Chain of events application in workplaces in safety engineering

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INTRODUCTION

For the risk assessment that accompanies work in an industrial plant there is a need to identify all possible threats. The aim of safety engineering activities is to create and maintain an adequate level of safety, in particular at industrial workplaces. This requires constant identification of threats, investigating the causes of threats and minimizing the effects of threats. In order to obtain information about the causes of the effects of threats, methods using logical analysis of events are often used. They can indicate the primary and secondary causes of a potential accident or breakdown (material loss).

METHODOLOGY OF RESEARCH

There are many methods for identifying hazards in the subject matter literature. Most often, these are retrospective methods such as document analysis, checklists, or accident card analysis. For identifying dynamic dangers (for example gas hazards), prospective methods of hazard identification are most commonly used (Pauliček et al., 2012). They involve identifying threats and anticipating possible threats. These include: change analysis, failure mode and effect analysis (FMEA) (Kotus et al., 2014, Hąbek & Molenda, 2017), gross hazard analysis (GHA), hazard and operability analysis (HAZOP), job safety analysis (JSA), technique of operations review (TOR), total job analysis (TJA) and Preliminary Hazard Analysis (PHA) (Idzikowski & Bajdur, 2011). In the processes of machines and people work, deductive methods are often used, such as: fault tree analysis (FTA) (Ignac-Nowicka, 2018c, Ignac-Nowicka, 2018d), event tree analysis (ETA) (Ignac-Nowicka, 2018a) and analysis of the event chain using elements of the theory of events.

The use of events theory elements to identify hazards depends on the analysis of a chain of events culminating in the accident or material damage (Ignac-Nowicka, 2017a, Ignac-Nowicka, 2015). Analysis of such a chain of events makes it possible to identify favorable (progressive) conditions for the creation of hazardous situations. That is why a deep analysis of the circumstances preceding the hazardous event must be made.

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OCCUPATIONAL SAFETY AND WORK ENVIRONMENT PARAMETERS

The work environment is defined as a set of objects and the crew associated with them organizationally to produce specific values in the work process. Parameters of the work environment that relates to its objects have the biggest influence work safety. The direct or indirect effects of work environmental parameters on crew and the operations of the industrial plant can be expressed as follows:

– physical parameters associated with a industrial environment such as the magnitudes of critical temperatures, pressures, voltage and electric current, noise, vibration, radiation etc.
– geometrical magnitudes such as: the dimensions of the heading, machines and devices and their functionality and location
– air pollution by gases and/or dusts (Bobrowski, 1980).

The working space crew may encounter directly or indirectly with such operating environment facilities as: machines, equipment and working tools, equipment (eg. safety barriers, fire equipment, alarm signaling, spraying equipment) and various types of production materials and etc. (Cichowski, 1998).

When the parameters of the work environment, were the crew is located, are approximately constant or slightly changing, than it may be called normal conditions. Normal working conditions generally entail a relatively constant relationship between the conditions of the work environment and the location. Emergency conditions, on the other hand, usually entail sudden and significant changes in the conditions of the work environment, including such events as a sudden increase in temperature, air pressure, toxic gases or significant change in the shape of the workspace. It is not always possible to provide completely comfortable working conditions. Therefore, existing safety standards in the some industry represent a compromise between working comfort and production requirements. It is, however, expected that full safety measures be provided for all of the hazards known to be associated with an ongoing operation. Security standards for the conditions of the work environment are determined by mandatory safety regulations. These regulations are defined by:

– desirable work environment parameters,
– technical procedures for avoiding known hazards,
– an automatically controlled atmosphere with regard to the allowable concentrations of gases.

In addition, in accordance with the safety rules, the highest allowable concentrations of toxic substances (MAC) and the highest permissible intensity of nuisance factors (MAI) should be controlled (PN-N-18001, 2004).

EVENTS OCCURRING IN THE WORK ENVIRONMENT DESCRIBED BY ELEMENTS OF THE THEORY OF EVENTS

Events occurring in the work environment are assigned two logical values, 1 or 0. The logical value 1 is assigned to the occurring events (true events), while the logical value 0 is assigned to events that do not occur. The description of events in the work environment uses basic logical functions, such as conjunction, alternative, negation, implication and equivalence. In addition, logical laws are used to describe events according to mathematical logic (Bobrowski, 1980, Pasenkiewicz, 1968).

The working environment can be considered as a set of elementary events. All events occurring in the environment can be divided into static events, signifying states, and kinetic events, signifying changes in these states. The kinetic events are the cause and static events are results of a sequence of conditions (Idzikowski & Bajdur, 2011). Besides the elementary events are macro- and micro-complex events, with varying degrees of complexity consisting of environmental subsets. Complex events consist of certain number of static and kinetic events occurring simultaneously and/or one after the other. They represent a specific process taking place in the work environment. In certain circumstances, crew activities can directly or indirectly cause of an activation of a specified hazard (Ignac-Nowicka, 2015, Leniewicz, 1975).

The sequence of events determines the principle: every effect is clearly and sufficiently appointed by the general causes and conditions in which it occurs. A sequence of events illustrates causes and effects in the work process. A set of events immediately preceding the change (qualitative and quantitative) presents a sufficient conditional sequence of events. A sufficient condition-specific effect consists of:

– cause and main conditions (permanent),
– side conditions (random).

Principal conditions occur whenever they are a necessary condition for a result representing a qualitative change (Cichowski, 1998, Szczurowski, 1984). For example, spark or high temperature and explosive gas cloud are the cause and the main condition which are necessary to initiate a gas explosion. Side conditions in a sequence of conditions are random variables that can make the accident more or less likely or affect the size, the course and range of the event. For example, when gas explodes, side conditions determining its strength and range are: the size of the room that determines the growth of the dangerous concentration, the proportion of other volatile components (Ignac-Nowicka, 2011, Kotus et. al., 2014, Pauliček et. al., 2012) etc.

Phenomena occurring in the work environment can be described by using the chain events model. A model of such an events chain is well illustrated by dominoes blocks, standing side by side. Knocking over all of the dominoes requires the toppling of the first block, which knocks over the second domino, and so on, until the last. In order for the dominoes to fall, the toppling of the first domino must appear as a factor initiating the entire sequence of events. Relevant combinations of necessary event sequences in the work environment of the chemical plant can be events both in terms of work environment parameters (materials factors) and the human factors (actions and decisions) (Ignac-Nowicka, 2018e). The scope of activity of the chemical plant is the cause of the hazards of the specified work environment parameters, their change, the processes that affect them and finally, the activities and states on the side of the crew, are the effects of their action. For example, the effect of an action might be: crew members present in a particular place, use ordered technologies under specified conditions. Uncontrolled event sequences occurring in the workplace, on the side of the work environment parameters and the human factors side, can lead to the initiation of the full hazard, that is to say, to undesired processes immediately preceding the harmfulness. The necessary events chain preceding the accident shows the arrangement of subsequent indirect effects and necessary reasons for remaining in the causal relationship (Ignac-Nowicka, 2015, Ignac-Nowicka, 2018b).

These processes, in which events are considered due to their arrangement, can be assigned to an image geometry, called a graph. A graph is a topological mapping of an events sequence, defining unequivocally the relationships between the individual events. In the graph, nodes represent the necessary conditions of the events sequence, and the branches oriented towards the implication represent indirect results, that can turn into causes in in the nodes and/or principal conditions of the event sequence (Pasenkiewicz, 1968). Figure 1 shows a simplified graph events sequence. In the graph there are three external nodes and one internal node, that represents necessary condition of sequence events. Three branches represents a result gk and essential ingredients of necessary sequence of events, ie. the cause ek and principal condition es.

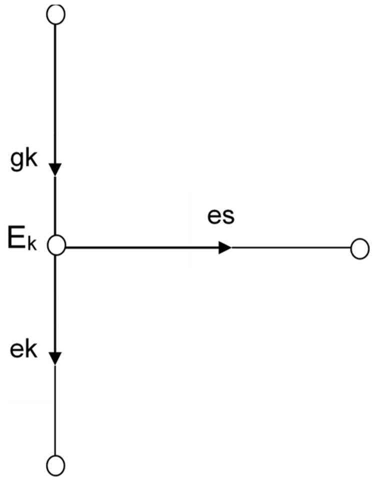

Fig. 1 Reduced graph sequence of events

ACCIDENT AND MATERIAL DAMAGE IN THE EVENTS CHAIN

As mentioned before, the accident hazard is considered with a hazard of material damage which can accompany some of the accidents. Accidents at work WY or/and material damage SM imply a injury UR and chain of necessary conditions events sequence in the phase of the full hazard. The essential chain necessary conditions elements in the phase full hazard are:

- accident event – ZW,
- activation of accident hazard from the side of parameters of work environment and the human factor – AZ^P, AZ^C,
- crew staying within range hazard AZ^P – ys
- actual threshold of hazard from the objects or the dose of harmful factors – RZ_c, RZ_{dwy},
- undesirable change of the lithosphere parameters, the technosphere, atmosphere and other – AZL, AZT, AZA.
- The essential ingredients of necessary conditions of initiation the full hazard phase are:
- uncontrolled processes, uncontrolled parameters changes or uncontrolled crew activities,
- activities performed by the crew currently,
- the state of the workspace,
- influence crew on the work process,
- influence management on the industry plant movement (Szczurowski, 1984).

In order to determine, whether defined event is an important component of the necessary conditions chain, it should be considered whether without this event events sequence would be possible. In accordance with applicable safety regulations (PN-N-18001, 2004) accident at work is a sudden event caused by external circumstances that occurred in connection with work and led to the injury. Sufficient condition to recognize event as an accident at work is the presence of macroevent, that is a set of events:

$$WY = \{UR \wedge c_1 \wedge c_2 \wedge c_3\}$$

where:
UR – injury,
c_1 – event giving reason the injury, which lasts no longer than a period of one work shift,
c_2 – injury induced an external cause,
c_3 – injury is related to the work.
In order to considered an event could be regarded as an accident at work there must be fulfilled all four of these essential components of a sufficient condition. Examples injuries are; injury, bone fracture, burns, paralysis, lesion the physiological or psychological functions of the body, etc. A necessary condition but not a sufficient appearance of an injury UR is to fulfill a set of accident events. Generally it can be said that a necessary condition of accident event ZW is a set of events Y_k:

$$ZW \Rightarrow Y_k \equiv \{[AZ^P \wedge ys] \vee \left[AZ^C \wedge \left[RZ_c \vee RZ_{dwy}\right]\right]\}$$

where:
AZ^P – activation of accident hazard on the part of the work environment parameters,
ys – crew staying within range AZ^P,
AZ^C – activation of accident hazard on the human factor side,
RZ_c – actual threshold of accident hazard from the environment objects, which represent objects dangerous for the crew,
RZ_{dwy} – actual threshold hazard from the dose harmful factor.
Examples of actual thresholds of accident hazard RZ_C are moving machine elements or equipment or live, dangerous for humans and all stiff, angular, hard, sharp, hot, etc. objects of work environment. The actual threshold accident hazard on the side of harmful factors dose can be achieved in particular by undesirable changes in the air stream parameters such as pressure, temperature and presence of toxic or suffocating gases in normal or emergency conditions (Kalinowski, 2003). Such parameters should be monitored at the workplace.

RESULTS FOR THE SELECTED HAZARD AT THE WORKPLACE

For the cause of event identification purposes, which effect is an accident and/or material failure SM, the causation of an undesired sequel of events prior for selected case should be analyzed. Usually there is a risk of material damage associated with accidental hazards, which may accompany some accidents. Accident at work WY or/and material injury SM implies trauma UR and a chain of conditions necessary of sequence of events in the full-risk phase. The essential components of the conditions necessary for the initiation of the full-risk phase are:

– uncontrolled processes, uncontrolled parameter changes or uncontrolled crew operations,
– activities currently performed by the crew,

- technical condition of the industry installation,
- the influence of the crew on the course of technological processes,
- the influence of the management on the maintenance of the industry plant (Ignac-Nowicka, 2018b).

To determine whether a particular event is an essential component of the chain of necessary conditions, it should be considered whether without this event it would be possible to consider the consequence of events.

Below is an analysis of the chain of events for the threat in the form of a gas explosion at the workplace. For the analyzed hazard: gas explosion EG, essential chain components of the conditions necessary in the full hazard phase are:

- gas leaks on the valve – WGz,
- unsealing of the tank – RZ,
- leakage of other components of the gas installation – NI.

A gas explosion may occur when two conditions are present: the occurrence of a spike ZI or a high temperature ZT with the simultaneous leakage of gas from the gas system (Ignac-Nowicka, 2017b, Tutak, 2018). Event string Π (EG) accompanying the hazard of gas explosion EG is the following set of events Zz:

$$EG \Rightarrow WY \wedge SM \Rightarrow UR \Rightarrow \Pi(EG) \equiv Zz \equiv \{[ZI \vee ZT] \wedge [WGz \ \vee RZ \vee NI]\}$$

The expanded chain of events is as follows:

$$EG \Rightarrow WY \wedge SM \Rightarrow UR \Rightarrow \Pi(EG) \equiv \{Zz \equiv \{[ZI \vee ZT] \wedge \left[WGz \quad \equiv \left\{Ae \vee Uz \vee Bs \equiv \{no\}\right\}\right] \vee [RZ \\ \equiv \{Pp \wedge Bsy \equiv \{ac \vee no\} \wedge Wc \equiv \{np \vee ns\}] \vee [NI \equiv \{Og \wedge Bsy\}]\} \Rightarrow \\ no \wedge ac \wedge np \wedge ns,$$

where:

Ae – electrovalve failure,
Uz – external damage,
Bs – control error,
no – operator inattention,
Wc – increase in pressure or temperature in the tank,
Bsy – no pressure sensor signal,
Pp – production process,
eg – abnormal chemical process,
ns – incorrect control,
ac – sensor failure,
Og – the presence of gas in the installation.

The analysis of the event chain for the incident and material loss in the form of gas explosion has identified three direct causes: gas leaks on the valve, unsealing of the tank, leakage of other components of the gas installation and five indirect causes: external damage, control error, increase in pressure or temperature in the tank, no pressure sensor signaling, electrovalve failure. In the event chain, three main conditions were also identified for the analyzed event: production process, the presence of gas in the installation, leakage of the installation, and four first cause: sensor failure, irregularities in the chemical process, incorrect control and operator inattention. The above analysis points to human errors committed in the control and control process of the production process and minor faults, such as the failure of the gas concentration signaling sensor, which are the first cause of the analyzed event and can lead to serious consequences. Possible undesirable sequence of events preceding a gas explosion in a chemical plant is the essence of a gas hazard that poses a certain risk to the production process.

CONCLUSIONS

Creating a security system, which aim is to eliminate the harmfulness, as well as the identification of relative hazard, requires the determination of all significant components necessary events sequence preceding the results (losses) in the industry plant. To that end the chain of necessary conditions preceding harmfulness and losses are analyzed. The use of events theory elements to identify hazards very clearly show the complexity of the harmfulness (loss) causes. This analysis gives a broad knowledge about the factors (direct and indirect) influence on events such as: an accident, material damage and occupational disease in the workplace. During the analysis events chain hazards are identified, which are cause of interim and final effects and the relationships between causes and effects (losses) in the industry. As a result of such analysis, a list of causes of the event (losses) and cause and effect relationships between these events is obtained.

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Abstract. The article presents the hazard identification process as a sequence of events that leads to accident and/or material loss at the workplace. The chain of events can be described as an orderly set of circumstances conducive to the emergence of a threat. The article presents an analysis of the application of elements of the events theory to the identification of hazards in an industrial plant on the example of a gas explosion. The circumstances supporting the emergence of a gas explosion hazard were identified by determining the direct and indirect causes of the event and the main conditions leading to the event (loss). Also indicated is the cause of gas explosion hazard, which is the initiating factor in the chain of events.

Keywords: chain of events, sequence of events, hazard identification, security deficits