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THE INTEGRATED SAFETY PERFORMANCE MODEL BASED ON SAFETY INDICATORS AND SAFETY LIFECYCLE

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Abstract: Systems approach in safety is applied during the analysis of complex safety systems and identification of key performance indicators. The integration of the safety system is necessary to enable efficient use of safety resources, and to take into consideration all technical, human and organizational aspects of safety. Safety lifecycle is an engineering process designed to optimize safety system and increase the level of safety. The main advantage of applying this model in real systems is increasing the effectiveness of the protection of employees and goods and the efficiency of safety resource use. In this paper, we describe the model for safety performance assessment of integrated safety systems, based on selected safety indicators and safety lifecycle.
Keywords: safety, safety performance, safety indicators, safety lifecycle, integrated safety system

INTRODUCTION

Safety system is a complex combination of resources (people, materials, equipment, hardware and software components, data, information, knowledge, services) integrated with the aim to fulfill the specific needs related to the protection of human, material and immaterial goods. The system is human-made system, physical according to the form of existence, dynamic and open according to the relationship with the environment. Its main task is to achieve optimal conditions in working and living environment, which leads to: the effective discharge of duties in an appropriate work environment in which employees are protected from the harmful effects that can lead to injuries, occupational diseases or deaths; minimal impact of work processes on the environment from the point of pollutant emission, waste generation and use of non-renewable resources; taking into account the potential risk of natural disasters and catastrophes.

The essence of a successful safety system is to focus on the causes of adverse events, to prevent their occurrence, or to reduce to reduce negative effects of their appearance if they cannot be avoided. The safety system, its elements and interaction with the environment are presented in Figure 1.

Many economic and social factors can influence decisions on safety, such as maintenance of devices and equipment and the implementation of certain measures.

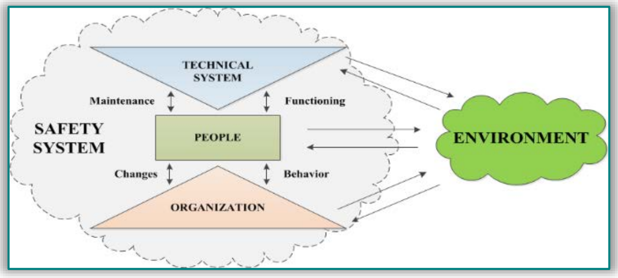

Figure 1. Safety system as an open system, and its environment

Therefore, the basic elements of the safety system are: technical and technological system, people (employees and employers), organizations and environment with which the system interacts (Figure 1). Technical-technological system requires proper maintenance during the functioning. An organizational change and organizational safety culture influence the behavior of employees. The environment affects the safety system by certain norms and standards that must be applied in the safety system.

MATERIAL AND METHODS

Safety indicators

The level of safety is described by a set of indicators. These indicators describe the safety outcomes and some safety activities carried out with the aim of increasing the level of protection and education of employees, and preventing adverse events. A lot of indicators are used to describe the level of safety, general or special for a particular industry. These indicators describe human aspects in safety (e.g. human activities, human errors, etc.), technical aspects (e.g. system malfunctions, reliability, availability, maintenance, etc.), and organizational aspects (e.g. hierarchy of decision making in safety, organizational procedures, safety reporting, etc.). Also, there is also a significant impact of the environment in the form of standards that apply in a particular industry (e.g. ISO, OHSAS, ANSI, IEC or HACCP standards, etc.), that are in [1] included as environmental (external) indicators.

According to [1], the following factors are taken into consideration: technical factor, human factor, organizational factor, and environmental (external) factor. The most important indicators for every factor are presented in Table 1. Some other interesting indicators can be found in [2-5].

Table 1. Safety factors and indicators

The factor	The indicators	Type
Technical	The number of safety levels	Activity
	The number of failures of technical safety systems	Outcome
	The number of accidents	Outcome
	The intensity of maintenance	Activity
	Maintenance costs	Outcome
Human	The rate of injuries	Outcome
	An index of skills of employees	Activity
	The degree of compliance with operating procedures	Activity
	Employee satisfaction index	Activity
	The number of errors and omissions	Activity
Organizational	The efficiency of safety resource management	Activity
	The share of jobs with higher risk	Activity
	The number of controls of workplace safety in practice	Activity
	The annual average number of hours of employee training	Activity
	The number of guidelines for occupational health and safety	Activity
External	The level of safety technologies	Activity
	The level of implementation of legislation	Activity
	The number of implemented voluntary standards	Activity
	The number of available databases on accidents	Activity
	The amount of available funds	Outcome

Safety indicators by themselves, whether they describe safety activities, or safety outcomes, are not sufficient to improve the safety system or the level of safety. One of the solutions to increase the efficiency of the safety system is the integration of the system.

The integration of safety systems increases the efficiency of safety resources consumption, and reduces cost and risks. The integrated safety system is important in organizations to efficiently use safety resources [6].

Lifecycle of integrated safety systems

The purpose of integrated safety system is to integrate technical systems with human resources, and to enable documented risk management. Integrated safety system conceptually means that safety is not treated as an independent entity, neither its technological nor human and organizational aspects. It requires a slightly different approach for safety interpretation, starting with the identification of activities and defining the concept of the system, its implementation or adaptation of the existing system, the continuous maintenance, improvement and development of the system.

To be able to achieve better efficiency of safety resources consumption and the highest possible level of safety, safety lifecycle was introduced. As safety system is usually treated as a complex socio-technical system, only its technical part was initially analyzed and described by means of safety lifecycle [7-11]. Safety lifecycle is and engineering process designed for systematic specification, development and optimization of a safety system. The most prominent standards that include description of safety lifecycle are IEC 61508, IEC 61511, ANSI/ISA S84 and EN 50126 [7-10].

Initially, it was applied for technical part of safety system. The lifecycle also includes the effects of the environment where this system is functioning, organizational structure that defines work activities, as well as people that perform certain activity, at least in the context of the operation and maintenance of safety instrument systems. Safety lifecycle of integrated safety system is presented in Figure 2.

The lifecycle starts with identification of goals and purpose of the system, and definition of concepts and the scope of the system. Identification of potential risks is the most important phase during the creation of safety system. The risks, cost and social responsibility are defined as the most important criteria for definition of integrated safety system [1].

Selection of key safety indicators

Analysis of the effectiveness of the safety system is based on several criteria. Multidisciplinary and interdisciplinary character of safety requires that more people participate in design, implementation, analysis and improvement of the safety system.

These processes are based on the analysis of multiple criteria (attributes or indicators), so it is natural to employ methods of multi-criteria (multi-attribute) analysis. Among others, the analytic hierarchy process (AHP) and its fuzzy extension, fuzzy analytic hierarchy process (FAHP) are applied for occupational safety decision-making problems and for determining priorities of criteria and indicators in occupational safety systems.

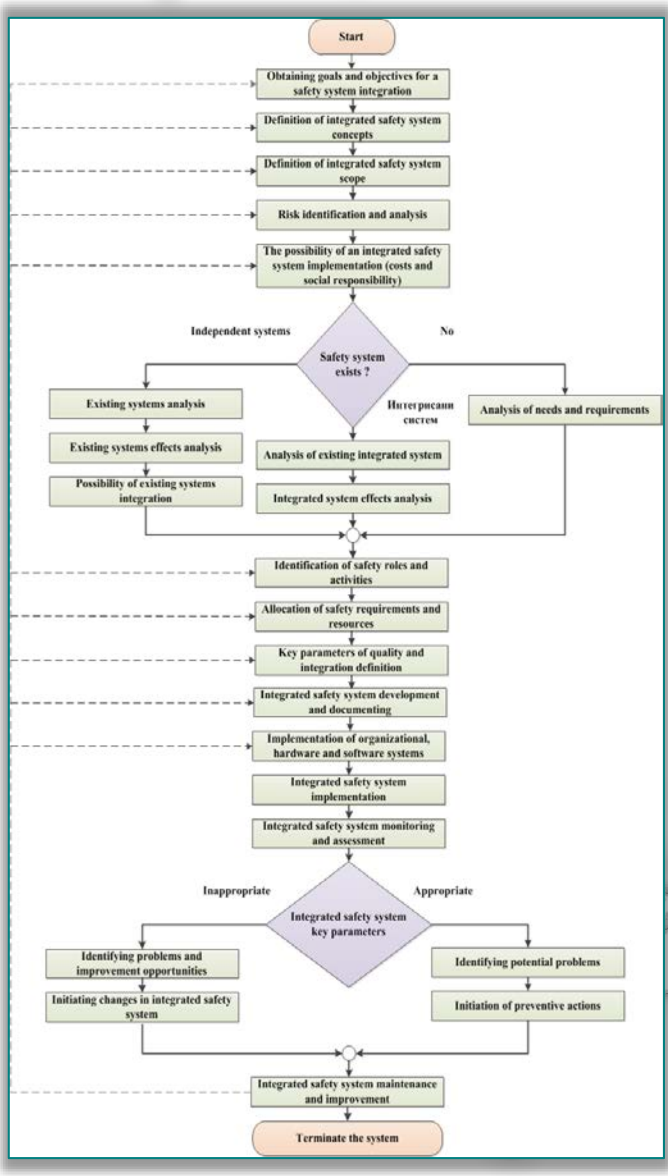

Figure 2. Safety lifecycle of integrated safety systems with safety performance assessment

It is recommended that the number of indicators is limited, so that each of the indicators could have a sufficient impact on the efficiency and effectiveness of a safety system. In [1], proposed number of key performance indicators is 20, or 5 indicators for each factor. In some situations, "less is more". The complexity of the safety system sometimes requires a larger number of monitoring indicators than proposed, or an update of the number and types of indicators that are taken into consideration when deciding on the safety system.

It is recommended that the participation of a larger number of experts in the selection of indicators. Recommended minimum number of experts is 5, to cover all social, technical and organizational aspects of a safety system.

Method of selection of appropriate indicators for evaluating the integrated system of protection under the protection of the life cycle takes place in two steps:

1. Selection of key indicators using the experts' ranking, where experts rank n indicators, assigning them ranks from 1 to n;
2. The ranking of key indicators using a method of multi-criteria analysis, by comparing the selected key indicators in pairs, or by using some other methods of identification of weights of indicators.

Table 2 shows some specific methods that can be used during the ranking of key safety indicators.

Table 2. Multi-criteria methods

Category	Weighting methods
Unique synthesizing criteria	Analytic hierarchy process (AHP), Data envelopment analysis, Fuzzy Analytic hierarchy process (fuzzy AHP), Grey relational analysis, Multi-attribute value theory (MAVT), Multi-attribute utility theory (MAUT), The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Utility theory additive (UTA)
Outranking	Elimination and Choice Expressing Reality (ELECTRE), Preference ranking organization method for enrichment evaluation (PROMETHEE), Organization, Rangement Et Synthese De Donnes Relationnelles (ORESTE)

In [1], it is proposed the method for selection and ranking of occupational safety indicators based on the expert evaluation method and the fuzzy analytic hierarchy process (fuzzy AHP). Also, group decision-making based on aggregation of individual judgments or individual ranks is recommended.

DISCUSSION

Safety system is a complex system that needs an engineering approach for specification, development, assessment and optimization, and continuous improvement. The main goal of the improvement process is increasing the level of safety, reducing the number of accidents, occupational injuries and illnesses related to work, and at the same time using effectively all available safety resources.

Based on the described algorithm, the existing safety systems in organization are analyzed. They can be modified, and included as parts of integrated safety system. Based on defined requirements, new roles, models of management and control, and phases are identified. More precise definition of roles, processes and safety activities simplifies implementation of organizational mechanisms and safety instrumented systems, with improved safety requirements allocation and connection with unique work processes.

Detailed development and documentation of integrated safety system becomes the most important, and also definition of key performance indicators of quality of safety system, as well as the quality indicators of the process of integration. The next step is implementation of integrated safety system. The application of the system is connected with the adequate monitoring and assessment of the system, identification and benchmarking of key performance indicators.

Inappropriate values of key performance indicators of the system affect the occurrence of adverse effects. Identification of these problems can initiate improvement and changes in the system. Even when key parameters of the system are appropriate, some leading indicators can be used for identification of potential problems and for initiating preventive activities [12]. This double confirmation mechanism is the most important in maintenance and continuous improvement of integrated safety system.

Based on identified problems, expanding the scope and purpose of the system is initiated, additional concepts are defined, and scope of the system is expanded.

Further, the possibility of realization of a modified system is assessed, the analysis of the effects of the existing system is applied, and new roles and / or phase are introduced. Also, it can be proposed the introduction of new hardware and software solutions, allocated new requests for protection and defined additional key parameters of safety and integration quality.

The ranking of key safety performance indicators is based on the AHP or fuzzy AHP method. It can be also done by applying the other methods, such as interval-based AHP method, TOPSIS, VIKOR, ELECTRE, PROMETHEE, or the combination of several methods (e.g. AHP and goal programming, or AHP and TOPSIS).

CONCLUSIONS

Industrial development has demanded changes in the safety approach, is caused by a sudden increase in risk and the number of accidents. Thus, safety approach was changed in accordance with technological challenges, to enable use of new approaches and methods of risk management. Incremental development of safety is not enough good, because it is necessary to solve certain problems immediately, regardless of the lack of prior experience on them, with a broad understanding of the potential causes and methods of prevention of adverse events.

In this paper, the integrated safety performance model based on safety indicators and safety lifecycle is presented. It is based on systems analysis and continuous improvement of integrated safety system, monitoring of key performance indicators values (leading and lagging safety indicators). Safety indicators are not enough to make adequate decisions. Some decision-making procedures and methods, based on multiple available criteria, are needed.

The main problems in safety management are limited safety resources and the existence of multiple independent systems responsible for the quality and variety of forms of safety and security (occupational safety, fire protection, environmental protection, and safety instrumented systems). A lack of coordination between these independent systems leads to inefficient use of resources, and inadequate data exchange to ignore certain potential causes of adverse events. The problem can be eliminated by applying the systems approach supported by safety lifecycle and safety benchmarking based on indirect and direct safety performance indicators, as described in presented model.

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