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Development of system of automated protection of employees from COVID-19 and other infections at the enterprise

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ABSTRACT

Purpose: To develop a system of automated protection of employees from Covid-19 and other infections, it is implemented through minimizing the risks of contracting the SARS-CoV-2 virus and other respiratory viral infections within the enterprise.

Design/methodology/approach: Analysis of legal normative documents and scientific and technical literature – to update the scientific problem and formulate the research tasks; methods of system analysis - to build the overall structure of the system and to establish relationships between its elements; simulation methods - to develop the algorithms of functioning and interaction of sensors and actuators of the corresponding subsystems; methods of decision theory and data mining - to develop the training programs and testing the knowledge of employees on epidemic safety.

Findings: The system of automated protection of employees from Covid-19 and other infections was developed, which, due to the connection of functionally independent elements according to a certain scheme, allows minimizing the risk of contracting the SARS-CoV-2 virus and other respiratory viral infections of employees at the enterprise and increasing their protection from the occurrence of the corresponding infections by implementing a complex of anti-epidemic measures within the system and providing and constant support of the quarantine regime at the enterprise in accordance with WHO recommendations. The developed system was implemented and pilot tested at the industrial enterprise "Odessa Experimental Plant" (Odessa, Ukraine). Based on the results of the development of the system, an application was filed for obtaining a patent for invention No. a 202105894 dated 20.10.2021.

Research limitations/implications: The number of system elements can change (increase / decrease) depending on the number of workplaces, as well as areas requiring control.

Practical implications: The implementation of the proposed system allows increasing the level of economic sustainability of the enterprise in a complex epidemiological situation of the state or world level by minimizing the risks of enterprise shutdown as a result of the need to limit social and labour connections between employees due to implementation a full range of anti-epidemic measures (in accordance with WHO recommendations) at the enterprise and constant compliance with the established quarantine regime by the employees at enterprise.

Originality/value: For the first time, the system of automated protection of employees from Covid-19 and other infections was developed and proposed for use at enterprises, institutions and organizations, which, unlike others, allows the implementation of a full range of appropriate anti-epidemic measures at the enterprise (according to WHO recommendations) and ensure compliance with the established quarantine regime by the employees, due to the constant management of the sanitary-epidemic control modes of admission to the enterprise, disinfection of surfaces, ventilation and air decontamination of industrial premises etc.

Keywords: Safety and health management, Covid-19, Acute occupational disease, Quarantine regime, System of automated protection

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

At the end of 2019, the world community faced a biological danger unprecedented over the past 100 years in scale and consequences – the epidemic of the Covid-19 corona virus infection caused by the SARS-CoV-2 virus (hereinafter referred to as the Covid-19 infection). The epidemic not only caused the death of more than 4.5 million people in the world, but also caused the largest economic crisis since the Great Depression, which experts from the International Monetary Fund called the “Great Quarantine” or “Great Self-Isolation” [1]. This name quite accurately characterizes the current economic crisis, since one of its main reasons, according to the conclusions of the International Labour Organization (ILO) experts, was the drop in industrial production caused by the forced quarantine restrictions introduced within almost all countries of the world [2]. These quarantine restrictions, first of all, included the need for limit or prevent social contacts between people, which led to the actual enterprise, institutions and organizations shutdown indefinitely. It should be noted that in contrast to the usual economic crisis caused exclusively by economic conditions, such as lack of demand, solvency on the part of consumers or overproduction of goods and services, this crisis was caused by the need to social and labour disconnection between people to prevent the spread of the disease within societies [3,4]. The problem of restoring economic activity with maintaining compliance with isolation measures was partially solved by introducing distant working conditions. But these measures were able to give only a slight positive economic effect, since they could be applied only in very limited areas of economic activity, usually in the IT field [2,5]. At the same time, in the real economic sector – industrial production, in which, due to the specificities of the organization of technological processes the employees should be directly involved in workplaces, it is not possible to implement distant working conditions [2-4, 6,7].

Thus, according to the ILO, at the beginning of 2021, intra-industry restrictions regarding admission to work-places at enterprises (forced inaction) concerned about 77% of employees [7]. For comparison, the corresponding peak in July 2020 was not much higher and amounted to 85% [7]. A high and relatively stable percentage of these restrictions is explained by the results of research by specialists from the Brookings Institution [8]. According to them, such measures of the existing quarantine restrictions as mandatory social isolation and the prohibition of the operation of enterprises have been ineffective in maintaining the spread of the Covid-19 infection [8]. A more effective measure of its maintaining was the vaccination campaign introduced in the world, which made it possible to remove certain quarantine restrictions in parts of countries with a fairly high percentage of vaccinated persons, including the restoring of the operation of enterprises whose technological processes require the direct involvement of employees in workplaces. At the same time, according to research data, even a vaccinated person, given the peculiarities of the immune system of his body, the presence of certain chronic diseases, a decrease in the effectiveness of the protective effect of the vaccine over time (usually 3-6 months after vaccination), as well as constant mutation processes virus (the emergence of new strains) cannot be completely safe from infection (re-infection) with Covid-19 in production conditions [9,10]. Therefore, in order to increase the level of occupational safety of employees at such enterprises, according to the recommendations of the World Health Organization (WHO), it is necessary to additionally develop and implement a set of effective quarantine (anti-epidemic) measures to minimize the risk of their infection [6,9,10]. Considering that Covid-19 infection is mainly transmitted from a sick person to a healthy person (even if they are both vaccinated) either by airborne droplets or through direct contact of a healthy person's body with infected surfaces (equipment, door handles, etc.), anti-epidemic measures should be aimed at minimizing precisely these risks of infection of employees within the enterprise and implemented by solving the following main tasks (according to WHO recommendations) [6, 11-15]:

- minimization of the risk of penetration of the this infection into the enterprise from the outside (ensuring the sanitary-epidemic regime of control of the admission of employees and other persons to the enterprise);
- ensuring constant control over the compliance with the quarantine measures by the employees at the enterprise (compliance with the mask regime, disinfection measures, etc.) and prompt response to their violation by the responsible persons and services;
- constant ensuring and control of a high level of knowledge of employees regarding the mechanisms of the spread of infection, industrial culture in a difficult epidemic situation, as well as the level of their own responsibility for violation of quarantine measures;
- ensuring a continuous disinfection the surfaces of industrial (administrative) premises through which infection can be transmitted (common areas);
- ensuring rational modes of ventilation of the air in the working area of industrial (administrative) premises, depending on the modes of work and rest established at the enterprise and in compliance with the established optimal (acceptable) microclimatic indicators for the corresponding categories of work;
- ensuring continuous safe decontamination of air in the working area during the shift (using screened UV-emitters).

The effectiveness of the implementation of these anti-epidemic measures is confirmed by a number of conducted researches [16-18]. Taking into account the nature of these tasks (about the need to constantly monitor many parameters within the ensuring anti-epidemic measures, promptly responding to their deviations from the set values, ensuring the functioning of other relevant processes in the specified modes) and the need to apply a systematic approach in their implementation (which is associated with the existing relationships between the tasks and their focus on achieving a common goal), it is obvious that the practical implementation of a set of quarantine measures at an enterprise is possible only within the functioning of a certain automated system [19]. At the same time, the implementation of these measures allows ensuring the protection of employees not only from Covid-19, but also from known seasonal (influenza, etc.) and from new, previously unknown infections. It should be noted that the protection of employees from new infections (along with protection from Covid-19) is an urgent scientific and practical problem, the solution of which, given the experience of the readiness of the countries of the world for the sudden spread of the Covid-19 pandemic, will allow, if not prevent, then significantly decrease the negative impact on the economy of new sudden epidemiological threats, the emergence of which in the future, according to the forecasts of WHO experts, is quite probable [20,21]. However, despite the urgency of a identified problem, a conducted analysis of the scientific and literature, as well as a patent search showed that today there are no automated systems that could comprehensively ensure the complex implementation of anti-epidemic measures to ensure the quarantine regime at enterprises within the set (according to WHO recommendations) tasks [6, 12].

Thus, the purpose of this study is to develop a system of automated protection of employees from Covid-19 and other infections, it is implemented through minimizing the risks of contracting the SARS-CoV-2 virus and other respiratory viral infections within the enterprise.

2. Literature review

A conducted analysis of the scientific and literature, as well as a patent search showed that the existing system of automated protection of employees from Covid-19 have the following disadvantages that make it impossible to comprehensively implement anti-epidemic measures to ensure the quarantine regime at enterprises within the set (according to WHO recommendations) tasks.

Thus, in the study [22], the automated system aimed at preventing the spread of an infection (MERS) within a certain institution (medical) was developed by the authors. To solve this problem, the system monitors the movement routes and contacts of persons (employees, visitors, patients, etc.) using technical means based on Bluetooth technology. Each person is provided with an electronic bracelet or other means to monitor his movement across the territory. These tools interact with location sensors and contain information about the health status of each of the specified persons (infected person or not). Thus, the system allows identifying possible contacts of a healthy person with an infected person and, accordingly, takes the envisaged anti-epidemic measures promptly, as well as allows for early warning of such contacts for a healthy person, if he approaches an infected person (2 meters or closer) or of its location in a zone (premise) where the infected person was. However, a significant disadvantage of the system is the lack of implementation within its framework of any other anti-epidemic measures, except limiting of social contacts (as provided for by the WHO recommendations), which, as noted above, proved to be ineffective in minimizing the risks of Covid-19 infection [8]. In particular, the system does not provide for measures to monitor compliance with the mask regime, the implementation of disinfection measures and other mandatory (according to WHO recommendations) anti-epidemic measures. In addition, the recommendatory nature of the employees distancing measures may be ineffective, due to the possible neglect (or improper performance) of the specified measure by a healthy person (the impact of the "human factor" signs). Thus, the presence of these disadvantages significantly reduces the possibility and effectiveness of using this system to protect employees from Covid-19 and other diseases at the enterprise.

In research [23], in order to minimize the risk of dangerous situations of an epidemiological nature at enterprises, a system with the functions of employees testing for an infections (Covid-19), namely, measuring body temperature and performing (according to the established schedule) express tests was proposed. These tests are carried out at the enterprise checkpoint and, in case of a negative result (a person is not infected) the employee is allowed to enter the territory (to the workplace). In case of identification the corresponding symptoms or suspicion of a disease, the employee is not gained admission to the workplace and is sent for additional medical screening. In this case, the disadvantage of this measure can be considered an imperfect system for controlling the admission of employees to the enterprise, namely, a sufficiently long period required to obtain the results of an express test (at least 20–30 minutes). The proposed approach can contribute to the creation of a crowd of employees and the violation of the social distance between them, the violation of the operating mode of the enterprise and other negative consequences. The system also allows monitoring social contacts between employees, although, as noted earlier, this measure is ineffective. Among other significant disadvantages, the lack of such mandatory anti-epidemic measures as decontamination, disinfection, ventilation, compliance with the mask regime by employees, etc., which increases the risk of infection into the territory from outside the enterprise (on the surface of hands, shoes etc.) and, accordingly, its distribution among employees (including by airborne droplets) should be highlighted. Thus, despite the existence of positive aspects (for example, ensuring the admission regime to the enterprise), the system does not solve the full range of tasks to ensure the quarantine regime at the enterprise, that can have a significant impact on its efficiency.

The system proposed in the research [24] is almost similar in its functions to the system [23]. Within the system, compliance with the quarantine regime is provided exclusively by ensuring the sanitary-epidemic regime for admission of employees to the enterprise, which, in turn, is implemented on the basis of express testing (using a unique method). Accordingly, the specified system has all the main disadvantages of the previously analysed system. Namely, the impossibility of implementing such mandatory anti-epidemic measures as disinfection, decontamination, compliance with the mask regime, etc.

Developed within the research [25], a system of sanitary control is designed to ensure compliance with the regime for disinfecting the surface of their hands, namely, the quality of ensuring this process (in real time) by employees. The system monitors the quality of the process of directly washing, drying and disinfecting the hands of employees and collects and analyses data from persons who have undergone this procedure (using the personal identification module). The positive aspect of the system is the ability to provide a high-quality procedure for disinfecting the surfaces of the hands, however, the impossibility of implementing a set of other mandatory anti-epidemic measures within the system (in accordance with the WHO recommendations) does not allow for use it to minimize the risks of spreading infection by other ways (airborne droplets, through the surfaces of industrial premises etc.). Accordingly, these disadvantages do not allow the use of this system for the comprehensive protection of employees from the corresponding infections at the enterprise.

In research [26], a system to combat the spread of infections, in particular at enterprises was developed. The system is designed to minimize the risks of social contacts between a healthy and a sick (potentially sick) person by checking the data of the national database about each employee for the presence of: antibodies to SARS-CoV-2 (based on the results of PCR tests included in this database), received doses of vaccination, etc. before admission to the workplace (at the checkpoint of the enterprise). In the absence of such information in the database, the system provides for express testing of the employee with loading the corresponding results into the database. Thus, if the employee's health does not meet the established admission criteria, the system does not allow him to admission to the workplace. Apparently, within the system, only one of the complex of anti-epidemic measures recommended by WHO has been implemented, namely, ensuring the admission regime. However, due to the not envisaged other accompanying necessary measures to ensure such a regime (disinfection, mask control, etc.), the risk of penetration of the SARS-CoV-2 virus from outside the enterprise into its territory (on the surface of the hands, soles, etc.) and spread between employees remains very high, which is a significant disadvantage of the system. Another significant disadvantage of the system is the lack of foresight of other necessary (according to WHO recommendations) anti-epidemic measures (decontamination of the surfaces of industrial premises, the air of the working area, etc.). The impossibility of implementing a set of all the necessary anti-epidemic measures within the system (according to WHO recommendations) does not allow for the quarantine regime and significantly reduces the degree of protection of employees from Covid-19 within the enterprise.

In research [27], a system for the prevention and control of Covid-19 in a medical institution, which provides for the introduction of a set of anti-epidemic measures of an organizational nature, was developed. Namely, ensuring compliance with the social distance (which, as noted, is an insufficiently effective measure), training in the use of personal protective equipment, disinfection of the surfaces of hands, medical equipment, materials, informing about the need to comply with the quarantine regime (including the constant wearing of a protective mask, washing hands, etc.). The main disadvantage of the system is exclusively organizational nature of all these measures, that is, the quality and the mandatory to implement measures within the system are monitored only by the administration, not constantly and not systematically. This disadvantage is very significant, since the effectiveness of the implementation of measures is determined exclusively by the conscientiousness and personal consciousness of the employee, that is, the effectiveness directly depends on the "human factor" signs. In addition, the system does not provide for other necessary anti-epidemic measures, such as rational ventilation, safe air decontamination, which, along with the above disadvantages, does not allow for the functioning of an effective quarantine regime at the enterprise (according to WHO recommendations).

In the research [28], a system for protecting employees at workplaces from Covid-19, which provides for the mandatory temperature screening of each employee (before the work, before and after a work shift at the checkpoint), monitoring the presence of a protective mask on the face (at the checkpoint of the enterprise) and its giving if necessary, the need for hand disinfection, an increase the number of disinfection measures in common areas (elevators, stairs, etc.) during the work shift, etc., was developed. However, a significant disadvantage is fact that the quality of the implementation of these measures is either not monitored (for example, disinfection of hands, common areas) or is improperly monitored. So, for example, the presence of a protective mask on the face is controlled only at the checkpoint and exclusively by an employee of the corresponding service (the impact of the "human factor" signs is possible). In addition, the system does not provide for such mandatory anti-epidemic measures as rational ventilation of premises, safe decontamination of air in them, etc. These disadvantages can significantly reduce the effectiveness of protecting employees from Covid-19 and other infections, due to the risk of spreading the SARS-CoV-2 virus by airborne droplets or through the surfaces of industrial premises that are common areas remain high. The lack of the possibility of using a full range of anti-epidemic measures within the system and the dependence of the effectiveness of their implementation on the negative "human factor" signs does not allow the use of this system to ensure the quarantine regime at the enterprise in accordance with WHO recommendations.

As can be seen from the results of the analysis, the main and significant disadvantage of existing studies is fact that none of the analysed systems is able to provide a complex and comprehensive solution to all the necessary basic tasks for the implementation of a set of anti-epidemic measures within the quarantine regime at the enterprise (according to the recommendations WHO). That is, each of the above systems is capable of solving only one (for example, ensuring measures for disinfecting the surface of the employee's hands) or several tasks (ensuring admission to the enterprise and disinfection regimes) to protect employees from Covid-19 and other infections at the enterprise (some of them not in full, taking into account the possible impact on the effectiveness of the their implementation result of negative the "human factor" signs), but not everything in an integrated manner. Thus, the problem of implementing a full range of anti-epidemic measures at the enterprise and ensuring a quarantine regime to protect employees from Covid-19 and other infections (in accordance with WHO recommendations) remains an urgent unsolved scientific and practical problem. Solve this problem, taking into account the need to control a large number of parameters in the implementation of anti-epidemic measures (ensuring admission regimes for employees to the enterprise, rational ventilation of premises, disinfection of surfaces, safe air decontamination, etc.) and the need to ensure a prompt reaction (by the Control Authority of quarantine regime) in case of violation by employees or other persons of the quarantine regime, it is possible (as noted earlier) only within the development of an appropriate automated system, consisting of a complex of relevant functional elements, software tools for managing them, as well as an operator (to perform functions that cannot be automated, etc.). The need to implement such systems at an enterprise, their development and invest in their development in order to create a sustainable occupational health and safety system in a crisis is defined as an urgent and priority task for 2021-2022 by the International Labour Organization [15].

3. Materials and methods

The following set of research methods was used in the study. Analysis of legal normative documents and scientific and technical literature in the field of building and functioning of anti-epidemic protection systems for employees at enterprises – to update the scientific problem and formulate research tasks.

Methods of system analysis – to build the overall structure of the system of automated protection of employees from infections and to establish relationships between its elements (sensors, actuators, etc.), as well as to determine the parameters and criteria for their functioning.

Simulation methods, namely the discrete-event simulation (DES) of stochastic processes – to develop the algorithms of functioning and interaction of sensors and actuators of subsystems, which are responsible for:

- compliance with the sanitary admission regime to the enterprise territory (in particular, disinfection modes for shoe soles, the surface of the hands of employees and visitors enterprise, control of body temperature, the presence of a protective mask on faces, as well as its issuance, the functioning of the admission turnstile);
- ensuring the disinfection of the surfaces of industrial premises (door handles, etc.);
- ensuring compliance with the mask regime in common areas (including recognition of the violator of the regime with the establishment of his identity).

Discrete-event simulation of deterministic processes of management of ventilation modes of industrial premises and decontamination of air in the working area - to develop of the algorithms of functioning and interaction:

- time relay and speed regulator of the electric motor of the air exchange subsystem;
- time relay and starting device for switch on/off the shielded UV emitter of the air decontamination subsystem.

Methods of decision theory and data mining – to develop the program of express testing for each employee's knowledge of the rules and norms of compliance with the quarantine regime established at the enterprise, as well as programs for unscheduled instruction of employees who have not passed express testing (taking into account those done errors); to develop the individual training programs for an employee from the technical personnel and for automated control of the level of his knowledge on occupational health and safety during the preparation and use of disinfectant solutions.

The developed system was tested at the Odessa Experimental Plant, Ministry of Education and Science of Ukraine (Odesa, Ukraine). The efficiency of the system was determined by collecting and analysing data from its subsystems (for the period from September 2021 to February 2022), namely: compliance with the sanitary and access regime at the enterprise; air ventilation of the working area; disinfection of air of the working area; ensuring disinfection of the surfaces of industrial premises; compliance with the mask regime in common areas; control of knowledge of employees of the technical staff group as well as by interviewing employees of the enterprise. According to the data received from the subsystem of compliance with the sanitary and access regime at the enterprise, 4028 persons (employees and visitors) visited the territory of the enterprise during this period. The personnel arrangements of the enterprise during this period remained unchanged – 32 persons.

4. Results and discussion

This study is based on the task of creating an system of automated protection of employees from Covid-19 and other infections (SAPEI), which due to the connection of functionally independent elements according to a certain scheme, allows minimizing the risks of infection of employees with the SARS-CoV-2 virus and other relevant respiratory viral infections within the enterprise and increase the protection of employees from the occurrence of Covid-19 and other infectious (influenza and others) by ensuring the continuous functioning of a complex of anti-epidemic measures within the quarantine regime established at the enterprise (in accordance with WHO recommendations).

SAPEI includes interconnected: the motion sensor and the level sensor of the disinfectant solution in the cartridge for the treatment of the mat, located at the checkpoint of the enterprise; the electronic terminal (with built-in camera); the non-contact body temperature scanner; the face scanner for the presence of a protective mask; the motion sensor on a device for non-contact treatment of hands with a disinfectant solution; the level sensor of the disinfectant solution in the hand treatment cartridge; the sprayer of disinfectant solution on the mat located at the checkpoint of the enterprise for disinfecting the soles of shoes; the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution for treating the mat; the light and sound signalling device, which reports increased body temperature; the turnstile blocking device; the light and sound signalling device, which reports the absence of a protective mask on the face; the automatic a protective mask dispenser; the non-contact sprayer of disinfectant solution for treating hands; the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution for treating hands; the normalizing converters and the signal amplifiers. SAPEI also includes: the motion sensor located behind the turnstile; the time relay for the ventilation system; the time relay for shielded UV emitter; the motion sensor located above the door handle of the industrial premises; the level sensor of the disinfectant solution in the cartridge, installed above the door handle of the industrial premises; the electronic terminal installed in the premises for technical personnel; the camera with a function of recognition of face without a protective mask installed in common areas (corridor, stairs, etc.); the speed regulator of the electric motor of the air exchange system of the industrial premises; the starting device for switching on / off the shielded UV emitter; the sprayer of disinfectant solution installed above the door handle of the industrial premises; the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution located above the door handle of the industrial premises; the light and sound signalling device, which reports non-admission of employee from technical personnel and blocking his personal magnetic card; the normalizing converters; the personal computer of the duty operator of the occupational health and safety service; the microprocessor control device (MCD); the signal amplifiers. The number of electronic terminals, the sensors, the time relays, the cameras with function of recognition of the face without a protective mask and actuators can change (increase / decrease) depending on the number of employees in the enterprise (organization, institution), industrial premises, workplaces, dangerous areas (common areas, surfaces of industrial premises) requiring control and treatment.

SAPEI aims to solve the following tasks (according to the WHO recommendations) [6, 12]:

- Ensuring a constant and prompt implementation of the process of disinfection of the surfaces of industrial premises, primarily those that are common areas and through which the transmission of infectious agents from the surfaces of the human body (employee), who is (potentially can be) a vector of such agents, on the surface of the body of a healthy employee (door handles of industrial premises, etc.) is possible.
- Increasing the safety level of employees, whose peculiarities of the labour process include the work in premises where several workplaces are located, by ensuring the process of constant decontamination of the air in the working area and rational modes of air exchange.
- To minimize the risk of spreading infections by airborne droplets by ensuring the process of monitoring the presence of protective masks on the face of employees and visitors at the checkpoint of the enterprise, as well as in common areas (corridors, stairs, etc.) and by ensuring automatic issuance of the protective masks in case their absence (due to minimizing the negative "human factor" signs).
- Reducing the occurrence of the "human factor" signs from technical personnel regarding the need for mandatory control of the presence of the required amount of disinfectant solution in disinfecting devices due to the use of level sensors of the corresponding solution.
- Reducing the risk of the acute occupational disease caused by strains of the Covid-19 viral infection and other occupational dangers of a biological nature. Elimination (minimization) of the risk of penetration of infectious agents from outside the territory of the enterprise, through constant monitoring of the employee's body temperature at the checkpoint of the enterprise, disinfection of the employee's shoe soles, hand disinfection, etc.
- Improvement of the quality control process for disinfection of surfaces of industrial premises and equipment performed by employees from technical personnel.
- Management of the sanitary and anti-epidemic regimes that established at the enterprise aimed at preventing the spread of infections.
- Increasing the social attractiveness of the enterprise by significantly reducing the level of infectious disease associated with dangerous and harmful productive factors of biological nature (in particular, Covid-19).
- Achievement of an increase in the economic effect at the enterprise, by reducing the number of social insurance payments (sick leave, etc.) and increasing its economic sustainability in a crisis caused by biological dangers of an infectious nature.

The schematic diagram of SAPEI is shown in Figure 1.

Listed in Figure 1 system elements are interconnected in that order. The motion sensor 1 and the level sensor of the disinfectant solution in the cartridge for the treatment of the mat 2 are connected to the corresponding normalizing converters 15 and 16, whose outputs are connected to the inputs of the microprocessor control device (MCD) 28. The electronic terminal (with the built-in camera) 3 is connected to the input of the MCD 28. The non-contact body temperature scanner 4, the face scanner for the presence of a protective mask 5, the motion sensor on a device for non-contact

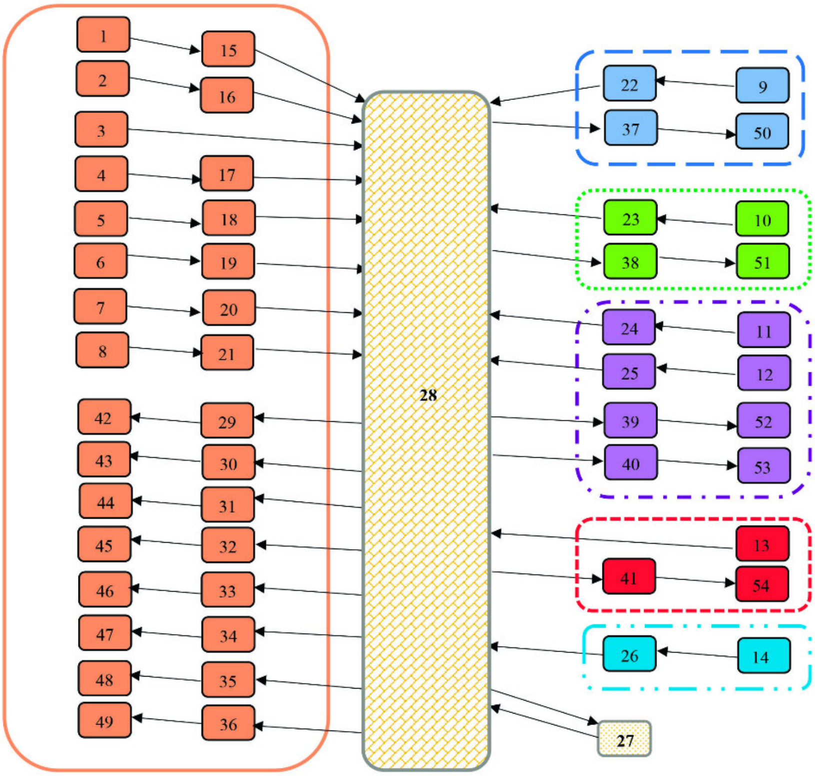

Fig. 1. Schematic diagram of SAPEI: 1 – the motion sensor; 2 – the level sensor of the disinfectant solution in the cartridge for the treatment of the mat, located at the checkpoint of the enterprise; 3 – the electronic terminal (with a built-in camera); 4 – the non-contact body temperature scanner; 5 – the face scanner for the presence of a protective mask; 6 – the motion sensor on a device for non-contact treatment of hands with a disinfectant solution; 7 – the level sensor of the disinfectant solution in the hand treatment cartridge; 8 – the motion sensor located behind the turnstile; 9 – the time relay for the ventilation system; 10 – the time relay for shielded UV emitter; 11 – the motion sensor located above the door handle of the industrial premises; 12 – the level sensor of the disinfectant solution in the cartridge, installed above the door handle of the industrial premises; 13 – the electronic terminal installed in the premises for technical personnel that using (preparing) disinfectant solutions for cleaning and processing the premises of the enterprise; 14 – the camera with a function of recognition of face without a protective mask installed in common areas; 15-26 – the normalizing converters; 27 – the personal computer of the duty operator of the occupational health and safety service; 28 – the microprocessor control device (MCD); 29-41 – the signal amplifiers; 42 – the sprayer of disinfectant solution on the mat located at the checkpoint of the enterprise for disinfecting the soles of shoes; 43 – the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution for treating the mat; 44 – the light and sound signalling device, which reports increased body temperature; 45 – the turnstile blocking device; 46 – the light and sound signalling device, which reports the absence of a protective mask on the face; 47 – the automatic a protective mask dispenser; 48 – the non-contact sprayer of disinfectant solution for treating hands; 49 – the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution for treating hands; 50 – the speed regulator of the electric motor of the air exchange system of the industrial premises; 51 – the starting device for switching on / off the shielded UV emitter; 52 – the sprayer of disinfectant solution installed above the door handle of the industrial premises; 53 – the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution located above the door handle of the industrial premises; 54 – the light and sound signalling device, which reports the non-admission of employee from the technical personnel and blocking his personal magnetic card.
Subsystem of compliance of sanitary admission control at the enterprise; Subsystem of ventilation; Subsystem of decontamination of the air working area; Subsystem for ensuring disinfection of surfaces of industrial premises; Subsystem of compliance with the mask regime in common areas; Subsystem of monitoring the knowledge of employees from the technical personnel

treatment of hands with a disinfectant solution 6 and the level sensor of the disinfectant solution in the hand treatment cartridge 7 are connected to the corresponding normalizing converters 17, 18, 19, 20, which are connected to the corresponding inputs of the MCD 28. The motion sensor 8 is connected to the normalizing converter 21, which is connected to the input of the MCD 28. The time relay for the ventilation system 9, the time relay for the shielded UV emitter 10, the motion sensor located above the door handle of the industrial premises 11, the level sensor of the disinfectant solution in the cartridge, installed above the door handle of the industrial premises 12 and the camera with a function of recognition of face without a protective mask installed in common areas 14 are connected to the corresponding normalizing converters 22, 23, 24, 25, 26, which are connected to the corresponding inputs of the MCD 28. The electronic terminal installed in the premises for technical personnel that using (preparing) disinfectant solutions for cleaning and processing the premises of the enterprise 13 is connected to the input of the MCD 28.

The sprayer of disinfectant solution on the mat 42, the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution for treating the mat 43, the light and sound signalling device, which reports increased body temperature 44, the turnstile blocking device 45, the light and sound signalling device, which reports the absence of a protective mask on the face 46, the automatic a protective mask dispenser 47, the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution for treating hands 49 are connected to the corresponding signal amplifiers 29, 30, 31, 32, 33, 34, 35 and 36, whose the inputs are connected to the corresponding outputs of the MCD 28.

The speed regulator of the electric motor of the air exchange system of the industrial premises 50, the starting device for switching on / off the shielded UV emitter 51, the sprayer of disinfectant solution installed above the door handle of the industrial premises 52, the light and sound signalling device, which reports the need to replace the cartridge with a disinfectant solution located above the door handle of the industrial premises 53 and the light and sound signalling device, which reports the non-admission of employee from the technical personnel and blocking his personal magnetic card 54 are connected to the corresponding signal amplifiers 37, 38, 39, 40 and 41, whose the inputs are connected to the corresponding outputs of the MCD 28. The input and the output of the personal computer of the duty operator of the occupational health and safety service 27 are connected to the corresponding output and input of the MCD 28.

SAPEI works as follows. The signal from the motion sensor 1 through the normalizing converter 15 is transmitted to the MCD 28, processed and through the signal amplifier 29 close / open the contactor groups of the sprayer of disinfectant solution on the mat 42. The signals from the sensors 2, 7, 12 through the normalizing converters 16, 20, 25, respectively, are transmitted to the MCD 28, processed and through the signal amplifiers, for example 30, or all 30, 36, 40 close / open the contactor groups of the light and sound signalling devices, for example, the light and sound signalling device 43, or all 43, 49, 53, which reports the need to replace (or fill) the corresponding cartridge or cartridges. The signal from the electronic terminal (with a built-in camera) 3 is transmitted to the MCD 28 and processed. The electronic terminal (with a built-in camera) 3 is intended for carrying out express testing of an employee in order to determine the level of necessary knowledge of the general safety requirements during quarantine restrictions, as well as for registering visitors to the enterprise. At the same time, the electronic terminal (with a built-in camera) 3 transmits to the MCD 28 information containing the visitor's photo and his personal data. The MCD 28 generates a unique visitor ID number and enters it into the general production database together with the visitor's photo. Thus, in the case of a violation by a visitor, for example, of the rules for compliance with the mask regime in common area, he can be identified in order to apply to him, for example, certain fines or other sanctions provided for by law. Express testing involves several questions related to detecting the level of knowledge of compliance with the quarantine regime at the enterprise. To obtain admission to the enterprise territory and to his workplace, the employee must provide more than 60% of correct answers, otherwise the system invites the employee to familiarize himself with the relevant information presented in the form of diagrams, drawings, videos, etc. (for better perception of information), and then retesting [29, 30]. If the results of repeated express testing are negative (less than 60% of correct answers), the employee must be unscheduled instructed in the occupational health and safety department and then control tested. During this time, the employee's admission to the enterprise territory is limited, and his personal magnetic card is blocked. The questions to answer through the electronic terminal 3 are selected randomly from the general production database, which is constantly updated taking into account the answers of the employees. It should be noted that for each work shift, for each test, the system offers different questions for employees. The time during which the employee's admission to the workplace is limited (personal magnetic card is blocked) is recorded and transmitted to the personnel department and the accounting department of the enterprise to take into account this information when calculating wages and work experience (number of working hours, number of non-working hours, etc.).

The signal from the non-contact body temperature scanner 4 through the normalizing converter 17 is transmitted to the MCD 28 and processed. In case of exceeding the established criterion of body temperature, the MCD 28 through the signal amplifier 31 close / open the contactor groups of the light and sound signalling device, which reports increased body temperature 44, while the employee's personal magnetic card is blocked, and this information is transmitted to the personnel department and the medical services of the enterprise, for the purpose of further processing.

The signal from the face scanner for the presence of a protective mask 5 through the normalizing converter 18 is transmitted to the MCD 28 and processed. If the scanner 5 detects the absence of the protective mask on the employee's (or visitor's) face, the MCD 28 through the signal amplifiers 33, 34 close / open the contactor groups of the light and sound signalling device 46 and the automatic a protective mask dispenser 47. The employee (or visitor) need to wear the protective mask on the face, after that the scanner 5 re-scans the face and, if it detects the presence of the protective mask, then transmits the signal to the MCD 28 for processing, and the light and sound signalling device 46 and the automatic a protective mask dispenser 47 work in regular mode.

The signal from the motion sensor on the device for non-contact treatment of hands with disinfectant solution 6 (in the case of raising hands into the area of disinfecting solution spraying) through the normalizing converter 19 is transmitted to the MCD 28, processed and through the signal amplifier 35 close / open the contactor groups of the non-contact sprayer of disinfectant solution for treating hands 48.

The turnstile blocking device 45 is in the locked mode, to restrict the admission of employees and visitors to the enterprise territory during all processing the signals from the electronic terminal (with a built-in camera) 3, the non-contact body temperature scanner 4, the face scanner for the presence of a protective mask 5, the motion sensor on a device for non-contact treatment of hands with disinfectant solution 6, the MCD 28. The turnstile blocking device 45 is unlocked after receiving the signal from MCD 28 through the signal amplifier 32. Such a signal is transmitted only if the MCD 28 receives cumulatively the signals: from the electronic terminal (with a built-in camera) 3 regarding the positive result of the employee's express testing (the employee provides more than 60% of correct answers to the questions), from the non-contact body temperature scanner 4 about not exceeding the set body temperature criterion, from the face scanner for the presence of a protective mask 5 and from the motion sensor on a device for non-contact treatment of hands with disinfectant solution 6. After unlocking the turnstile blocking device 45, the employee passes through the turnstile, it is fixed by the motion sensor 8 located behind the turnstile. A corresponding signal from the motion sensor 8 through the normalizing converter 21 is transmitted to the MCD 28, processed and through the signal amplifier 32 close / open the contactor groups of the turnstile blocking device 45 and locks the turnstile.

The signal from the time relay for the ventilation system 9 through the normalizing converter 22 is transmitted to the MCD 28, processed and through the signal amplifier 37 close / open the contactor groups of the speed regulator of the electric motor of the air exchange system of the industrial premises 50. The operating modes of the ventilation system are set depending on the schedule of the working process in the corresponding industrial premises. Two hours before the start of the work shift, the time relay 9 through the normalizing converter 22 transmits the signal to the MCD 28, which is processed and through the signal amplifier 37 transmitted to the speed regulator of the electric motor of the air exchange system of the industrial premises 50, while the speed regulator 50 switches to the mode of intensive air exchange. The time relay 9 begins counting the time until the start of the work shift. Upon reaching the established time, the time relay 9 through the normalizing converter 22 transmits the signal to the MCD 28 regarding the change in the speed of the electric motor and the transfer of the ventilation system to the regular work mode, in which the air exchange speed in the industrial premises complies with the established sanitary-hygienic requirements and begins the counting the time until the start the intra-shift break (in accordance with the rational modes of work and rest established at the enterprise). Upon reaching the established break time, the time relay 9 through the normalizing converter 22 transmits the signal to the MCD 28 about the need to transfer the speed regulator 50 to the mode of intensive air exchange. The time relay 9 begins counting the time until the end of the intra-shift break. At the end of the established break time, the time relay 9 through the normalizing converter 22 transmits the signal to the MCD 28 for changing the speed of the electric motor of the air exchange system and transferring the ventilation system to the regular work mode. The time relay 9 begins counting the time until the start of the next break, and at the end of the last intra-shift break - until the end of the work shift. Upon reaching the end time of the work shift, the time relay 9 through the normalizing converter 22 transmits the signal to the MCD 28, which is processed and through the signal amplifier 37 transmitted to the speed regulator of the electric motor of the air exchange system 50, which transferred to the mode of intensive air exchange at the same time. The time relay 9 begins counting the time until ventilation system shutdown time. Upon reaching the established time, signal from the time relay 9 through the normalizing converter 22 is transmitted to the MCD 28, processed and through the signal amplifier 37 close / open the contactor groups of the speed regulator of the electric motor of the air exchange system 50. The time relay 9 begins counting the time until the next activation of the ventilation system.

The signal from the time relay for the shielded UV emitter 10 through the normalizing converter 23 is transmitted to the MCD 28, processed and through the signal amplifier 38 close / open the contactor groups of the starting device for switching on / off the shielded UV emitter 51, installed in the industrial premises for decontamination of the working zone air, according to the recommendations [31,32]. Two hours before the start of the work shift, the signal from the time relay 10 through the normalizing converter 23 is transmitted to the MCD 28, processed and through the signal amplifier 38 switches on the shielded UV emitter 51. The time relay 10 begins counting the time until the end of the work shift in the corresponding industrial premises. Upon reaching the established time, the time relay 10 through the normalizing converter 23 transmits a signal to the MCD 28 about the need to switch off the shielded UV emitter through the starting device for switching on / off the shielded UV emitter 51, and the time relay 10 begins counting the time until the next switching on, that is, two hours before the start of the work shift.

The motion sensor, located above the door handle of the industrial premises 11 fixes the process of contact of the hand of an employee or visitor with the door handle of the industrial (administrative) premises, after which transmits the corresponding signal through the normalizing converter 24 to the MCD 28, where it is processed and through signal amplifier 39 open / close the contactor groups of the sprayer of disinfectant solution installed above the corresponding door handle of the industrial premises 52.

The electronic terminal 13 is installed in the premises for technical personnel using (preparing) disinfectant solutions for cleaning and processing the premises of the enterprise. The electronic terminal 13 is intended for testing employees using (preparing) disinfectant solutions for cleaning and processing the premises of the enterprise, in order to determine the level of necessary knowledge regarding the general requirements for the preparation, using of disinfectant solutions, as well as safety requirements during work with them. Testing involves the answering the questions by an employee of the technical personnel and is carried out before the start of each work shift. To obtain admission to the workplace, the employee must provide more than 60% of correct answers. In the case, when the employee provides less than 60% of correct answers, the signal from the electronic terminal 13 is transmitted to the MCD 28, processed and through the signal amplifier 41 close / open the contactor groups of the light and sound signalling device (located at the workplace of the duty operator of the occupational health and safety service) which reports the non-admission of the employee from the group of technical personnel to the workplace and blocking his personal magnetic card 54. The system invites the employee to return to the stage of familiarization with the instruction text and retesting. If after retesting the employee provides less than 60% of the correct answers, he is suspended for the duration of unscheduled training and instruction on relevant issues. At the same time his personal magnetic card is blocked, which is reported by the light and sound signalling device 54, and the corresponding information is transmitted to the personnel department and the accounting department of the enterprise.

The camera with a function of recognition of face without a protective mask installed in common areas 14, in which, according to the rules, it is necessary to be in a mask, automatically finds (in the control zone) the face of employees or visitors (who must receive the temporary pass at the checkpoint through the electronic terminal 3 with obtaining unique ID number and face recognition) without a protective mask (or if the mask is worn incorrectly) and through the normalizing converter 26 transmits the corresponding information to the MCD 28. The system identifies the employee (visitor) without a protective mask (with an incorrectly worn mask) by comparing the image received from the camera with the photos of employees from general production database of the enterprise (or a photo by the ID number of the visitor). Information about the person violating the mask regime at the enterprise is transmitted through the MCD 28 to the personal computer of the duty operator of the occupational health and safety service 27 and entered into the general production database of the enterprise. This information is available to employees of the occupational health and safety service, medical service, personnel department and accounting department and is used for unscheduled instructions, etc. Also, the information about existing violations is displayed on the electronic terminal 4, when the employee scanning his personal magnetic card. When choosing questions for daily express testing, the system takes into account the corresponding violations. If a visitor is a violator, this information can be transferred to law enforcement agencies to collect fines (which the visitor is warned about during admission to the enterprise territory).

The information about the corresponding signals from sensors 1, 2, 6, 7, 8, 11, 12, electronic terminals 3, 13, scanners 4, 5, time relays 9, 10, camera 14, as well as about the functioning of actuators 42, 45, 47, 48, 50, 51, 52 and light and sound signalling devices 43, 44, 46, 49, 53, 54 is transmitted to the personal computer of the duty operator of the occupational health and safety service 27, which is connected to the MCD 28, is processed and entered into the general production database. It should be noted that since measures to ensure the protection of employees from the occurrence of an acute occupational disease Covid-19 and other occupational dangers are exclusively within the competence of the occupational health and safety service, it is this service represented by the operator on duty manages the quarantine regime at the enterprise within the SAPEI [33,34].

SAPEI works in the automatic mode, however, manual control of system elements in case of emergency situations is also provided [35, 36]. For this, there is an interaction between the processing of signals in the MCD 28 and the personal computer of the duty operator of the occupational health and safety service 27 simultaneously through the interface, namely:

- information about the modes of the sensors, the scanners, the time relays, the electronic terminals, the cameras, the actuators, the light and sound signalling devices, the turnstile blocking device is processed and presented in a graphical form;
- commands concerning the mode change of functioning of the sensors, the scanners, the time relays, then electronic terminals, the cameras, the actuators, the light and the sound signalling devices, the turnstile blocking devices are transmitted;
- information about the detection of employees and visitors with an increased body temperature, without face protective masks, as well as employees not gaining admission to the workplace due to violation of the requirements of instructions for preparation, using of solutions for cleaning, processing of industrial premises, surfaces of common areas is processed and fixed;
- the time of crossing the enterprise checkpoint and receiving the protective mask by employees and visitors is displayed and, as well as, messages reminding the need to change the protective mask are transmitted to mobile phones (SMS, messages in a messenger, etc.) and / or work computers of employees at the regular intervals.

Thus, in the case of an emergency situations in the system functioning, the occupational health and safety service can ensure the functioning of the quarantine mode at the enterprise in manual mode (during elimination of violations of the system functioning) [37].

SAPEI unlike other automated systems, which are designed (as can be seen from the results of the analysis) to solve only certain tasks of prevention the spread of SARS-CoV-2 virus within the enterprise (for example, ensuring measures to disinfect the surface of employees' hands or some other individual tasks), for the first time allows to provide a systematic approach to the implementation of a full range of anti-epidemic measures (according to WHO recommendations) to minimize the risk of infection of employees with this virus and other respiratory viral infections within the enterprise. This is achieved through the constant management of the regimes of sanitary and epidemiological control of admission to the enterprise of employees and visitors; disinfection of public surfaces of industrial premises (door handles, etc.); ventilation and disinfection of air of industrial premises; compliance with the mask regime in common areas, as well as control of knowledge of employees in the field of anti-epidemic safety, which is provided by connecting according to a certain scheme of functionally independent elements of the system. In turn, these properties of SAPEI, in contrast to other systems, solve another urgent scientific and practical problem – increasing the level of economic stability of the enterprise in a difficult epidemiological situation of state or world level, which may be caused by new biological dangers (such as SARS virus), by minimizing the risks of enterprise shutdown as a result of the need to limit social and labour connections between employees.

The developed system is implemented at the industrial enterprise "Odessa Experimental Plant, Ministry of Education and Science of Ukraine" (Odessa, Ukraine) and was tested. During the testing period, from September 2021 to February 2022, according to the data received from the subsystem of compliance with the sanitary and access regime at the enterprise, 4028 persons (employees and visitors) visited the territory of the enterprise. The personnel arrangements of the enterprise during this period remained unchanged - 32 persons. According to the results of the analysis of data from the subsystems of SAPEI, the total number of violations of the quarantine regime set at the enterprise in early February 2022 in contrast to early September 2021 decreased by 83%. In particular, among employees of the enterprise the number of violations decreased by 92%. The lowest number of violations (with a steady decline in time) was recorded in the period from December 2021 to February 2022, this is due to the both increasing labour self-discipline, as a result of the tolerance to quarantine rules and the impacting administrative measures for violators, as a result of their prompt detection by the relevant elements of the SAPEI (according to the interviewing employees). Among the main violations were violations of the mask regime in common areas – 64% (most violations are due to visitors), as well as violations related to lack of knowledge in the field of anti-epidemic safety (31% of employees are sent for unscheduled training). The nature of these violations suggests that they are all related to certain "human factor" signs (conscious or unconscious human actions), and not to the algorithm of the relevant subsystems. The relevant elements of these subsystems detected such violations in a timely manner and provided information to the relevant services of the enterprise, which allowed to promptly eliminate them. This leads to the conclusion about the effectiveness of SAPEI in relation to minimizing the "human factor" signs. It should be noted that according to the results of the analysis, namely the inefficiency or inability to minimize the "human factor" signs was identified as one of the main disadvantages, that are inherent in existing automated protection systems against Covid-19.

About 5% of other violations of the quarantine regime were related to technical problems of settings the operation of subsystems to the specificities of technological processes in the enterprise (settings of ventilation, disinfection of air and surfaces of industrial premises, etc.). These violations were not systemic.

Given that the functional properties of SAPEI aimed at protecting employees from the dangers associated with the risks of respiratory viral infections in the enterprise, which in turn is one of the main tasks of the health and safety management system at the enterprise, solution of integration SAPEI to the previously developed system of automated management of occupational health and safety (SAOHSM) in order to increase the efficiency of its operation is the direction of further studies [35].

Based on the results of the development of the system, an application was filed for obtaining a patent for invention No. a 202105894 dated 20.10.2021.

5. Conclusions

According to the results of the research, a system of automated protection of employees from Covid-19 and other infections at the enterprise was developed, which consists of the following main independent elements connected according to a certain scheme: the motion sensors and the sensors for the level of disinfectant solution in cartridges for non-contact treatment of the surfaces of soles shoes and hands of employees and visitors of the enterprise, the electronic terminal with a video camera, the scanners of body temperature and face, the motion sensor of admission employees to the enterprise territory and the actuators for the subsystem of compliance of the sanitary admission control at the enterprise; the time relay and actuators of subsystems of ventilation and decontamination of the air working area; the motion sensors and level of disinfectant solution in cartridges, as well as the actuators of the subsystem for ensuring disinfection of surfaces of industrial premises; the cameras with the function of face recognition of subsystem of compliance with the mask regime in common areas; the electronic terminal, the magnetic card blocking devices of subsystem of monitoring the knowledge of employees from the technical personnel; the normalizing converters; the microprocessor control device; the signal amplifiers.

The combination of these elements is aimed at minimizing the risk of contracting of employees with the SARS-CoV-2 virus and other respiratory viral infections at the enterprise, which in turn provides increased protection of employees from the Covid-19 and other infections (influenza, etc.) by implementing a complex of anti-epidemic measures within the system and providing constant support of the quarantine regime at the enterprise (in accordance with WHO recommendations. Namely, by: ensuring a constant and prompt implementation of the process of disinfection of the surfaces of industrial premises, through which infection can be transmitted (door handles, etc.); ensuring a continuous process of decontamination of air in the working area and a rational modes of air exchange in the premises, where several workplaces are located; ensuring a continuous process of monitoring the presence of protective masks on the face of employees and visitors at the enterprise checkpoint, as well as in common areas (corridors, stairs, etc.); ensuring of employees and visitors automatic issuance of the protective masks, if their absence; reminding the need to change the protective mask after the time usage are ended; minimization of the "human factor" signs during the mandatory control of the presence of the required amount of disinfectant solution in disinfecting devices due to use of the level sensors of the corresponding solution; minimization of the risk of penetration of the infectious agents from outside the territory of the enterprise, through constant monitoring of the employee's body temperature at the enterprise checkpoint, disinfection of the employee's shoe soles, hand disinfection, etc; improvement of the quality control process for disinfection of surfaces of industrial premises and equipment performed by employees from the technical personnel; ensuring the process of monitoring, training and checking the knowledge of compliance with the quarantine regime at the enterprise by employees, etc.

The developed system is implemented at the industrial enterprise "Odessa Experimental Plant, Ministry of Education and Science of Ukraine" (Odessa, Ukraine) and was tested. During the testing period (from September 2021 to February 2022) the total number of persons who visited the territory of the enterprise was 4028 ones (employees and visitors). According to the results of the analysis of data from the subsystems of SAPEI, the total number of violations of the quarantine regime set at the enterprise in early February 2022 in contrast to early September 2021 decreased by 83%. In particular, among employees of the enterprise the number of violations decreased by 92%. Among the main violations were violations of the mask regime in common areas – 64% (most violations are due to visitors), as well as violations related to lack of knowledge in the field of anti-epidemic safety (31% of employees are sent for unscheduled training). These violations are related to certain "human factor" signs (conscious or unconscious human actions), and not to the algorithm of the relevant subsystems. About 5% of other violations of the quarantine regime were related to technical problems of settings the operation of subsystems to the specificities of technological processes in the enterprise (settings of ventilation, disinfection of air and surfaces of industrial premises, etc.). These violations were not systemic.

Based on the results of the development of the system, an application was filed for obtaining a patent for invention No. a 202105894 dated 20.10.2021.

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