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A PROCESS-ORIENTED EVALUATION OF NINE ACCIDENT INVESTIGATION METHODS

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ABSTRACT

A range of methods for accident investigation have been published. They focus on different aspects and provide support in various respects to the entire investigation process. Previous research has examined strengths and weaknesses of methods in analytical terms, but few or none so far have studied their capability to support the accident investigation process. During a number of training courses on advanced accident investigation methodology, held annually at Karlstad University since 2003, systematic tests of nine accident investigation methods were performed. The methods' process supporting properties were qualitatively evaluated against a general model of the investigation process. The results show that none of the methods provide strong support for all steps of the investigation process. A few methods, including STEP and Deviation analysis, however, provide a relatively strong support for certain key elements of the process. Most methods are supportive to the analysis phase, but less supportive to the planning and concluding phases. This in turn implies that several methods should be termed accident analysis methods rather than accident investigation methods. The results also point to differences in analytical principles and output formats, which also affect their usefulness.

Keywords: Accident investigation, method evaluation, investigation process.

1. INTRODUCTION

Accident investigations play a central role in efficient safety management and serve as a fundamental basis for learning from accidents and safety improvement (Kjellén, 2000; Rasmussen and Svedung, 2007; Stoop, 2004). An accident investigation can be performed in several ways, within different contexts and according to various procedures.

Several studies indicate that authorities and companies rarely use established accident investigations methods (Henderson et al., 2001; Roed-Larsen et al., 2004). However, in recent years interest in methods has increased considerably, at least in Sweden. A general impression is also that when a certain method is applied, the choice of method is made unreflected and without argumentation. The lack of consciously chosen methods may in turn negatively affect the accident investigation work and lessons learned from accidents (Benner, 1975; Frei et al., 2003; Zotov, 2000). Hence, this paper is based on the assumption that the use of systematized investigation methods will enhance quality and efficiency by supporting the investigative process, including its analytical parts.

Almost 100 accident investigation methods are described in the literature (Strömgren, 2010; Swedish Civil Contingencies Agency, 2009). Some are evaluated in earlier comparative studies (Björklund et al., 2007; Energy Institute, 2008; Fahlbruch and Wilpert, 1997; Hollnagel and Speziali, 2008; Kontogiannis et al., 2000; Livingston et al., 2001; Morrison, 2004; Nivolianitou et al., 2004; Sklet, 2004; Wagenaar and van der Schrier, 1997; Ziedelis and Noel, 2011). These are mainly literature studies, covering aspects such as procedures, types of result, underlying theoretical frameworks, advantages/disadvantages, analytical approaches, identification of causes, check lists, event sequencing/timeline, barriers, societal levels of analysis, problem solving, and training needs.

Besides analytical aspects, investigation methods are also often expected to support the practical application; that is, to plan, carry out and conclude an investigation. To our knowledge, no studies so far have evaluated the process supporting properties of accident investigation methods, neither theoretically nor empirically. Therefore, this article aims to evaluate and categorize nine established accident investigation methods empirically with regard to their ability to support a generic investigation process. The overall purpose is to contribute to a more systematic and conscious choice of methods among accident investigation practitioners.

2. ANALYTICAL FRAMEWORK – A PROCESS MODEL

There are several models for describing accident investigations. These models have many features in common and many of them are process-oriented (DOE, 1999; ESReDA, 2009; Lundberg et al., 2009). In order to characterize methods more in detail, an elaborated process model have been developed, see figure 1. The analysis phase is here divided into three closely connected but functionally separate sub-steps. Another important phase relates to the evaluation of relevant findings, which is often overlooked in other descriptions of the investigation process.

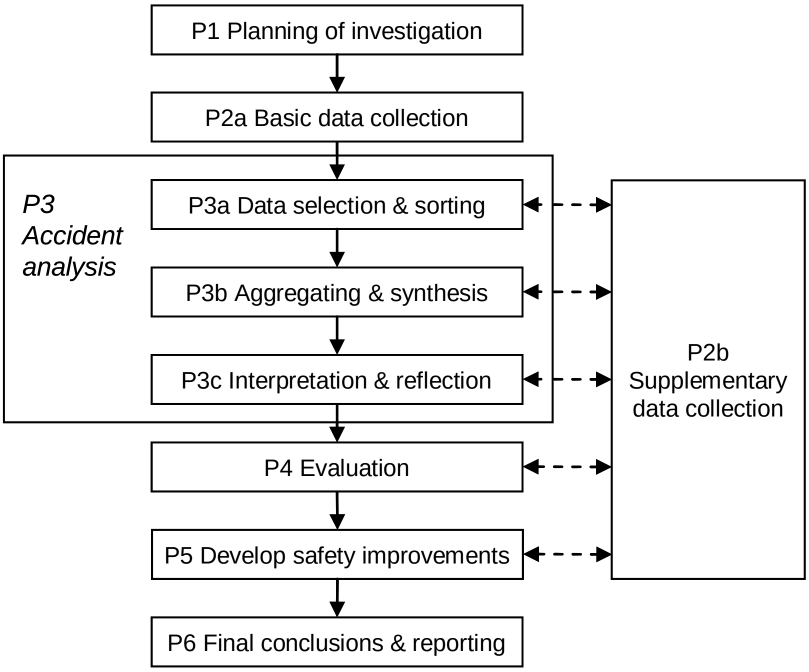

Figure 1. A generic model of the accident investigation process.

3. METHODS SUBJECTED TO EVALUATION

Training courses on advanced accident investigation methodology have been held annually at Karlstad University since 2003. They have involved theoretical studies and hands-on exercises, combined with considerations of the practical use of the methods. More than 15 methods have been presented in the training courses.

One criterion for the choice of methods in the course was that they should be established and published. Another basis was that the methods shall represent different accident models and approaches to accident analysis and prevention.

In this study, nine of these methods were selected for a deeper analysis. The basic for this was that they had been taught and trained systematically in the courses and were internationally published. Table 1 provides a short account of the nine selected methods. In the courses, Swedish references (manuals) have been used when available, but in Table 1 international references have been used when suitable.

Table 1: Descriptions of the methods subjected to evaluation, including basic references.

Investigation method	**Short description**	**Reference**
AcciMap	The accident is analyzed with reference to different hierarchical levels of society. Identification and analysis of socio-technical context, decision and information flows between different actors.	Rasmussen and Svedung, 2007; Svedung and Rasmussen, 2002
AEB (Accident Evolution and Barrier Function Method)	The method highlights the interaction between the human and the technical sub-systems, as well as barrier functions involved. Technical and human failures are modeled.	Svenson, 1991, 2000, 2001
Deviation Analysis	The method identifies and assesses deviations that occurred before, during and after the accident, and help prioritizing proposals for correction.	Harms-Ringdahl, 2001; Kjellén and Larsson, 1981
DREAM (Driving Reliability and Error Analysis Method)	DREAM is adapted for road traffic accidents and includes analysis of cognitive and perceptual processes, as well as the interaction between human actions and technological systems. DREAM is based on a method called CREAM (Cognitive Reliability and Error Analysis Method).	Ljung et al., 2004; Wallén Warner et al., 2008
Fault tree analysis	Safety problems are analyzed based on logical combinations of necessary or alternative/possible causes.	Harms-Ringdahl, 2001; Henley and Kumamoto, 1981
MTO event investigation	The method investigates sub-events sequentially, and analyses the direct and underlying causes and safety barriers. Organizational factors are also considered.	Rollenhagen, 2003, 2011. A short description in English is available in Sklet, 2002.
SCAT (Systemic Cause Analysis Technique)	Based on questionnaires, accidents causes are identified and related to shortcomings in the work environment, performance factors and management systems.	Bird and Germain, 1985
SFA (Safety Function Analysis)	Analysis of various forms of technical, organizational and administrative systems (safety functions), aimed to control and reduce risks.	Harms-Ringdahl, 2001, 2009
STEP (Sequential Timed Events Plotting)	Analysis of the accident sequence by the identification of actors and sub-events in time order, plus their interactions as well as safety problems.	Hendrick and Benner, 1987

4. DATA COLLECTION AND ANALYSIS

4.1 Tests done during the courses

This study is based on data collected from participants in eight courses in advanced accident investigation methodology at Karlstad University in Sweden held in years 2003 to 2010. The course participants, in total 172 persons, represented practitioners such as accident investigators, safety managers, and consultants, as well as researchers from a broad range of fields, such as occupational health and safety, fire and rescue services, energy production, health care, road traffic, railway, aviation, shipping, process industry, and military defense.

Each selected accident investigation method was theoretically explained and exemplified in the training situation. Teaching principles, literature and teachers were kept fairly unchanged between the courses and methods.

Groups of 4-6 participants tested three or four methods, each applied to one and the same accident (unique for each group) selected by the group members in dialogue with the course leaders. This makes a total of 114 method tests from 36 group sessions applied to 36 different accidents. The accidents covered a variety of events ranging from minor incidents to severe accidents with fatalities. All events have occurred in real life in Sweden during the last decade. Table 2 shows the distribution of tests by methods and types of events/industries.

Table 2: The number of tests and their distribution by methods and types of events/industries.

Events/industries

Method	**Aviation**	**Ski lift**	**Chemical**	**Electrical**	**Fire in building**	**Maritime**	**Medical**	**Military**	**Occupational**	**Railway**	**Road traffic**	**Total (number of fests)**
AcciMap	1	1	2	1	4	2	2	1	2	3	2	**21**
AEB	1		1			1			1	1		**5**
DREAM (CREAM)					1		1			4	2	**8**
Deviation Analysis		1	4	1	3	1	2	1		1	3	**17**
Fault Tree Analysis					1	1						**2**
MTO event investigation	2	1	5	2	1	2	3		4	2	3	**25**
SCAT	1		1	1		1	1		3		1	**9**
SFA	1		3				1		2	2	2	**11**
STEP			3	2	3	2		1		2	3	**16**
Total (number of tests)	**6**	**3**	**19**	**7**	**13**	**10**	**10**	**3**	**12**	**15**	**16**	**114**

The group tests were limited to the analysis phase of the investigation process (P3 in figure 1), and related to the accident sequence, causes, contributing factors and other circumstances of relevance for suggestions on safety improvements. Issues like data collection and report writing were excluded from the formal tests, but were discussed with teachers and other groups. The groups informed themselves about their selected events from various sources, such as documentation, photos, existing investigation reports, plus verbally from one informant in each group representing in-depth knowledge on the selected case. Usually they worked with each method for 2-3 hours. The groups were supervised by the course leaders during the tests. Each group made an independent evaluation of each method after each test. All test results were documented by means of the same questionnaire and jointly discussed in seminars with the course leaders. In addition to these group tests, the methods' implications on the overall investigation process, as well as additional features such as training needs and inter-investigator reliability, were discussed and evaluated jointly by the course participants and the three course leaders.

4.2 Parameters in evaluation

Our approach is qualitative rather than quantitative. A number of parameters for the evaluation have been used, which are connected to the phases in the model of the investigation process (figure 1). For these parameters, a set of scales was developed. The course leaders have developed these scales themselves.

Phase 1

The planning phase (P1) is independent from the specific methods since this phase could include the choice of investigation method. Therefore, the evaluation here refers to the method manuals and considers in which way these manuals gives support.

A. Step-by-step, or
B. Iterative/creative, or
C. Framework-oriented (free usage)

Phase 2-6

In these phases (P2-P6) the principle is to evaluate to what extent the methods provide support and guidance for the work in each phase.

Table 3: Scales for assessment of accident investigation methods regarding their supportiveness to the analysis part of the investigation process (phase 2-6 in figure 1).

Support in method	**Description / comments**
0. No support	The phase is not mentioned or regarded.
1. Some support	The phase is mentioned and generally discussed.
2. Advice	The phase is described and contains instructions and/or categorizations.
3. Extensive advice	The phase is a distinct activity in the method and is clearly described.

Training needs

Training needs is a parameter intended to indicate the difficulty of the methods in terms of training needed to gain knowledge and experience enough to apply the methods on real accident situations.

Assessment scale from 1-5:

1. No training needed, just a short introduction and a simple instruction.
2. Practical training needed for a few hours.
3. Education and training needed for some days.
4. Comprehension and skills corresponding to some weeks of training and practice is needed.
5. Expert-knowledge with extensive experience needed.

Reliability

This parameter intends to estimate how much the result of the method is dependent or independent of the investigator. Differences and similarities between the methods as well as outputs were discussed group-wise in conjunction with the method testing. Based on that, the inter-investigator reliability was assessed in joint classroom sessions, presuming experienced investigators, identical data sets, and identical aims and scopes of the investigations. This scale applied here is tentative.

1. Varies greatly
2. Varies somewhat
3. Quite independent
4. Reproducible
5. Highly reproducible (highly specified and structured form)

Output format

This parameter identifies some common types of output format. The output format differs between the selected methods and can take many forms and shapes. Often, the visual output is a strong “trademark” of the specific method and a basis for further conclusion, reporting and communication of results.

A. Graphic representation
    A1. Accident evolution process (sequence)
    A2. Tree-format
    A3. Web connecting elements

B. Table (≥ two parameters)
C. List
D. Free text
E. Other

4.3 Evaluation process

To summarize, the evaluation process consisted of:

1. Group tests of the analysis phase alone.
2. Assessment of the methods' feasibility for the entire investigation process, based on:
   a. Group test results and seminar discussions with course leaders.
   b. The course leaders own assessments based on educational and practical experience.
3. The course leaders have made both individual and joint assessments from the course results.

5. RESULTS

5.1 General characteristics of the methods

Table 4 summarizes the main results from our evaluations. The higher score (0-3), the better support to investigation work in specific phases. The classification A-C refers to type of procedure (A = step-by-step, B = iterative/creative, C = Framework-oriented (free usage). Numbers in brackets are alternative values when the assessments are uncertain.

The table shows variation among methods regarding their ability to support the investigation process in different respects. No single method gives strong support to the entire process. The table shows that Deviation Analysis and STEP score highly in supporting a number of phases in the process model.

Most methods show their main strengths in the accident analysis phases (P3a-P3c). All methods gives Advice or Extensive advice (grade 2 or 3) in phase P3b (Aggregation & synthesis). Even P3a (Data selection & sorting) were generally well supported by the methods. The phase P3c (Interpretation & reflection), however, were found less well supported by most methods.

Several methods had low scores for most criteria. This indicates that they provide poor support to the entire investigation process. However, this does not necessary mean that these methods are meaningless in accident investigation. The support to the different phases will indeed vary among the methods.

Table 4: Summary of results from a process evaluation of accident investigation methods. Scores varies between 0-3 (0 = No support, 1 = Some support, 2 = Advice, 3 = Extensive advice) and classification from A to C (A = Step-by-step, B = Iterative/creative, C = Framework-oriented (free usage)).

Criteria	**AcciMap**	**AEB**	**Deviation Analysis**	**DREAM (CREAM)**	**Fault Tree Analysis**	**MTO event investigation**	**SCAT**	**SFA**	**STEP**
P1 Planning of investigation	C	A	A	A	B	B	A	A	A
P2a Basic data collection	1	0	1 (2)	1	0	0	2	1	3
P2b Supplementary data collection	1	0	2	1	0	1	0	1	2
P3a Data selection & sorting	1 (2)	2 (3)	3	3	1	1 (2)	2	3	3
P3b Aggregating & synthesis	2 (1)	2	2	3	2	2	2	2	3
P3c Interpretation & reflection	1	1	1	0	2	0	0	0	3 (2)

P4 Evaluation	0	1	3	0	1	0 (1)	0	3	1
P5 Develop safety improvements	0	2 (3)	3	0	0	1	1	2 (3)	2
P6 Final conclusions & reporting	1	1	1	1	0	1	0 (1)	1 (2)	2 (1)

Numbers in brackets are alternative values.

5.2 Comments to the methods

With reference to table 4, the results are further commented below, method by method. *Manuals* in the text below correspond mainly to the method references listed in Table 1.

The **AcciMap** manual provides a very loose framework for the investigation process. The manual gives some guidance on types of data needed, but not on how to collect them (P2a). The method gives quite strong support to P3b and c, by focusing on interactions of actors, decisions and information. During the analysis, questions often arise forming the basis for supplementary data collection (P2b). The method does not include support for prioritizing or judging safety issues (P4 and P5) but provide some comments on these matters. The method gives weak support for P6, and additional explanations and descriptions are often needed to reach a comprehensive understanding of the accident. AcciMap is often seen as a secondary or complementary method to other methods or investigation approaches. However, the method provides an overall view of the accident process.

AEB has a well-structured manual with clear step-by-step guidance. The method, however, is most supportive in the latter part of the investigative process. Data collection (P2a and b) is not touched upon at all, but instead the method gives detailed support to the analysis phases (P3a-c). The method also provides some support for the evaluation and prioritization of safety problems (P4). AEB gives support for the development of safety improvements (P5). However, this phase is often overlooked and the application of AEB in this phase (P5) appears to be limited. The method gives weak support for P6, and provides a limited picture of accident sequence.

Deviation Analysis has a clear manual, providing step-by-step guidance for the greater part of the investigative process. While the method provides limited support for the initial data collection (P2a), it gives fairly strong support for supplementary data collection (P2b), if group interviews are used. Deviation Analysis gives good guidance for the analysis phases (P3a-c). In particular, P3a is well supported by clear structure and guidance for the sorting of data and analysis parameters. Deviation Analysis is one of the few methods that provide strong support and guidance for the evaluation of safety problems (P4) and the development of safety improvements (P5). The method provides only weak support for P6. The method gives no picture of the accident sequence.

DREAM is a customized method for road accidents. The method has a manual that provides detailed guidance step by step. However DREAM gives very limited support for other phases than the analysis phases (P3a-b). For phases P3a and P3b the method gives rigorous support for data sorting and synthesis. For data collection (P2a-b) the method gives some indirect support by clarifying data categories needed in the analysis phases. The method provides no support for P3c-P5, only week support for P6 and gives no picture of the accident sequence.

FTA is a strict method for risk analysis, and often manuals provide clear step-by-step assistance. The method provides no support for data collection (P2a-b) but it gives a good support for the analysis phases, primarily P3b and c. Here FTA gives a logical picture of the relationships between sub-causes. Some manuals (e.g. Harms-Ringdahl, 2001; Henley and Kumamoto, 1981) also include elements of quality control, which provide clear support in P3c. The method provides some support for P4 by identifying weaknesses in the logical gates and causal links. FTA gives virtually no support for P5 and P6 but logical gates and the causal links analyzed in P3a-c can be valuable. The method gives a picture of the accident evolution.

MTO exists in several versions. Manuals give generic guidance rather than a detailed step by step support. The method provides no support for P2a but relates in part to P2b by raising many why-questions. MTO provides support for the analysis phases P3a-b, but no support for interpretation and reflection (P3c). The method provides no significant support for P4. For P5 and P6 limited support is given. The barrier analysis (a stage in the method) can be a basis for P5. The method provides a detailed picture of the accident sequence.

SCAT's manual is quite strict. The method provides support for the initial data collection (P2a) but no support for P2b. A categorization of causal factors gives good support for the analysis phases P3a-b but virtually no support for P3c. The method provides no support for P4. Weak support is given for P5 and P6. The method provides no significant picture of the accident sequence.

SFA is a flexible method with a clear step by step manual. The method gives weak support for data collection, P2a-b. SFA provides strong support for the analysis phase, the data sorting (P3a) and relatively good support for P3b but not for P3c. The method provides strong support for P4 and P5, but more limited support for P6. The method gives no picture of the accident sequence.

STEP is a comprehensive method, dealing with many parts of the investigative process. The manual gives clear step-by-step guidance. The method provides much guidance on data collection procedures (P2a-b) and gives clear support for the analysis modules (P3a-c) as well. STEP contains important elements for quality control in P3c. The method gives weak support for P4 but strong support for P5 and P6. In practical use however, the method's support for phases P2a-b, and P5 are not always utilized. The method provides a detailed picture of the accident sequence.

5.3 Additional features

Beside the investigation process related parameters, Table 5 shows some additional attributes potentially influencing the choice of methods. Numbers and classifications in brackets are alternative values. Training needs reflect the “threshold” to get started with the method and to feel comfortable with it. It is not a parameter for the time needed when performing an investigation. The methods AcciMap and Fault Tree Analysis score highly (scale 4) in training needs and many course participants experience these methods as quite difficult at first. Comprehension and skills corresponding to some weeks of training and practice are needed. The methods AEB, Deviation Anlysis, SCAT, SFA and STEP are found easy to learn. A few hours training is sufficient to start to use the methods for accident investigation.

Table 5: Additional attributes of potential importance for the choice of method.

Criteria	AcciMap	AEB	Deviation Analysis	DREAM (CREAM)	Fault Tree Analysis	MTO event investigation	SCAT	SFA	STEP
Training needs	4	2	2	3	4	3 (2)	2	2	2
Reliability	1	3	3 (2)	4	2 (3)	3 (2)	3 (2)	2 (3)	3 (2)
Output format	A3 (A1) C	A1 + C	B	A2	A2	A1 + A3	C (A2)	B (A3)	A1 + A3

The parameter reliability is partly dependent on the type of manual. Not surprisingly, “free” manuals seem to give more “freedom” to the investigator but influence the reliability negatively. This parameter is approximate and reflects the participants’ perception of the methods’ inter-investigator reliability. AcciMap is considered less reliable since different investigators are likely to reach different results when using AcciMap independently on the same accident. In contrast, DREAM is perceived highly reliable meaning that results are less dependent on the individual investigator. The other methods appear between these extremes. The methods generally provide fairly stable results, however the investigator will always influence the results to some extent.

Several of the methods’ output formats include some form of graphic representation of the accident, causes or contributing factors. However, there are some differences in style and some methods combine different output formats. Their output formats may influence how the results can be communicated and have also, in some cases, been established as a “trademark” for the methods. Many methods provide graphic output formats in some different ways. Some of them show the course-of-events (primarily MTO and STEP) while other (AcciMap, AEB, FTA, DREAM) show logical or other types of connections between various causal factors. Some of these methods include graphic representations such as a “tree” or “web”. Deviation analysis and SFA differ from many other methods by providing tables instead of traditional graphics. Some lists and combination of output format are also present among the methods.

5.4 Impressions of the methods

Table 6 shows a summary of the course participants’ subjective impressions. After each test of a method, the testing group had summarised positive and negative experiences of that method. These were the basis of summing up impressions done in common discussion session. This has been done for all eight courses, and Table 6 shows a condensed version of these results. The results between different courses vary only to a limited extent. It should be noted the impressions are based on a classroom exercise, and not on real applications.

Tabell 6: The participants overall impressions and summary of method properties.

Method	Positive	Negative	Other
AcciMap	Gives an overview and promotes a holistic approach.	Complex method requiring system knowledge. Weak attention to the course of events and resulting proposals. Perceived as time consuming.	The graphical result promotes a visual understanding.
AEB	Simple and quick method. Well structured. Suitable for identification of barriers.	Much focused on error (guilt thinking). Disregards organizational aspects and parallel events.	Searching for error rather than causes.
Deviation Analysis	Quick and easy method. Open, creative and preventatively constructive approach. Provides an approach to risk analysis as well (broader than the actual accident).	The deviation concept is difficult to define. Draws attention to the negative. Difficult to find the "true" causes. Does not show the sequence of events.	Provokes discussions (for better or worse).
DREAM (CREAM)	Quick and well-defined method without requiring expertise in human factors. Includes stop rules. Provides a basis for data collection and statistics.	Difficult to get an overview when browsing between tables. Stop rules appears very soon. Separate analyses per actors make it difficult to observe connections. Limited room for unexpected causes.	The method can be adapted to other contexts and types of accident. This method requires systematized data collection.
Fault Tree Analysis	Gives a good picture of parts of the sequence of events. Reveals strict causal links.	The method is very technical and requires strict causality. Difficult to use for non-specialists.	The method is usually applied to technical systems, but can be used more broadly. The method is originally intended for risk analysis and is less suited for accident investigation. Causality can be interpreted more loosely.
MTO event investigation	The method provides a simple and clear picture of the sequence of events. All levels and barriers are captured.	Parallel events are difficult to manage. The analysis may be superficial at the top level.	The graph is usually a key result.
SCAT	Quick and easy method with a logical structure. The manual is easy to follow.	Rigid method based on old-fashioned rule-based model. The method requires a safety control system. Missing links to safety proposals.	Perhaps more suited for auditing than accident investigation.
SFA	Quick method showing systemic deficits and capable of dealing with many safety functions. Targets different system levels.	Does not capture the course of events. The method might appear difficult to handle. Can be converted into a risk analysis method beyond the actual accident.	Uncertainty regarding its practical use. Considered practically immature. Not sufficient as single method.
STEP	Good, overarching and quick method. Provides simple and clear picture of the sequence of events. Logical and easy to understand. The method supports multiple actors and parallel sequences. Includes quality checks.	The method does not capture underlying factors, latent weaknesses or organizational deficiencies. The method tends to be overly ambitious when few operators are involved.	Needs delimitations. Useful as a first method in order to map events and actors.

6. DISCUSSION

6.1 Accident investigation methods and the process

The selection of methods can be compared to former compilations and studies (e.g. Energy Institute, 2008; Hollnagel and Speziali, 2008; Livingston et al., 2001; Sklet, 2004) and examples from accident investigation in Western Europe, USA and Australia. One difference is that the attention here has been on how well various methods can support the practical investigation work.

The selection of nine methods represents only a fraction of the nearly 100 accident investigation methods described in the literature. This choice of methods can of course be discussed. On the other hand, the approach for analysis is fairly generic and can to some extent be applied also for other investigation methods, which are described on sufficiently detailed level. There are common approaches, such as “Root Cause Analysis” and “Barrier Analysis”, which were not included. An explanation for this is that they sometimes designate a group of methods, or a specific method.

Several types of results are observed in this study. The comparison shows both differences and similarities between different methods for accident investigation. A number of previous studies support the conclusion of this study that different methods aid in different directions and provide different types of support during the investigation process (Benner, 2003; Hollnagel and Speziali, 2008). Divergent perspectives, accidents models and other aspects, are then usually highlighted, forcing investigators to think in new directions (Katsakiori et al., 2009; Lundberg et al., 2009).This study also points to differences and similarities in how the selected methods support and influence the investigative process.

We note that no method fully supports all phases in the investigative process. Moreover, some methods have rather limited impact on the practical investigative work, such as data collection, the development of safety recommendations and report writing. We think that the practical investigation work and the entire process are more influenced by branch praxis and general investigation procedures than by specific methods.

Not surprisingly, the methods have their strength in the analysis phase. The methods, therefore, usually focus on clarifying the same types of causes, contributing factors and relationships that the accident model emphasizes. The purpose of the methods is often to promote understanding and learning from the accident. This is also how they have become used in practice. Data collection and initial investigation actions are usually independent of the method except when the investigating organization has a certain default method. In these cases the method can influence the entire investigative process.

The observation that the methods primarily support the analysis phase implies that the standard term “accident investigation method” is somewhat misleading. A more accurate term would be “accident analysis method”. Similar ideas have also been raised by others (DOE, 1999; Hollnagel and Speziali, 2008).

When decomposing the investigative process and concentrating on the analysis phase it becomes easier to understand the opportunities of using multiple methods of analysis. Experience from the courses shows that there are often obvious advantages in using several methods for the analysis of an accident. Since the methods represent different approaches and perspectives, it is usually enriching to use more than one method. This also increases the quality of the analysis and the overall view of the event. Triangulation by using multiple methods of analysis is commonly recommended in case study research (Yin, 2003; Zotov, 2000), as illustrated by Baumann and Cowell (1999) in the context of environmental analysis.

The order in which different methods are being used may have importance. The course experience is that a method which clearly analyzes the sequence of events is a good one to start with. Methods with a starting-point in simple chains of events (e.g. STEP, MTO analysis) or otherwise quick and uncomplicated methods (e.g. Deviation Analysis) would work well as initial methods. More complex methods (e.g. AcciMap, FTA) seem to function better as secondary methods. Further, it is inevitable that the results and perspectives derived from the application of one method spill over to the next method, resulting in considerable bias when many methods are being used on the same event.

6.2 Choice of methods for investigations

The basic aim of this study is to provide guidance for the choice of method. There are indeed many aspects to consider when selecting a method, since the methods relate to different theoretical frameworks, various types of manuals and different forms of analysis.

The starting point has been the investigative process (Figure 1). This model has been more precisely described by a set of parameters, each with defined scales (Section 4.3). Based on this, nine methods have been evaluated (Table 5). In theory, the selection of methods can then be based on the parameters considered most essential in the relevant situation.

For example, there are clear differences between manuals (Table 4; P1 Planning of investigation). Some manuals give a clear step by step description, while others form a freer description of how the analysis should be carried out. Our experience is that there is great value in complying fairly strictly with the method's manuals. This usually helps best in the investigation process, and also often provides a specific quality control for the analysis.

An important aspect is the purpose of the specific accident investigation. If possible the methods should be chosen to match the purpose of the investigation. Choice of method could also correspond to the need of support in various phases (P2-P6 in Table 4) or additional attributes (Table 5). Other experiences – both from the courses and real cases – are that it often is valuable to combine two or more methods.

6.3 Reflections on the study

Studies of this kind raise challenges with regard to validity. Our approach is qualitative, and should not be judged quantitatively. Similar studies on single methods applied to authentic cases have been published earlier. Svenson et al. (1999) and Fridleifer and Lindberg (1996) give examples of studies where the method AEB was systematically tested on various accidents. These studies show similarities with our study with regard to the analytical approach.

It might be seen as a weakness that no tests were done in real accident investigation situations. On the other hand, we were able to maintain structure and uniformity throughout the tests, comparisons, and assessments made of the methods. The testing environment of the course can certainly differ from real life application of the methods, but it gives, on the other hand, more stable and reliable results for these kinds of comparisons.

Three of the four authors have had a teaching role in the courses, which means that they had a major impact on both how the methods were taught and how they were evaluated and compared. This can be seen as a weakness of the study but also as strength ensuring that teaching and comparisons have been made consistently and systematically. The large number of course participants from many sectors during eight years should vouch for a certain quality of the study.

The quality of our results also depends on the selection of methods, the understanding of their underlying theories, previous knowledge and experience of the methods, as well as the context and nature of cases subjected to testing. The orders in which methods have been applied may also have affected the evaluations at the test. The test groups were free to choose the testing order, but as teachers we have seen that the first method generally have given the richest outcome while the following methods provided complementary insights and perspectives. This may have affected the assessments of methods, but this is balanced by the large number of tests and the randomness of the ordering of the tests. On the other hand, an experience through all courses is the repeatability by which the groups have perceived the differences between the methods and the spontaneous insights the tests have always given.

Another issue is how well the selection of methods corresponds to what is used in official accidents investigations. A study involving several European countries (Roed-Larsen et al., 2004) showed that methods were seldom used in accident investigation. This means that this issue is hard to address. In recent years, we have observed a growing interest in the quality of investigations and the application of accident investigation methods.

7. CONCLUSIONS

A general conclusion is that choice of accident investigation method matters and that comparative studies are important to provide guidance on the choice between methods. Methods have been compared earlier (Energy Institute, 2008; Livingston et al., 2001; Sklet, 2002), however with limited or no empirical support. Although there are limitations also in this study, the large number of systematic and uniformly performed tests in this study should vouches for a result potentially useful to guide the choice of investigating methods.

In conclusion, this study reveals considerable differences among accident investigation methods with regard to their ability to support the different steps of a generic accident investigation process. The choice of method therefore influences the practical investigation procedures as well as the accident analysis and its outcomes.

One key observation is that the methods evaluated here mainly support the analysis phase of the investigative process and only to a lesser extent the whole accident investigation process. The methods STEP and Deviation analysis provide relatively strong support for several key elements of the process, while other methods predominantly gives support only to the analysis phases. This implies also that it would be more appropriate to term these methods accident analysis methods instead of accident investigation methods.

Another experience from the courses suggests that methods focusing on clarifying the sequence of events provide a good starting-point and can subsequently be supplemented with other more complex methods.

Based on this study, further research should focus on the practical application of the methods and their significance for real safety improvement. Further research on objective formulation and choice of strategy when planning an accident investigation is also desirable.

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