DEVELOPMENT OF A MOBILE AUTOMATED AIR QUALITY MONITORING SYSTEM FOR USE IN PLACES OF TECHNOGENIC ACCIDENTS ON RAILWAY TRANSPORT

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Abstract.

A mobile air quality monitoring system (MAQMS) has been designed and implemented at railway infrastructure facilities. The system (or MAQMS) consists of two main parts: a single data processing server and information collection devices. The transmitter is based on the ATmega328 microcontroller. For component devices of MAQMS, the operation of which depends on Wi-Fi, a transmitter based on an ESP8266 microcontroller is used, which ensures stable communication according to the 802.11n standard. This standard is the main data transfer protocol between environmental data collection devices and the MQTT server. In the implemented MAQMS, the data processing server receives information via the MQTT protocol from all devices about the status of each sensor and the location of the device at the site of a railway accident accompanied by environmental pollution. All data with a certain periodicity is written to the database on the server in the appropriate format with timestamps. To access the stored data, a WEB interface is used, which allows you to administer the MAQMS from all devices that have a web browser.

Keywords: *mobile monitoring system, software, railway transport, environmental monitoring,*

1. INTRODUCTION.

One of the most important problems of the development of global industrial civilization is environmental pollution by anthropogenic emissions.

Land transport in the industrialized regions of the world has become the basis for the development of other sectors of the economy. At the same time, the environmental impact on the environment (Env.) from transport also remains significant. The analysis of the ecological component of the triad of the system "transport - nature (Env.) – man" showed that the aggravation of environmental problems in transport and the strengthening of its negative impact on the environment were the result of insufficient attention to the ecological component of this triad. However, this problem today has begun to affect the environmental situation in the world due to the outpacing pace of development of transport, primarily by road and air, and the peculiarities of the interaction of transport systems with the environment.

Meanwhile, one of the most dangerous phenomena that occur during the operation of transport is emergencies accompanied by emissions of dangerous toxic substances.

A necessary stage of the modern approach to the formation of an effective environmental management system in railway transport is the creation of a special environmental information

system, which will allow an objective assessment of environmental and economic damage both in the process of nature management and in cases of emergency incidents with negative environmental consequences. Mobile air quality monitoring systems (MAQMS) at the infrastructure facilities of railway transport (RT) can become an integral part of such an environmental information system.

2. LITERATURE REVIEW AND ANALYSIS.

Some aspects of the environmental activities of the railway are reflected in the works of Kazakh scientists, as well as specialists in other European countries (Russia, Ukraine, Germany, France, etc.), the USA, China, and other states that develop railway communication [1–3].

To increase the efficiency of the processes of localization of the consequences of accidents and catastrophes on the railway transport (RT) due to the improvement of automated environmental safety assessment tools, it is necessary to conduct a detailed analysis of the impact of such cargo on the environmental condition of the Env. This problem is reflected in many regulatory documents and legislative acts and is widely discussed in scientific and practical literature and the press.

The analysis of the situation that has developed as a result of an emergency situation during the transportation of dangerous goods (DG) requires the availability of accurate and sufficiently simple models for calculating the development of dangerous factors in such situations. It is also necessary to use the potential of effective and inexpensive automatic means of environmental safety assessment in the aftermath of railway accidents.

Thus, an urgent task is the task of choosing a model for predicting the development of dangerous factors of emergency situations with DG on the railway.

Another area includes studies that consider the processes of development of dangerous factors of emergency situations and technologies for eliminating the consequences of such situations during the transportation of DG.

The trends in the development of dangerous phenomena in emergency situations, the assessment of the probabilities of accidents escalating into accidents, as well as the prediction of the occurrence of emergency situations, including on the railway, are devoted to works [4–6]. These studies show that the probability of accidents on the railway depends on the volume of traffic and, under certain conditions; the flow of railway accidents is a simple Poisson flow. The paper considers a mathematical model for the implementation of an accident with a DG, taking into account the volume of traffic, the intensity of emergency situations, the speed of the train at the time of the accident and the maximum collision speed at which the packaging of the cargo is not destroyed yet. The results of the simulation show that it is possible to achieve a reduction in the intensity of accidents with DG either by reducing the average speed of the train, or by increasing the stability of packaging structures, which have their own economic and technical limits. Much attention is paid to the issues of emergency response and assessment of damage from them.

The general problems of eliminating the consequences of accidents during the transportation of the main environmentally DG organized criminal groups are considered in [6]. It examines the types of physical processes of the development of accidents and the directions of elimination of the consequences of emergency situations, defines the main approaches to the effective conduct of liquidation work. Some attention is paid to the definition of requirements for organizational measures and technical solutions for the elimination of accidents, in particular, the need to develop technological processes for localization, capture or neutralization of environmentally hazardous substances that have fallen into the Env. The author emphasizes that in order to effectively carry out liquidation work, it is necessary to have mechanisms for predicting the development of accidents and reliable communication between all participants in the process of liquidation work.

The issues of improving preventive measures during the transportation of DG are considered in [6,7]. It is emphasized that the main properties that determine the conditions of transportation and storage of petroleum products are their easy flammability, increased viscosity and solidification at subzero temperatures, high ability to evaporate, corrosive effect on metal and harmful effects on the human body. The general requirements for the means and technological process of eliminating the environmental consequences of railway emergencies have been established. The mechanisms of soil and water pollution are

considered in detail. It is shown that the time interval between the moment of the accident and the start of work to eliminate their consequences should be as small as possible. This is especially true for volatile fractions of petroleum products, which have a high rate of migration through the soil and their spread over the surface, as well as a negative impact on the atmosphere in the affected area.

In work [8] methods for improving the efficiency of oil spill response are considered and a technological scheme for the elimination of such spills is developed. The author describes the technologies that provide constant and prompt access to the sorbent of petroleum products in the area of liquidation work. The equipment allowing transferring sorbents in the form of sorption booms directly on the tank for transportation of oil products is offered. This makes it possible to shorten the time interval from the beginning of the contact of DG with the Env.to their absorption on the surface of the sorbents.

In [9], the problems of protection of Env.during the elimination, neutralization and blocking of pollution during the spill of petroleum products transported by rail are considered. The problem is solved through the introduction of new technological solutions, in particular the use of adhesive substances.

In [10], the issues of assessing risks and losses during the transportation of DG railways in interaction with road and pipeline transport are considered.

The principles and methods of assessing the environmental risks of accidents at the RT are covered in [11, 12], which consider the main aspects of the formation of environmental risks in the conditions of greening transport processes and propose methods for assessing the likelihood and some principles of environmental risk management at the RT. Unfortunately, in these works, the classification of transport accidents with their consequences has not been carried out, the main properties of DG of various hazard classes have not been analyzed according to their impact on the Env., and the quantitative and qualitative characteristics of the negative impact of DG on the environment have not been considered.

In the analyzed works, there was no place for a model for predicting the processes of development of probable emergency situations with DG and their impact on the Env.

In many foreign countries, much attention is currently being paid to the problem of intellectualization of transport processes, including increasing the level of transportation safety, improving the environmental situation, reducing the negative impact of the human factor on the quality of management, and the like.

Another area of scientific research devoted to scientific and methodological approaches to the creation of intelligent transport systems, taking into account the peculiarities of the functioning of railways, is the use of expert systems (ES) and decision support systems (DSS) in their composition, the use of information technologies, the latest communication systems and monitoring of the state of infrastructure and rolling stock. Some aspects of such approaches are considered, in particular, in [13].

The results of the analysis of modern principles of management of the state of the Env.on the RT in the processes of transportation and use of petroleum products are presented in [10]. In this research, one of the ways to optimize the existing schemes of such management in order to improve environmental and economic indicators is proposed.

In the work [12], the issues of organizing the interaction of emergency rescue services of multiple subordination in the elimination of consequences of railway emergencies with a DG are considered.

The work [15] is devoted to the methods of managing the safety of the transportation process of the DG and ways to improve environmental safety, including through the development of new principles for the design of transport safety systems of the DG based on information technology.

Works are devoted to the use of DSS and expert systems in managing the processes of train movement, passenger and cargo transportation, reducing car downtime, carrying out repairs of infrastructure facilities and PS [10, 16].

In [16], it is proposed to develop a multi-level DSS with communication between levels based on the railway communication network using terminals installed at the corresponding mobile and stationary control points. It proposes to consider the amount of forces and means necessary to eliminate an emergency situation as a function of the harm caused by it.

As the analysis of the conducted research showed, the authors of theoretical works practically didn't pay attention to the problems of

treating mobile computerized monitoring systems for tasks or rail transport. The works [3,6,8,10] are focused exclusively on stationary monitoring systems, which makes them unsuitable for use in rail transport, which has its own specifics of operation.

This circumstance was for our research, which is focused on the development and hardware and software implementation of a mobile automated air quality monitoring system for use in places of technogenic accidents on the rail transport.

3. THE PURPOSE OF THE WORK is to develop and implement a mobile automated air quality monitoring system for use in places of man-made accidents on railway transport.

4. METHODS AND MODELS.

The prototype of the MAQMS designed as part of the study was developed on the Arduino Nano platform – one of the most miniature Arduino boards [17,18]. This board is selected based on its overall dimensions and is often used in projects in which compactness is important.

The ESP8266 [19], a microcontroller from the Chinese manufacturer Espressif with a Wi–Fi interface, is also used in the MAQMS. In addition to Wi-Fi, the microcontroller is capable of executing programs from an external flash memory with an SPI interface.

The microcontroller does not have non-volatile memory on the chip for the user. The program is executed from an external SPI ROM by dynamically loading the necessary program fragments into the instruction cache. Up to 16 MB of external program memory is supported.

The ESP8266 can operate both as an access point and as an end station. During normal operation of the local network, the ESP8266 is configured for endpoint mode. For this device, you need to set the SSID of the Wi-Fi network and, in closed networks, an access password.

Since it is possible to spray radioactive substances during transportation of certain materials, the MAQMS is equipped with a Geiger counter, see fig. 1.

Figure 1 : Ionizing Radiation Detector

This MAQMS module made it possible to assemble a dosimeter based on an Arduino controller. The MAQMS module is compatible with most of the Geiger sensors used. The expansion board was equipped with a sound and visual radiation indication system.

The assembled device can be used as a high-precision detector of dangerous radiation levels and radioactive materials at the site of a railway accident.

A separate sensor, the GP2Y1010AU0F optical dust sensor, was used to monitor the dust level in the MAQMS. The GP2Y1010AU0F optical sensor is designed to measure the degree of dust or smoke in the air (up to 0.6 mg / m3).

The air sensor module contains a combination of sensors SI811, Si7021 and BME280; measuring most air parameters, see fig. 2.
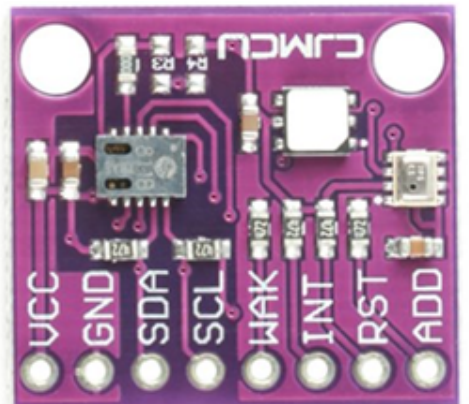

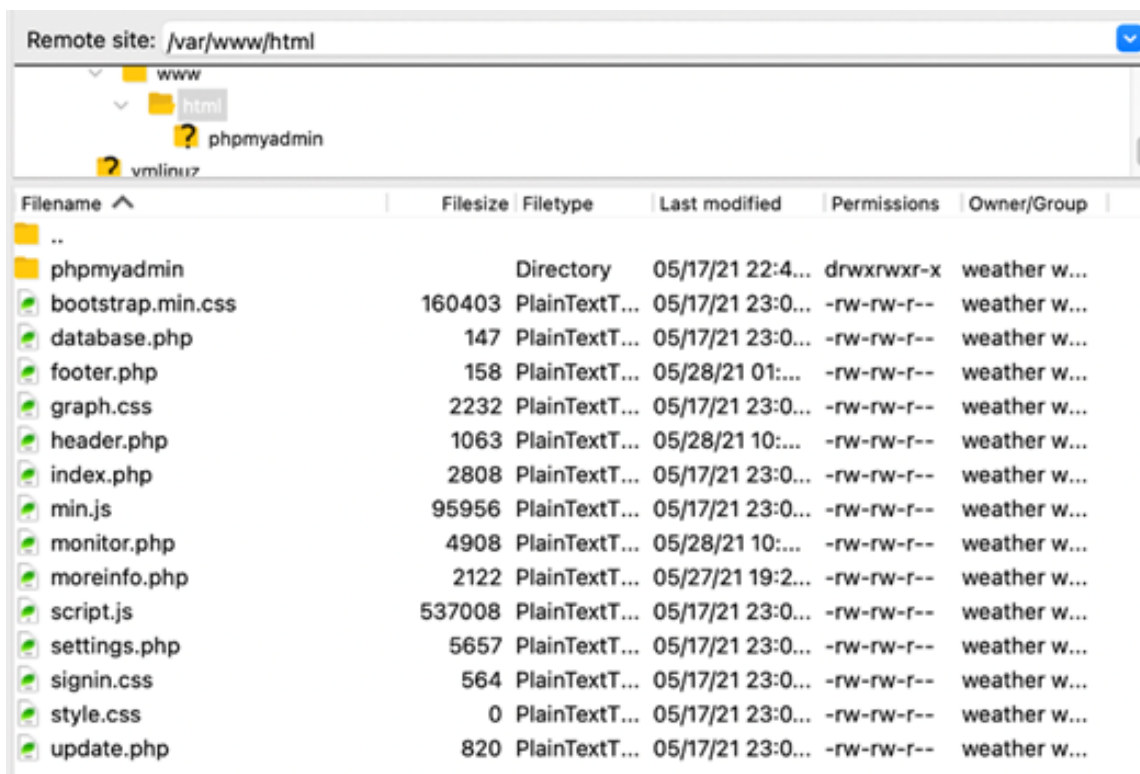*Figure 2 : Air Quality Sensor Module At The Railway*

Accident Site

To connect the Arduino to the sensors, an I2C serial interface was used.

The built-in CCS 811 sensor supports several measurement modes,

The output of the necessary information in MAQMS is carried out using a web interface, which is also a system for the administration of devices with sensors.

On the settings page, you can add and remove devices. To install the site, you need to copy all the files to the /var/www/html folder, the result of this operation is shown in fig. 3.

Figure 3 : Contents Of The /Var/Www/Html Folder

The air quality monitoring site at the site of a railway accident or emergency consists of five web pages:
- The main page of the MAQMS;
- connected devices monitoring page;
- Pages of detailed information on graphs for each device;
- System developers' page;
- Device management page.

After entering the website address, the user gets to the main page of the system. This page contains general information about the system.

For devices that have a GPS module, the map with the location is loaded automatically. The page shows the latest update data from the MAQMS sensors for the following parameters:
- Data from the ionizing radiation sensor;
- Data from the dust sensor;
- Ambient temperature;
- Air humidity;
- Atmospheric pressure;
- eCO2 concentration;
- Light level;
- The level of carbon monoxide and other gases.

For each device that is part of MAQMS, you can view detailed information for the past 24 hours. The information on the website is presented in the form of graphs for each of the MAQMS sensors. An example of a page with MAQMS charts, see fig. 4.

On the settings page, you can add and remove devices from the database and the MAQMS monitoring system. A device connected via MQTT, but not added to the database, will not be displayed in the system. When adding a new device, the system automatically creates a new table for it in the

database for storing indicators from the MAQMS sensors.

The site displaying the monitoring results, for example, in the railway control room, is written in the following programming languages: PHP, HTML, CSS, JS, Python, and SQL. In case of errors in connecting the MACMQV to the database, the system will notify the user with the appropriate error code. When you delete a device, its table is also deleted from the database, so it will be impossible to restore the saved data. The settings page is protected by the user's login and password, see fig. 5.

The MAQMS hardware can work on different types of microcontrollers, devices based on Atmega328 and ESP8266 microcontrollers have been successfully tested during the work. The modularity of the MAQMS provides various variations of connecting sensors to microcontrollers. The MAQMS system is designed to connect up to 100 devices with five sensors on each. Each device has its own unique identifier from 00 to 99. The main requirement for microcontrollers is the ability to transmit data over the MQTT protocol. For use in places, the devices can use an urban Wi-Fi network to transmit data to the server, in case of use in rural areas; the devices can be equipped with a GPRS communication module to ensure reliable communication in remote and non-electrified areas.

TP4056 and MT3608 microchips are used for uninterruptible power supply of components and recharging of MAQMS batteries. Batteries of the 18650 type, with a capacity of 2000mA / h in the amount of three pieces, are used.

Figure 4 : Additional Information Display Page With Graphs On The Air Condition At The Railway Accident Site

Sensors for temperature, humidity, atmospheric pressure, and CO2 concentration are located outside the housing to reduce additional heating by internal components and rapid air exchange.

The server software performs one of the most important functions in the air quality monitoring system in the places of railway accidents. The server receives data from devices in the area of the accident, filters and stores information from sensors and provides access to viewing stored information in the form of graphs. To perform these server functions, you need to provide a sufficient amount of computing resources. The actual server load with two devices connected and data transfer every minute is shown in fig. 6.
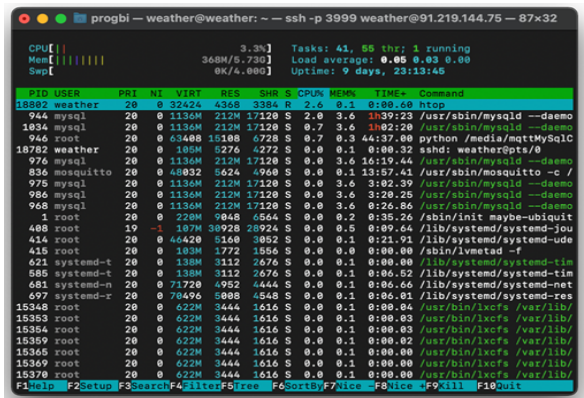
Figure 5 : Server Load

To check the connection of devices using the MQTT data transfer protocol, you can use the MQTTool mobile application. An example of connecting to an FTP server via a mobile application is shown in fig. 6. To connect, you must enter the server address, connection port, login and password in the program parameters.
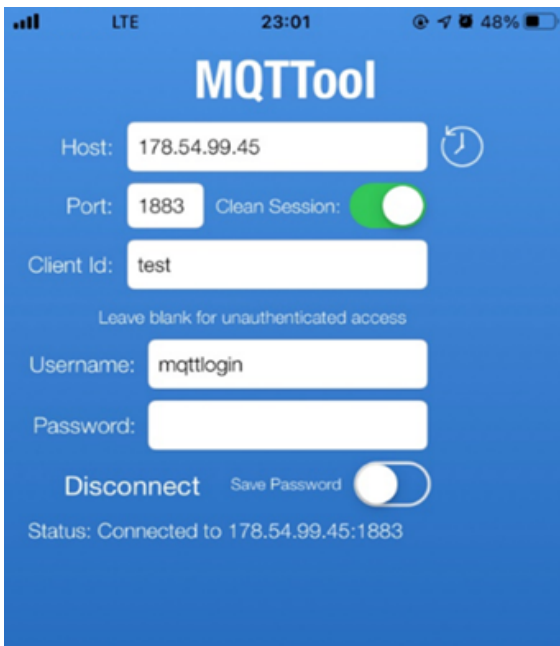

Figure 5 : Checking The Connection To The Mqtt Server

The air quality monitoring devices at the railway transport work remotely, therefore, it is not possible to physically connect to everyone quickly. To monitor the stability of the devices, the parameter "Number of Transmission sessions after switching on" is passed to the server. This parameter allows you to determine how long the device has been working without restarting, for

example, if this parameter is 10000, and data on this device is sent every second, then this device works without restarting for 2 hours and 47 minutes.

During testing, it was revealed the need to install an external GSM antenna with a gain of 3 dB to receive mobile communications in remote or noisy areas, see fig. 7.

Figure 7 : External Antenna

To test the capabilities of the server, test devices transmit data every minute or second, this allows you to simulate a system with a large number of devices with a normal data transfer period for the required time interval. In this mode of operation, the MAQMS works stably for a long period. Figure 8 shows an example of the installation of a MAQMS with a network connection using a mobile connection.

Figure 8 : Assembled Air Quality Monitoring System

The device is powered by a 127V or 220V network, which is connected to a power supply with an output voltage required for the 5V system. In remote territories of the railway of the Republic of Kazak, it is possible to use solar panels for powering MASMKV. The operating

time of the MAQMS test sample from the built-in battery is 18–24 hours. Depending from the temperature of environment. This stock is enough to work all night on a summer day.

The final view of the device in a moisture-proof housing with the antennas, power connectors and the power button removed is shown in fig. 9.

Assessment of the situation with the help of MAQMS, modeling of the degree of workload of liquidation units with the help of the developed software product, diverse planning of measures necessary to respond to emergency situations, bringing the decisions made to the executors, monitoring the processes of implementation of such decisions and the development of corrective measures is carried out by the heads of all management units. As a rule, all these measures are implemented in conditions of time shortage.

It usually occurs in conditions of uncertainty of information about the circumstances of a traffic accident, the presence of a threat to people, objects, passenger and freight trains, while the decision-maker (LPR) may be in a state of stress, in addition, the implementation of the decision is hindered by factors inherent in the railway transport.
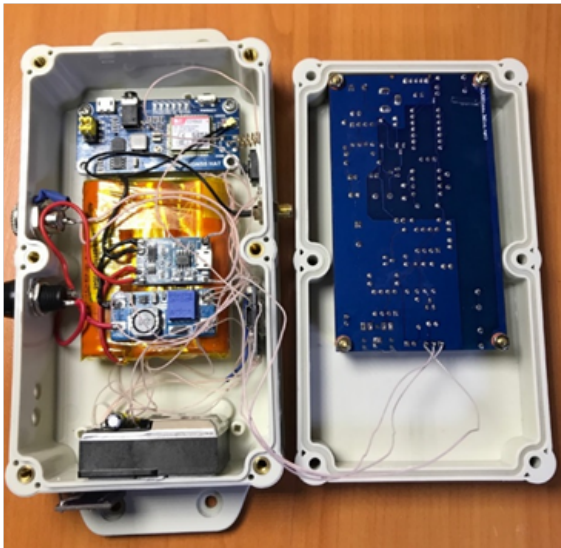

Figure 9 : Internal View Of The Device

Therefore, the situation centers of control points should include sufficiently productive complexes of automation tools for information analysis in order to promptly and objectively assess the situation, form solutions for information and calculation tasks for predicting the development of an environmentally

dangerous emergency situation, develop action plans for special units to eliminate it, take measures to comprehensively ensure such actions, as well as automated workstations of the operational headquarters, workplaces of railway specialists and specialists of other organizations involved in the liquidation work.

The development of a complete software package for such tasks goes beyond the boundaries of this article, but the basic components of such an automated system are implemented in the course of our research. First of all, this is a mobile automated air quality monitoring system (MAQMS), which allows to automatically assess the air quality at the scene of an accident on the railway, as well as the software implementation of a formal description of the actions of emergency units as the processes of functioning of the queuing system without time constraints on the technology platform ADO.net.

Software implementation of a formal description of the actions of emergency units as the processes of functioning of the queuing system without time constraints on the technology platform ADO.net.

Five types of applications are considered, which describe the work on the localization of an emergency situation and the elimination of its consequences, as a queuing system (QS) without time limits for servicing "requirements" (dangerous factors to respond to) and being in the queue for service. With such a theoretical approach, it is possible to use classical and mathematical methods of TME adapted to specific tasks.

One of the applications must have the highest priority (served out of turn). It is necessary to take into account the probability of changing the type of application during the liquidation work at the accident site. You should also take into account the probability of the application leaving the queue. This situation may occur if the request has been in the queue for too long and no channel can process it at the moment. The time of application formation and the time of its processing should be generated as random numbers in the specified range using a random number generator. The QS should provide modeling objects with tools for assigning unique identifiers and generating random values.

All simulation parameters are configured in a separate window immediately before the start of the simulation of the liquidation work, and in particular to eliminate the consequences for the

environment. Intermediate simulation results are displayed on the screen in real time, see fig.10–12.

The developed software product is based on the models presented in works [20, 21].

During the liquidation work, the relevant departments (divisions 1–4) in fig. 10–12 have to deal with different types of service requests, which are performed with different intensity (productivity). Such works include: preservation of cargo residues, pumping of cargo residues (for example, liquid hazardous substances from damaged tanks to reserve ones); work of excavators during excavation work (for example, removal and removal of the top layer of soil impregnated with dangerous liquid) and other work.

These liquidation units and funds can be used simultaneously to perform various types of work, and these works, depending on the nature of the emergency and the plan for eliminating its consequences, may end at different times. Thus, the total duration of the liquidation work will be determined by the time from the beginning of the "first" (in order of priority) work (assessment with the help of MAQMS of the degree of air pollution) to the end of the "last" work, and its determination and minimization can be carried out using appropriate mathematical methods.

Using the data obtained from the instrumental means of measuring the contamination of the components of the Env. directly at the accident site (data on the state of air, soil, water sources, etc.), it is possible with the help of DSS or information systems not only to simulate different scenarios for the development of the situation at the accident site, but also to obtain preliminary assessments of risks and consequences if the development of the scenario of contamination of the Env. will advance according to a pessimistic scenario. Studies by many authors in the field of environmental safety in transport show that the development of automated and intelligent systems for assessing environmental safety in the aftermath of accidents at railway transport can give a new impetus to the introduction of such systems into practice. In particular, this is necessary to increase the objectivity of assessments and reduce the time deficit in the process of liquidation work at the site of accidents of a railway carrying an DG, which may lead to damage to the Env.

At the output of the DSS, they will provide information containing an assessment of the state of the Env. on the studied territories at the accident site. Also, the computing core of the DSS contains models that allow you to make predictions about the health status of the population in the accident zone and assess the situation from an economic point of view and the consequences for the Env. The information obtained can also be used by various management structures. For example, such information will be useful in the process of developing measures to eliminate the consequences of accidents and allocating financial resources to restore the Env.to its original state, see fig. 13.
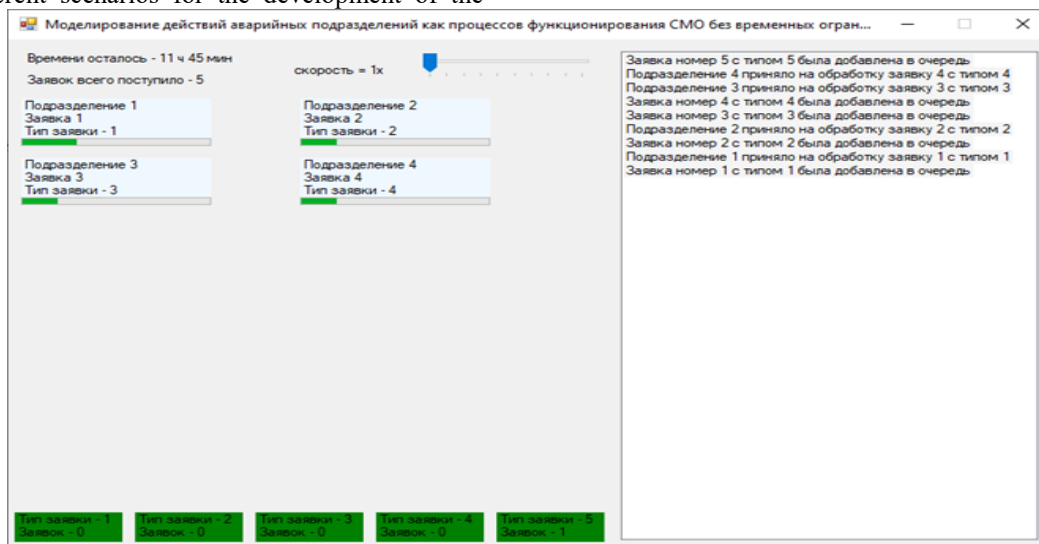

Figure 10 : Demonstration Of Situations With The Workload Of Liquidation Units At The Site Of The Railway AS (All Divisions Are Free And Can Serve Applications)
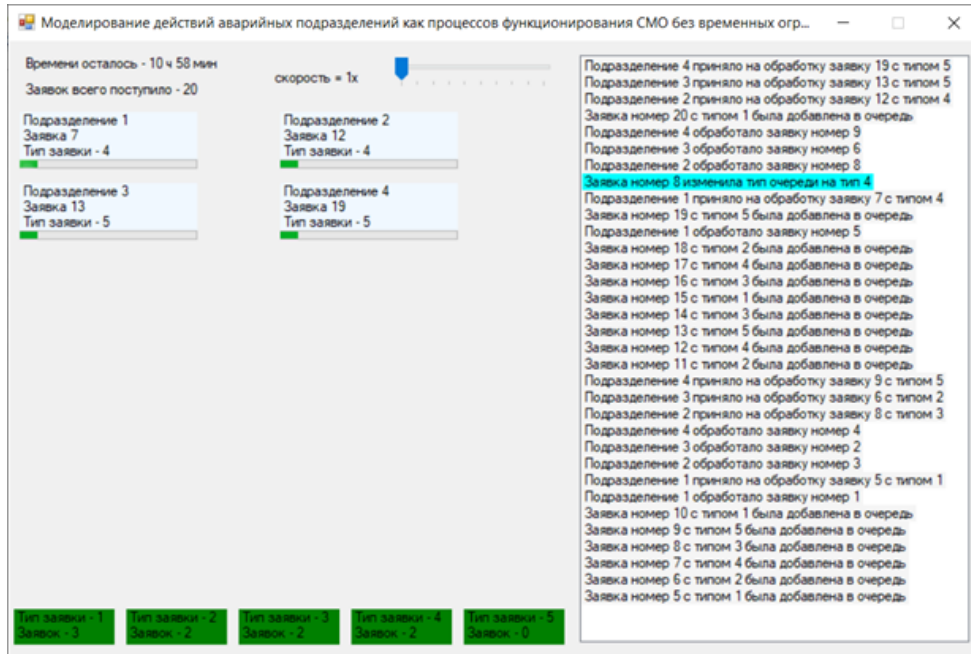
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*Figure 11 : Demonstration Of Situations With The Workload Of Liquidation Units At The Site Of The Railway AS
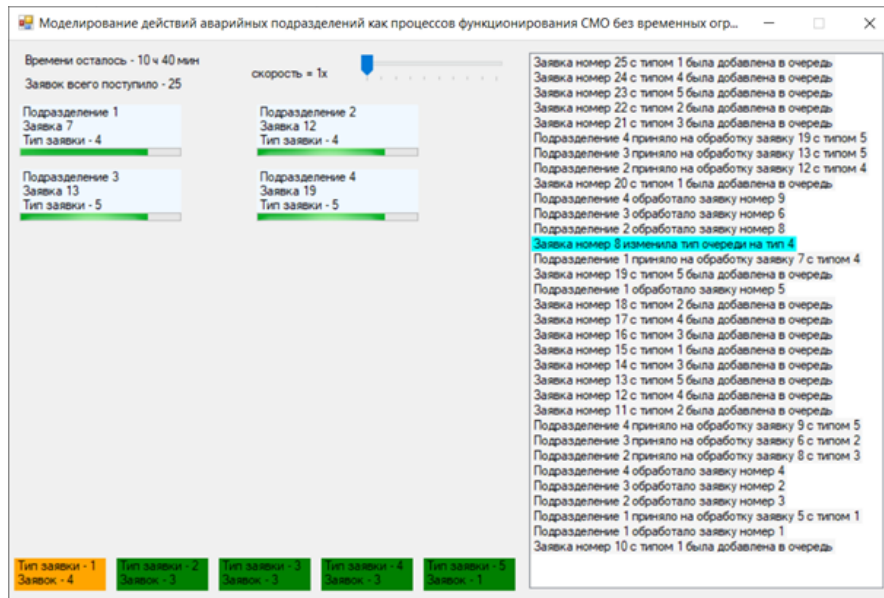(One Of The Applications Changed The Queue Type)*

*Figure 12 : Demonstration Of Situations With The Workload Of Liquidation Units At The Site Of The Railway AS (One
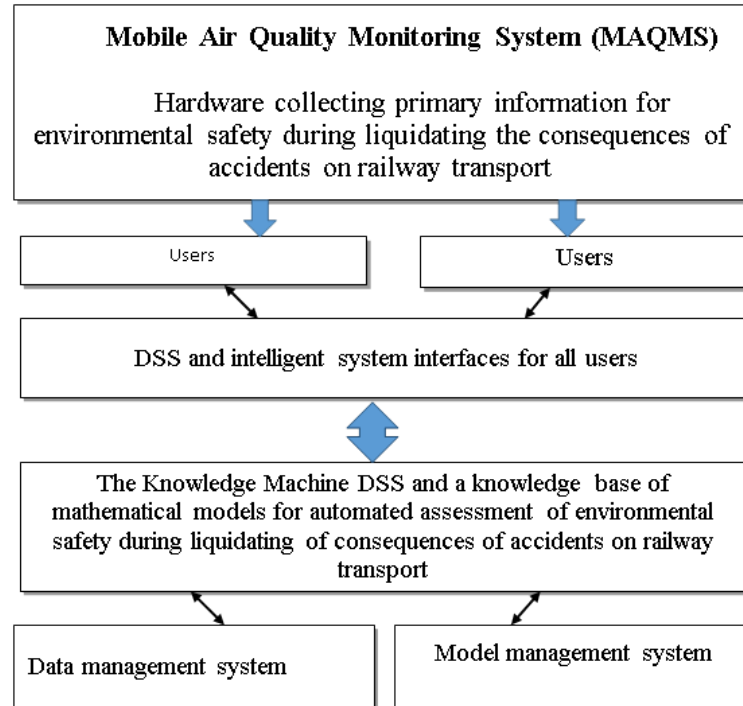Of The Applications Changed The Queue Type Or Left It)*

Figure 13 : The Basic Architecture Of The DSS With Modules For Automated Assessment Of Environmental Safety In The Aftermath Of Accidents On Railway Transport

In the structure of information and automated systems for environmental management tasks, the main component is a database that provides the system with information and determines its structure, functions and abilities to solve management tasks based on modeling the situation.

An analysis of the current environmental safety management scheme of the railway infrastructure indicates its imperfection and the absence in its structure of an organized system for obtaining and analyzing data for timely management decisions on rational environmental management and minimizing the negative impact on the Env.

Assessment of the situation with the help of MAQMS, modeling of the degree of workload of liquidation units with the help of the developed software product, diverse planning of measures necessary to respond to emergency situations, bringing the decisions made to the executors, monitoring the processes of implementation of such decisions and the development of corrective measures is carried out by the heads of all management units. As a rule, all these measures are implemented in conditions of time shortage. This usually happens in conditions of uncertainty

of information about the circumstances of a transport accident; the presence of a threat to people, objects, passenger and freight trains, while the decision-maker (DM) may be in a state of stress, in addition, the implementation of the decision is hampered by factors inherent in the railway transport.

Therefore, the situation centers of control points should include sufficiently productive complexes of automation tools for information analysis in order to promptly and objectively assess the situation, form solutions for information and calculation tasks for predicting the development of an environmentally hazardous emergency situation, develop action plans for special units to eliminate it, take measures to comprehensively ensure such actions, as well as automated workstations of the operational headquarters, workplaces of railway specialists and specialists of other organizations involved in the liquidation work.

The development of a complete software package for such tasks goes beyond the boundaries of this study, but the basic components of such an automated system are implemented in the course of our research. First of all, this is a mobile automated air quality monitoring system (MAQMS), which allows to

automatically assess the air quality at the scene of an accident on the railway, as well as the software implementation of a formal description of the actions of emergency units as the processes of functioning of the queuing system without time constraints on the technology platform ADO.net.

5. CONCLUSIONS

Based on the conducted studies, the following results were obtained:

An air quality monitoring system has been designed and implemented at railway infrastructure facilities. The system (or MAQMS) consists of two main parts: a single data processing server and information collection devices. The transmitter is based on the ATmega328 microcontroller [23–27]. For component devices of MASMKV, the operation of which depends on Wi-Fi, a transmitter based on the ESP8266 microcontroller is used, which ensures stable communication according to the 802.11n standard. This standard is the main data transmission protocol between environmental data collection devices and the MQTT server.

It is shown that the advantages of this choice of the 802.11n protocol are: ease of use, simple administration, and low load on the communication channel, work in conditions of constant loss of communication or other problems on the line, no restrictions on the format of the transmitted content.

In the implemented MAQMS, the data processing server receives information via the MQTT protocol from all devices about the status of each sensor and the location of the device at the site of a railway accident accompanied by environmental pollution. All data with a certain periodicity is written to the database on the server in the appropriate format with timestamps. To access the stored data, a WEB interface is used, which allows you to administer MAQMS from all devices that have a web browser.

The monitoring system (MAQMS) has been successfully tested by the railways of Ukraine and Kazakhstan for stability and speed of operation. During testing, data transmission devices were modified. In particular, the power system has been modified through the use of additional high-frequency filters. The operation of the MAQMS web application has been tested on different virtualization systems and with different amounts of computing resources provided.

The software realization of the formal descriptions of the actions of emergency units as the processes of functioning of the queuing system without time constraints on the technology platform has been carried out ADO.net. Quantitative correlations have been established between the intensity of exposure to hazardous factors of the railway AS, the time of arrival, deployment and productivity of actions of liquidation units and the effectiveness of liquidation work related to minimizing damage to the environment from dangerous goods transported by the railway transport.

The results of computer modeling using the developed application show that a significant reduction in the negative impact of the consequences of the railway transport AS on the environment is possible with a reduction in the duration of liquidation work, as well as with a reduction in the time of concentration of units and the use of forces and means of the necessary productivity. And an increase in concentration time requires an increase in the productivity of such forces and means at times. In the course of simulation computing experiments on a computer, it was found that if the means of eliminating the consequences of the railway transport AS do not correspond to its nature and / or are extremely unproductive, then even with their timely concentration at the place of liquidation, they will not be effective. Or, even if the means of liquidation are quite effective, but their concentration on the place of occurrence of this situation occurred late, they will also not have an effect.

At the moment the authors of the research are considering the possibilities of establishing small scale production of the developed design of a mobile automated air quality monitoring system for use in places of technogenic accidents on rail transport.

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