Evaluation and Monitoring for Disaster Management

Alexander Ryjov
Department of Mechanics and Mathematics
Lomonosov' Moscow State University
Moscow, Russia
e-mail: ryjov@intsys.msu.ru

***Abstract*—This article describes the main ideas of disaster management based on technology for status evaluation and progress monitoring of complex processes. Our work analyzes features of the disaster management process and the characteristics of the available information. The article also discusses the technological capabilities for evaluating and monitoring complex processes to support decisions at the stage when urgent assistance is needed.**

Keywords-disaster management; technology for evaluation and monitoring of complex processes; perception-based descriptions; fuzzy hierarchical systems.

I. INTRODUCTION

Disaster management has become an important task for every country. For example, in 2012 (an average year in terms of disasters) we have the following statistics [1]:

- There were 905 natural catastrophes worldwide, 93% of which were weather-related disasters.
- Overall costs were US$170 billion and insured losses $70 billion.
- 45% were meteorological (storms), 36% were hydrological (floods),12% were climatological (heat waves, cold waves, droughts, wildfires) and 7 % were geophysical events (earthquakes and volcanic eruptions).
- Between 1980 and 2011 geophysical events accounted for 14% of all natural catastrophes

Figures 1 – 3 [2] show us the trends:

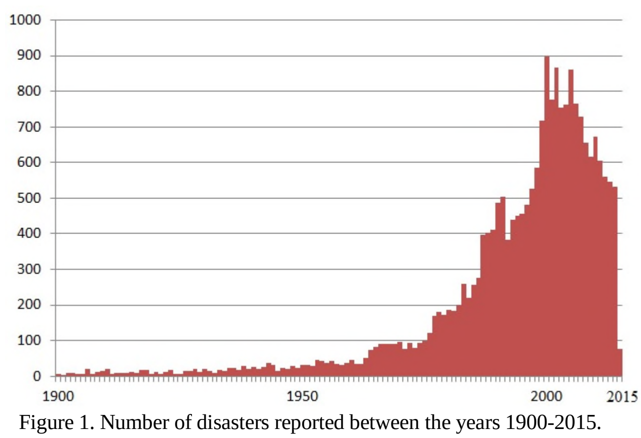

Figure 1. Number of disasters reported between the years 1900-2015.

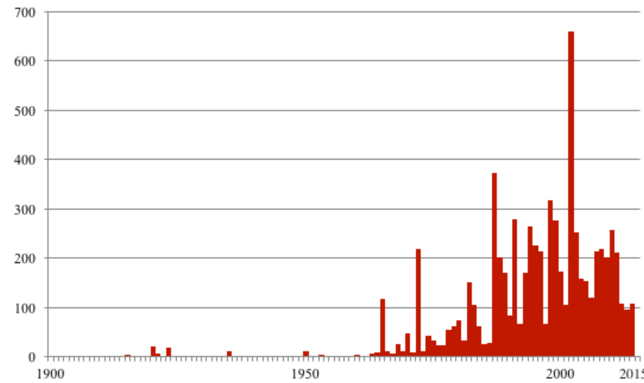

Figure 2. Number of people (in millions) reported affected by natural disasters between the years 1900-2015.

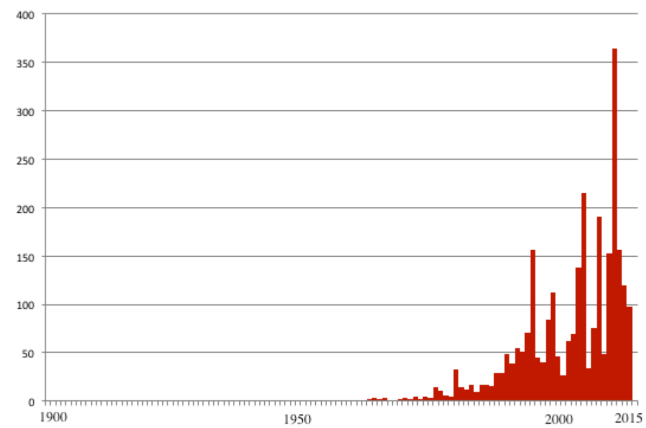

Figure 3. Estimated damages (in $US billions) caused by reported natural disasters between the years 1900-2015.

This problem is a focus for international (The United Nations Disaster Assessment and Coordination - UNDAC [18]), regional (for example, Emergency Response Coordination Centre European Commission - ERCC [19]), and national organizations (the majority of countries have a Ministry of Emergency Situations, or similar).

Information and communications technologies can help disaster managers quickly access, contextualize, and apply near real-time information, improving the speed and effectiveness of critical actions such as warning the population at risk – examples of such information and communications technologies can be found on the web sites

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mentioned above. In this article, we focus on the intellectualization of this type of systems.

The rest of this paper is organized as follows: Section II exposes the main features of disaster management systems and the main characteristics of the available information. Section III provides a description of the technology used for evaluation and monitoring of complex processes. This technology allows us to process information that is uncertain, fragmentary, and variable over time. In conclusion, we collect pro and contra arguments for the applicability of the technology for disaster management.

II. DISASTER MANAGEMENT CHALLENGES

In recent years, the field of disaster studies has emerged as a new academic field [3] [4] [5]. Specialization in disaster management includes all three stages (before, during and after) – risk analysis and contingency planning, management and coordination during the event, and a disaster recovery plan. The most important and dangerous type of disasters is Large Scale Sudden Disasters (LSSD) [3]. LSSD management stages are presented in Figure 4.

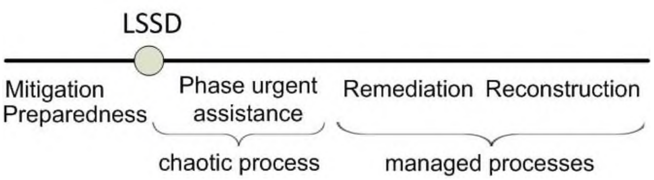

Figure 4. LSSD management stages.

The Remediation and Reconstruction stages are controllable enough, and modern information and communications technologies are capable to support these stages. The Urgent assistance stage is the main challenge from this point of view. The Urgent Assistance Phase has maximal uncertainty and maximal importance. We can single out the following top-5 characteristics for the Urgent Assistance Phase:

- Poor forecast – unexpectedness or short time for preparation
- Lack of information about the situation – huge uncertainty
- Lack of information about the available forces and resources – huge uncertainty
- The situation changes very fast – very short time for decision making
- High cost for wrong decisions

Based on this characterization, we can assert that the current status of decision support systems does not allow us to develop such a system for the Urgent Assistance Phase. The challenges are:

- Rationalize decision making for disaster preparedness
- Provide a base for vulnerability assessment and priority setting
- Provide monitoring and control for the Urgent Assistance Phase
    - o Time pressure
    - o Uncertainty
    - o Fast changes

III. TECHNOLOGY FOR EVALUATION AND MONITORING OF COMPLEX PROCESSES

Systems for Evaluation and Monitoring of Complex Processes (SEM) relate to a class of hierarchical fuzzy discrete dynamic systems. The theoretical base of such class of systems is made by the fuzzy sets theory, discrete mathematics, methods of the analysis of hierarchies which was developed by Zadeh [16] [17], Messarovich [7], Saaty [15] and others. SEM process uniformly diverse, multi-level, fragmentary, unreliable, and varying in time information about complex processes. Based on this type of information, SEM monitor the process' evolution and work out strategic plans of process development. These capabilities open a broad area of applications in business (marketing, management, strategic planning), socio-political problems (elections, control of bilateral and multilateral agreements, terrorism), etc. One of such applications is a system for monitoring and evaluating a state's nuclear activities (department of safeguards, International Atomic Energy Agency (IAEA)) [8]. This application is briefly described in this article.

A. *Basic elements of SEM and their characteristics*

The basic elements of SEM at the top level are the information space, in which information about the state of the process circulates, and the expert(s) who are working with this information and making conclusions about the state of the process and forecasts of its development (Figure 5).

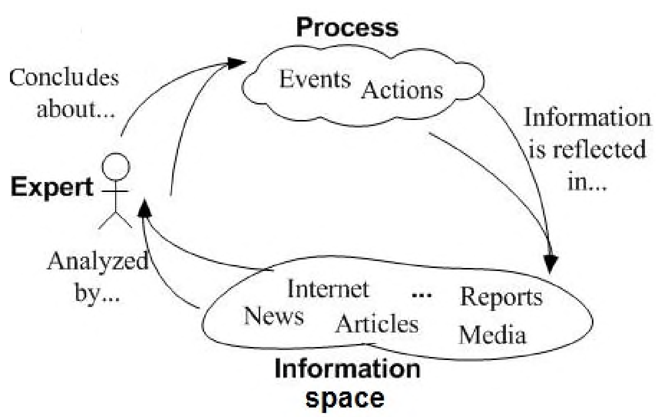

Figure 5. Basic elements of SEM.

The information space represents a set of various information elements, which can be characterized as follows:

- Diversity of the information carriers, i.e., presentation of the information in the articles, newspapers, computer kind, audio- and video-information, etc.;
- Fragmentary. The information most often related to any fragment of a problem, and the different fragments may be differently "covered" with the information;

- Multi-levels of the information. The information can concern the whole problem, some of its parts, or a particular element of the process;
- Various degree of reliability. The information can contain the particular data which has a various degree of reliability, indirect data, results of conclusions on the basis of the reliable information or indirect conclusions;
- Possible discrepancy. The information from various sources can coincide, differ slightly or be contradictory;
- Varying in time. The process develops over time, therefore, the information about the same element can be different between two different moments in time;
- Possible bias. The information reflects certain interests of the source of the information; therefore it can have tendentious character.

The experts are an active element of the monitoring system and, observing and studying elements of the information space, they draw conclusions about the state of the process and prospects of its development taking into account the properties listed above about the information space.

B. Basic principles of technology for evaluation and monitoring of complex processes

Systems for evaluation and monitoring of complex processes allow:

- to process uniformly diverse, multi-level, fragmentary, unreliable, information varying in time;
- to receive evaluations of status of the whole process and/or its particular aspects;
- to simulate various situations in the subject area;
- to reveal "critical ways" of the development of the process. This means to reveal those elements of the problem, the small changes that may qualitatively change the status of the process as a whole.

Taking into account the given features of the information and specific methods of its processing, it is possible to declare the main features of the technology as follows:

- The system provides the facility for taking into account data conveyed by different information vehicles (journals, video clips, newspapers, documents in electronic form, etc.). Such a facility is provided by means of storage in a database of a system of references to an evaluated piece of information, if it is not a document in electronic form. If the information is a document in electronic form, then both the evaluated information (or part thereof) and a reference thereto are stored in the system. Thus, the system makes it possible to take into account and use in an analysis all pieces of information, which have a relationship to the subject area irrespective of the information vehicle.
- The system makes it possible to process fragmentary information. For this purpose, a considerable part of the model is represented in the form of a tree/graph (Figure 6).

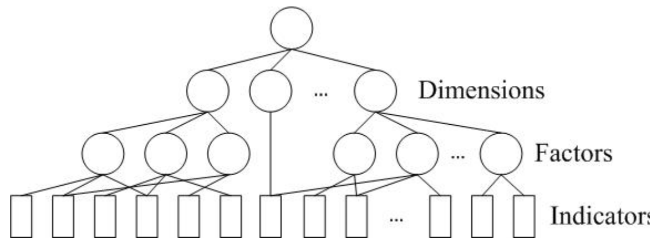

Figure 6. Structure of process model.

- Information with different degrees of reliability, some of it possibly tendentious, can be processed in the system. This is achieved by assessing the influence of a particular piece of information on the status of the elements of the model using fuzzy linguistic values.
- Time is one of the parameters of the system. This makes it possible to have a complete picture of the variation of the status of the model with time.

The summary of the information processing in SEM is presented in Figure 7.

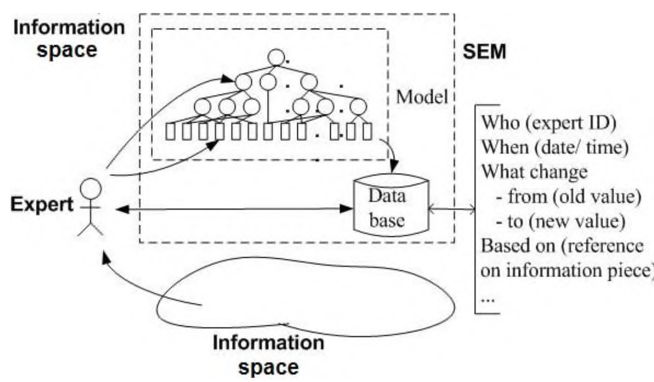

Figure 7. SEM workflow.

Thus, the systems constructed on the basis of this technology allow having the model of the process developing in time. It is supported by the references to all information materials, chosen by the analysts, with general and separate evaluations of the status of the process. Using the time as one of the parameters of the system allows to conduct the retrospective analysis and to build the forecasts of development of the process. There is the opportunity of allocation "of critical points", i.e., which are element(s) of the model for which a small change can cause significant changes in the status of the whole process. The knowledge of such elements has large practical significance and allows to reveal "critical points" of the process, to work out the measures on blocking out undesirable situations or work towards the achievement of desirable situations, i.e., somewhat operate the development of the process in time in the desirable direction.

C. Theoretical Basis

For effective practical application of the proposed technological solution, it is necessary to tackle a series of theoretical problems, the results of which are given below.

It is assumed that the expert describes the degree of inconsistency of the obtained information (for example, the readiness or potential for readiness of certain processes in a country [8]) in the form of linguistic values. The subjective degree of convenience of such a description depends on the selection and the composition of such linguistic values. Let us explain this on a model example.

Example [8]. Let it be required to evaluate the quantity of plutonium. Let us consider two extreme situations.

Situation 1. It is permitted to use only two values: "small" and "considerable quantity".

Situation 2. It is permitted to use many values: "very small", "not very considerable quantity", ..., "not small and not considerable quantity", ..., "considerable quantity".

Situation 1 is inconvenient. In fact, for many situations both the permitted values may be unsuitable and, in describing them, we select between two "bad" values.

Situation 2 is also inconvenient. In fact, in describing a specific quantity of nuclear material, several of the permitted values may be suitable. We again experience a problem but now due to the fact that we are forced to select between two or more "good" values. Could a set of linguistic values be optimal in this case?

It is assumed that the system tracks the development of the problem, i.e., its variation with time. It is also assumed that it integrates the evaluations of different experts. This means that one object may be described by different experts. Therefore it is desirable to have assurances that the different experts describe one and the same object in the most "uniform" way.

On the basis of the above, we may formulate the first problem as follows:

Problem 1. Is it possible, taking into account certain features of the man's perception of objects of the real world and their description, to formulate a rule for selection of the optimum set of values of characteristics on the basis of which these objects may be described? Two optimality criteria are possible:

Criterion 1. We regard as optimum those sets of values through whose use man experiences the minimum uncertainty in describing objects.

Criterion 2. If the object is described by a certain number of experts, then we regard as optimum those sets of values which provide the minimum degree of divergence of the descriptions.

It is shown that we can formulate a method of selecting the optimum set of values of qualitative indications (collection of granules [10]). Moreover, it is shown that such a method is stable, i.e., the natural small errors that may occur in constructing the membership functions do not have a significant influence on the selection of the optimum set of values. The sets which are optimal according to criteria 1 and 2 coincide. The results obtained are described in [12]. Following this method, we may describe objects with *minimum possible uncertainty*, i.e., *guarantee optimum operation of the SEM* from this point of view.

Technology for evaluation and monitoring of complex processes assumes the storage of information material (or references to it) and their linguistic evaluations in the system database. In this connection the following problem arises.

Problem 2. Is it possible to define the indices of quality of information retrieval in fuzzy (linguistic) databases and to formulate a rule for the selection of such a set of linguistic values, the use of which would provide the maximum indices of quality of information retrieval?

In [12] was shown that it is possible to introduce indices of the quality of information retrieval in fuzzy (linguistic) databases and to formalize them. In [13] was shown that it is possible to formulate a method of selecting the optimum set of values of qualitative indications (collection of granules [13]) which provides the maximum quality indices of information retrieval. Moreover, in [12] [13] was shown that such a method is stable, i.e., the natural small errors in the construction of the membership functions do not have a significant effect on the selection of the optimum set of values. This proves that the offered methods can be used in *practical tasks* and can *guarantee optimum work of SEMs*.

Because the model of the process has a hierarchical structure, the choice and selection (tuning) of aggregation operators for the nodes of the model is one more important issue in the development of SEM. We may formulate this problem as follows:

Problem 3. Is it possible to propose the procedures of information aggregation in fuzzy hierarchical dynamic systems which allow us to minimize inconsistency in the model of process in SEM?

It is shown that it is possible to propose the following approaches based on different interpretations of aggregation operators: geometrical, logical, and learning-based. The last one includes leaning based on genetic algorithms and learning based on neural networks. These approaches are described in detail in [11].

D. Application's features

Some applied information monitoring systems based on the technology described above has been developed. Based on this experience, we can formulate the following necessary stages of the development process:

- conceptual design;
- development of the demonstration prototype;
- development of a prototype of the system and its operational testing;
- development of the final system.

The most difficult point in the development process is the elaboration of the structure of the process model. In some well-developed areas (marketing, medicine), we used descriptions of the process from professional books and references (like [6]) as a draft of the model. We then coordinated this draft with the professional experts (conceptual design and development of the demonstration prototype stages), and "tuned" this improved draft during testing of the system (development of a prototype stage). Sometimes the process for monitoring is formalized enough for application of information monitoring technology. An example of this situation is a state nuclear program evaluation procedure in IAEA [8]. The previously developed physical model of the nuclear fuel cycle was a good base for the model of the process in SEM. Based on this model, a prototype of the information monitoring system has been developed.

In order to develop a SEM for disaster management purposes, we need to develop the model of the process. The current status of the model is a result of the Mitigation Preparedness stage (Figure 4). We can understand the level of our readiness for disasters and our weak points (critical paths) for any time (in particular, for disaster momentum). Using critical paths, we can "calculate" the impact of different actions to the level of our readiness for disasters. After LSSD starts (urgent assistance stage) we can organize our work in the most effective and efficient manner because we have the actual status of our preparedness (from the previous stage). We can easily input changes into the situation, and see the result of those actions as a new situation.

The application of the technology for evaluation and monitoring of complex processes for one of the task in disaster management is presented in [14] (Case Study Risk-based evaluation Bridge under Flooding).

IV. Conclusion

Effective disaster management is an important task for all countries, regions, and the planet as a whole. The most dangerous disasters are large scale sudden disasters. For LSSD, the most important stage is the urgent assistance phase. Due to huge uncertainty and time pressure we cannot use standard information technologies for effectively supporting the analysts and decision makers during this stage. In this article, we have discussed an idea to use technology for evaluation and monitoring of complex processes for this stage. We have presented examples of successful applications of technology in similar areas (in terms of features of the available information).

SEMs are solving evaluation and monitoring task, allow user input of all available information in a "natural manner" and capable of:

- saving the history of process development,
- evaluating current status,
- modeling the future of process development.

SEMs are effective when:

- we do not have (cannot develop) a mathematical model of the process in the form of equations, automatas, etc.
- we have experts who are performing monitoring task.

We can develop SEM with minimal requirements for the task, when:

- it is possible to develop "semantic model" of the process in the form of set of concepts and their inter-dependencies
- we work with real information (we can learn or tune the system)

We can develop an optimal system in terms of:

- how easy it is for the user to input information (expert, analyst)
- co-ordination of estimations of users (experts, analysts)
- information support of processes of input information and modeling.

The capabilities described in this article represent useful information for disasters management centers.

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