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IMPORTANCE OF ACCIDENT ANALYSIS METHODS FOR IMPROVEMENT OF OHS MANAGEMENT

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Abstract: The aim of the work is to review the basic methods of accident analysis in terms of the possibility of using them to improve occupational safety management. Analyzing accident events is a very good way to obtain information on the practical functioning of OSH management. Although the analysis of accidents and near misses is included in the reactive activities, the changes that will be introduced as a result of this analysis are the most proactive. These irregularities can be related to all elements and aspects of the functioning of the organization from the technical, organizational, human, environmental and management side, and the accident analysis helps to identify them. The paper reviews and characterizes the basic methods of accident analysis, with particular emphasis on accidents at work. Moreover, the basic classification criteria and the main guidelines for the selection of these methods are presented in such a way that they can be effectively used to improve the OSH management system.
Keywords: management, improvement, accident analysis, OHS

1. INTRODUCTION

Organizations today are complex and dynamic social engineering systems. They pursue many goals: productivity, safety, reliability and employee well-being. They are characterized by complex social structures, close connections, technological complexity and environmental conditions. They integrate many cooperating parties from different social and technical disciplines, performing different tasks in a different time-space system.

Modern "work" is highly specialized and potentially dangerous to both personnel and the environment. It is more and more difficult to define as wholly physical or mental, more and more often it requires an abstract understanding. Today's "tools" of work are becoming more and more complex and abstract. More computer systems and less practical work require an employee to be highly specialized and, at the same time, to understand the operation of the entire system (Eurofund, 2015).

In this context, the problem of analyzing accident events is of particular importance. To be effective, incident analysis must go beyond the simplest approaches and solutions, recognizing that an accident occurs in a system with specific components and internal and external interrelationships. The answer to this complexity is that very different accident analysis methods can be used.

2. IMPROVING THE OHS MANAGEMENT SYSTEM

According to the most general definition, an occupational health and safety management system (OHSMS) is part of the overall management system that is related to the development, implementation, execution, review and maintenance of an organization's occupational health and safety policy. (ILO, 2013; Klimecka – Tatar and Niciejewska, 2016).

All organizations manage their activities, including those relating to the development of safe working conditions (Zanko and Dawson, 2012). This management is more or less systemic in nature, the aim of these activities is at least to maintain the current state.

On the other hand, improving the effects of action means improvement. Improvement takes place by making the desired changes (qualitative and / or quantitative) in the right place in the system and at the right time.

Improvement may be manifested through small improvements, continuously introduced to selected elements of the system, as well as large changes within the entire system (Denton, 1982; Law et al., 2006, Cadiuex and Desmarais, 2006).

For the improvement process to be effective, it is essential that changes are based on a well-thought-out assessment of the situation, using appropriate information and data (CEN, 2009; Tabor, 2019). Accident analysis methods, through defined and described analytical procedures, are a very useful means of obtaining information (Lindberg et al., 2010).

3. PLACE OF ACCIDENT ANALYSIS ACTIVITIES IN OHS MANAGEMENT

There is no single commonly accepted definition of an accident. Despite the differences in the formulation of accident characteristics, there is widespread agreement that accidents are unintentional, undesirable and unplanned events. The other features are subject to major differences that can be boiled down to three positions (Laflamme and Menckel, 1995).

According to the first position, an accident is equated only with an injury. According to the second position, an accident is an event causing injury together with the situation that preceded it. In the third way of understanding an accident, sustaining an injury is considered to be one of its possible consequences.

The concept of an accident is used interchangeably with the concept of an accident, under which two additional events are added: a deviation and an incident. The definition of the derogation, i.e. "Sleeping accident" refers to the immediate causes that could potentially cause an accident. On the other hand, the term incident defines events that are inherently dangerous but do not cause injuries.

Traditionally, accidents are viewed as the result of a chain of contingency events, each associated with its own "causal" event or other events. Traditional techniques for safety analysis and accident risk assessment are therefore based on the linear concept of causality. With today's complex systems, this approach has severe limitations in accident modeling and analysis.

An accident analysis is a specific subset or part of an accident study. It focuses on how to best understand what happened based on the available data and information. The analysis makes certain assumptions about the accident theory, accident models and accident analysis methods. As a result, the analysis determines the method of collecting and analyzing data (e.g. the tools used) and influences the scope of recommendations after the study.

On the other hand, an accident investigation covers everything from initial planning, how to investigate an accident, through resource allocation and planning, data and information collection, analysis, recommendations after analysis, implementation of recommendations, and finally assessment of the effects of recommendations. Otherwise it could be called an "investigation into ...". The individual steps in the accident investigation procedure (including an accident at work) result from the adopted examination method and, in practice, are determined locally, within the framework of national legal regulations.

Investigation of accidents and near misses is a permanent element of the structure of OSH management systems according to all models, from the beginning of the development of the system approach to OSH management (BSI, 2007; ILO, 2001; Hasle and Zwetsloot, 2011; IOSH, 2011). Although the necessity to investigate accidents results from legal regulations, the selection of the method to be analyzed remains at the discretion of the persons conducting the investigation. Various types of reviews and taxonomies of currently used methods can assist in the selection.

4. REVIEW OF ACCIDENT ANALYSIS METHODS

The theories, models and methods of accident analysis are constantly evolving. An accident as a phenomenon should be analyzed taking into account the objectives of such analysis and the context of the event, as theories, models and methods can be both very simple and very complex. Table 1 presents a short description of selected accident analysis methods.

Table 1

Brief characteristics of selected accident analysis methods

Method name	**Short description**
Acci-Map (Rasmussen and Svedung, 2000)	The method is used to graphically represent failures, decisions and accident actions throughout the system. The method assumes that different levels of the system (government, regulators, company, company management, personnel and work) are involved in security management and treat security as a property resulting from interactions between actors at each of these levels. Each system level is involved in safety management by controlling hazardous processes through regulations, rules and instructions. For systems to function safely, decisions made at higher levels should be reflected in decisions and actions at lower levels of the system (vertical integration). Without this integration, systems can lose control of the processes they are supposed

	to control. The behavioral differentiation that occurs then is conducive to accidents.
AEB (*Accident Evolution and Barrier Function)* (Svenson, 2000, 2001)	The accident is presented as a series of interactions between a human and a technical system. Interactions include breakdowns, faults and errors that may indirectly lead to an accident or directly cause an accident The method forces the user to analyze human and technical systems simultaneously during an accident investigation.
BA *(Barrier Analysis)* (DOE, 1999, DOE, 2012)	The method is used to identify the hazards that could lead to an accident and the barriers that should be in place to prevent it. A barrier is all measures and solutions used to control, prevent or hinder a threat from reaching its destination.
CA *(Change Analysis)* (DOE, 1999, DOE, 2012)	The method is used to analyze an accident by examining the difference between what happened before or what was expected and the actual sequence of events. The user identifies specific differences between a no-accident situation and an accident scenario, and then assesses them to determine if they caused or contributed to the accident.
CREAM *(Cognitive reliability and Error Assessment Method)* (Hollnagel, 1998)	The method is based on the distinction between what can be observed (phenotypes) and what needs to be deduced (genotypes). Genotypes are divided into three categories: individual, technological and organizational.
ECFC *(Events and Casual Factors Charting)* (DOE, 1999)	A graphical method that consists of building a graph of events and causal factors. A graph showing the chronology of the accident. The method is primarily used to collect and organize information in order to visualize a sequence of events.
ECFCA *(Events and Casual Factors Charting and Analysis)* (DOE, 1999)	The method uses a graph of the events and causal factors of the accident. Based on the chart, the root causes of the accident are determined. The method requires deductive reasoning to determine which events and / or conditions actually contributed to the accident.
ETA *(Event Tree Analysis)* (Ferry, 1988; Villemeur, 1991)	The method is used for a detailed description - modeling of the threat that may be triggered by the occurrence of a specific initiating event. In order to build a threat model, it is necessary to map the predictable sequences (scenarios) of secondary events that may occur after a given event. The mapping is presented as a tree.
FRAM *(Functional Resonance Accident Model)* (Hollnagel, 2004; Sawaragi et al., 2006; Nouvel et al., 2007)	A method of accident analysis and risk assessment based on the description of the system functions. Functional resonance is used to describe the nonlinear propagation of accident events.
FTA *(Fault Tree Analysis)* (Høyland and Rausand, 1994)	The method implements an analytical approach to the identification and verification of compounds, but does not provide researchers with any specific guidelines for collecting information about an accident. The tree enables a graphical representation of the logical connections between the causes leading to the top event. Top events are linked to previous events and conditions (e.g. technical factors, human activities)

	through two logic gates. Using these gates, a sequence of causes and their logical relationships are created.
HERA (Isaac et al., 2002)	A method of identifying and quantifying the impact of the human factor on incidents and accidents. It also enables the anticipation of potential new forms of error resulting from new technology. Human error is seen as a potential weak link in the system and therefore measures should be taken to prevent errors and their consequences.
MORT *(Management and Oversight Risk Tree)* (Johnson, 1980)	The method assumes that the accident occurs as a result of management oversight, located in the management system and consciously undertaken risk. The accident is preceded by an initial sequence of planning errors as well as operational and organizational errors that result in a failure to adjust to human or environmental factors.
MTO *(Man, Technology and Organization Analysis)* (Worledge, 1992; Rollenhagen, 1995; Bento, 1999)	The method uses the basic classification of accident factors, taking into account the human, organizational and technical factors to the same extent in determining the causes of accidents.
RCA *(Root Cause Analysis)* (Wilson et al. 1993; DOE, 1997)	The method identifies the main shortcomings in the safety management system. If the irregularities are corrected, this will prevent the same and similar accidents from occurring. The method uses results from other primary analytical techniques to determine the most important causes of an accident.
SCAT *(Systemic Cause Analysis Technique)* (Kjellén and Hovden, 1993)	According to the method, the result of an accident is loss (damage to people, property, products or the environment). An accidental event is an event preceding a loss. The immediate causes of the accident are the circumstances that immediately precede the contact with the energy. You can usually see or feel them. These circumstances are called unsafe activities (non-conforming to operating standards) or hazardous conditions (non-conforming conditions).
STAMP *(System-theoretic Model of Accidents)* (Leveson, 2004)	The systems are composed of interrelated components that are kept in dynamic equilibrium through the feedback of information and control. Accidents happen when external disturbances, component failures, or dysfunctional interactions between system components are not properly controlled. Determining why the accident occurred requires identifying why the control structure was ineffective. Preventing future accidents requires designing a control structure that enforces proper operation.
STEP *(Sequential Timed Events Plotting)* (Hendrick and Benner Jr., 1987)	Systematized accident analysis procedure using multi-line sequences of events and a process view of accident phenomena. In procedural terms, a specific accident begins with the activity that initiated the change of the described process into an accidental process. The accident ends with the last related harmful event.
TRIPOD (Wagenaar et al., 1994)	The method is based on the assumption that hidden organizational failures are the main causal factors of accidents. Organizational failures are the result of decisions

	made. Instead, they result in technical and human errors. Accident analysis is about identifying hidden failures and the underlying risk factors associated with them.
WAIT (Jacinto and Aspinwall, 2003)	According to the method, an accident begins with hidden errors, i.e. deficiencies and weaknesses in the work organization system and working conditions. Hidden errors combined with unsafe employee behavior create a hazardous situation. The hazardous situation, combined with equipment failures and failure of safety measures, lead to an accident. Therefore, the key to the accident analysis is to identify the weaknesses and conditions of the organization's system, which will allow for the formulation of appropriate corrective actions.

Source: Own study based on the cited literature

Accident analysis methods can be classified according to various criteria. The most popular criteria in the literature include:
- the accident model adopted in the method,
- taking into account the analyzed event in the sequencing method,
- taking into account safety barriers in the method,
- levels at which we can analyze the accident event, and
- the specificity of the system in which the accident happened.

The accident model is a working concept for the implementation of accident analysis programs and goals. The following accident models can most often occur in methods (Kjellén, 2000):
- Casual-sequence model (Heinrich, 1959; Reason, 1990),
- Process model (Kjellén and Larsson, 1981; Larsson, 1993),
- Energy model (Haddon, 1968),
- Logical tree model (Leplat, 1978; Wells et al., 1992),
- Management model SAM (System-Action-Management) (Pate-Cornell and Murphy, 1996).

The classification of the methods according to the accident model used is presented in Table 2.

Table 2
Classification of accident analysis methods according to the accident model used

Classification	**Examples of methods**
Methods with the cause and sequence model of accidents	RCA, TRIPOD
Methods with the accident energy model	BA
Methods with the accident process model	ECFC, ECFA, CA, STEP, MTO, AEB
Methods with the accident logical tree model	FTA, ETA

Source: Own study based on the cited literature

Analysis methods can also use mixed models:
- MORT uses a logical tree model and a management model,
- SCAT uses a cause-sequential model and a management model,

- Acci-Map uses four different models: cause-sequential, process, logical tree and management.

The accident model has a significant impact on how the analysis is performed. According to Benner (1985), the accident model should be: realistic, definable, satisfying, comprehensive, disciplining, compatible, direct, functional as well as comprehensible. The influence of individual properties of the accident model on the analysis process is presented in Table 3.

Table 3
Relationship of the accident model with the accident analysis according to Benner (1985)

The accident model should be	**The influence of the accident model on the analysis process**
Realistic	The analysis should result in a realistic description of the events that actually took place.
Definable	The analysis process should provide criteria for identifying and defining the data needed to describe what happened.
Satisfying	The results should be satisfactory for the people who initiated the analysis and for others who want the results of the analysis.
Comprehensive	The analysis process should be comprehensive so that there is no confusion as to what happened, no unexpected gaps or holes in the explanation, or a conflict of understanding between those reading the report.
Disciplining	The analysis process should provide a structured, systematic framework and set of procedures to discipline the activities of accident investigators in order to focus their efforts on important and necessary tasks and to avoid duplication or irrelevant activities.
Compatible	The model must theoretically be consistent with the concepts of enterprise safety programs.
Direct	The analysis process should produce results that do not require more data collection before needed controls can be identified and changes made.
Functional	The analysis process should be functional for the work to be efficient, e.g. helping the investigator to identify which events were part of the accident process as well as those that were not related to each other.
Comprehensible	The results should be easy to understand.

Another criterion for the classification of methods is taking into account the sequencing of the analyzed event. Sequential approach means that an accident is the result of successive events, each of which is the result of a previous event and a cause of a future event. The sequence can be single or multi-line - FEM - Multilinear Events Sequencing Model (Benner, 1975). Examples of methods taking into account the sequencing of an accident event are presented in Table 4.

Table 4
Classification of accident analysis methods with regard to the sequencing of events

Classification	**Examples of methods**
Sequential methods	STEP, ECFC, ECFA, MTO, TRIPOD
Non-sequential methods	BA, CA, FTA, RCA, ETA, MORT, SCAT, AEB, Acci-Map

Source: Own study based on the cited literature

Safety barriers are physical and non-physical measures designed to prevent, control or mitigate adverse events or accidents. Each barrier performs a specific safety function. Barriers usually form a deliberate system of barriers that should be designed and implemented as a result of hazard identification and risk assessment. Barriers can be physical, functional, symbolic or immaterial (Sklet, 2006).
Table 5 summarizes the methods of accident analysis due to the use of the concept of safety barriers.

Table 5
Classification of accident analysis methods considering safety barriers

Classification	**Examples of methods**
Methods with safety barriers	ECFA, BA, FTA, ETA, MORT, MTO, AEB, TRIPOD, Acci-Map
Barriers-free methods	ECFC, CA, RCA, SCAT, STEP

Source: Own study based on the cited literature

According to the concept of Rasmussen (1997), an accident event can be analyzed on 6 different levels: Level 1 - The work and technological system, Level 2 - The Staff, Level 3 - The management, Level 4 - The company, Level 5 - The associations and regulators , and Level 6 - The Government. The classification of methods according to the possible level of analysis is presented in Table 6.

Table 6
Classification of accident analysis methods due to the possible level of analysis

Classification	**Examples of methods**
Methods with the 1st and 2nd level of analysis	BA, FTA
Methods with the 1st, 2nd and 3rd level of analysis	ETA, AEB
Methods with the 1, 2, 3 and 4 levels of analysis	ECFC, ECFA, CA, RCA, SCAT, MTO, TRIPOD, MORT (without level 1)
Methods with all six levels of analysis	STEP, Acci-Map

Source: Own study based on the cited literature

Different systems require different approaches and methods to analyze accidents. For the purposes of proper selection of analysis methods, Hollnagel and Speziali (2008) proposed the classification of systems according to two properties: coupling and tractable.
The coupling concerns the couplings - connections within the system, between its elements. In extreme situations, systems (or processes) can be loosely connected (e.g. universities) or tightly connected (e.g. power grids).
A system (or process) is tractable if the rules of operation are known, if the system descriptions are simple and contain little detail, and most importantly if the system does not change as it describes. Overall, such a system is "easy to do". (Hollnagel and Speziali, 2008).
A system or process is non-tractable if the operating principles are only partially known or even unknown, if the system descriptions are extensive with many details, and if the system is subject to change before the description is complete. For example

accidents during operations in a hospital emergency department. In this case, the activities are not standardized and change so quickly that it is never possible to create a detailed and complete system description. Overall, such systems are "difficult" (Hollnagel and Speziali, 2008).

Most systems are weakly coupled and tractable. Examples of modern accident analysis methods for systems with different dependencies and vulnerabilities are presented in Table 7.

Table 7
Classification of accident analysis methods due to the specificity of the system

Classification	**Examples of methods**
Methods for weakly coupling and tractable systems	AEB, HERA, RCA
Methods for highly coupling and tractable systems	TRIPOD, MTO, CREAM
Methods for highly coupling and non-tractable systems	STAMP, FRAM

Source: Own study based on the cited literature

For weakly coupling and non-tractable systems, no specific accident analysis methods have yet been developed. Systems of this type are, for example, universities, R&D companies, i.e. social rather than technical systems.

5. GUIDELINES FOR THE METHOD SELECTION

The primary purpose of an accident analysis is to provide information for preventive activities. Therefore, the choice of an accident analysis method should take into account: (a) the purpose of the analysis (information gathering, indirect cause analysis, root cause analysis), (b) the scope of the analysis (small, medium, large and very large) and (c) the system in accident. Hollnagel (1998) proposed the most universal criteria for evaluating accident analysis methods: reliability, audit capabilities, time to learn, resources needed and accuracy of findings.

Table 8 presents a short description of these criteria.

Table 8
Brief characteristics of criteria for assessing accidents analysis methods according to Hollnagel (1998)

Criterion	**Short description**
Reliability	Will the method give the same result if re-applied (or in a similar case) and the extent to which the method is independent of the user / analyst and his knowledge and experience.
Audit capabilities	Is it possible to recreate the analysis and recreate the choices, decisions or categorizations made during the analysis.
Time to learn	How long does it take to learn to use the method and become a proficient user. While this is a one-time investment, it is sometimes seen as an argument against adopting a new method.
Resources needed	How difficult / easy is the method to use. Among the main resources are people (working hours), time, information and documentation needs, etc.
Accuracy of findings	Are the results obtained with the method appropriate? This is a very controversial matter because there is no easy way to determine whether a study is valid. The same accident can be investigated in more than one way, and there are no obvious, independent criteria against which to judge the results obtained in the studies.

6. DISCISSION AND CONCLUSION

The work does not exhaust the subject of the variety of accident analysis methods and guidelines for their selection. Models and methods of analysis are constantly evolving, as is understanding of the systems that organizations are and the systems within which organizations operate today.

The paper reviews and characterizes the most popular accident analysis methods in terms of the possibility of using them to improve occupational safety management. An accident event provides managers with a variety of information about the functioning of the management system, both quantitative and qualitative. The occurrence of an accident event proves real problems in safety management in the organization, of a technical, organizational or human nature. The description of the circumstances and causes of the event indicates what, where and when has failed, as well as what, where and when should be corrected.

The classification criteria and guidelines for the selection of analysis methods make it possible to select the appropriate method or methods to analyze an accident event in a non-accidental manner. It is always possible to identify the method that is most appropriate in view of the purpose and scope of the analysis and the skills of the accident investigation team.

The methods of analysis are very diverse, and there are many of them, even within one category. An accident investigating, using a properly selected analysis method, is not only the acquisition of specific knowledge, but also a good way to learn behaviors and procedures for all direct participants of the study and for the organization as a whole. The considerations presented in the paper can make a significant contribution to the improvement of occupational health and safety management systems.

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