Selection of Incident Investigation Methods
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Summary
This paper identifies the requirements for an incident investigation process. The investigation process and its investigation methods must (1) provide a chronological and logical event sequence, (2) identify failed or ineffective barriers and (3) identify root causes that explain the failure of these barriers. Acceptance of the findings and organisational learning will be helped if the method is transparent, proportional to the incident type and allows participation. Finally, methods should be conceptually simple and understandable, comprehensive and should be recognized by the industry of interest.

A number of tools as described in public sources are described and rated against these requirements. The paper ends with a comparison of the available methods. It is concluded that Tripod Beta and a combination of ECFA+/3CA or MORT satisfy these requirements to the largest extent.

Keywords: Incident investigation; Incident investigation methods, ECFA+; Event sand Conditional Factors Analysis; Fault tree; Why tree; Barrier analysis; Change analysis; 3CA; Control Change Cause Analysis; SCAT; Systematic Cause Analysis Technique; MORT; Management and Oversight Tree; Tripod Beta; Apollo Root Cause Analysis

Investigation Method Requirements

Literature Study
The main tasks of an incident investigation process are defined by Frei et. al. (2003) in a paper that discussed the different tools that are available for investigation in relationship to the tasks. These tasks are the following:

Organising facts sequentially
This is necessary to structure the events and circumstantial facts and order them according to incident chronology and cause and effect relationships. This structure serves as a model for the incident under study.

Generate hypotheses
Hypothesis generation is necessary to explain uncertainties in the incident model and search for additional facts.

Identifying norms, novelties and deviations (NND)
The occurrence of an incident may signal the failure of control of a specific activity. This can be characterized as a deviation from a norm. The applicability of and the deviation from the norm must be verified and it must be shown that the adherence to the norm would have prevented the incident. On occasion, the event may be quite novel (i.e. a failure mode that has never been identified before). In this case, the novel problem must be characterised.

Analysis of Root Causes
Analysis helps to identify why events occurred, aimed at the management level of an organisation. This is different from the direct causes that immediately preceded the event.

A toolbox for incident investigation should be built so that the complete range of tasks is covered. Several tools may cover more than one task, however. In addition, the toolbox should
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contain tools that complement each other: several methods for one task may be specifically
designed for collaboration with another tool.

A research project in order to identify and explore the relative merits of alternative accident
models and investigation concepts and methods was carried by Ludwig Benner (Benner, 1985)
for the US Government (OSHA). For this report, the most relevant aspect is the identification of
criteria for accident investigation methodologies. The criteria identified in his study can be
summarized as follows:

1. Methodologies should encourage parties to participate in investigations and have their views
   heard
2. The methodology should produce blameless output, including the role of management,
supervisors and employees
3. The methodology should support personal initiatives for positive descriptions of accidents
4. It should allow timely discovery of safety and health problems
5. It should increase competence of employees through training in the detection, diagnosis,
   control and amelioration of risks.
6. It should provide definitive corrections so that countermeasures can be defined, evaluated
   and selected, avoiding personal opinions
7. It should show expectations and behavioural norms that can be enforced
8. It should encourage parties to take their responsibility by providing them with consistent,
   reliable accident reports
9. It should be accurate: the accident must be described in a way that it can be “truth-tested”
   for completeness, validity, logic and relevance
10. It should be Closed-Loop so that results can be linked routinely to design improvements,
    including (pre-incident) safety analyses.

The highest ranked methodologies as identified by Benner reflected applications of risk-oriented
events-process energy-flow accident models with links to work flow design and management
systems. Examples of these methodologies are MORT (Management Oversight and Risk Tree)
and events analysis. Methods as “statistical data gathering” and “completing forms” scored very
low. “Personal/good judgement” scored average on these criteria.

Investigation Qualities were defined by Kingston (2004) as follows:

- Transparency of
  o Approach (what is investigated and how)
  o Causal factors identified
  o Causal factors analysed
  o Evidence, and how it resulted in findings and recommendations
- Proportionality
  o Investigative effort scaled to occurrence (of incidents)
  o Scaling by actual loss, risk and uncertainty
- Accountable, verifiable and open to continuous improvement

Discussion

The requirements for incident investigation that are identified in the previous section refer to the
tasks of an investigation (Frei) and to requirements with respect to the quality of the investigation
process (Benner and Kingston). However, with respect to Frei’s list, we do not regard
“Hypothesis Generation” as a core task, since it is only applicable in cases where relevant
uncertainties are present about the course of events or the causes of these.

For a practical appreciation of the complete investigation process, the criteria of Benner can be
grouped into the following three sets: The methodologies should:

- Encourage participation and learning for all parties involved (1,2,3,5 – refer to Benner’s
criteria above))
- Give clear and practical recommendations (4,6,7,10)
- Provide accurate and consistent reports (8,9)
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Only the first criterion applies to the selection of a specific set of tools for incident investigation. The second and third criteria relate more to the investigation process as a whole. The “accountable, verifiable and open to continuous improvement” criterion of Kingston is very closely related to the “transparency” requirement, and in our view essentially identical for the choice of any method.

The requirements for (a set of) investigation tools can thus be summarized in the following lists. As core tasks, the investigation toolbox should:

- Provide a *chronological and logical event sequence* (What happened?)
- Identify ineffective *barriers* (equivalent to norms, novelties and deviations) (How did it happen?)
- Identify *root causes* (Why did it happen?)

These are essential requirements of any investigation. The following requirements deal with the utilization and acceptance of the method and its results. These are not mandatory, but help to obtain a valid investigation:

- *Transparency* is required for acceptance of the method and the results of the investigation
- *Proportionality* is helpful: it allows that the same method can be used for “small” and “large” investigations
- *Participation* of the personnel creates involvement of the organisation and opportunities for individual and organisational learning

However, in our opinion the following criteria have to be added to the lists above, although they are again not mandatory:

- The tools should be preferably conceptually simple and *easy to understand*; the complexity of a tool should not be a barrier for using it. However, this is only applicable for methods used for concise and simple investigations. Complex accidents require thorough investigations and possible complex methods.
- The toolbox should be *comprehensive*: it should provide a reasonable degree of completeness and reproducibility
- The tool should be preferably have some degree of *recognition* in the company or industrial sector of interest

These criteria will be used to select the methods that will be described in the following sections.

**Investigation Methods Description**

**ECFA+ (Events and Conditional Factors Analysis)**

The Events and Conditional Factors Analysis method (ECFA+) was developed by the Noordwijk Risk Initiative (2007) and produces a sequential description of an incident, which accounts for a logical relationship from the facts presented. Facts are based on witness narratives and other evidence. Events and conditions are worded according to simple but strict grammatical rules to oblige the team of investigators to rigorous thinking. The events, conditions and unknowns are written on pre-printed and coloured Post-It notes and put on a wall. The notes are connected to represent causal relationships. A simplified ECFA+ chart looks like this (figures copied from NRI, 2007):
Example of an ECFA+ Chart (Noordwijk Risk Initiative, 2007)
The building blocks are written on the following notes:

Post-It notes used in ECFA+ (Noordwijk Risk Initiative, 2007)

The ECFA+ chart shows the sequence of events and the actors as it can be reconstructed by the available knowledge. Uncertainties (events, conditions or relations) are identified and can be further investigated or left as such. Resolution of these may require the formulation and testing of hypotheses.

Constructing the ECFA+ chart is a group exercise. No special training, other than an explanation about the method is needed for the participants. The necessary tools are limited to a meeting room with a "long white wall" and a pack of pre-printed Post-It notes. The ECFA+ method is available in the public domain.

Once the event sequence of the incident is established, an analysis with other tools is usually necessary to identify the critical events, causes and formulate recommendations.

ECFA+ has been applied for the Enschedé fireworks disaster in The Netherlands in 2002, especially for the reconstruction of the operations of the fire brigades. It is also in use at the UK Health & Safety Executive and the Dutch fire brigade organisation.

**Brainstorm Methods**

Brainstorming methods include HAZOP and “What-If” studies, which are very well established in the chemical industry. HAZOP (Hazard and Operability) studies rely on guidewords that focus the discussion, such as “High Pressure”, “Low Level”, etc. If these guidewords prompt for a credible scenario, potential causes, consequences and (available or assumed) safeguards are identified.

“What-If” studies involves the team asking questions about failures of equipment, people etc, such as “What if the procedure was wrong? What if the steps were performed out of order?” (CCPS, 2003). These questions can be generic or highly specific in nature.

**Fault and Event Trees**

The construction of fault trees and event trees can help to formulate hypotheses. A fault tree (CCPS, 2003) start at the top event (e.g. the incident) and works its way down to the potential causes using logical AND and OR gates. It helps to structure the facts and to identify any events that are supposedly necessary to produce the top event. By working down from the top events and including known facts, the influence of preliminary conclusions about bottom causes is reduced. If a fault tree is carefully constructed and hypothetical issues are identified as such, it could be used to establish the event sequence and identify barriers for simple analyses.
An event tree (CCPS, 2003) is an inductive technique that helps in understanding the potential outcomes of combinations of events. Each event, such as equipment failure, process deviation, control function, or administrative control, is considered in turn by asking a simple yes/no question. The tree branches then in a number of parallel paths until all combinations are exhausted. Paths that lead to the observed consequence can then be further inquired for validity.

Examples of fault and event trees are shown below:

**Example of fault and event trees (CCPS, 2000)**

**Why Three and Causal Tree Methods**

The Why Tree and Causal Tree methods (CCPS, 2003) are variants of the fault tree method. In the Why Tree, all direct losses and associated consequences are entered into separate boxes. These are then challenged by asking “why?”, and the answers entered in new boxes and again challenged by asking the “why” question. The process stops when management system factors are identified that could have prevented the incident. Recommendations are then developed. According to the “Baker Report” (Baker 2005), this method (the “Five Why”) “can lead to a very narrow and superficial incident analysis and may not identify the best corrective actions—especially if the investigation team is not properly trained.”

In the Causal Tree method, the adverse events are explained in a multidisciplinary group session by asking the following three questions at each level of the constructed tree:

1. What was the cause of this result?
2. What was directly necessary to cause the end result?
3. Are these factors (from question 2) sufficient to have caused this result?

The team is generally required to identify three root cause factors for the last question, an organisational, human and material factor. This reflects the notion that most incidents have multiple root causes.

**Barrier Analysis**

Barrier Analysis identifies which safety or control functions have failed and allowed the incident sequence to occur. It is based on the notion that the “Barrier” stands between the “Energy” (any harmful agent) and the “Target” (anything that should be protected from the Energy). Barriers may be physical (safety valve, blast wall), temporal or spatial. These barriers, sometimes requiring acts can have an administrative or cognitive component (procedures, standards, supervision, knowledge, experience). These components (e.g. procedures) are not barriers itself, only a good procedure (i.e. aimed at prescribing a barrier) that is properly applied in the situation it is intended for.
In a Barrier Analysis (NRI, 2009; described in the MORT manual), for each significant episode in the incident sequence, the Energy Flow and the Target are identified and precisely described. The Barriers that should be in place are then identified, and verified whether they were available.

**Change Analysis**

Change Analysis (Johnson, 2003) is used to determine whether abnormal operating practices contributed to the causes of an adverse occurrence. Change Analysis helps to identify the differences between what was expected to occur and what actually occurred in performing the following steps:

1. Define the problem
2. Establish what should have happened
3. Identify, locate and describe the change
4. Specify what was and what was not affected
5. Identify the distinctive features of the change
6. List the possible causes
7. Specify the most likely causes

Practical difficulties of this method arise, however, when it is difficult to establish what should have happened, or if change is a normal aspect (e.g. in start-up/shutdown and batch operations). However, the method is claimed to be useful in case of vague, difficult to describe and to understand failures.

**3CA (Control Change Cause Analysis)**

3CA (Control Change Cause Analysis) is a combination of barrier analysis, change analysis and root cause analysis. On basis of the ECFA+ chart, the “risk-increasing” events are selected and further analyzed, and possible missing or ineffective barriers identified. The upstream reasons for these ineffective or missing barriers are then further elaborated. For each event, it the following is determined in a tabular form (NRI 2002a):

1. Change to a person or thing (e.g. the officer walks from verge towards Car 2)
2. Agent of change (what exactly is changing: the officer walks)
3. Adverse effect of change (officer in path of oncoming traffic)
4. Work controls (barriers) implied in (1) and (2) (e.g. segregation from people and traffic)
5. Significance rating for subsequent analysis
6. Describe in what way each measure in (4) was ineffective
7. What upstream processes failed to identify or prevent the problems noted in (6) (e.g. insufficient training)
8. “Why?” (with respect to all entries in column 7)

3CA identifies thus the failed barriers (steps 0 – 6) and the reasons for this (7 – 8). The “Why” question identifies Root Causes. The 3CA method is freely available from NRI (2002). It has been developed by the Noordwijk Risk Initiative as a Root Cause Analysis method for the Humber Chemical Focus, an UK industrial association.

**SCAT (Systematic Cause Analysis Technique)**

SCAT (Systematic Cause Analysis Technique) is a commercial and proprietary, checklist-based tool for incident investigation. It is primarily aimed at occupational injury cases, and can thus not directly be used for other incident types. Event types are linked to a number of immediate causes, then to basic causes and then to corrective action areas, all of which are pre-defined. It has thus some built-in “intelligence”. This should make the use of (E-)SCAT fairly straightforward and easy.

The validity of SCAT is difficult to judge, not the least because there is no public scientific reference available. We believe that the use of predefined trees invites people to do very superficial investigations: the tool, and not the investigator, determines the depth and the quality of the investigation. The investigation can be done on pre-printed forms or with the aid a computer program (eSCAT®, via www.dnvtraining.com).
**MORT (Management Oversight and Risk Tree)**

The MORT (Management Oversight and Risk Tree) is a pre-defined logical diagram which ‘asks’ the investigator all kinds of relevant questions about the losses that constitute the top event, that are key events, as identified in other phases of the investigation of the incident. MORT is designed to use in concert with a preceding Barrier Analysis (NRI, 2009). Key episodes are for example:

- A vulnerable target exposed to......
- An agent of harm in the....
- Absence of adequate barriers

MORT is based on the hypothesis that either a loss is the outcome of a problem in the organisation, or it is the outcome of an accepted risk. The first step in a MORT analysis consists of understanding the energy flow and which barriers have failed, and to find whether the loss is caused by “Oversights and Omissions”. The next decision point separates what happened from why it happened. The “what happened” branch addresses the barriers/controls that should be in place, while the “why” considers general management factors. Eventually the tree breaks down to each of these factors until root causes are reached, which can take up to 13 levels of the tree and some 1500 different root causes.

If no “Oversights and Omissions are found, the risk is an “Assumed Risk” that must explicitly be identified, analyzed and accepted by the management. A simplified part of a MORT chart is shown below (CCPS, 2000):

![Simplified MORT chart](image)

**Simplified MORT chart (“LTA” is Less Than Adequate)**

In practice, the MORT chart is traversed for every key episode by noting problems, satisfactory issues and issues where more information is needed. MORT charts are printed on A0/A1 size. The chart and the manual are freely available from NRI (2009). The MORT chart should not be regarded as a checklist. It is rather a functional organisation model that is reviewed in order to identify areas of concern.

Because of its complexity and need of training and experience for the practitioner, a MORT analysis is only warranted for profound investigations of complex incidents. However, a simpler Mini-MORT variation has been developed by the U.S. Department of Energy (1992), with about 50 root causes.
**Tripod Beta**

The Tripod Beta analysis method can be regarded as a synthesis of a number of the methods described above, especially fault tree and barrier analysis. Tripod Beta adds a human failure model to this. Barriers fail due to (generally) human substandard acts (called immediate causes). These acts are made more probable by an adverse context or precondition. The precondition explains the person’s mindset and is described as the physical, psychological or organisational context. An individual’s “proneness” to substandard acts cannot be influenced, but his context or precondition can, by the organisation. Tripod Beta looks for Underlying Causes at management level that shape the adverse preconditions involved in the accident.

Tripod Beta has been developed by Shell and the universities of Leiden and Manchester (Groeneweg, 2002) and is used in a large number of industries.

The incident is modelled with Agent-Event-Object trios. An unwanted event occurs when an Agent of Change (something able to do change or harm, e.g. energy, toxic, budget cuts) acts on an object (something being changed or harmed, e.g. person, equipment, reputation). Agents, events and objects can be conceptual things. Events can be transformed in Hazards or Targets for the next trio. Existing barriers or barriers that should reasonably be expected to be present are placed in the trios.

**Hypothetical Tripod Beta Core Diagram**

Next, the causal path for each failed or missing barrier is determined:

**Causal Path of Failed or Missing Barriers to Underlying Causes**

Incident investigation with the Tripod Beta method is supported by software marketed by TripodSolutions (www.tripodsolutions.com).
**Apollo Root Cause Analysis**

Apollo Root Cause Analysis ([www.apollorca.com](http://www.apollorca.com)) is a logical problem solving technique that relies on building a fault tree of the incident, and trying to arrive at the root causes by repeatedly asking the “why” question. We could not find any independent references about this method, and the Apollo website and the demo version of the software (RealityCharting) gives little information. However, Apollo RCA is used for incident investigation and problem solving in general in several large US firms. According to one company, the method is very easy to learn and is used in all layers of the organisation (including the work floor) to investigate simple and complicated incidents. It is experienced as very useful and its mass application provides many learning opportunities for the organisation.

**Other Commercial Packages**

A number of other integrated commercial packages are on the market, such as TapRoot ([www.TapRoot.com](http://www.TapRoot.com)) and REASON ([www.rootcause.com](http://www.rootcause.com)). These tools are essentially combinations of the tools already discussed. They are all software-based and claim to have some degree of in-built intelligence. From a glance at the demo versions of the software, the tools are similar in the way that they first help to construct an ECF chart, then look for critical events and related causes, do (some) logic checking or provide suggestions for immediate and root causes and generate a report.

**Discussion**

The various tools that were discussed (except Apollo, TapRoot and REASON, due to lack of information) are compared according to the requirements discussed in the first section of this paper. This comparison is qualitative and based on the author’s appreciation of the method’s principles and face validity. Therefore, this comparison is open to discussion. The three shaded columns refer to the core tasks of incident; the other columns deal more with the utilization and the acceptance of the methods and their results.

**Comparison of Investigation Tools**

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<tr>
<th>Tool</th>
<th>“What” Event Sequence</th>
<th>“How” Barriers Identification</th>
<th>“Why” Root Causes</th>
<th>Transparency</th>
<th>Proportional or Scalable</th>
<th>Participation</th>
<th>Easy to Learn and Apply</th>
<th>Comprehensive Recognition (within industry)</th>
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+ Method complies with requirement
- Method does not comply
o Method complies to some extent
Depends on circumstances or application

Tripod Beta and ECFA+ in combination with 3CA (or MORT) both offer a comprehensive toolkit for a thorough investigation of incidents. Of these, Tripod Beta is firmly based on a validated human error model, while 3CA/MORT deal more with organisational structures. These methods are not simple, however, and require trained and experienced practitioners. They are generally used for investigation of high-risk incidents.

Some other methods (HAZOP, What-If, Fault and Event Tree) are primarily supporting tools for e.g. generation and testing of hypotheses.
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