Use of selected methods for investigating events to identify and analyse their causes

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Abstract. Accidents and occupational diseases are directly associated with the conditions of work and the hazards existing in the work environment. Work conditions analyses are conducted when employees are accepted to work at a given position, and also when solutions preventing accidents and occupational diseases are implemented. Despite the solutions, workplace accidents still occur. Hence, to prevent accidents of similar causes, it is necessary to know the causes and the conditions in which an accident occurred, and then take actions which will stop similar accidents from happening in the future. The article discusses the basic division of causes of accidents, basic methodology of investigating accidents with WAIT and TOL methods and presents examples of their applications.

1. Introduction
In 2017, in Poland, there were 88 330 people injured in workplace accidents (according to form Z-KW Statystyczna Karta Wypadku Report of Injury). The number includes 661 people injured in serious accidents, and 269 fatalities [1]. The data indicate an increase of 42.5% in the number of the injured in serious accidents, of 12.6% in the number of fatal accidents, and an increase in the total number of the injured of 0.2% when compared with the previous year. The losses incurred by the society, associated with the costs of workplace accidents, are high. Actually, they are much higher than the costs of accidents incurred by entrepreneurs [2]. For entrepreneurs, the negative result of accidents may mean the necessity to increase a contribution for accident insurance following the regulations of the Decree of the Minister of Labour and Social Policy of 29 November 2002 on differentiation of the interest rate of social security contributions for workplace accidents and occupational diseases depending on occupational hazards and their consequences [3]. One of the basic mechanisms aimed at preventing accidents, especially accidents of similar causes (“similar accidents”), are actions taken within the framework of the post-accident proceeding, intended to determine and implement conclusions and prevention recommendations. To determine proper preventive measures, it is necessary to identify causes of an accident and its circumstances.

A properly conducted accident investigation, which results in identifying all the causes of an accident [4], provides important data on the solutions which ought to be implemented and enables limiting the probability of charges being pressed by the controlling institutions and employees’ claims against the employer. It refers particularly to a situation when the accident which occurred shares the same or similar causes as the past events in a given enterprise.
2. Accident Investigation

The first stage of the accident investigation process is the identification of its causes. Accidents result from several causes which occur in a certain sequence. We can distinguish two main groups of them:

- direct causes,
- indirect causes (first and second degree).

Direct causes – they have the closest temporal relationship with an accident [5]. Such direct causes are e.g. movements of the ground or the deck leading to the loss of equilibrium.

First degree indirect causes – they lead to the states which promote accident occurrence (probability of its occurrence increases). Such a first degree indirect cause is e.g. work at a height without required safety measures.

Second degree indirect causes – their influence on an accident is distant in time. Most often they answer the question why the event or the hazardous situation occurred. That is why they are often referred to as source causes. Source causes are tightly associated with the occupational health and safety policy of an enterprise and applied occupational health and safety management system procedures. An example of a second degree indirect cause may be insufficient training of the personnel working at a height or lack of proper equipment, as well as tolerating performing works without required safety measures.

Identifying source causes enables determination of factors which led to the first degree indirect cause and the direct cause. It means that source causes are the first ones in the chain of events leading to the final stage – an employee’s accident. To avoid another accident of the same or similar causes it is necessary to eliminate the source cause [5] or introduce such solutions which limit its influence if it is impossible to eliminate it.

Most often, the easiest task is to know the sources of direct causes of an accident and there are problems to identify indirect causes. Hence, it is worth applying available analytical methods in the investigation, which enable accident analyses and investigation in the following steps: gathering information – evidence and facts; analyses of the obtained material; identification of the causes and planning corrective – preventive actions. However, there are no “ideal” nor “universal” methods which will always bring the best results while analysing all the events.

It is important to know various methods of investigating accidents and how to apply them. The National Labour Inspectorate states that the quality of accident investigations is also influenced by the expertise and qualifications of the investigation teams. Moreover, the Inspectorate observes that the accident investigation often misses the course of the accident in the cause and effect system [6].

Given methods and models applied in them differ as regards the assumptions made and procedures applied to identify causes of an accident. There are many methods of investigating accidents, e.g.: the Technical–Organizational–Human (TOH) method, barrier analysis method, extended method of determining technical, organisational and human causes, change analysis method, fault tree analysis method, WAIT method. In the article there are presented applications of the extended method of determining technical, organisational and human causes (TOH) and the WAIT method.

3. Extended method of determining technical (T), organizational (O) and human (H) causes

The TOH method is employed in two basic versions to investigate accidents. The first one is based on the analysis of causes only. The other one additionally considers two important elements: an analysis of the course of an accident and a barrier analysis. Following the assumptions of the method, it is realized in five steps [7]:

1. Description of the sequence of events.
2. Search for causes and conditions in which the accident occurred.
3. Identification of barriers.
4. Analysis of consequences.
5. Preparing recommendations and corrective actions - total injuries in work accidents,

The first step is "Description of the sequence of events". It means presenting the accident chronologically in a linear form, basing on all the data concerning the accident obtained through
analysing available sources, e.g. witnesses’ statements, blueprints, manuals, photos, victims’ statements. The sequence of events is recreated without determining the cause and effect relationship between them. The result of the analysis is presented graphically e.g. with geometric figures.

The second step is “Search for causes and conditions in which the accident occurred”. It covers analyses of factors, events and personnel’s behaviour, considering their influence on the occurrence and the course of an accident. As a result of the analysis, the causes are identified and split into three groups: technical, organizational and human. The analysis covers all the types of causes i.e.: direct causes, indirect causes and source causes.

The third step is “Identification of barriers”. At the stage, all the barriers which could prevent the accident or minimize its effects are searched for. They include:

a) defunct barriers – barriers insufficient to stop or limit the energy, damaged barriers, inactive barriers,

b) operating barriers – barriers which worked as intended (properly),

c) missing barriers – barriers, which were missing but could prevent the occurrence of an accident or minimize its consequences.

All the barriers identified during the analysis are placed in a diagram.

The fourth step is “Analysis of consequences”. It is an example of a prospective analysis which answers the questions: what else could happen, what the further course of the accident would be, what other consequences it could have. The stage is particularly important while investigating accidents which could potentially lead to further accidents or deteriorate the effects of the accident (e.g. collective accident).

The fifth step is “Preparing recommendations and corrective actions”. It is the final stage and it is when there are formulated recommendations and corrective action plans aimed at eliminating or minimizing factors which lead to the accident.

3.1. Example of an analysis of an accident which occurred when a roadway was driven, extended TOH method

Step 1. Sequence of events.
The personnel were driving a roadway with a roadheader and installing the arch support. After assembling the arches, when they were installing the lining standing on the work deck, the boom moved downward in an uncontrolled way. The work deck shook and one of the employees, a coal-face miner, lost his balance. He fell from the height of approx. 2.3m and hit the roadheader apron, bruising his shoulder and fracturing the right hand wrist. The sequence of events is presented schematically in figure 1.

Figure 1. Sequence of events for an accident which occurred when a mine working was drive.

Step 2. Search for causes and conditions in which the accident occurred.
The conditions in which the accident occurred: the face of a roadway driven with a roadheader and V29/10 arch support with 0.75m arch spacing. The lining was made of welded wire mesh. The support was stabilised with ten arch tube spreaders. The roadway was ventilated with WLE fan and a \( \phi 1000\)mm air duct. The roadheader lights worked properly. An additional source of light was located approx. 3m from the place of the incident. The work deck did not have any railing. The personnel did not use any fall arrest equipment. A few days before the event the boom had fallen, which was reported to the mechanical department. The personnel of the mechanical department, inspected the machine and, after checking the system, did not find any malfunctions. Due to the fact that there were
further reports concerning the same problem, and the inspections were not able find the malfunction which resulted in such behaviour of the boom (falling), the personnel of the mechanical department contacted the manufacturer. Despite reported malfunctions works did not stop, probably because of the unusual nature of the malfunction, as it did not render further work impossible and its symptoms occurred occasionally.

Identification of causes:

- technical: Malfunctioning power system of the telescopic boom, no railing on the work deck.
- organizational: The equipment was not checked prior to work by the persons responsible for it; no railing around the work deck, no rules concerning a situation when the mechanical department cannot find a malfunction – lack of communication/understanding between the mechanical department and the operator.
- human: Work did not comply with the developed technology and occupational health and safety rules (e.g. no fall arrest harness) when the support arches were assembled, using the equipment despite problems reported by the previous shift, lack of proper communication between the mechanical department and the operator’s department.

Step 3. Identification of barriers.

In the analysed accident the following barriers were diagnosed:

- work deck railing,
- fall arrest harness,
- proper control of the equipment prior to work,
- locking the ON switch after a malfunction is observed (abnormal performance parameters – a millisecond drop in pressure),
- the head protective gear worn by the victim prevented a head injury during the fall.

The first of the barriers was not installed (missing barriers), the second barrier was not used to prevent the fall (missing barriers), the third barrier failed to diagnose the problem (inactive barrier), the fourth barrier was not applied in the device (missing barriers), the fifth barrier worked properly (active barrier).

Step 4. Analysis of consequences.

If the employee had been hit on the head without wearing any protective gear, or his body had been oriented differently during the fall, he could have died. The accident could have affected more of the employees present on the work deck.

Step 5. Preparing recommendations and corrective actions.

Basing on the analysis of the accident, the following recommendations were suggested:

- discuss the accident with the personnel driving roadways,
- conduct additional training on conducting works following the planned technology, including occupational health and safety rules and regulations,
- while supervising the works, pay special attention to the proper use of the work decks and works associated with using roadheaders to assemble support arches,
- in co-operation with the roadheader manufacturer, determine if it is possible to prevent the equipment from switching ON when there is a malfunction (abnormal performance parameters – millisecond drops in pressure),
- periodically provide extra supervision of works conducted on work decks.

The result of the conducted analysis of accident circumstances and causes is presented in a graphic form (figure 2). The first level, marked green, presents the course of the accident and the barriers. The second level, marked yellow, presents direct causes and first degree indirect causes. The last level, marked orange, presents second degree indirect causes (source) of an accident.
4. Work Accidents Investigation Technique (WAIT) Method

The method is relatively simple, therefore it enables linking its results with an occupational hazard assessment. The WAIT method assumptions are based on the contemporary version of the domino model and the organisational model of workplace accidents [8]. In the WAIT method we do not use the concept of a cause of accidents. Instead there are failures in the actions and the conditions leading to an accident. The failures are divided into two groups: active failures – corresponding direct causes, and latent failures – corresponding indirect causes of an accident.

The first stage of the method, called simplified accident investigation, consists of four steps [8].

Step 1. Gathering information – information concerning the course of an event and what had an influence on it (influence factors). The information comes from persons involved in a given event – the injured and witnesses. The method of an interview with a questionnaire is applied as the tool to obtain the data. The data collected in such a way can be supplemented with schematics, drawings, photos and other types of documentation concerning the conditions in which the accident occurred.

Step 2. Identification of active failures – The method recognizes three groups of failures:
- a) failure mode – failures associated with the tangible work environment (tools, substances, materials),
- b) error mode – failures associated with the behaviour of employees, wrong decisions or lack of them,
- c) deviations – incidents deviating from the assumed work process associated with failure or error mode.
**Step 3.** Determination of the influence factors – determining which factors and to what extent caused the failure.

**Step 4.** Comparison of the analysis results with the results of an occupational hazard assessment – an analysis of the existing occupational hazards for the posts associated with the accident to introduce potential changes.

The next stage of the in-depth analyses of workplace accident consists of the further five steps [8]:

**Step 5.** An analysis of individual factors and factors associated with work – its aim is to identify fully the aforementioned factors, answer why the failures occurred and propose actions which ought to be taken to avoid similar accidents.

**Step 6.** An analysis of the enterprise’s organizational and management system – its aim is to identify latent failures associated with the occupational health and safety management system (indirect causes). The analysis is conducted in five groups: procedures, management, technical, training, safety.

**Step 7.** Linking results of the analysis with the occupational health and safety management system – results of the analysis are employed to introduce changes to the safety management system.

**Step 8.** Developing recommended preventive actions – basing on the analysis of steps 1 – 3, corrective actions, concerning active failures which are direct causes of an accident, are defined and implemented. The actions ought to be realised in short time. Basing on step 4, there are introduced corrections to an occupational hazard assessment. Time of their realisation depends on their influence on the result of an occupational hazard assessment. Basing on the analysis made in steps 5 – 7, there are implemented corrective actions towards the identified shortcomings and flaws within the occupational health and safety management system, or even to the enterprise management system. The actions are mostly realised over a longer span of time.

**Step 9.** Search for positive influence factors – the aim of the stage is to identify all the positive events which limited effects of the accident. The analysis of the obtained information is employed to prepare recommendations to improve occupational health and safety.

### 4.1. Example of an accident analysis, which occurred when materials were transported with a diesel-powered locomotive, WAIT method

**Step 1.** Gathering information – description of an accident.

The accident occurred when materials were transported with SCHARF diesel-powered locomotive. The accident happened when the locomotive was driving up along an inclined drift. The drive wheel started sliding on wet rails. The pointsman to increase friction intended to sprinkle some dust on the rails. To do so, he went approx. five meters down the drift looking for some stone dust. In the meantime the locomotive rolled approx. seven meters down as the supply hose got unplugged. The locomotive stopped when the emergency brake worked as the control lever was set in position 0. During the accident the victim was in a forbidden place (next to a locomotive in motion when the drive wheels are sliding). Basing on the analysis of the documentation, it was determined that the victim did not write any entry in the Inspection Checklist Book of the locomotive. He also did not check previous entries. It was determined that the rails and the drive wheels of the locomotive were in bad technical condition.

**Step 2.** Identification of active failures.

a) technical irregularities – unplugging the power hose (caused by pressure), bad technical condition of the rails, water on the rails, bad technical condition of the drive wheels.

b) human errors – leaving the locomotive and standing in the forbidden area, the supervisors’, drivers’ and pointsmen’s lack of reaction to bad technical condition of the rails (controls were conducted but no actions were taken), the drivers’ and operators’ lack of reaction to bad technical condition of the drive wheels, no steps were taken to protect the rails from water.

c) deviation from the normal state – the locomotive sliding while going up the drift (inclination approx. 10 degrees), using the locomotive in spite of its bad technical condition, using rails in bad technical condition.
Step 3. Determination of the influence factors: the driver getting off the locomotive (drive wheels turning), the power hose unplugging (direct influence); synergistic (common) interaction between the drive wheels and wet rails (both in bad technical condition) along the inclined section of the rails (the locomotive was driving despite the bad state of the wheels and rails; it stopped in the section where friction was lower due to wet rails). Latent failures: no actions taken by the supervisors and the personnel responsible for checking the technical condition of the locomotive and the rails.

Step 4. Comparison of the analysis results with the results of the occupational hazard assessment. The hazard of being hit by an object in motion was identified in previous occupational hazard assessments; because of the accident and the conducted analysis, the probability of the event increased, which caused a very high result of an occupational hazard assessment in workplaces associated with diesel-powered locomotives.

Step 5. Analysis of individual factors and factors associated with work. The pointsman gets off (a) – the failure resulted from the decision taken against the occupational health and safety regulations, caused by the locomotive stopping. The failure would have not occurred if the technical condition of the rails and the locomotive had met the requirements. The event would have not happened if, in the circumstances, the operator had stopped the locomotive and walked down the drift or just switched off the drive. Then the safety measure preventing the locomotive from rolling would activate, making it impossible to move, even if the power hose got unplugged and the pressure dropped in the drive. To avoid such accidents in the future, it is necessary to introduce technical solutions which would switch off the hydraulic drive when the crew gets off. Unplugging the power hose (b) – the failure could have been caused by mechanical damage while driving, normal wear, material failure or flaws in the hose fittings. Such situations cannot be prevented. It is only possible to minimise probability of their occurrence through controlling the technical condition of the hose and fittings. That is why it is necessary to introduce technical solutions which prevent the locomotive from driving in the direction opposite to the one intended by the operator. Wet rails (c) – the failure was caused by lack of technical solutions securing the rails from water. It is necessary to introduce a solution which protects the rails from direct and local flooding e.g. in a form of a canopy and cleaning (mechanically) the places of lowered friction on the rail tracks in inclined mine workings.

Step 6. Analysis of the enterprise organisation and management system – procedures and management: no sufficient provisions in the procedures: Underground transport, mechanical hazards, supervision of work conditions. Technology – no system solutions concerning rail track maintenance. Training: adding a training course on the proper behaviour of the locomotive personnel during malfunctions. Safety: increasing supervision over the technical condition of the locomotive.

Step 7. Connecting results of the analysis with the occupational health and safety management system – results of the analysis ought to be introduced into the procedures of the occupational health and safety management system in the following areas: Underground Transport, Mechanical Hazards, Work Conditions Supervision.

Step 8. Preparing recommended preventive actions (concerning the active failures) it is necessary:

- to discuss the rules of behaviour when drive wheels slide on rails,
- to increase supervision over the personnel as regards controlling technical condition of the locomotive and making entries in the Inspection Checklist Book (personnel obliged: supervisors of the department where the equipment is used).

Concerning latent failures:

- within 14 days, control the rail tracks and clean them in the areas of lowered friction, build roofing to prevent direct flow of water onto the rails (personnel obliged: supervisors of the department responsible for the maintenance of the rails),
- within 30 days, introduce recommendations into the procedures of the occupational health and safety management system (personnel obliged: occupational health and safety department personnel),
- together with Electromechanical Department and the equipment manufacturer, analyse possibility of introducing technical solutions described in point five,
in the future, technical requirements for the tenders to purchase new vehicles ought to include solutions which switch off the hydraulic drive of a locomotive when the crew members get off (personnel obliged: Purchasing Department and Electromechanical Department).

Step 9. Searching for positive influence factors – reaction of the operator to the drop in pressure in the hydraulic drive (setting the lever in position “0”), emergency brakes worked.

5. Conclusions
The models of accident investigation found in the literature differ as regards the detailed level of analysis, and therefore the amount of work required to apply them. Selection of a specific method will always depend on a specific accident i.e. its course, the data concerning what information the accident investigation team had, and the effects of the accident. To investigate some of the accidents, e.g. serious, collective or fatal, it is worth applying various methods and compare their results at the stage of formulating conclusions.

The extended TOH method is the easiest one to apply and like the WAIT method enables direct identification of causes and failures, whose source is in the existing occupational health and safety management system.

Direct linking of the results obtained with the WAIT method analysis with the analysis and updating occupational hazard assessment, as well as correlating them with the occupational health and safety management system, makes the method more effective when changes are introduced to the system.

Presenting causes of accidents in a graphic form with the extended TOH method makes it easier to understand the results of the analysis and to understand the conclusions.

Use of analytical methods helps formulate proper conclusions and propose recommendations to prevent similar accidents in the future. It also enables presentation in the accident documentation, how it was analysed with the selected methodology, which means that the accident circumstances and causes can be recreated even after a few years.

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