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Relationships between accident investigations, risk analysis, and safety management

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Abstract

Several different approaches to achieve safety are in common use, and examples are accident investigations (AI), risk analysis (RA), and safety management systems (SMS). The meaning of these concepts and their practical applications vary quite a lot, which might cause confusion. A summary of definitions is presented. A general comparison is made of application areas and methodology. A proposal is made how to indicate parameters of variation. At one end of the scale there are organisations, which are highly organised in respect to safety. At the other end are small companies with informal safety routines.

Although the three concepts differ in a number of respects, there are many links between them which is illustrated in a model. A number of relations have been described mainly concerned with more advanced organisations. Behind the practical safety work, there are varying sets of more or less explicit explanations and theories on safety and accident causation. Depending on the theory applied, the relations between approaches can be more or less clear and essential.

Keywords: Risk analysis; Safety; Accident; Accident investigation; Safety management

1. Introduction

Safety is a prominent feature in complex systems, and there is an abundance of different traditions how to deal with this. Obviously there is a terminology which differs quite a lot. Risk analysis would be a completely different thing for a toxicologist or a bank official. Also among the technological disciplines the concepts vary much, even if you limit the discussion to accidents. However, it is not only technical terms that might differ, there are also underlying concepts and theories, as well as various methods for analysis and investigations.

The aim of this paper is to compare and discuss different definitions and concepts related to accident investigations (AI), risk analysis (RA), and safety management (SM). The intention is to consider high-risk as well as low-risk aspects.

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2. Definitions

2.1. General

At first, it appears easy to find a set of general definitions that could work for most occasions. However, it quickly emerges quite a lot of competing definitions of terms. One essential source for technically oriented terms is an IEC-standard [1], which has given a set of related terms. However, this does not include all aspects, and there are alternatives to the viewpoints in the standard.

Just a small selection of the definitions in the safety area will be given here. However, it should be noted that definitions are formulated in different ways. They could:

- give a simple statement of the meaning of a term, and/or
- sum up all elements which usually is included in practical use, and/or
- include the good characteristics aiming at perfect results.

The first type of definitions might be classified as descriptive, and others as normative (saying how it should be done).

Other definitions are influenced by underlying theories, or related to formulation of goals that should be achieved. This makes the situation a bit more intriguing, and points at need to simultaneously be aware of related models and conceptual framework.

In this paper the focus is on applications related to accidents and accident investigations. In many cases it is preferable to use the term "event analysis" which is broader.

> An "event" can be defined as a deviation in an activity or technology which leads towards unwanted negative consequences [2]. It can be an accident, a near-accident, or e.g. a defective a barrier in a safety system.

2.2. Definitions of accident investigations

It was hard to find a straightforward definition of accident (or event) investigation. Perhaps the term is regarded as self-explanatory, which actually is good enough. Example of a normative definition [3] is:

> An accident investigation is the determination of the facts of an accident by inquiry, observation, and examination and an analysis of these facts to establish the causes of the accident and the measures that must be adopted to prevent its recurrence.

The author's suggestion for a simple description is:

> An event investigation is the collection and examination of facts related to an occurred specific event.

2.3. Definitions of risk analysis

2.3.1. The reliability tradition

Within the area of dependability and reliability, there is an international standard [1] that defines "risk analysis" and a number of related terms.

> Risk is defined as a combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event.

> Risk analysis is the systematic use of available information to identify hazards and to estimate the risk to individuals or populations, property or the environment.

The standard also gives a number of alternative terms to the same definition, namely probabilistic safety analysis, probabilistic risk analysis, quantitative safety analysis, and quantitative risk analysis.

Other terms defined in this standard are:

> Risk estimation is the process used to produce a measure of the level of risks (a part of risk analysis).

> Risk evaluation is the process in which judgements are made on the tolerability of the risk (based on the risk analysis).

> Risk assessment is the overall process of risk analysis and risk evaluation.

2.3.2. Other definitions of risk analysis

The term risk analysis is used in many different application areas. It can be used in toxicology, in environmental studies, in financial considerations, insurance etc. It is good to be aware of the variety of terms, and that different meanings might be entailed.

In the chemical industry, the preferred term is risk analysis for all type of methods. In the nuclear industry, safety analysis appears to be more common. The term is used in many other applications as well. However, it was difficult to find a direct definition, and the author's impression is that safety analysis is used in a broader sense (e.g. [4]). One suggestion [5] runs as follows:

> Safety analysis is a systematic procedure for analysing systems to identify and evaluate hazards and safety characteristics.

2.4. Definitions of safety management

Risk management and safety management are used in varied ways and are often seen as identical. The IEC-standard [1] gives the definition:

> Risk management is the systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling risk.

In several types of industry the word "safety" is preferred, and one example [6] is:

> Safety management may be defined as the aspect of the overall management function that determines and implements the safety policy. This will involve a whole range of activities, initiatives, programs, etc., focused on technical, human and organisational aspects and referring to all the individual activities within the organisation, which tend to be formalised as Safety Management Systems (SMS).

Both this definitions have their point of departure in the policy of the company. That is in line with both quality and environmental standards, and one example [7] is:

> Environmental management system is a part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy.

These three definitions are based on the existence of policy, consequently there is no safety management if a policy is lacking. All three are also normative, saying how it shall be done. Such definitions might be acceptable in high-risk industries, where such practices are common and compulsory.

However, many companies do not have a formulated policy (especially SME), but they have safety management to deal with their hazards, in one way or another. Accordingly, there is a need for a comprehensive and descriptive definition. One suggestion for a simple definition of occupational health and safety management—a systematic way of managing the occupational health and safety risks of a company [8].

However, management can exist without being "systematic", which is related to some kind of norm. This leads to a suggestion of a simple definition:

Safety management is a way of managing the hazards (safety risks) of a company.

3. Variations in concepts and goals

3.1. Spread in applications

There is a large spread in application areas and need for efficient approaches. Take for example nuclear installations, aviation companies, and large chemical industries, which often are associated with a potential for major accidents and also rigorous SMS. On the other hand, you can have more uncomplicated types of production, where minor accidents are frequent and safety is managed in a much more relaxed way.

Table 1 gives a summary of parameters defining different situations. In discussions of advanced safety features, you can easily get trapped by a stereotype related to Group A. It is easy to focus on the first type and neglect the second type, which produces much more injuries and damages (e.g. [5]). It is a reason, why also less sophisticated applications have been considered in the section about definitions.

It should be noted that a specific company or organisation could have parameters in both groups at the same time. For example, the company has a formal safety management system, but changes are common which give improvisations and informal safety actions a more prominent role.

Table 1
Parameters of management and risks

Parameter	Group A	Group B
Accidents	Large consequences, infrequent	Small consequences, occasional
Organisation size	Large, complex	Small, simple
Regulation	Precise, strictly enforced	General
General management	Structured, formal	Informal
Safety management	Formal	Informal
Economy and resources	Good	Poor
Stability	Invariable	Changes are common

3.2. Event investigation

Event investigations can be seen as collection and analysis of facts resulting in a report with a number of recommendations. A second view is that the investigation is an organisational learning process with a search for opportunities for improvement. All levels of the organisation can and should learn [9].

In both perspectives there can be a number of conflicting goals. Especially related to responsibility issues, when liability should be fixed, punishment meted out, and compensation claimed. It is common with difficulties to establish links between the accidents and with safety management or regulatory systems.

3.3. Methods and tools

Methods are regarded as almost inevitable when a risk analysis is performed on a technical or socio-technical system. The analyst is supposed to apply one or more recognised analysis methods, of which there a large amount published in the literature [5,10,11].

Also for investigations of accidents there are several methods in use. According to a recent study in Europe [12], the use of methods is less common and self-evident compared to applications in risk analysis.

3.4. Concepts and theories

Explanations and theories about accidents and their prevention are numerous. They are essential also in the practical world, as they influence how (safety) management systems are designed, the application of risk analysis tools, and the accomplishment of event investigations.

Hale [9] points out that there is some consensus for the two first "ages" of safety, which are related to technical and human failures respectively. In the third "age", with concern for complex socio-technical and safety management systems, developments are still in an early stage. Although there might be a basic agreement in the scientific community concerning technical and human failures, as a whole the variation on conceptions about accident causation is large.

An interesting aspect is the coupling between accident models and how an event analysis is accomplished. Hollnagel [13] has made a classification of methods in accident investigations, which are divided in three major groups. The first is "*Sequential accident models*", which describe the accident as the result of a sequence of events in a specific order, e.g. the Domino theory. Such models often turned out to be limited in their capability to explain what happened in more complex systems.

"*Epidemiological accident models*" describe an accident in analogy with a disease, i.e. as a combination of "agents" and environmental factors that can generate unhappy conditions. Examples are the concept of "latent conditions" and the Swiss cheese analogy [14].

A third type of model is called "*Systemic accident models*", which endeavour to describe the performance of the whole system, rather than on cause–effect "mechanisms" or specific factors. The concept of "normal accidents" [15] is in agreement with this type of model.

4. On the relationships

4.1. General

Depending on the spread of application areas and of different concepts, it is hard to define general relationships between accident investigations, risk analysis, and safety management. However, there are many interesting and essential relations and aspects on these, but they cannot be expressed in a too stereotype way.

The account below takes its departure from "Group A" company, and then discusses a number of variable aspects and relations.

4.2. The basic relations

Assume a company which is in a "Group A" situation as defined in Table 1. It has an elaborated corporate management with a safety management system, good stability, and fine economy. Fig. 1 gives an overview of some of the elements. In a conceptual meaning and according to the definitions, AI is a type of RA. However, in practice they are seen as separate activities, which justifies that they are separated in the model.

In this type of situation, the SMS prescribes when and how RA and AI shall be done. These activities produce reports with observations and recommendations. The figure does not show the feedback to the SMS from audits, RA and AI.

Of course, there is a great variability also for this type of situation. Let us here concentrate on the AI aspects, but much of the reasoning also holds for RA.

In principle, the SMS defines what is done in the AI, and how the obtained information shall be used. The aim can be to produce a report about the course of events, recommendations, and sometimes fixing responsibilities. The report goes to responsible manager and for information to others. A common situation is that AI reports include ready-built classifications for statistical purposes.

4.3. The feedback relations

Another perspective is to regard AI as a learning process (e.g. [9]). This will widen the scope of the investigation. It can influence the conception of the feedback loops and what can improve the system.

Fig. 2 illustrates a number of relationships which can be apparent in a learning type of AI. We assume here that a specific event is being investigated, and the AI will raise a number of questions. A few comments to the numbered links are given.

(1) *The AI process itself*. The investigator could scrutinize the investigation process itself, especially earlier investigations which might have disregarded certain problems. The actual event—is it a special unique surprise or something rather common and expected?
(2) *The mutual link AI and RA*. A number of aspects are interesting, which are developed in Section 4.5.
(3) *The link to the SMS*. In one direction, the SMS gives directives about how and when AIs are performed. How could the event occur despite the SMS and its actions? The instructions might be improved in some respects. However, a basic question is if it is allowed at all to scrutinize the SMS and its role.

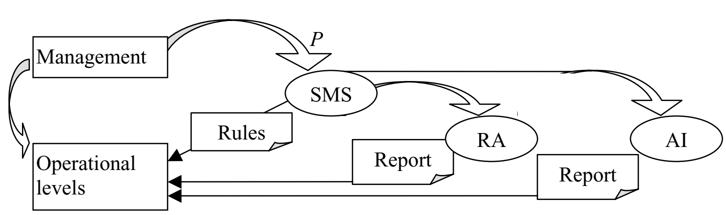

Fig. 1. Elements and relations in a "Group A" type of company.

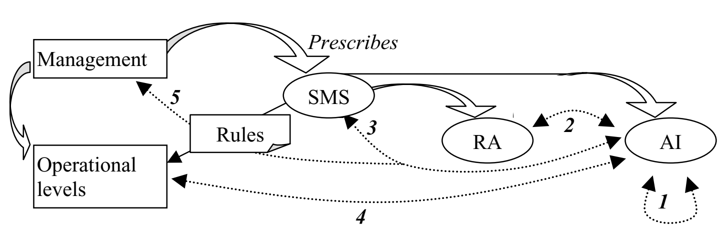

Fig. 2. Links in a learning process accident investigation in a "Group A" type of company.

(4) *The mutual link between AI and operational management*. In an AI, the role of operators and line management are always examined. However, there should be a mutual interest here, so all involved should learn and be able to benefit from the findings and the fact finding process.
(5) *Company management*. The leadership of the company and its role is essential in the Group A type of companies. Usually the top-down dimension is pronounced, but the bottom-up could be equally important. Also here you can ask if it is permissible to permit a critical investigation, and if it is meaningful.

4.4. Relations in Group B situations

The parameters defining Group A and Group B situations (Table 1) can be combined in numerous ways. Nevertheless, the model in Figs. 1 and 2 above can be used as a starting point to define activities (boxes) and the flow of instructions and information (arrows). In general, the Group B situation might deteriorate some of the boxes and/or the flow of information.

This can be illustrated by a case study of an incident at an electricity-distribution company [16]. The study is based on an in-depth event investigation based on safety functions. At first, the company appeared to be of Type A. However, essential organisational changes had been made, and for example, maintenance jobs had been transferred to a separate company.

One finding was that a large number of safety functions had failed in preventing the incident. In particular, the analysis indicated low efficiency of functions related to higher organisational levels.

In Fig. 3, examples are shown of deteriorations in relation to the ideal relationships in Fig. 1 (as they appeared in the case study). Four types of deteriorations are indicated by bars, which are commented upon below.

(A) *Prescriptions of safety management*. The changes had made general prescriptions out of date; for example, they addressed non-existent organisational entities, and the safety policy was inadequate and hard to find.
(B) *Safety rules*. Safety rules had become out of date and were incomplete. One aspect here is that the changes meant that rules concerning several companies with separate responsibilities had become necessary but were not in place.
(C) *Management control*. One example is that more companies were involved in operations, and that their procedures for responsibilities and safety were not harmonised well enough.
(D) *Reporting incidents*. Information on incidents and problems no longer reach personnel efficiently, which entailed weakening of feedback and less work on improvement.

But there are also positive aspects of Type B situations. Informal contacts and daily meetings are important means by which people are informed. In this case, many of the problems were counter-balanced through informal contacts between people who used to be in the same company, but had since been separated. As well as improving the safety management system, means to support informal exchange of information were proposed to improve the situation.

4.5. AI, RA, and the methods

Especially in complex systems, there are many relations between AI and RA. Some issues that could be raised in an investigation are:

- Has this type of event been studied earlier in an RA?
- Did the RA overlook this event, and then why?
- Can the accident occur along other sequences of events? There can be a need for an RA to check that.
- The AI can recommend that an RA is made for a particular system or situation.

From the RA perspective, there are aspects such as:

- An RA could establish that a specific type of event is essential and hard to evaluate. If this should occur, the AI should investigate this type of event extra carefully.
- Data from AIs are important input to RAs.
- In order to improve the safety management, an RA could be performed on the AI process. This could concern what can be missed in an investigation, wrong conclusions are made, results are not used, conclusions are denied, the report is met with silence and no actions.

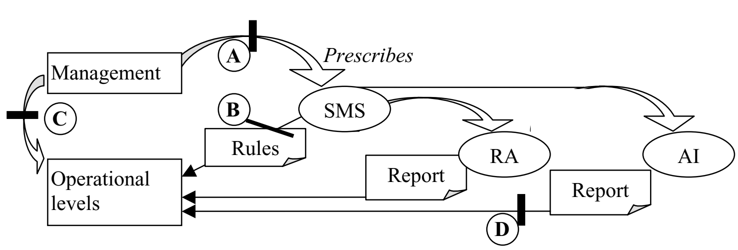

Fig. 3. Examples of deterioration in relationships in a “Group B” type of company.

A development of such relationships could improve the understanding (and perhaps efficiency) between teams doing RA and AI, respectively.

In an RA, it is usually self-evident to apply a recognised method, which however is rarer in AI [12]. The connection between RA and AI could be improved also on the methodology side. There are methods which could be used with minor modifications both for analysing systems and investigation of events [5]. Examples are barrier analysis, deviation analysis, event tree, fault tree, MORT, safety function analysis, and SMORT.

4.6. About the organisation and the responsibilities

The three last links in Fig. 2 implicate that management actions or lack of actions can be questioned and discussed. Examination of management aspects has many similarities with an audit. However, that checks the management on its own terms and mandate. An AI makes it search from a bottom-up perspective and can give a different type of findings and other types of lessons.

Potential problems that might be obvious are the existence of conflicting goals or inefficient procedures. Many systems can also have sectors with developed SMS, but handle other sectors in a more relaxed way.

However, there are many obstacles for system changes. As Hale [9] formulates it—learning means that there must be somebody there to learn. Both individuals and organisations have some kind of “natural” behaviour to protect themselves against changes and new responsibilities.

One major difficulty with organisational learning is how to handle questions of responsibility and liability. The problem of responsibility is connected to the complexity of modern technological systems, which create a large distance between human action and its result. Responsibility is the result of complex conditions, which cannot be evaluated on a black and white scale [17].

4.7. Other aspects

The discussion above has presupposed an organisation which mainly is of type A (see Table 1). This is a simplification in many ways. Even formal systems have a number of essential features, which cannot be simply expressed by the rule-makers or is not known by them. There are also a number of issues in such companies that are handled quite informal.

Most companies and organisations do not have formal SMS. This makes “informal” estimates and indicators interesting, i.e. the functioning of the safety practice and its efficiency. This variability of applications makes it obvious that the relationships vary even more.

The model (Figs. 1 and 2) of safety management could easily be supplemented with links related also to RA and SMS. The model could in principle also be used to analyse more informal management systems. It could support the identification of existing links and links that the company would regard as useful.

Both in type A and other organisations, there appear to be many advantages with a holistic perspective on AI, RA, and safety management. The main reason is that there are many relationships which can give a mutual benefit for all three elements. Such a mutual perspective could embrace:

- the theoretical concept on how accidents occur,
- prevention strategies, and
- application of methods.

5. Conclusions

A number of definitions have been identified, which describe risk analysis, accident investigation, and safety management. However, the explanations are often normative and based on assumptions of the situation. Generic and descriptive definitions were harder to find.

It is essential to carefully consider the large spread of application situations, and a proposal is made how to indicate parameters of variation. At one end of the scale, there are type A organisations, which are highly organised in respect to safety. At the other end, there are small companies with informal safety routines.

There is a complicated web of relationships between RA, AI, and SMS. A number of such relations have been identified, which mainly were concerned with type A organisations. It appears to be several advantages with a conscious co-ordination between the three approaches based on a theoretical coherent basis. That could encompass concepts on how accidents can occur, prevention strategies, and application of methods.

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