Comparison of some selected methods for accident investigation

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Abstract

Even if the focus on risk management is increasing in our society, major accidents resulting in several fatalities seem to be unavoidable in some industries. Since the consequences of such major accidents are unacceptable, a thorough investigation of the accidents should be performed in order to learn from what has happened, and prevent future accidents.

During the last decades, a number of methods for accident investigation have been developed. Each of these methods has different areas of application and different qualities and deficiencies. A combination of several methods ought to be used in a comprehensive investigation of a complex accident.

This paper gives a brief description of a selection of some important, recognised, and commonly used methods for investigation of accidents. Further, the selected methods are compared according to important characteristics.
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1. Introduction

Even if the frequency is low, major accidents seem to be unavoidable in some low-frequency, high consequence industries. The process industry accidents at Longford [1] and on the Piper Alpha platform [2], the loss of the space-shuttles Challenger [3] and Colombia [4], the high speed craft Sleipner-accident [5], and the railway accidents at Ladbroke Grove [6] and Åsta [7] are all tragic examples on major accidents in different industries. The consequences of such major accidents are not accepted in our society, therefore major accidents should be investigated in order to prevent them from reoccurring (called organisational learning by [8]). This is also in accordance with the evolutionary strategy for risk management (one out of three main strategies) described by [9].[1]

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[1] [9] described the following three strategies for risk management:

- The empirical strategy, which is related to occupational safety (frequent, but small-scale accidents), and safety is typically controlled empirically from epidemiological studies of past accidents.
- The evolutionary strategy, where protection against medium size, infrequent accidents evolve from design improvements in response to analysis of the individual, latest major accidents.
- The analytical strategy, where protection against very rare and unacceptable accidents must be based on reliable, predictive models of accident processes and probability of occurrences (probabilistic risk/safety analysis.

The accident investigation process is described somewhat different by different authors. DOE [10] divides the process in three (partially overlapping) main phases: (i) collection of evidence and facts; (ii) analysis of evidence and facts and development of conclusions; and (iii) development of judgements and need and writing the report. Other authors, like Kjellén [11], also include the implementation and follow-up of recommendations as part of the investigation. The focus in this paper is on phase (ii), more specifically on methods available for analysis of evidence and facts helpful for development of conclusions.

CCPS [12] describes three main purposes of techniques for accident investigation. The first purpose is to organise information about the accident once evidence has been collected. The second is to help in describing accident causation and developing hypothesis for further examination by experts, and the last is to help with the assessment of proposed corrective actions. In addition, the analytical techniques may also ensure that the results are transparent and verifiable.

During the last decades, a number of methods for accident investigation have been developed and described in the literature. Authors like Johnson [13], Handrick and Benner [14], Groeneweg [15] and Svensson [16] have developed and described their own investigation method, while CCPS [10], DOE [12] and [17] have reviewed and described several methods. In addition, a lot of companies and authorities

in different countries have developed their own manuals for investigation of accidents.

Each of these methods has different areas of application and different qualities and deficiencies. Therefore, a combination of several methods ought to be used in a comprehensive investigation of a complex accident. There are two main objectives of the paper. The first objective is to give a brief description of some important, recognised, and commonly used methods for investigation of accidents, and the second is to compare and discuss these methods according to some characteristics.

The accident investigation process is briefly introduced in this section. The next section outlines the characteristics which the different methods for accident investigation are compared according to. Further, a brief description of the selected methods is given, and the methods are compared according to the described characteristics. In the last section the discussion is concluded.

2. Framework for comparison of accident investigation methods

Within the field of accident investigation, there is no common agreement of definitions of concepts, but tend to be a little confusion of ideas. Especially the notion of cause has been discussed in the literature. While some investigators focus on causal factors [18], others focus on determining factors [19], contributing factors [1], active failures and latent conditions [20], or safety problems [14]. Kletz [21] recommends avoiding the word cause in accident investigations and rather talk about what might have prevented the accident. Despite different accident investigators may use different terms, frameworks and methods during the investigation process, their conclusions about what happened, why it happened and what may be done in order to prevent future accidents ought to be the same. Use of formal methods for investigation of major accidents may support the investigators during the investigation process and in the presentation of results and recommendations. Further in this section, some important characteristics of these methods are considered. The selected methods will be compared to these properties later in the paper.

Regardless of the purpose of an accident investigation, any conclusion should be based on a complete understanding of the events leading to the accident. Whether the methods give a graphical description of the event sequence or not is the first characteristic discussed. A graphical description of the accident sequence may be useful during the investigation process because it gives an easy understandable overview of the events leading to the accident and the relation between different events. Further, it facilitates communication among the investigators and the informants and makes it easy to identify eventually "missing links" or lack of information.

An important principle for prevention of major accidents is the principle of defence-in-depth [20,22,23] (also denoted as multiple safety barriers or multiple layers of protection). Analysis of major accidents should therefore include an analysis of how safety barriers influenced the accident. To what degree the methods focus on safety barriers is therefore the second feature compared.

The level of scope of the different analysis methods (from the work and technological system to the Government level) is the third attribute discussed due to the arguments presented by Rasmussen [9] who states that all actors or decision-makers influencing the normal work process might also influence accident scenarios, either directly or indirectly. This complexity should also be reflected in accident investigations. The selected methods are compared according to a classification of the socio-technical system involved in the control of safety (or hazardous processes) [9], comprising the following levels:

1. The work and technological system.
2. The staff level.
3. The management level.
4. The company level.
5. The regulators and associations level.
6. The Government level.

The next characteristic considered, is what kind of accident models that have influenced the method. This characteristic is assessed because the investigators' mental models of the accident influence their view of accident causation. The following accident models are used (further description of the models is given by Kjellén [11]):

A. Causal-sequence model.
B. Process model.
C. Energy model.
D. Logical tree model.
E. SHE-management models.

Whether the different methods are inductive, deductive, morphological or non-system-oriented is also discussed. The deductive approach involves reasoning from the general to the specific, the inductive approach means reasoning from individual cases to a general conclusion, while the morphological approach is based on the structure of the system being studied.

Further, the different investigation methods are categorised as primary or secondary methods. Primary methods are stand-alone techniques, while secondary methods provide special input as supplement to other methods.

The last attribute discussed, is the need for education and training in order to use the methods. The terms "Expert", "Specialist" and "Novice" are used. Expert indicates that formal education and training are required before people are able to use the methods in a proper way. Novice indicates that people are able to use the methods after an introduction to the methods without hands-on training or experience. Specialist is somewhere between expert and novice.

3. Methods for accident investigation

A number of methods for accident investigation have been developed, with their own strengths and weaknesses. Some methods of great importance are selected for further examination in this paper. The selection of methods is based on the following selection criteria: The methods should be widely used in practice, well acknowledged, described in the literature and some of the methods should be relatively recently developed. Based on these criteria, the following methods were selected for comparison:

- Events and causal factors charting and analysis.
- Barrier analysis.
- Change analysis.
- Root cause analysis.
- Fault tree analysis.
- Influence diagram.
- Event tree analysis.
- Management and Oversight Risk Tree (MORT).
- Systematic Cause Analysis Technique (SCAT).
- Sequential Timed Events Plotting (STEP).
- Man, Technology and Organisation (MTO)-analysis.
- The Accident Evolution and Barrier Function (AEB)-method.
- TRIPOD.
- Acci-Map.

3.1. Events and causal factors charting (ECFC) and events and causal factors analysis

Events and causal factors charting [10] is a graphical display of the accident's chronology, and is used primarily for compiling and organising evidence to portray the sequence of the accident's events. The events and causal factors chart consists of the primary events sequence, secondary events sequences and conditions influencing the events.

The primary sequence of events that led to an accident is drawn horizontally, chronologically, from left to right in the diagram. Secondary events are then added to the events and causal factors chart, inserted where appropriate in a line above the primary sequence line. Events are active and are stated using one noun and one active verb. Conditions that affect either the primary or secondary events are then placed above or below these events. Conditions are passive and describe states or circumstances rather than occurrences or events.

Events and causal factors analysis is the application of analysis to determine causal factors by identifying significant events and conditions that led to the accident. As the results from other analytical techniques are completed, they are incorporated into the events and causal factors chart. "Assumed" events and conditions may also be incorporated in the chart.

The events and causal factors chart are used to determine the causal factors of an accident, as illustrated in Fig. 1.
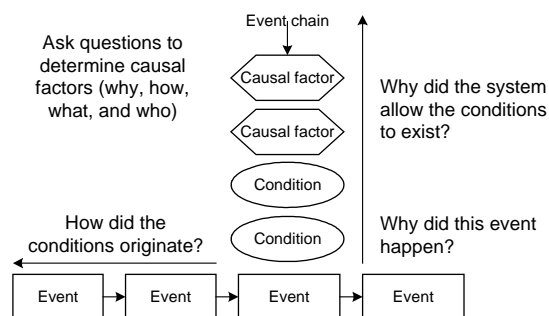

Fig. 1. Events and causal factors analysis [10].

This process is an important first step in later determining the root causes of an accident. Events and causal factors analysis requires deductive reasoning to determine which events and/or conditions that contributed to the accident.

3.2. Barrier analysis

Barrier analysis [10] is used to identify hazards associated with an accident and the barriers that should have been in place to prevent it.

A barrier is any means used to control, prevent, or impede the hazard from reaching the target. Two main types of barriers are described: physical barriers and management barriers. To analyse management barriers, investigators may need to obtain information about barriers at three organisational levels responsible for the work: the activity, facility and institutional levels.

The barrier analysis addresses:

- Barriers that were in place and how they performed.
- Barriers that were in place but not used.
- Barriers that were not in place but were required.
- The barrier(s) that, if present or strengthened, would prevent the same or similar accidents from occurring in the future.

The basic steps in a barrier analysis are:

1. Identify the hazard and the target.
2. Identify each barrier.
3. Identify how the barrier performed.
4. Identify and consider probable causes for the barrier failure.
5. Evaluate the consequences of the failure in this accident.

3.3. Change analysis

Change analysis [10] examines planned or unplanned changes that caused undesired outcomes. Change is anything that disturbs the "balance" of a system operating as planned. Changes are often the sources of deviations in system operations. In an accident investigation, this technique is used to examine an accident by analysing the difference between what has occurred before or was expected and the

actual sequence of events. The investigator performing the change analysis identifies specific differences between the accident–free situation and the accident scenario. These differences are evaluated to determine whether the differences caused or contributed to the accident.

3.4. Root cause analysis

DOE [10] describes Root cause analysis as any analysis that identifies underlying deficiencies in a safety management system that, if corrected, would prevent the same and similar accidents from occurring. Root cause analysis is a systematic process that uses the facts and results from the core analytic techniques to determine the most important reasons for the accident. While the core analytic techniques should provide answers to questions regarding what, when, where, who, and how, Root cause analysis should resolve the question why. Root cause analysis requires a certain amount of judgement.

A rather exhaustive list of causal factors must be developed prior to the application of root cause analysis to ensure that final root causes are accurate and comprehensive. One method for Root cause analysis described by DOE is TIER-diagramming. TIER-diagramming is used to identify both the root causes of an accident and the level of line management that has the responsibility and authority to correct the accident's causal factors.

3.5. Fault tree analysis

Fault tree analysis is a method for determining the causes of an accident (or top event) [24]. The fault tree is a graphic model that displays the various combinations of normal events by use of logic gates, equipment failures, human errors, and environmental factors that can result in an accident. A fault tree analysis may be qualitative, quantitative, or both. Possible results from the analysis may be a listing of the possible combinations of environmental factors, human errors, normal events and component failures that may result in a critical event in the system and the probability that the critical event will occur during a specified time interval.

The strengths of the fault tree, as a qualitative tool are its ability to break down an accident into root causes.

3.6. Influence diagram

Influence diagram may also be used to analyse the hierarchy of root causes of system failures: management decisions, human errors, and component failures (see Fig. 2) [25].

First, the elements (basic events and the dependencies among them) of the accident sequence (noted E_i) are systematically identified. The "failure path" or accident sequence in the Piper Alpha accident included: (1) initiating events; (2) intermediate developments and direct consequences of these initiating events; (3) final systems' states; and (4) consequences (i.e., the losses of the accident).
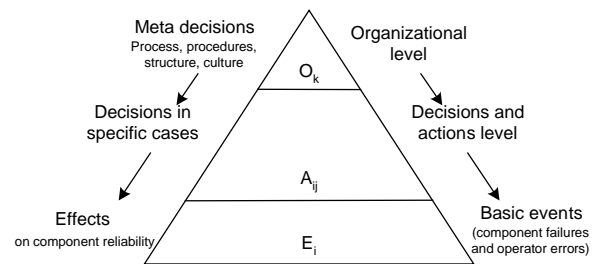

Fig. 2. Hierarchy of root causes of system failures [25].

Second, for each of these basic events, the human decisions and actions (noted A_{ij}) influencing these basic events are identified and classified in meaningful categories (in the case of Piper Alpha, these categories were: (i) design decisions; (ii) production and expansion decisions; (iii) personnel management; and (iv) inspection, maintenance, and correction of detected problems).

The third step is to relate the decisions, human errors, and questionable judgements that contribute to the accident to a certain number of basic organisational factors. These factors may be rooted in the characteristics of the company, the industry or even the government authorities.

Both the basic events (accident scenario), the decisions and actions influencing these basic events, the basic organisational factors, and the dependencies among them, are illustrated in an influence diagram.

3.7. Event tree analysis

An event tree is used to analyse event sequences following after an initiating event [26]. The event sequence is influenced by either success or failure of numerous barriers or safety functions/systems. The event sequence leads to a set of possible consequences. The consequences may be considered as acceptable or unacceptable. The event sequence is illustrated graphically where each safety system is modelled for two states, operation and failure.

An Event tree analysis is primarily a proactive risk analysis method used to identify possible event sequences, but the event tree may also be used to identify and illustrate event sequences and to obtain a qualitative and quantitative representation and assessment. In an accident investigation we may illustrate the accident path as one of the possible event sequences.

3.8. MORT

MORT [13] provides a systematic method (analytic tree) for planning, organising, and conduction a comprehensive accident investigation. Through MORT analysis, investigators identify deficiencies in specific control factors and in management system factors. These factors are evaluated and analysed to identify the causal factors of the accident.

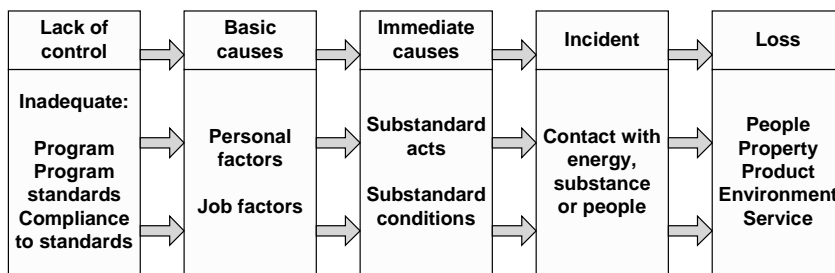| Lack of control	Basic causes	Immediate causes	Incident	Loss
Inadequate: Program Program standards Compliance to standards	Personal factors Job factors	Substandard acts Substandard conditions	Contact with energy, substance or people	People Property Product Environment Service

Fig. 3. The ILCI Loss Causation Model [27].

Basically, MORT is a graphical checklist in which contains generic questions that investigators attempt to answer using available factual data. This enables investigators to focus on potential key causal factors.

3.9. Systematic Cause Analysis Technique (SCAT)

The International Loss Control Institute (ILCI) developed SCAT [12] for the support of occupational incident investigation. The ILCI Loss Causation Model [27] is the framework for the SCAT system (see Fig. 3).

The Systematic Cause Analysis Technique is a tool to aid an investigation and evaluation of accidents through the application of SCAT chart. The chart acts as a checklist to ensure that an investigation has looked at all facets of an accident. There are five blocks on a SCAT chart. Each block corresponds to a block of the Loss Causation Models.

3.10. Sequential Timed Events Plotting (STEP)

The STEP-method [14] proposes a systematic process for accident investigation based on multi-linear sequences of events and a process view of the accident phenomena. STEP builds on four concepts:

1. Neither the accident nor its investigation is a single linear sequence of events. Rather, several activities take place at the same time.
2. The event Building Block format for data is used to develop the accident description in a worksheet. A building block describes one event, i.e., one actor performing one action.
3. Events flow logically during a process. Arrows in the STEP worksheet illustrate the flow.
4. Both productive and accident processes are similar and can be understood using similar investigation procedures. They both involve actors and actions, and both are capable of being repeated once they are understood.

A STEP-worksheet provides a systematic way to organise the building blocks into a comprehensive, multi-linear description of the accident process. The STEP worksheet is simply a matrix, with one row for each actor and events (an action performed by an actor) along a horizontally timescale. Arrows are used to link tested relationships among events in

the accident sequence. The STEP methodology also includes a recommended method for identification of safety problems and development of safety recommendations. Safety problems are marked with diamonds in the STEP worksheet.

3.11. MTO-analysis

The basis for the MTO-analysis is that human, organisational, and technical factors should be focused equally in an accident investigation [28,29].[2] The method is based on Human Performance Enhancement System (HPES) which is not described further in this paper.

The MTO-analysis is based on three methods:

1. Structured analysis by use of an event- and cause-diagrams.
2. Change analysis by describing how events have deviated from earlier events or common practice.
3. Barrier analysis by identifying technological and administrative barriers in which have failed or are missing.

Fig. 4 illustrates the MTO-analysis worksheet. The first step in an MTO-analysis is to develop the event sequence longitudinally and illustrate the event sequence in a block diagram. The next step is to identify possible technical and human causes of each event and draw these vertically to each event in the diagram. Further, analyse which technical, human or organisational barriers that have failed or was missing during the accident progress and illustrate all missing or failed barriers below the events in the diagram. Assess which deviations or changes in which differ the accident progress from the normal situation. These changes are also illustrated in the diagram (see Fig. 4).

A checklist for identification of failure causes is also part of the MTO-methodology [29]. The checklist contains the following factors: Work organisation, Work practice, Management of work, Change procedures, Ergonomic/deficiencies in the technology, Communication, Instructions/procedures, Education/competence, and Work environment. For each of these failure causes, there is a detailed checklist for basic or fundamental causes.

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[2] The MTO-analysis has been widely used in the Norwegian offshore industry recently, but it has been difficult to obtain a comprehensive description of the method.
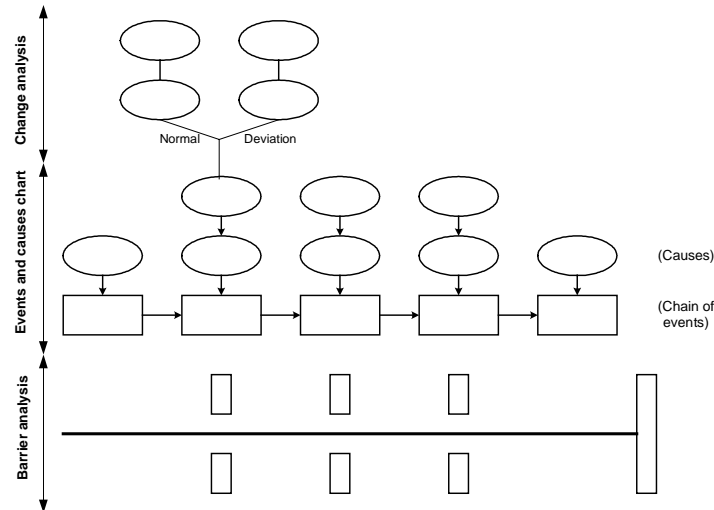
Fig. 4. MTO-analysis worksheet.

3.12. Accident Evolution and Barrier Function (AEB) method

The Accident Evolution and Barrier Function (AEB) [16] model provides a method for analysis of incidents and accidents that models the evolution towards an incident–accident as a series of interactions between human and technical systems. The interaction consists of failures, malfunctions or errors that could lead to or have resulted in an accident. The method forces analysts to integrate human and technical systems simultaneously when performing an accident analysis starting with the simple flow chart technique of the method.

The flow chart initially consists of empty boxes in two parallel columns, one for the human systems and one for the technical systems. During the analysis these error boxes are identified as the failures, malfunctions or errors that constitute the accident evolution. In general, the sequence of error boxes in the diagram follows the time order of events. Between each pair of successive error boxes there is a possibility to arrest the evolution towards an incident/accident. Barrier function systems (e.g., computer programs) that are activated can arrest the evolution through effective barrier functions (e.g., the computer making an incorrect human intervention modelled in the next error box impossible through blocking a control).

3.13. TRIPOD Beta

The idea behind TRIPOD [15] is that organisational failures are the main factors in accident causation. These factors
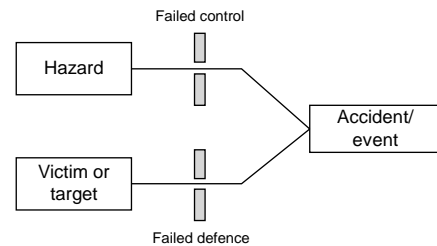

Fig. 5. "Accident mechanism" according to HEMP.

are more "latent" and, when contributing to an accident, are always followed by a number of technical and human errors.

The TRIPOD Beta-tool is a computer-based instrument that provides the user with a tree-like overview of the accident that is investigated. It is a menu driven tool that will guide the investigator through the process of making an electronic representation of the accident.

The BETA-tool merges two different models, the Hazard and Effects Management Process (HEMP) model and the TRIPOD model. The merge has resulted in an incident causation model that differs conceptually from the original TRIPOD model. The HEMP model is presented in Fig. 5.

The TRIPOD Beta accident causation model is presented in Fig. 6. The latent failures are related to 11 defined Basic Risk Factors (BRF). This string is used to identify the causes that lead to the breaching of the controls and defences presented in the HEMP model.

Although the model presented in Fig. 6 looks like the original TRIPOD model [31], its components and assumptions
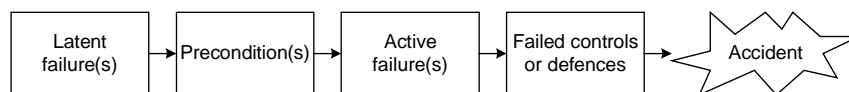

Fig. 6. TRIPOD Beta Accident Causation Model.

are different. In the Beta-model the defences and controls are directly linked to unsafe acts, preconditions and latent failures. Unsafe acts describe how the barriers were breached and the latent failures why the barriers were breached.

3.14. Acci-map

Rasmussen and Svedung [30] described a recently developed methodology for proactive risk management in a dynamic society. The methodology is not a pure accident investigation tool, but a description of some aspects of their methodology is included because it gives some interesting and useful perspectives on risk management and accident investigation not apparent in the other methods.

They call attention to the fact that many nested levels of decision-making are involved in risk management and regulatory rule making to control hazardous processes. Low risk operation depends on proper co-ordination of decision making at all levels.

4. Comparison and discussion

The methods briefly described above are compared according to the following characteristics (described in an earlier section):

- Whether the methods give a graphical description of the event sequence or not?
- To what degree the methods focus on safety barriers?
- The level of scope of the analysis.
- What kind of accident models that has influenced the methods?
- Whether the different methods are inductive, deductive, morphological or non-system-oriented?
- Whether the different methods are primary or secondary methods?

- The need for education and training in order to use the methods.

A summary of this comparison is shown in Table 1.

The first characteristic is whether the methods give a graphical description of the event sequence or not. The methods ECFC, STEP and MTO-analysis all give a graphical illustration of the whole accident scenario. By use of ECFC and MTO-analysis, the events are drawn along a single horizontal axis, while the STEP diagram in addition includes the different actors along a vertical axis. My subjective opinion is that STEP gives the best overview of the event sequence. This method makes it easy to illustrate simultaneous events and the different relationships between events (one-to-one, one-to-many, many-to-one and many-to-many). The "single axis" approach used by ECFC and MTO-analysis is not able to illustrate these complex relationships that may lead to major accidents, as well as STEP.

The graphical illustrations used by ECFC and MTO-analysis also include conditions that influenced the event sequence and causal factors that lead to the accident. In STEP, safety problems are illustrated only by triangles or diamonds and are analysed separately. A strength of the MTO-analysis is that both the results from the change analysis and the barrier analysis are illustrated in the graphical diagram.

Some of the other methods also include graphical symbols as part of the method, but none of them illustrate the total accident scenario. The fault tree analysis uses predefined symbols in order to visualise the causes of an initiating event, while the event tree uses graphical annotation to illustrate possible event sequences following after an initiating event influenced by the success or failure of different safety systems or barriers. Dependencies between different events in the accident scenario are illustrated in the influence diagram. The AEB method illustrates the different human and technical failures or malfunctions leading to an accident (but not the total event sequence). The TRIPOD

Table 1
Characteristics of different accident investigation methods

Method	Accident sequence	Focus on safety barriers	Levels of analysis	Accident model	Primary/secondary	Analytical approach	Training need
Events and causal factors charting	Yes	No	1–4	B	Primary	Non-system oriented	Novice
Events and causal factors analysis	Yes	Yes	1–4	B	Secondary	Non-system oriented	Specialist
Barrier analysis	No	Yes	1–2	C	Secondary	Non-system oriented	Novice
Change analysis	No	No	1–4	B	Secondary	Non-system oriented	Novice
Root cause analysis	No	No	1–4	A	Secondary	Non-system oriented	Specialist
Fault tree analysis	No	Yes	1–2	D	Primary/Secondary	Deductive	Expert
Influence diagram	No	Yes	1–6	B/E	Secondary	Non-system oriented	Specialist
Event Tree analysis	No	Yes	1–3	D	Primary/Secondary	Inductive	Specialist
MORT	No	Yes	2–4	D/E	Secondary	Deductive	Expert
SCAT	No	No	1–4	A/E	Secondary	Non-system oriented	Specialist
STEP	Yes	No	1–6	B	Primary	Non-system oriented	Novice
MTO-analysis	Yes	Yes	1–4	B	Primary	Non-system oriented	Specialist/expert
AEB-method	No	Yes	1–3	B	Secondary	Morpho-logical	Specialist
TRIPOD	Yes	Yes	1–4	A	Primary	Non-system oriented	Specialist
Acci-Map	No	Yes	1–6	A/B/D/E	Primary	Deductive & inductive	Expert

Beta illustrates graphically a target (e.g., worker), a hazard (e.g., hot pipework) and the event (e.g., worker gets burned) in addition to the failed or missing defences caused by active failures, preconditions and latent failures (BRF) ("event trios").

Several of the methods focus on safety barriers. First of all, the only purpose of barrier analysis is analysis of safety barriers. The results from the barrier analysis may also be included in the Events and Causal Factor Analysis as causal factors. The fault tree analysis is suitable for analysis of failures of barriers, while the Event tree analysis may be used to analyse the effect of failure or success of different safety barriers. Failure or loss of safety barriers may be illustrated directly in an influence diagram. In a STEP-analysis, missing, or failures of barriers may be illustrated as safety problems and investigated further in separate analyses. Analyses of barriers are separate parts of both MTO-analysis and the AEB-method. Both failed and functioning barriers are illustrated in the schemes. TRIPOD Beta used the term defence, and identification and analysis of missing defences is a vital part of the tool. An assessment of whether barriers are less than adequate (LTA) is also a part of MORT. Acci-Map does not focus directly on safety barriers, but indirectly through the effects of decisions made by decision-makers at all levels of the socio-technical system.

Concerning the scope of the methods, it seems as the scope of most of the methods is limited to Level 1 (the work and technological system) to Level 4 (the company level) of the socio-technical system involved in the control of safety (or hazardous processes). Although STEP was originally developed to cover Level 1–4, experience from SINTEF's accident investigations show that the method also may be used to analyse events influenced by the regulators and the Government. In addition to STEP, only influence diagram and Acci-Map put focus on Level 5 and 6. This means that investigators focusing on the Government and the regulators in their accident investigation to a great extend need to base their analysis on experience and practical judgement, more than on results from formal analytical methods.

The investigation methods are influenced by different accident models. Both the Root cause analysis, SCAT and TRIPOD are based on causal-sequence models. Events and causal charting and analysis, change analysis, STEP, MTO-analysis, and the AEB-method are all based on process models. The barrier analysis is based on the energy model, while fault tree analysis, Event tree analysis and MORT are based on logical tree models. MORT and SCAT are also based on SHE-management models. The influence diagram is based on a combination of a process model and a SHE-management model, while the Acci-map is based on a combination of a causal-sequence model, a process model, a logical tree model, and a SHE-management model.

There is also made an assessment whether the methods are a primary method or a secondary method. Primary methods are stand-alone techniques, while secondary methods provide special input as supplement to other methods. Events and Causal Factors Charting and Analysis, STEP, MTO-analysis, TRIPOD and Acci-map are all primary methods. The fault tree analysis and Event tree analysis might be both primary and secondary methods. The other methods are secondary methods that might give valuable input to the other investigation methods.

The different methods may have a deductive, inductive, morphological, or non-system oriented approach. Fault tree analysis and MORT are deductive methods while event three analysis is an inductive method. Acci-map might be both inductive and deductive. The AEB-method is characterised as morphological, while the other methods are non-system oriented.

The last characteristic assessed, is the need of education and training in order to use the methods. The terms "Expert", "Specialist" and "Novice" are used in the table. Fault tree analysis, MORT and Acci-map enter into the "expert"-category. ECFC, barrier analysis, change analysis and STEP enter into the category "novice". "Specialist" is somewhere between "expert" and "novice", and Events and Causal Factors Analysis, Root cause analysis, Event tree analysis, SCAT, MTO-analysis, AEB-method and TRIPOD enter into this category.

5. Conclusion

Seen from a safety scientist's view, the aim of accident investigations should be to identify the event sequences and all (causal) factors influencing the accident scenario in order to be able to suggest risk reducing measures suitable for prevention of future accidents. Experience from accidents shows that major accidents almost never result from one single cause, but most accidents involve multiple, interrelated, causal factors. All actors or decision-makers influencing the normal work process might also influence accident scenarios, either directly or indirectly. This complexity should be reflected in the accident investigation process, and there may be need for analytical techniques to support the investigators to structure information and focus on the most important features.

Several methods for accident investigation have been developed during the last decades. Each of the methods has different areas of application and qualities and deficiencies, such that a combination of methods ought to be used in a comprehensive investigation of a complex accident. A selection of methods is described in this paper and the methods are compared according to some characteristics. This comparison is summarised in Table 1.

Some of the methods may be used to visualise the accident sequence, and are useful during the investigation process because it provides an effective visual aid that summarises key information and provide a structured method for collecting, organising and integrating collected evidence to facilitate communication among the investigators. Graphical illustrations also help identifying information gaps.

Most of the examined methods include an analysis of safety barriers, but it seems that most of the methods are limited to focus on Level 1 (the work and technological system) to Level 4 (the company level) of the socio-technical system involved in the control of safety (or hazardous processes). This means that investigators focusing on the Government and the regulators in their accident investigation to a great extend need to base their analysis on experience and practical judgement, more than on results from formal analytical methods.

During the investigation process, different methods might be used in order to analyse arising problem areas. Among a multi-disciplinary investigation team, there should be at least one member having good knowledge about the different accident investigation methods, being able to choose the proper methods for analysing the different problems. Just like the technicians have to choose the right tool on order to repair a technical system, an accident investigator has to choose proper methods analysing different problem areas.

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