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Simulator for training mining locomotive drivers

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Abstract

The training of mining locomotive drivers using simulators will increase the efficiency and intensity of training. Due to this, a decrease in financial and time expenditures for training a driver, an increase in the safety and productivity of his labour will be achieved. The number of errors in the work and damage to equipment, which are sometimes caused by the driver's inexperience, will be reduced. The mining train driver's simulator is manufactured as an autonomous training tool with the trainee immersion in a virtual environment that is as close as possible to a real working environment and is a training complex consisting of hardware and software. The software simulates the operation of all locomotive systems, mining sidings infrastructure and an interactive 3D panorama of the environment. In the driver's cabin of a mining locomotive, a real working environment is reproduced, control, alarm and indication elements of the locomotive, as well as other equipment of a real cabin necessary for performing all technological operations. Training complexes will never replace real experience in the workplace, but they can quickly increase the qualifications of trainees, help them develop the skills of acting in non-standard and emergency situations, which is extremely difficult in real work conditions.

1. Introduction

The use of information technologies in the field of training makes it possible to increase the efficiency, intensity of training, reduce the time and cost of training specialists. This is achieved due to the training in a virtual environment as close as possible to the real one (**Alfieri et al., 2020; Grube et al., 2011**). In recent decades, based on IT technologies, work environment simulators have been widely used in many areas of human activity, including in solving such important tasks as training, retraining and certification of specialists (**Nikitenko and Shvets, 2020; Radu et al., 2020**).

Effective training of mining locomotive operators is an important task for many mines around the world (**URL1, URL2, URL3; Ding 2010**). The training of

qualified drivers is extremely important for the successful operation and development of the mining industry (**Siahuei et al., 2021; Zhu et al., 2021**). World experience shows a constant growth in the use of simulators in the process of training, retraining and certification of drivers (**Alfieri et al., 2020; Naweed, 2014**). At the initial stage of training with the use of the simulator, the future driver receives not only theoretical, but also initial practical skills for future work (**Ogawa et al., 2011; Yin et al., 2016; Zhang et al., 2016; Zhelieznov et al., 2019**). Research shows that drivers who have been trained maintain higher levels of performance than those who have not received similar training (**Sharma et al., 2014; Strößenreuther and Halbach, 2005; Thorslund et al., 2019**).

Operating a locomotive in a constantly changing mine environment requires skills acquired during intensive training (**Akulov et al., 2017a, 2017b**). The fastest and most effective way to achieve this purpose is to train

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drivers using simulators. Locomotive simulators use sophisticated technologies to simulate the operation of equipment and a changing environment, as well as intensive training methods, which allow for an increase in operating efficiency, productivity and safety of train drivers (**Rentzsch et al., 2009; Tartakovskyi et al., 2016**).

The main purpose of this project is to create a simulator for training a mining locomotive driver in order to increase the efficiency and intensity of training (**Akulov et al., 2017a, 2017b; Akulov et al., 2014**). Due to this, a decrease in financial and time expenditures for training a driver, an increase in the safety and productivity of his labour will be achieved. The number of errors in the work and damage to equipment, which are sometimes caused by the driver's inexperience will be reduced (**Sharma et al., 2014; Sovička et al., 2017; Ding, 2010**).

2. Overview of technical characteristics of training simulators for locomotive drivers

The simulator, consisting of hardware and software, is a sophisticated training complex (**Alfieri et al., 2020; Naweed, 2014; Sovička et al., 2017**). If for each new type of self-propelled rolling stock the hardware has to be redone practically from scratch, then the software of simulators for various locomotive types can and should ensure reuse within acceptable limits. Indeed, different locomotive and multiple unit series have different control panels, their control elements are functionally similar, but structurally different. Thus, for the simulators designed for different types and series of locomotives, the hardware reuse is practically impossible. As for the software part, which includes a train model, a movement section model, a train situation control model, a locomotive system operation model, etc., many models can be reused here with minor changes or without changes. Such an approach to the development and manufacture of new training simulators for train drivers has significantly reduced the time for manufacturing and commissioning (**Akulov et al., 2017a, 2017b; Akulov et al., 2014**).

Figure 1 shows a diagram of the software part of the simulator. The software part is divided into modules made as separate programs. These programs have a functional part and a client part designed to exchange data with other modules through the server.

The developed structure of the software part of the simulator consists of the following functional parts:
- Server – designed to control data exchange between clients and manage their work.
- Clients – designed to perform individual software functions of the simulator:
  - Train module – designed to simulate the train movement along a section, simulate internal dy-
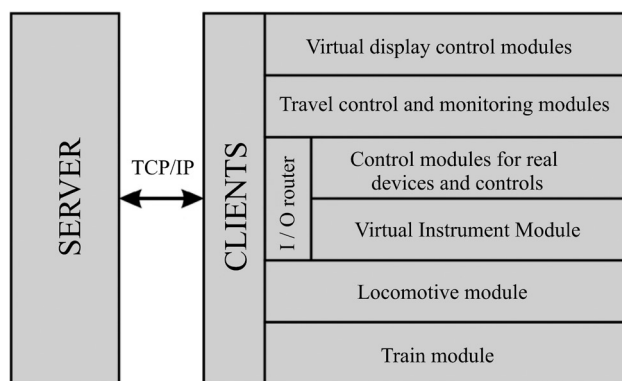

Figure 1: Scheme of the software part of the simulator

namic processes of interaction between train crews and calculate the car stability indicators;
- Locomotive module – designed to simulate the operation of the control, traction, braking systems and the locomotive cooling system;
- I/O router – designed to control the data exchange between real and virtual devices, control and indication elements of the driver's desk with other modules;
- Travel control and monitoring module – designed for preparing and storing a database of movement sections, characteristics of locomotives and cars, preparing a travel task, controlling a train situation during a travel, storing and analysing travel results;
- Section panorama control module – designed to control the display of the section panorama, signaling objects, train situation and weather conditions of the travel.

When loading the software part of the simulator in automatic mode, the server is first loaded, then all clients are loaded in turn and connected to the server. As soon as all clients establish a connection to the server, a connection check is performed between them, and the software part goes into operational mode.

Such a structure of the simulator software makes it quite easy to switch from one type or series of locomotives to another. For example, when switching from manufacturing a simulator for a DC freight locomotive to manufacturing a simulator for an AC freight locomotive, it is necessary to replace the locomotive module and reconfigure the I/O router for the configuration of the control and indication elements of the new locomotive. If these simulators are made for different sections, it goes without saying that the section database needs to be changed.

The train driver simulator can be made as an autonomous training tool with the trainee immersion in a virtual environment that is as close as possible to a real working environment. In addition, classrooms can be equipped, which can be used in technical centres for training, retraining and certification of drivers (see **Figure 2**).

Figure 2: View of a training classroom with an underground mining locomotive simulator (from **Akulov et al., 2017b**)
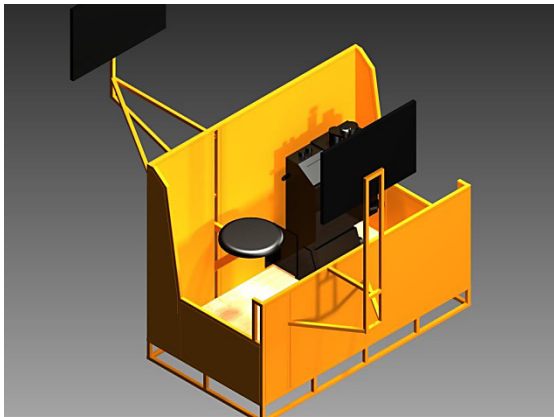

Figure 3: Mock-up of an underground mining locomotive cabin (from **Akulov et al., 2017b**)

The training subjects can be developed and changed according to the needs of the customer. The technical centre may consist of classrooms for studying the electrical part of locomotives, for conducting classes on practicing the necessary skills for performing shunting, loading and unloading and other types of work that a driver must perform in real work. Such a centre can be equipped with a variety of simulators that can be used for various educational purposes. For such simulators, it is necessary to develop software to simulate the operation of all locomotive systems, the infrastructure of mine sidings and an interactive 3D panorama of the environment. The same software can also be used in portable, small size simulators, which provide an ideal solution for operator training in classrooms where training in the centres is not available.

A mining locomotive driver's simulator should consist of a cabin or a locomotive's cabin mock-up as close as possible to the real one (see **Figure 3**). The cabin should reproduce the real working environment, accommodate control, alarm and indication elements of the locomotive, as well as other equipment of the real cabin necessary to perform all technological operations (**Akulov et al., 2017a, 2017b; Akulov et al., 2014**).

The cabin can be installed on a movable platform, which is able to reproduce vibrations close to the real ones in order to maximally approximate the training process to the real working conditions of the driver. The virtual surround panorama must be reproduced using a high-resolution projection system and high quality audio system. Control over all aspects of training and assessment of performing educational tasks is carried out in
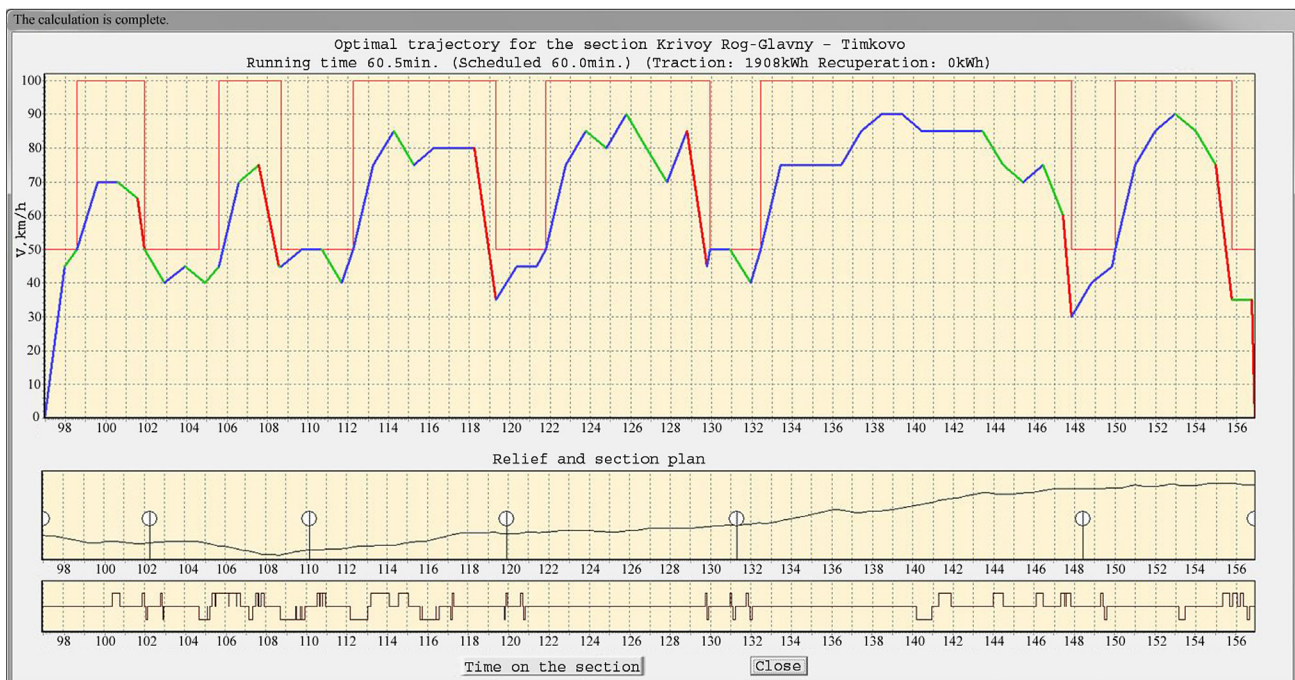
Figure 4: The result of calculating train driving modes (from **Zhelieznov et al., 2019**)
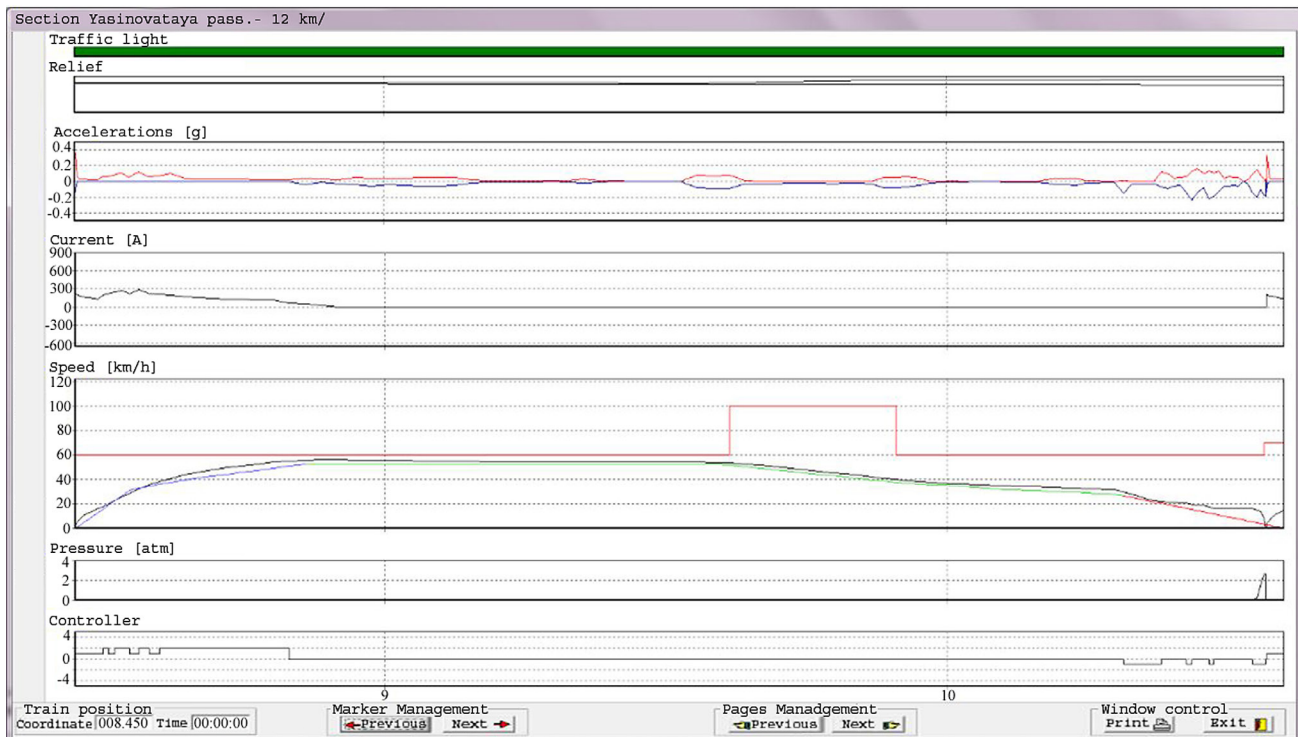
Figure 5: Graphical analyser

real time using the special software (**Akulov et al., 2017a, 2017b; Akulov et al., 2014**).

Before starting a trip, the instructor can calculate the driving modes for the selected train and section. The calculation is carried out taking into account the information about the movement section, train and locomotive.

As an example, **Figure 4** shows the result of such a calculation performed for a main-line locomotive (**Akulov et al., 2014; Zhelieznov et al., 2019**). The results are the modes of train driving along the section and speed changes, which are displayed graphically. The driving modes are shown in the graph in different colours. Blue – traction, green – coasting, red – pneumatic braking.

The broken line above the graph of the recommended movement trajectory shows the speed limits. The bottom part of the window shows the relief, the location of stations and curves in the plan of the selected section. The caption bar shows the resulting travel time, scheduled travel time, and fuel consumption. The name of the operation point on the graph of the section relief can be seen by pressing the left mouse button.

During the study travel, the driver, adhering to the recommended train movement trajectory, has the opportunity to improve his experience in terms of saving energy carriers, which are spent on train traction (**Akulov et al., 2014; Bogaers and Botha, 2016; Zhelieznov et al., 2019**).

In the graphical analyser (see **Figure 5**) of the modular trainer of the main-line locomotive driver, the following results are presented:

Figure 6: Training simulator for the ChS7 electric locomotive driver

– traffic light readings;
– relief;
– the greatest positive and negative accelerations of electric train cars;
– engine current;
– movement speed;
– pressure in the brake cylinder of the head car of an electric train.

All of these results are presented graphically. The speed graph shows the speed limits (red line), actual (black line) and energy saving speed trajectories. The colour of the optimal movement speed of the electric train displays the driving modes: red – pneumatic braking, brown – electric braking, green – coasting, blue – traction.

– the number of traction and braking positions.

For a more detailed graph analysis, a special marker is used. It moves through the graphs using the back and forward buttons located at the bottom of the graphical analyser.

In this case, the numerical values are displayed on the left panel of the graphical analyser, and the coordinate and travel time to the point where the marker is located – on the bottom panel on the left. In the same place on the bottom panel, there are buttons for switching pages of the graphical analyser, a print button and an exit button (**Akulov et al., 2014; Zhelieznov et al., 2019**).

The hardware part of the simulator is designed to connect a personal computer with the control and signalling bodies located on the driver's desk. The input/output modules of the modular simulator of the main-line locomotive driver are fixed on the mounting panel of the driver's desk.

The hardware part of the simulator is used to:
– determine the state of the locomotive control elements;
– provide indication on instruments, signalling means and indication of the locomotive control parameters and the state of the locomotive and train systems;
– control the locomotive speedometer in accordance with the train speed, obtained in the process of modelling its movement.

The hardware part consists of input/output modules of discrete and analogue information and an electromechanical drive with an electronic control panel for controlling a locomotive speedometer.

The mining locomotive driver's simulator was developed using many years of experience in creating simulator complexes for training mainline locomotive drivers (see **Figure 6**), and is also a training complex consisting of similar parts, hardware and software.

Only those control panels (cabins) of locomotives that are equipped with a video system with a recording of the section (sections) of circulation can be considered as simulators. In this case, a screen is installed in front of the driver to display the train situation in one-dimensional or three-dimensional format. The undisputed leaders in the production of such simulators are Thorough Tec, Immersive Technologies, Bombardier, etc.

After the initial training on the simulator, it is used in a prompt manner (when conducting technical training and analysing emergency situations), for conducting quarterly trainings and getting a credit, for training assistants for working as drivers, as well as for restoring driving skills after vacations and long breaks in the work of drivers.

It is believed that no simulator can replace work on a locomotive. However, there are a number of skills that can only be developed using simulators.

Unlike train operation, on all types of simulators, it is possible to ask the driver about abnormal train situations or locomotive malfunctions. Thus, the correct and operational skills are developed to eliminate problems that have arisen.

3. Description of the simulator for training mining locomotive drivers

Rail transport is the most common way of transportation of coal over long distances, and rail infrastructure acts as a key factor in economic development, a catalyst for business and help create jobs for many mining companies. The software for soil mining locomotive simulator allows performing functions identical to the train driver simulator.

The soil mining locomotive simulator can be used to train drivers to perform railway switching operations on station tracks (with or without moving to the station-to-station block) and marshalling humps in compliance with safety requirements and actions in non-standard and emergency situations that may arise during real work. The simulator for training mining locomotive drivers can be produced for any type of traction rolling stock and for any section of traffic and allows you to solve almost all issues related to education, training, professional development and certification of drivers. In addition to the above possibilities, the use of the driver's simulator will allow scientific research in the following areas:
• analysis of train control capability (getaway forces of locomotives, running through the slope parts of the mine, estimate the braking length in different modes etc.);
• investigation the influence of the traffic conditions and the train parameters (weight, length, types of carriages etc.) on the current consumption in different sections;
• evaluate the longitudinal stress loading of any train in the process of its operation in the real road and provide necessary security procedures in emergency situations;
• estimate the stability of each carriage to longitudinal forces which influence to the train.

The underground mining locomotive driver's simulator is created on the basis of the locomotive cabin, while retaining its original control and indication elements. Thus, the maximum approximation of the learning process to a real work environment is achieved. The surrounding panorama of a real mine is reproduced based on modern 3D modelling of the virtual world, supplemented by an audio system designed for audio accompaniment, which increases the reliability and brings the learning environment as close as possible to the real working one. The 3D panorama of the mine gives trainees the opportunity to familiarize themselves with a real mine in a virtual training environment.

When completing the training tasks, a driver is accommodated in the locomotive cabin and performs his main functional tasks:

– mining locomotive control;
– formation of trains and performance of shunting operations at loading and interchange points and overhead crossings;
– placing cars in the loading and unloading points;
– removal of goods, delivery of empty cars;
– delivery of people to the place of work and back;
– switching of points during the travel;
– regulating the speed of the underground mining locomotive depending on the track profile and train weight;
– equipment of electric locomotives and filling sanding devices;
– observation of the readings of measuring instruments;
– inspection and testing of control mechanisms;
– elimination of malfunctions in the operation of the equipment under service.

Simulator software:
– simulates physical processes of locomotive traction;
– calculates the movement speed of locomotive and each truck taking into account the profile and plan of the real mine track and the characteristics of the locomotive, including trucks;
– displays a 3D panorama of a real mine, rolling stock, loading and unloading points and other elements of the mine infrastructure that are important for training drivers;
– provides registration of the progress of the training task in order to quickly assess the correctness of the driver's actions;
– saves the results of completing educational tasks for later analysis.

The locomotive cabin (see **Figure 7, 8**) is installed on a platform with up to 6 degrees of freedom, designed to simulate operational vibrations. Cabin vibrations can be obtained in the form of records of spatial accelerations during experimental trips on a real locomotive or generated as quasi-random processes with specified characteristics.

The virtual mine display system consists of three large projection screens in the front and one screen in the back (see **Figure 8**). The front screens (left, middle, right) provide the trainee with a wide field of view (approximately 180°). The rear screen is needed for exercises that require the locomotive to move in the opposite direction.

To display the virtual model of the mine, a video recording of a real mine and photographing of individual objects of the mine infrastructure are performed, on the basis of which 3D models are built for the subsequent

Figure 7: Displaying a 3D panorama of a real mine with one projection screen
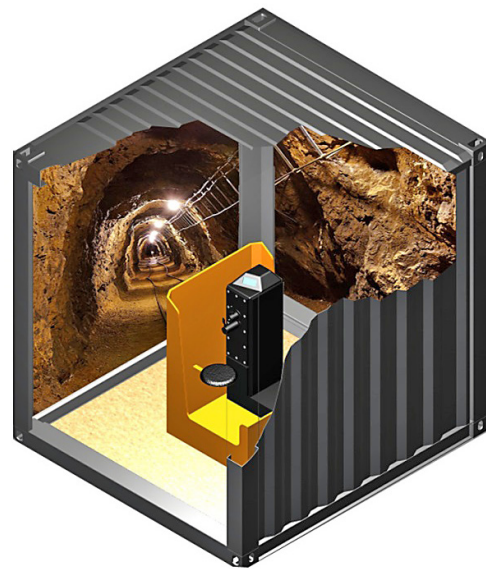
Figure 8: Virtual mine display system of three large projection screens (from **Akulov et al., 2017b**)

construction of the virtual world of the mine. The computer 3D models of other mine equipment, such as trucks, mining installations and others are used here. Real sound recordings are used to reproduce an authentic audio panorama of the mine. Thus, the panorama is built on the basis of the original section of the mine shaft and allows one performing various types of shunting work both inside the mine itself and on the surface. Other elements – people, equipment and vehicles – can be introduced into the virtual world of the mine to interact with the driver in order to assess and improve his skill level.

Complex physical models working in real time, modern 3D graphics capabilities, audio accompaniment and various operational details allow for a realistic reproduction of the movement of a real locomotive in a real mine. The use of the real control elements or their mock-ups close to the real ones, increases the realism of perform-

ing educational tasks on the simulator. The simulation of the dynamics of a mining train is based on the detailed mathematical models that provide a fairly accurate reproduction of the real processes. These train models provide realistic interactions between the locomotive, trucks and rails, including derailing in extreme conditions.

When performing the training task, the driver uses the full-scale locomotive control elements and sees the real surrounding panorama of the movement section (see **Figures 7** and **8**), which allows him to feel himself in the usual driving conditions. At the bottom of the screen, the energy-saving train movement trajectory is displayed only in the training travel mode.

For a more realistic perception of the train movement conditions by the driver, a large number of sound effects are simulated during the travel. All the driver's actions related to train driving, and the results of performing the tasks of the instructor are recorded and subsequently can be analysed using the results analysis system.

For the organizations that plan to use simulators, a training system can be developed that focuses on the safety of work or on reducing costs, such as reducing fuel consumption for diesel locomotives, engine hours, unplanned maintenance caused by improper operation of the locomotive. Training tasks can be configured to meet a variety of training needs, including working in challenging areas, interacting with the other vehicles and personnel in tunnels, and in emergencies. In some sections, training tasks for towing, loading and unloading, as well as emergency situations can be implemented.

The instructor has the ability to prepare and adapt training tasks for the driver, can monitor and evaluate the trainee during the training travel. The instructor can set some initial conditions before performing the task, as well as promptly intervene in the situation and analyse the student's actions when performing the task. The results of performing the educational tasks are stored in a database for later viewing and analysis. At the end of each exercise, the instructor receives a report describing the main results of performing the training task, such as energy consumption, compliance with the work safety rules, collisions, derailments, etc., which can be used to quantify the work of the driver.

The simulator supports work with the virtual reality headset Oculus Quest 2, including the online mode for group lessons – this is a new concept of using a virtual interface for students to interact with each other and with the teacher, in which the most important skills are interactively trained and practiced while interacting with a virtual worker environment, while creating a strong sense of presence.

A feature of this mode is its direct impact on the human psyche, on its body receptors, orientation in space and time, memory and identification in space together with other learners.

4. Conclusion

The process of training mining locomotive drivers takes a fairly long period of time and requires significant financial expenditures. The development of computer technology and related technologies makes it possible to develop modern interactive teaching aids. In the field of training the mining locomotive drivers, such aids include training simulators. The simulators can be made for any type of locomotive and for any real industrial enterprise where drivers will work after the training. In addition, the use of simulators will allow simulating various abnormal and even emergency situations that may arise in the real working conditions. This will teach drivers to make quick and correct decisions to avoid serious consequences in a real working situation. It is difficult to overestimate this aspect of the use of simulators, because in the real conditions it is impossible to deliberately create such situations. In addition, the use of simulators will significantly reduce the training time for the future specialists due to the intensification of the training process, which will lead to a reduction in the cost of the training.

The simulator provides training opportunities for both beginners and experienced drivers to improve their qualifications. Training on realistic simulators provides a quick transition to work on a real locomotive and allows drivers to demonstrate their skill level in an environment as close as possible to the working one. In addition, there is no need to remove equipment from the production process to train people. A simulator-trained driver gains experience in how the locomotive will react to the driver's actions in a wide range of real-life situations. These situations cannot always be realized in real-life mode without endangering people and equipment. For the trainee, it is a great advantage to work in a completely safe environment, knowing that his mistakes will not result in injury or equipment damage.

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SAŽETAK

Simulator za obuku strojovođa rudničke lokomotive

Osposobljavanje strojovođa rudarskih lokomotiva na simulatorima povećat će učinkovitost i intenzitet obuke. Zbog toga će doći do smanjenja financijskih i vremenskih troškova za obuku vozača, postići će se povećanje sigurnosti i produktivnosti njegova rada, smanjenje broja pogrešaka u radu i oštećenja opreme koji su ponekad uzrokovani neiskustvom vozača. Simulator vozača proizveden je kao autonomni alat za obuku, s polaznikom koji je postavljen u virtualno okruženje što sličnije stvarnomu radnom okruženju, i predstavlja kompleks za obuku koji se sastoji od hardvera i softvera. Softver simulira rad svih lokomotivskih sustava, pristupne infrastrukture rudnika i interaktivne 3D panorame okoliša. U kabini strojovođe rudničke lokomotive reproducira se stvarno radno okruženje, upravljački, alarmni i indikacijski elementi lokomotive te ostala oprema koja se nalazi u stvarnoj kabini i nužna je za izvođenje svih tehnoloških operacija.

Ključne riječi:
simulator, rudničke lokomotive, obuka strojovođa, napredna obuka

Author's contribution

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