers. The article describes a new specialized library of simulation models of mining machinery for coal mining in flat-lying coal seam. The library is based on the own visual interactive discrete simulation environment of technological processes. A number of models of coal-mining in flat-lying coal seam developed with using of the specialized library are presented. These libraries allow creating complex simulation models fast, interactively, and using them in all kinds of simulation tasks: "what-if" ones, presentation, training, hardware development with all "in-the-loop" manners.

***Keywords*—**Coal mining, hardware-in-the-loop, simulation environment, visual interactive simulation.

I. Introduction

IT is specified in different investigations, that situation in different areas of underground mining that requires automatic control (e.g. coal mining) is that resources become less available, and harder to be extracted.

The technologies of coal mining are well-known. Today mine uses mining machinery for mining, transportation, roof support, etc. How exactly will these machines function? What additional machines will they require? What is the "total cost ownership" of machines installed in mine? Will big universal machines be more appropriate rather than a lot of small, specialized mechanisms? What will the cost of a final product? These tasks can be solved with methods of computer-based simulation of coal mining process. These simulation tasks are known as "what-if" ones.

The problem of the particular mining installation is that it is effective in terms of minimum costs and maximum productivity only if it is correctly planned. Usually big layout has many components from different vendors interconnected. That makes it hard or, even, impossible to predict the exact effectiveness. This situation gets worse if there is also a requirement to create new components for management of a part of such layout. In all these cases, computer-based simulation can be used to solve these problems.

Because of the importance of these problems, there are a large number of papers on the use of simulation in the development and optimization of coal mining systems [1]–[8]. There are also a large number of simulation tools both universal simulation systems and specialized systems and packages for simulation of coal mining systems.

While lots of simulation tools solve the "what-if" problem, there is significantly less amount of such tools that allow building integrated simulation for mines hardware development.

A number of models for various technologies of coal mining were developed with the help of own simulation system. Technologies of coal mining are presented in section 2. Brief description of the simulation system is presented in section 3. Sections 4, 5, 6 contain description of a specialized library and examples of the models.

These models are used for developing of process control systems for underground coal mines in Kuznetsk Coal Basin (Russia, Western Siberia). The models include both "what-if" tasks and development of hardware for control systems.

II. Technologies of Coal Mining

There are several well-known technologies of coal mining.

A. Longwall mining

Longwall mining system is a highly-automated, very powerful and productive way to mine a product. It is most-widely applied around the world. Its main advantage is that it leaves almost no product inside mines. But it is limited with the depth of the mine (measured from the surface). Also it is applied in relatively flat areas of coal, from 0.8 up to 10 meters high, from 150 to 450 meters face, and up to 4 kilometers in depth.

Longwall system consists at least of armored face conveyor (AFC), a shearer, and roof support sections. The AFC is connected to outbound belt conveyor. The shearer cuts the product from coal seam face, in a series of passes along the

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AFC. The AFC delivers product to the belt conveyor connected. The roof support moves itself and the AFC, pushing it (and itself) forward with hydraulics.

One of the problems of longwall mining is roof caving. This can lead to serious environmental problems.

Another problem is that longwall requires significant amount of work to be done before its massive equipment is installed in production. This work must be planned as well.

One more problem includes a functioning of specialized signaling tools and control systems that monitor a marsh gas level, dust level, ventilation facilities. If any of parameters monitored systems exceed certain save value, the mining usually stops. The reason is usually not obvious for personnel in mines (gas has no smell, dust does not look dangerous) and it can result in turning off the monitoring systems by mine personnel in order to increase the mining. Simulation can help decide what sufficient level of ventilation will guarantee safe and efficiency.

B. Highwall mining

In case when it is impossible to mine a product with longwall or other systems, a relatively new technology can be applied, named Highwall. This is a shearer tool, mounted on the top of the chain of special sections. These sections can be updated to each other, making a long (up to 300 meters) support chain for a shearer. Each section can transport the product developed by shearer to the end of a sections chain.

The shearer and the chain of sections cut the product (coal) from the very thin and curved seams. This is the main advantage of the Highwall technology.

C. Coal mining of flat-laying coal seam

This approach uses a number of front-cutting mining machines that cut a coal on a special scheme, and a number of self-moving wagons that move a coal from mining machines to the storage area. It solves the same problem as highwall mining, but requires no specialized equipment. Also this approach can be used in deep mining.

III. The Simulation System

A visual interactive Manufacturing and Transportation Simulation System (MTSS) is developed at Design Technological Institute of Digital Techniques of Siberian Branch of the Russian Academy of Sciences (DTIDT) [9], [10]. It is a process-oriented discrete simulation system intended to the development and execution of models of technological processes.

MTSS is a set of program interfaces for creating elementary models and for forming complex models from them. The elementary model is a ready-to-use submodel of an equipment unit with capability of low-level control for it.

The elementary model consists of the following parts:

- Two-dimensional and three-dimensional graphic images.
- Input and output parameters.
- Functionality algorithm describing dependence between parameters.
- States which the elementary model can reach during the simulation process.
- Control commands defining switching process between elementary models states.

A model in MTSS is created by graphical connection of images of elementary models.

MTSS is also a tool for running of complex models built from elementary models. The running model performs the movement of the model time and visualization. Statistics is collected as well. Statistics are available as a short overview when model runs, and more statistics are available after model completion.

This simulation system is effective in solving the task for the rapid creation of correct simulation model by mining engineers. Usually engineers have not enough qualification to create a simulation models in details, but they know how to connect correctly elementary models to create the required topology.

MTSS uses the 2D as the graphical editor and 2D, 3D for the visualization of model running. Such approach seems more natural for mining engineers, when all installations and machines appear first on 2D plans. 3D is more useful for visualizing complex vertical movement.

Process control systems often have two levels: the low level of equipment and simple control logic and the upper level of complex control of production. Therefore one of the distinguishing features of MTSS is a separation of the logic of simulation model into two parts: low-level logic and an upper level logic.

Such separation allows us not only to correspond to the usual structure of the process control systems but to use such models for embedding them into actual process control systems in the following ways: to emulate equipment, to simulate upper level logic, and to send commands to actual process control system for debugging and testing. This separation into upper and lower logics allows also organizing a switch between various implementations of the decomposition. It allows coexisting simulation of upper level logic and a proxy that allows communicating with the upper level logic of actual process control system.

The model of coal mining can communicate with a new process control system developed in DTIDT, to be a source of input signals, emulate equipment, test actual control program with simultaneous visualization of overall process of mining.

This allows debugging and tuning of a new process control system in accordance with behavior of simulated system, even allows simulating various accidents. This allows minimizing time and costs on site for commissioning.

IV. Simulation of Coal Mining in Flat-Lying Coal Seam

A specialized library of simulation models of mining machines for coal mining was developed. This library is a part of MTSS and its prime goal is to simulate interactively and visualize various aspects of coal mining in flat-lying coal seam. The library consists of new elementary models of:

- Highwall mining system.
- Longwall mining system.
- Coal seam.
- Mining machines.
- Self-moving coal wagon.
- Storage area.

The library contains also a simulation model of a flat-lying coal seam. This model is a source of the product in a simulation model, while storage area is a consumer of a product. The product itself is coal.

These new components can communicate with existing libraries of MTSS [11]–[13] which simulate mines subsystems like:

- Belt conveyor subsystem.
- Power supply subsystem.
- Ventilation subsystem.

A simulation model of coal mining subsystem in a flat-lying coal seam was developed using the library of mining machines. Fig. 1 contains a sample layout in the simulation model of the flat-lying coal seam (2D and 3D view combined in different views).

The simulation model built from the content of the library will simulate movement of all mobile objects of the model. Both 2D (top view) and 3D visualization are available. Statistical data is also collected.

Fig. 2 shows a sample layout in another simulation model of the flat-lying coal seam. Main window consists of 6 areas:

1) 2D top view. It contains: main mine, side mines. The origin coordinates is at the left top corner of this view.
2) 3D view. On Fig. 2 there is a view from point 3.
3) Point of view for the 3D.
4) Parameters of a simulation model.
5) Specialized view for fast navigation in simulation model.
6) Settings for the time start, time end and current model time.

The model was created to visualize a new technology of coal-mining in flat-lying coal seam. This simulation model also allows receiving statistical results for usage of this technology.

As patent describes, mining is done by frontal winning machine, paired with self-moving coal wagons. Patent describes the directions of cut of a flat-lying coal seam for the frontal winning machine. Simulation model of this process allows visualizing the process described.

V. Simulation of Longwall Mining

For detailed simulation of longwall mining system we finished with next decomposition:

- Armored Face Conveyor (AFC).
- Shearer.
- Roof support sections.

Simulation model for longwall mining system can function if it is connected (in terms of MTSS) with belt conveyor simulation model.

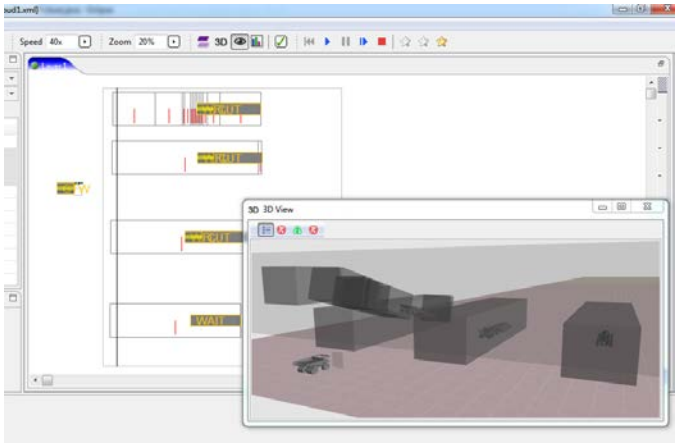

Fig. 1 mapping the simulation model of coal mining
in flat-lying coal seam (4 mining machines and 4 self-moving coal wagons)

Also this model requires a power supply chain, that means it will require a wire and power transformer facility model "connected" to it (in terms of MTSS).

The goal of creation of simulation of longwall mining system is:

- To create a smart, real-looking source of a product for whole mines simulation system. Our organization is not in charge for the control systems for longwall automation, therefore the primary goal is only to "produce" the product in simulation model.
- To investigate the possible pitfalls and bottlenecks of using different longwall configurations for different coal layers. In the other words, to do simulation research of longwall system itself, detached from the rest of mines simulation system.

The algorithm for longwall mining system simulation was done closer to the control algorithms of the real longwall mining system. Today our simulation contains one-way and two-way shearing (besides there are more shearing technics combined from these two).

Fig. 3 shows the simplest two-way shearing. In this case, shearer will mine the product while it moves in both directions. Roof support section will move itself forward (and AFC too) each time shearer passed it. Then it will advance the simulation to the time defined, and then simulate the roof support sections movement. The amount of a product mined will be moved to the AFC that will deliver it to the belt conveyor connected. Task will repeat these steps until the "done" or "postpone" conditions will be achieved.

Task is "done" when shearer reaches the end of an AFC line. Task is "postponed" when belt conveyor is overloaded and cannot accept the next portion of product or gas level is not safe.

During any of these steps, the simulation model of flat-lying coal seam simulates roof fall (behind the roof support) and gas level increasing. Also ventilation simulated in a simple manner (remove gas from working area, with some defined speed).

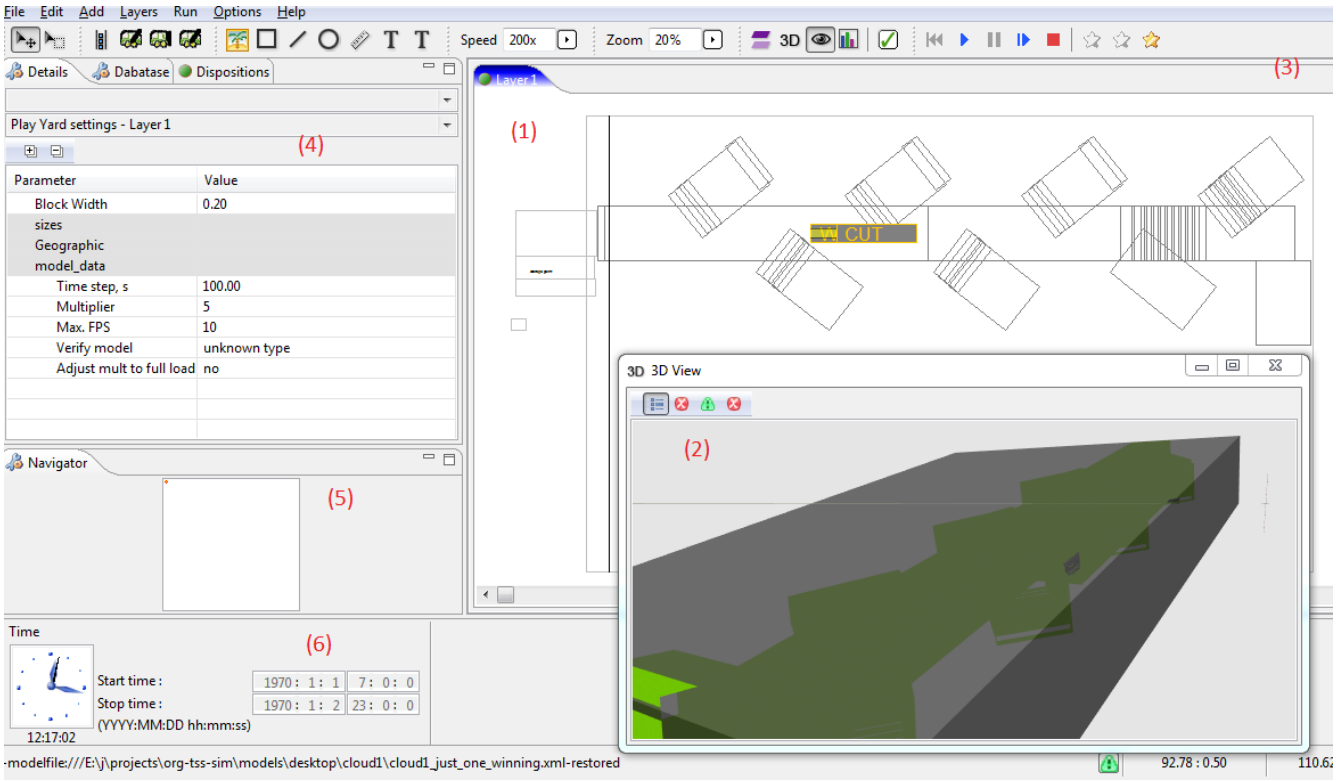

Fig. 2 mapping the main window of MTSS system while running of simulation model of coal mining in flat-lying coal seam

One-way shearing is to shear the product only in one direction. After shearing path is over, shearer will be returned to its starting position, and only then all roof supports advanced to the new position simultaneously.

In most cases, there is no need to simulate in details any technology like longwall or flat-lying coal mining, if it is used just as a source of a product for belt conveyor system, for example. All that is really needed in such cases are:

- To define that longwall or flat-lying coal mining is a source of a product for a big mining system like conveyor.
- To know the performance of the longwall coal mining during some time period (working day, 8-hours time interval, 1-hour time interval). Note that the emergency stops (like gas or coal dust) are already included in this statistical data.

The goals of simulation are:

- To predict how longwall or flat-lying coal seam mining automation will behave in details (i.e. movement of its parts depending on various situations in mines).
- To make a detailed visualization of mining process.
- To define how this mining will impact to the overall performance of the mines.
- To define scenarios of broken or temporarily inaccessible parts interactively [14].

The achievement of these goals requires a detailed decomposition of common longwall (or highwall) mining system and a detailed visualization of all its parts.

VI. Integrated Model (Case Study)

Fig. 4 shows one of the models used in our experiment which contains the following subsystems: belt conveyors, energy supply chains, longwall simulation. Belt conveyors can be in one of "in-loop" state connected to the real hardware or can be managed by simulation of the control hardware program. Longwall simulation (at right-hand side on Fig. 4) is for a detailed simulation of the processes in this type mining: gas level increasing, broken hardware i.e. factors that can lead to unpredicted behavior of common mines system. Such model can be used while examining the reaction of hardware when conveyor needs to be stopped or started.

Fig. 5 shows the hardware installation for the real "hardware-in-the-loop" with the simulation model similar to presented on Fig. 4 and the real control hardware for managing one of the belt conveyors presented in the model. The other conveyors are managed by simulation programs for these belt conveyors simulation models.

VII. Conclusion

Detailed simulation of longwall system, connected with detailed simulation of flat-lying coal seam (or multiple flat-lying coal seams), will allow creating of simulation that will not only predict the behavior of big underground mining system, but also simulation of land subsidence while using longwall, especially with very heavy longwall systems that can cut 10-meters-high coal seams.

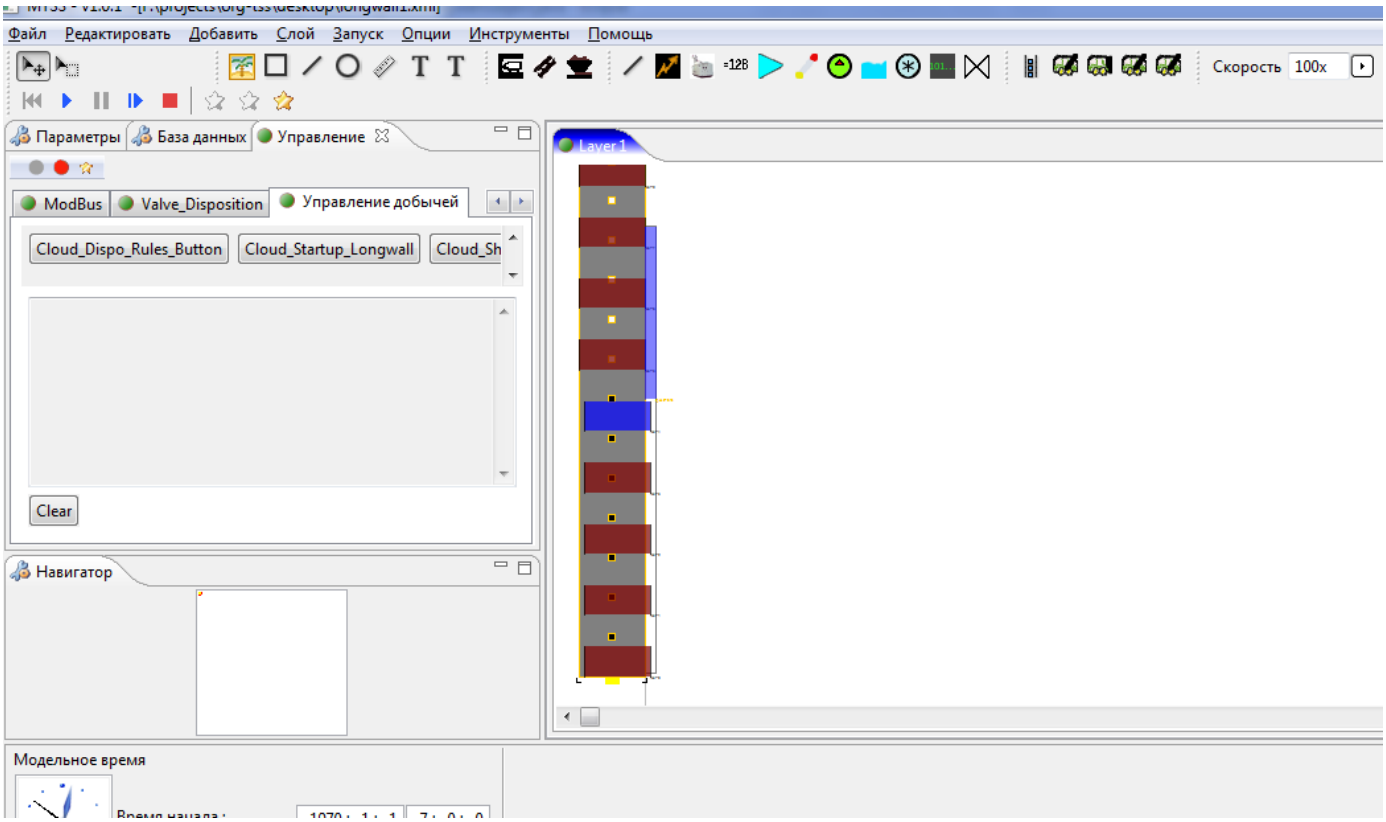

Fig. 3 mapping longwall shearer and roof support in two-way shearing

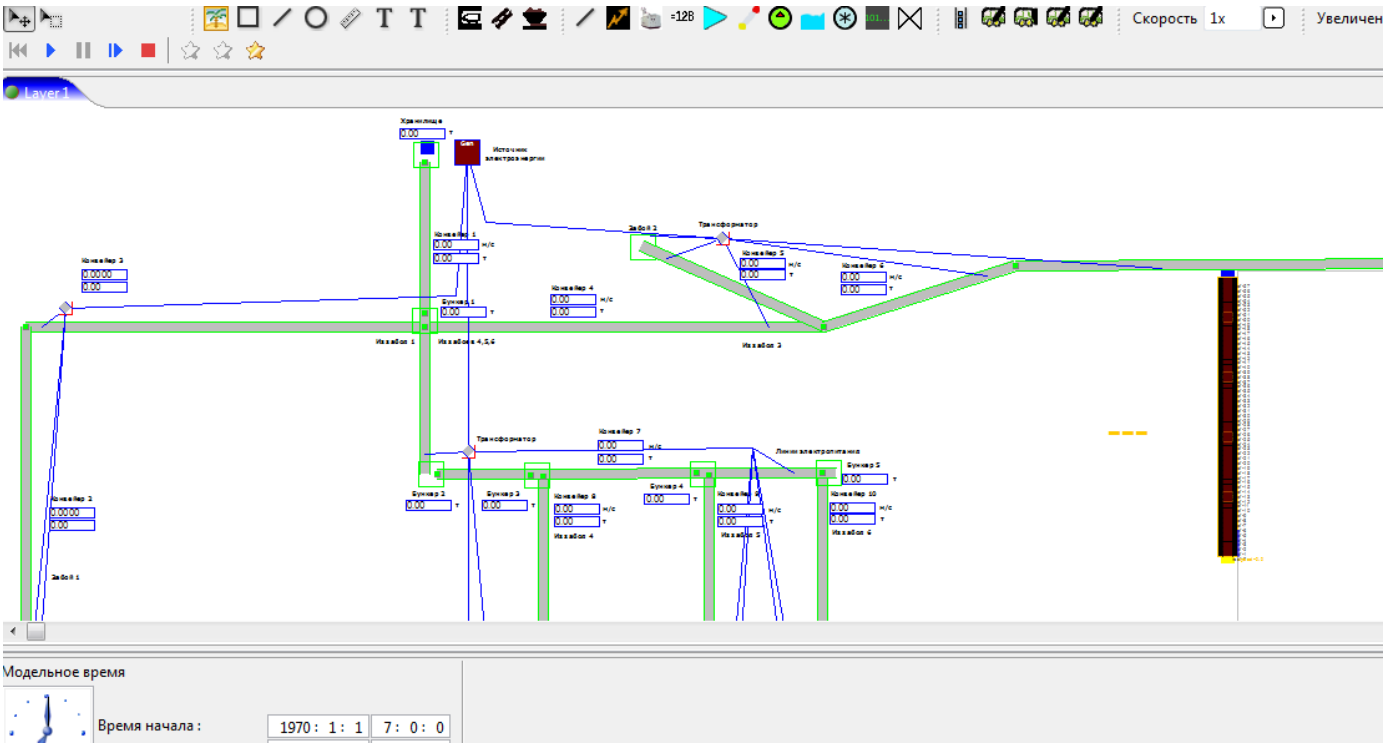

Fig. 4 mapping multiple subsystems in one simulation model

Simulation system MTSS can be used not only for simulation of existing coal mining techniques but also for perspective robotized techniques.

The library of elemental models is still growing. And now it is possible to create detailed simulation models of underground mining facilities, including belt conveyor systems, power supply, ventilation, and various coal face models.

Such simulation models can be used both in solving "what-if" tasks and in hardware development for control systems.

Fig. 5 mapping belt conveyor controlling hardware
connected to the simulation model of whole mines factory

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