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Abstract. Specialists now make the most of information and communication technologies at all stages of disaster risk management. These technologies, along with the ever-increasing number of Internet of Things devices, can assist in disaster risk reduction or emergency response decisions. At the same time, the existing Cyber-Physical Systems of natural disaster risk management are based on mathematical methods. But mathematical (quantitative) methods have a number of drawbacks, therefore, expert (qualitative) assessments are the only means of solving many control problems due to the ease of use for predicting almost any situation, including in conditions of incomplete information. Research aimed at developing a general methodology for managing disaster response shows that it is possible to view response management as a process and production management problem. Based on this view, process and production management system technology can be used to develop a common framework for a disaster risk management system. A model of situational management of such systems based on qualitative methods is proposed. The model will allow the creation of automatic cyber-physical systems for disaster risk management. At the same time, the proposed model is devoid of the shortcomings of mathematical models and is close to the human way of expressing knowledge.

Keywords: Cyber-Physical Systems, Information and communication technologies, Internet of Things devices, Disaster risk management system, Qualitative methods.

1 Introduction

Today, to build resilience to natural disasters, professionals make the most of information and communication technologies (ICT) at all stages of disaster risk management – reduction, preparedness, response and recovery. Along with the ever-increasing number of Internet of Things (IoT) devices, these technologies can aid decision-making in disaster risk reduction or emergency response [1]. The result of technologies is Cyber-Physical Systems (CPS), which is the name for a combination of the IoT and System

Control. So rather than just being able to “sense” where something is, CPS adds the capability to control the “thing” or allow it to interact with physical world around it [2].

That said, disaster risk management (like disaster response management) can be viewed as a process and production management problem. Based on this point of view, technologies applied in process and production management systems can also be used for a disaster risk management system, which also includes an adaptive (situational) decision-making system [3].

As a method, situational management is based on the assumption that all the necessary information about managing an object that people managed poorly or not very poorly before creating a control system can be obtained from direct observation of their work or from their verbal explanations. Moreover, the object management model can be obtained on the basis of special processing of texts in natural language, which describes a fairly large experience of people [4-6].

The concept of situational management boils down to the following [7]: each type of specific situation should have its own control procedure (scenario) with its own criteria and decision-making methods. The situational control method is used when the complexity of the control object and the particularities of the problem being solved do not allow constructing a mathematical model and setting a traditional problem, as well as when control is carried out mainly in conditions of uncertainty and poor structure of the problem. In this case, it becomes necessary to use heuristic procedures and use high-quality information.

The situational management system (SMS) use Intelligent control algorithms, which imply the rejection of the need to obtain an accurate mathematical model of an object, orientation to the use of “hard” (simple, usually linear) algorithms for generating control actions, and the desire to use synthesis methods known to the developer at any cost, previously positively recommended for other, simpler classes of objects [8].

The situational management method is one of the most relevant and promising methods that allow for a wide class of systems to solve the search problem (in the process of adaptation) of algorithms for disaster risk management systems, in particular CPS.

2 Analysis of recent research and publications

The relevance of the problem raised is confirmed by a sufficient number of publications. In [1], the use of ICT is considered, but only for organizing the dissemination of information, which, according to the authors, increases the efficiency of operations in emergency situations and increase public awareness.

The materials [2] describe the Smart Emergency Response System (SERS) capitalizes on the latest advancements in cyber-physical systems (CPS) to connect autonomous aircraft and ground vehicles, rescue dogs, robots, and a high-performance computing mission control center into a realistic vision. The system provides the survivors and the emergency personnel with information to locate and assist each other during a disaster. SERS allows organization to submit help requests to a MATLAB-based mission center (i.e. on a set of mathematical models). The command and control center optimizes the available resources to serve every incoming requests and generates an action plan for the mission. The Wi-Fi network is created on the fly by the drones equipped with antennas. In addition, the autonomous rotorcrafts, planes, and ground vehicles are simulated with Simulink (also on a set of mathematical models) and visualized in a 3D environment (Google Earth) to unlock the ability to observe the operations on a mass scale.

So, in [9], the issue of constructing a situational management strategy, relevant for managing complex objects in uncertain environments, when the lack of a strategy is associated with the possibility of default of operational (reactive) decisions, is considered. A method is proposed for constructing a strategy in situational management systems, which opens up the possibility of implementing algorithms such as "situation – strategy – decision".

But the construction of a strategy for transferring an object from the current situation to the target is carried out according to a mathematical model in the form of a situational network in which the degree of preference for a solution is determined by some objective, expert-defined function that has a quantitative expression.

In [10], a situational approach to the management of organizational and technical systems (OTS) was considered during the planning of operations (military operations). A variant of the functional model of the situational approach to the management of OTS is developed. To classify the signs of problem situations (technological relationships), the authors use the declarative knowledge of experts in the form of an oblique matrix, but then, when modeling problem situations, they use an efficiency criterion that has a quantitative expression. The proposed model, in essence, is automated only in the part of modeling problem situations – a description of the current situation prevailing at the control object is submitted to the OTS by the decision-maker (DM).

The review article [11] considers theoretical aspects related to the formation of effective management of the behavior of complex socio-economic objects in an unstable environment. It is noted that situational management of complex objects and fuzzy control algorithms, the organization of which is based on the application of accumulated experience and data obtained by interviewing highly qualified specialists in a given area, can most fully satisfy these requirements. The formation of decision support systems (DSS) on a situational basis and using fuzzy control algorithms is proposed as a promising form of management organization. The result of the work of such a DSS is a lot of output rules (products) for managers, providing various fuzzy (qualitatively expressed) values of the controlled parameters.

In [12], it is stated that the general task of situational management of complex objects is decomposed into the following tasks: decision management when detecting or predicting a problem situation in the process of managing objects and planning management of objects based on the decision made. The scheme of solving these problems is presented: determining the target situation corresponding to the mode of functioning of the managed object in the form of a decision-making task; the choice of a way to achieve the target situation in the form of a task of the direct control of an object. However, it is proposed to use mathematical models of Mayer, Lagrange or Bolza from the classical control theory as a DSS.

In [13], strategy of effective decision-making in planning and elimination of consequences of emergency situations is proposed and discussed. A system of partial indicators that characterize the prevented damage from emergency situations is proposed. To find the optimal resource allocation corresponded to the predicted disaster, the quantitative method of ideal point is used.

The staging work [14] presents the concept of a regional information and analytical system for emergency situations. The three-level architecture of such a system and the functions of its main components are described. The goals and peculiarities of the structural modules for the regional information and analytical system for the prevention and elimination of emergencies are detailed.

The article [15] proposes a universal model to assess the impact of external influences on the system based on the theory of utility (quantitative method). Also information technologies providing the procedure for assessing the risks and consequences of natural disasters in socio-economic systems are considered.

Despite the declared goal of [16] - the development of a management system that integrates the use of the IoT for the detection, prevention and management of natural risks, it is about the implementation of a computerized integrated system only for assessing the costs and benefits in some natural risk situations. The methodology that has been put in place is able to compare the costs of prevention, including the costs of the detection system, analysis and reporting, and an estimate cost to contain damage, with the benefits deriving precisely from the damage avoided.

The work [3] describes technologies for creating a networked Critical Infrastructure system. It is a complex socio-technical system with time-varying boundaries and topology, in which dynamic, uncertain and stochastic factors are present throughout the disaster management process. The article presents a study aimed at developing a general methodology for disaster response management to view the response management as a process and production control problem. Based on this point of view the control system technology is employed to develop a general framework for the disaster response management system, which also incorporates an adaptive decision system. It is proposed to use a methodology called FBS framework, which is a DSS, as part of the formalism for the development of the static part of the object model for the networked Critical Infrastructure system, and also to use the Petri Net as another part of the formalism to develop the dynamic part of the object model. It is proposed to divide the formalization of the control object model into static and dynamic parts and interactions between them. However, mathematical models are used to make decisions, and the Petri Nets methodology proposed for modeling dynamics has extremely low expressive qualities in comparison with existing similar methods.

At the same time in [17] it is emphasized that despite the widespread of mathematical methods in the solution of management tasks, it cannot be assumed that formal methods of modern mathematics will be the universal means of solving all problems arising in this area. Mathematical (quantitative) methods have several drawbacks related, on the one hand, with the necessity of high qualification of developers of such control systems, and on the other hand, errors induced by mathematical models, which have been used. In connection with the limited possibilities of application in management mathematical methods, lack in many cases of statistical and other information as well as reliable methods for the determination of conformity of mathematical models of real office objects, expert (qualitative) assessment is the only means of solving many tasks. The advantages of expert ratings include ease of use to predict almost any situation, including in the conditions of incomplete information.

The material presented in [18] is closest to the goal of this study in the context of the use of SMS based on qualitative methods for automated (and in some cases automatic) process control.

A review of the publications suggests that:

- the vast majority of the proposed solutions is based on mathematical models (quantitative methods), with their inherent errors;
- such systems are automated only in terms of modeling the control object;
- decision-making or entering a description of the situation requires decision-making;
- the main source for creating object management models for SMSs is the knowledge of experts who use terminology in their subject area, i.e. overwhelmingly qualitative data;
- disaster response management can be seen as a process and production management problem.

3 Purpose of the study

In quantitative methods, an implicit assumption is made that a person once measures a certain quantitative parameter, and the obtained value is the only one reflecting the preference of the DM. However, studies by psychologists [19], as well as the practical experience of using these methods, allow one to doubt the correctness of this assumption. As it is known, the DM is not an accurate measuring device that does not allow errors in quantitative measurements [20]. Psychophysics gives quantitative confirmation of a person’s inaccuracy in measuring physical parameters (weight, length, and so on). As a result, the direct assignment of quantitative criteria weights is always carried out with errors [21].

The need to take errors into account in quantitative measurements is rightly pointed out in [22]. In psychological experiments [19], it was shown that human “heuristics and biases” lead to significant errors in the information received (for example, when quantifying events probabilities).

Therefore, the development of the proposed model is based on the use of quality information - expert knowledge obtained from experts in terms of their subject area.

If we talk about expert knowledge, then they can be conditionally divided into two types [23]. One of them – facts, information, theories, problems, etc., is called **declarative knowledge** and is most often displayed in tabular form. They answer the question "What is this?" with their help, you can evaluate the results obtained in the course of any activity (process). Another type is the human ability to solve problems, compose music, treat patients, find faults in cars and devices, etc. called skill or **procedural knowledge**, displayed in the form of process diagrams. This knowledge answers the question "How to do this?" And with their help you can get the required results.

Let us consider in more detail the presentation forms and the content of expert knowledge most suitable for the requirements of the developed model.

Declarative knowledge is the knowledge base for DSS. It is possible to build such a DSS using the ORCLASS method (ordinary classification of alternatives) [20] from a set of verbal decision analysis methods developed under the guidance of academician O. Larichev. The basic principles of verbal decision analysis are formulated as follows:

- *use to describe the problem of definitions and wordings of estimates of decision options in the form that is natural for the DM, his advisers and active groups, without any conversion of such verbal formulations into quantitative meanings;*
- *building a decision rule based on logical, qualitative transformations of verbal variables, while observing the psychological and mathematical correctness of these transformations.*

The ORCLASS method is based on three concepts - an alternative, a criterion (and its values) and a class having the following semantic meaning:

- **alternatives** – data sets (research results). For the model under development, these are sets of process indicator values;
- **criteria** – a set of characteristics that distinguish alternatives from each other. For the model under development, this is a set of process indicators;
- **criteria values** – a set of all possible values of all criteria, while for each criterion they are ordered from best to worst. For the developed model, these are the values of the process indicators;
- **classes** – having their own unique characteristics, ordered (from best to worst) parts of the general list of all possible alternatives (for example, diagnoses, causes of malfunctions, rating or rating categories of something or someone, etc.).

The ORCLASS method allows:

- for any set of process indicators and their values, rank (sort by predefined classes) according to the principle “better – worse” any number of sets of process indicator values, i.e. build a decision rule;
- using the decision rule to unambiguously determine which of the classes belongs to any of the sets of values of process indicators received at the DSS input.

The decision rule (Table 1) is a table containing all possible alternatives, arranged in lexicographic order from the best (having the best values of all process indicators) to the worst (having the worst values of all process indicators) alternatives, each of which is assigned a class, to which it belongs.

Procedural knowledge of the combined model presented in fig. 4 is the knowledge base for the process executors and the software and hardware complex (SHC) necessary for the full implementation of the process control goals. Expert knowledge is displayed using one of the process modeling methods, namely BPMN (Business Process Model and Notation) [25]. BPMN is a specification of the language of graphic elements for displaying processes in modeling workflows occurring in the system under study. The resulting process model is a network of graphical objects that depict actions (tasks, subprocesses) associated with control flows (see Fig. 1).

Table 1. Fragments of the decision rule for DSS in Nuclear Emergency Management (process indicators from [24]).

N	Thyroid cancer	Other cancers	Positive effects	Negative effects	Costs	Political cost	Classes
1	best	best	best	best	best	best	Strategy 0
2	best	best	best	best	best	middle	Strategy 0
3	best	best	best	best	best	worst	Strategy 1
…	…	…	…	…	…	…	…
364	middle	middle	middle	middle	middle	best	Strategy 2
365	middle	middle	middle	middle	middle	middle	Strategy 2
366	middle	middle	middle	middle	middle	worst	Strategy 2
…	…	…	…	…	…	…	…
727	worst	worst	worst	worst	worst	best	Strategy 3
728	worst	worst	worst	worst	worst	middle	Strategy 4
729	worst	worst	worst	worst	worst	worst	Strategy 4

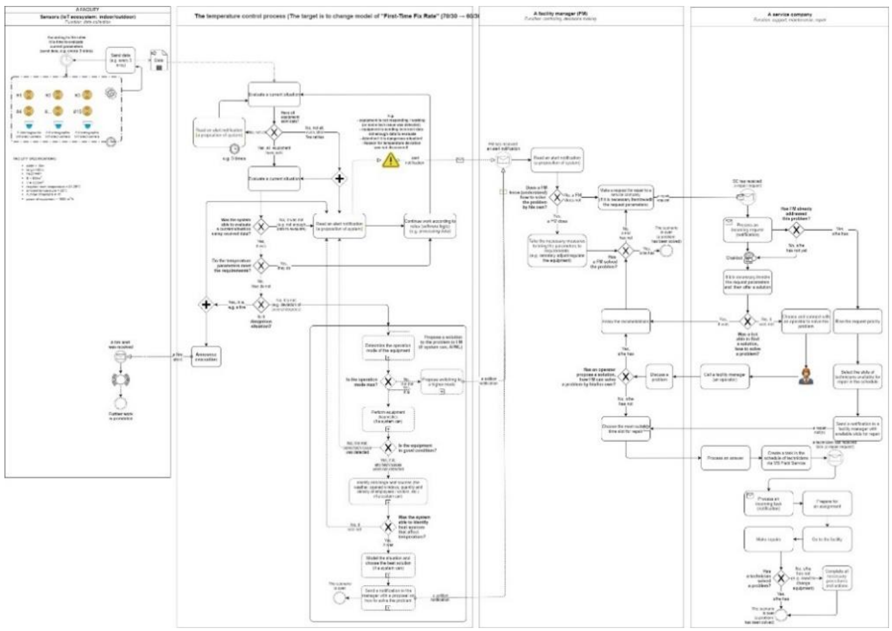

Fig. 1. An example of a process diagram of interaction with the IoT devices in BPMN notation.

Actually, the full specification of the language is difficult enough for non-specialists to understand and redundant to display most processes. Therefore, in the developed model, it is proposed to use the so-called DSL (Domain Specific language), namely, a set of graphic elements of the **language of visual modeling of regulations** (LVMR) [26]. The language is developed on the basis of BPMN and currently contains only 14 graphic elements (of which 2 are most often used), corresponding to BPMN elements, but having either more limited or modified functionality, which is determined by the specifics of the display of process regulations.

The minimum set of elements and their specific properties allow LVMR:

- to be a formal metamodel of knowledge representation about process regulations in any subject area in the form of logic circuits;
- automatically check received circuits not only for syntax but also for semantics.

LVMR, as well as BPMN, is intuitive – as practice shows, the experts with whom we had to work almost immediately begin to "read the diagram" despite the age and degree of technical education.

Analyzing the structure and content of the described forms of knowledge representation, we can draw the following conclusions:

- declarative knowledge with the implementation mechanism represents the level of decision-making – the choice of strategy, including monitoring (*Observe*) and evaluation of process indicators, as well as the choice of a process execution scheme corresponding to the current set of process indicators (*Orient*);
- procedural knowledge is an action plan in the form of a process diagram (*Act*), including the adoption of operative (tactical) decisions "stitched" in a diagram in situations corresponding to the current set of process indicators (*Decide*).

The interaction of knowledge representation forms is shown in Fig. 2.

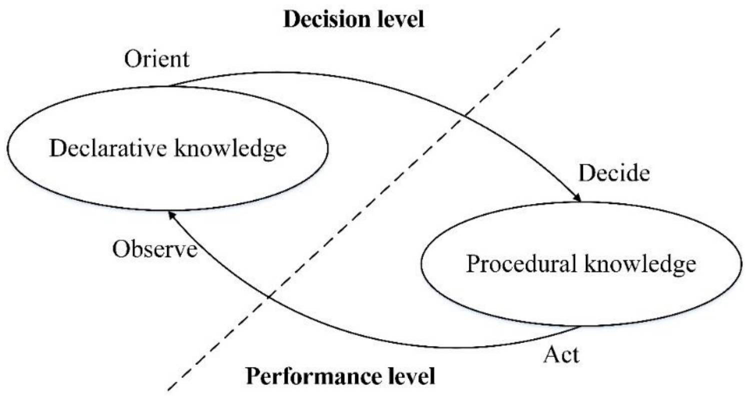

Fig. 2. An example of a process diagram of interaction with the IoT devices in BPMN notation.

The model presented in [18] determines the structure of an automated control system based on qualitative methods, including the following elements (see Fig. 3):

- **Process status evaluation unit** – DSS, which determines to which class the set of values of the process indicators received at the input belongs. DSS is built on the basis of a decision rule developed using the ORKLASS method of verbal analysis;
- **Library process diagrams** – process diagrams containing descriptions of actions in situations and related to classes that are defined in DSS. Schemes developed by LVMR;
- **Process control unit** – executors of the process and SHC, operating in accordance with the selected process scheme;
- **Experts** – make changes to the decision rule and process schemes in case of deviation of the process result from the expected ones or to compensate for the environmental impact;
- **Resources** – a set of resources (process executors, SHC, raw materials and components) supplied to the inputs of the process control unit and the process depending on the class to which the current set of process indicator values belongs.

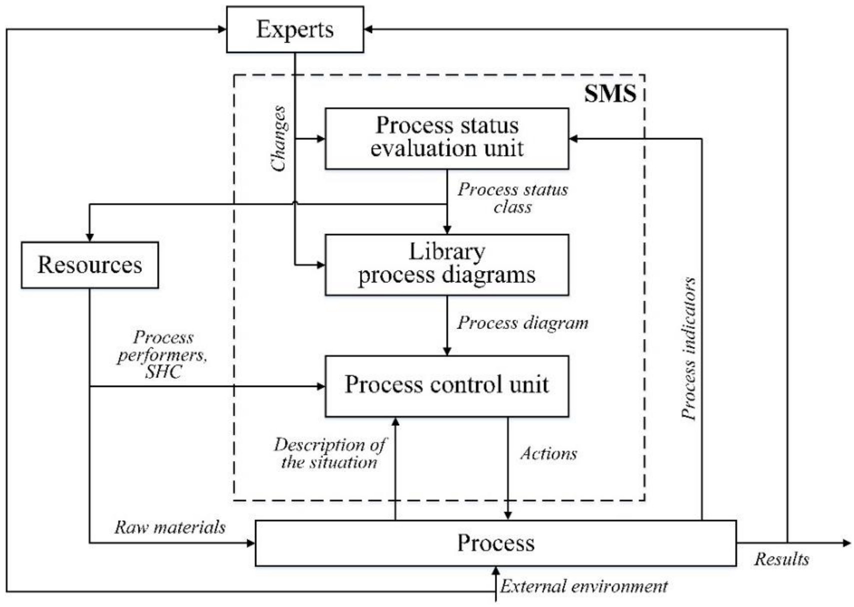

Fig. 3. The Structure of an automated system of situational management based on qualitative methods.

The difference between CPS and process control systems is as follows:

- the role of the process control unit is performed by a computer complex;
- the IoT devices act as executors and participants in the process.

In fig. 4 shows the structure of an automated Cyber-Physical System for situational disaster risk management based on qualitative methods, taking into account the above differences.

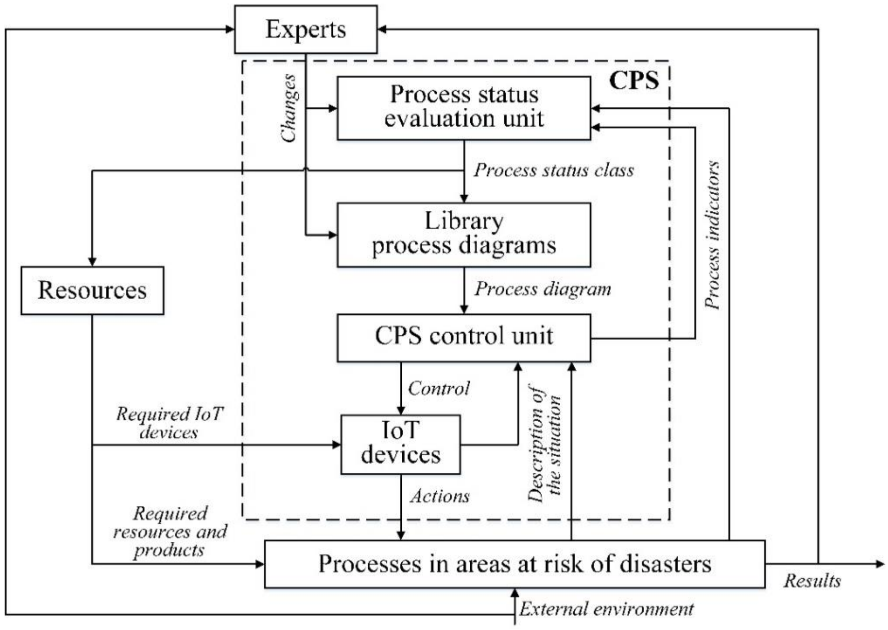

Fig. 4. The Structure of an automated Cyber-Physical System for situational disaster risk management based on qualitative methods.

The structure shown in Fig. 4, includes the following elements:

- **Process status evaluation unit** – DSS, which determines to which class the set of values of the process indicators received at the input belongs. DSS is built on the basis of a decision rule developed using the ORKLASS method of verbal analysis;
- **Library process diagrams** – process diagrams containing descriptions of actions in situations and related to classes that are defined in DSS. Schemes developed by LVMR;
- **CPS control unit** – a computing complex operating in accordance with the selected process diagram;
- **IoT devices** – process executors, functioning in accordance with the selected process scheme and supplying data on the current situation;
- **Experts** – make changes to the decision rule and process schemes in case of deviation of the process result from the expected ones or to compensate for the environmental impact;
- **Resources** – a set of resources, including the IoT devices, necessary for solving problems, depending on the class to which the current set of values of the process indicators belongs.

4 Conclusions

A model of an automated Cyber-Physical System for situational disaster risk management based on qualitative methods has been developed, which has the following features:

- based on expert knowledge in an arbitrary subject area, expressed in a qualitative way;
- produces an unambiguous (not approximate/rounded) result;
- involves the participation of an expert only in creating/modifying models;
- allows you to create both automated and automatic management systems;

After creating the appropriate software, it is possible to make the similar systems by users-expert who do not have programming and knowledge management skills.

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