ESReDA Working Group on Accident Investigation

European Safety, Reliability and Data Association

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Guidelines for Safety Investigations of Accidents

ESReDA - European Safety Reliability and Data Association

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(ESReDA)

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PREFACE

by the President of ESReDA

Operating feedback or learning from experience is recognised to be one of the pillars of safety management. In theory, it helps to reveal "failures" in the socio-technical system, which can be remedied so that - according to the standard phrase – such events "can never happen again". This is why investigations are seen as important sources of safety information, as they demonstrate how things can go wrong. Safety investigation of accidents is a field which is improving and expanding. The ambition of these guidelines is to reflect the state of art as well to address future challenges in accident investigation. By formulating these considerations, the intention is to support a learning process across sectors, and to improve the quality of investigations.

These guidelines have been written by a project group within the European Safety, Reliability and Data Association (ESReDA). ESReDA is a non-profit making association of European industrial and academic organisations concerned with advances in the safety and reliability field. The association always welcomes comments and contributions concerning their publications and invites all to submit ideas for further developments in the field of reliability data as well.

These guidelines would not have been possible without substantial individual effort of the ESReDA project group members who come from different companies, research institutes, universities and authorities. They have produced its contents without any financial support and have devoted considerable free time to the task. This publication collects considerable experiences from several industrial sectors (transportation, energy, chemical,…) and countries in Europe. ESReDA is proud to present the results of their work and hopes it will benefit the many organisations and individuals worldwide concerned with safety investigation of accidents and learning from experience.

ESReDA would like to thank the authors for their contribution and also the member organisations for funding travel expenses for its members. In particular special thanks are due to those organisations that have allowed working group members to participate in this work including giving free access to their extensive in-house expertise and experience. We record our appreciation and grateful thanks to:

- Institut National de l'Environnement Industriel et des Risques, (INERIS), France;
- Électricité de France, EDF R&D, France;
- EDP – Gestão da Produção de Energia, S.A., Portugal;
- Det Norske Veritas AS, Norway;
- N.V. Nederlandse Gasunie, the Netherlands;
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- Kindunos Safety Consultancy Ltd, the Netherlands;
- Karlstad University - Public Health Sciences/ Risk Research, Sweden;
- Rail Safety and Standards Board, United Kingdom;
- Tukes - Safety Technology Authority, Finland;
- European Commission, DG-Joint Research Centre, Institute for Energy, the Netherlands;

We hope these guidelines meet the expectations of members of the public and organisations who have shown interest in the work of the group in this important field.

Oslo, June 2009

Henrik Kortner
Chief Specialist
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PREFACE[1]

by the ESReDA Accident Investigation Working Group

These guidelines are the result of a joint effort by experts, in the fields of accident investigation, accident analysis, learning from experience and safety management, from 10 countries in Europe across almost every industrial sector. They attempt to represent a general approach to the concept of accident investigation across sectors and national borders in Europe. Safety investigation of accidents is a field which is improving and expanding. The ambition of these guidelines is to reflect the state of the art in accident investigation as well to address its future challenges. It was found important and challenging to balance the need for referring to the scientific background and theoretical framework with the objective of formalising practical guidelines for the future users of the guidelines. The contents of this publication are summarised below.

- Chapter 1 presents the main motivations for these guidelines, their objectives and scope;
- Chapter 2 takes upon the challenge of portraying a generic state of the art of principles, models, aims and methodologies for accident investigations;
- Chapter 3 addresses investigation preparedness issue and provides suggestions for what to do before the event occurs in order to be ready to undertake the investigation in an effective way;
- Chapter 4 describes the main elements of managing and conducting an accident investigation, in the aftermath of an event;
- Chapter 5 deals with the issue of communicating findings to stakeholders and how to present investigation process and results in reports;
- Chapter 6 focuses on how to learn from the results of the investigations when designing corrective actions and also looks at barriers to lessons learning;
- Chapter 7 proposes some future challenges that would have to be addressed by the investigation and safety management communities.

All members of the Working Group have been actively involved in preparing these guidelines. An overview of the group's participating members with names and affiliations is given after the prefaces.

The working group *"Accident Investigation"*, which was a follow up of the former working group *"Accident Analysis"*, has been an active group since 2001. The first publication by the working group was a working report *"Accident Investigation Practices – Results from a European Inquiry"*, published in 2003. The main results from the European survey were also presented at the Petten (NL) ESReDA seminar 12 – 13 May 2003 attended by some 150 delegates. It was jointly organised by the ESReDA working group and European Commission, Directorate General Joint Research Centre (DG JRC), Institute for Energy. The contribution was published in the pre-proceedings from the seminar. Several selected articles of the conference were presented in the Journal of Hazardous Materials 111 (2004). An ESReDA book – *"Shaping Public Safety Investigations of Accidents in Europe"* – was issued to present the development and the current situation of public accident investigations in several fields in Europe. A draft version of these guidelines was presented at the 33rd ESReDA Seminar on *Future Challenges of Accident Investigation* organised at JRC Ispra, Italy, on 13 – 14 November 2007. Some comments from seminar participating experts have been incorporated in the present final version.

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[1] The opinions and concepts expressed by the authors are solely their responsibility and do not reflect the policy or opinion of their company or organisation.

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The ESReDA Accident Investigation Working Group has been chaired by Ms Irmeli Muje (2001), Mr Roger Taylor (2002), Mr Christian Kirchsteiger (2003-2004), Mr Espen Funnemark (2005) and Mr. Nicolas Dechy (2006-2008).

Earlier publications from the ESReDA working groups "Accident Analysis" and "Accident Investigation":

- Directory of accident databases (1997)
- Accident databases as a management tool (1998)
- Guidance document for design, operation, and use of safety, health, and environment (SHE) databases (2001)
- Accident investigation practices – results from a European study (2003)
- Shaping public safety investigations of accidents in Europe (2005)

In addition, the ESReDA Working Group on Accident Investigation has organised **two ESReDA Seminars on accident investigation** in 2003 jointly with JRC-IE in Petten (the Netherlands) and in 2007 together with JRC-IPSC in Ispra (Italy). The papers/contributions from these seminars are collected and printed in proceedings which are available from the ESReDA secretariat.

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We would like to thank the following people who have reviewed the draft guidelines and provided valuable feedback: Ranveig K. Tinmannsvik (SINTEF), Kevin Ghirxi (Malta Maritime Authority), and Marc Voirin (EDF R&D).

SUMMARY

These guidelines have been prepared for investigators, investigation managers, people who order investigations, responsible persons who will have to learn from the event, victims and researchers. These guidelines provide a minimum, current and recognised cross-sectorial best practices oversight to conduct investigations related to **industrial, technological and organisational events**. These guidelines give practical and theoretical advices related to the different stages of such investigations.

In-depth analysis of accidents, incidents and crises clearly showed that any event is generated by direct or immediate causes (technical failure and/or "human error"). Nevertheless their occurrence and/or their development is considered to be induced, facilitated or accelerated by underlying organisational conditions (complex factors) found in socio-technical system and organisational networks. It implies to deal with different natures of causalities: mechanistic met in technical installations and more complex met in human and social systems. Addressing those causalities requires various competencies (with disciplines from exact sciences, to engineering and social sciences) to investigate and to learn from an accident.

Accident investigation can be performed for various reasons and objectives. They depend on the stakeholders (many types among companies, authorities, or public parties) and their perspectives. Several investigations could often be managed simultaneously (e.g. judicial, technical,…) and it may lead to interest and operational conflicts such as the access to the accident scene and witnesses, the collection of the facts, the preservation of evidence, the findings, the communication of findings,… Corporate, political, cultural and societal requirements will shape the context in which the investigation is conducted. This should be cleared and stated when defining the mandate of the investigation.

Despite all this variety of contexts, investigation obeys to general principles (protocols, coordination, competence, data and evidence, reporting, follow-up of lessons learned and communication) and to process phases (defining terms of reference, appointing team, collecting data, hypotheses generation, analysis, findings and recommendations). Connection between phases is not a linear process but rather an iterative one.

Any investigator gets skills and know-how, so accident investigation is influenced by a priori knowledge or initial models. Specific methodologies have been developed to facilitate some investigation tasks. They use different logical constructions, different underlying models, and address different levels of phenomena with various perspectives (what happened, why it happened and what is recommended to prevent its repetition). Organisations should prepare their protocols and train their investigators before the event occurs in order to be ready to undertake the investigation in an effective way. These guidelines aim to support those processes.

To communicate during and after the investigation process is an important issue. Aim is to provide stakeholders with findings through a report or other supports in order to initiate and facilitate the learning process. Many barriers to learn lessons can be faced by organisations.

Turning findings into recommendations (corrective measures) is a specific task that requires specific knowledge of the organisational network and the socio-technical system behaviour. The corrective measures can be challenged by reality and a specific follow-up should be put in place.

Finally, some future challenges that would have to be addressed by the investigation and safety management communities conclude the present guidelines.

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1 INTRODUCTION

1.1 Motivation and aim of these guidelines

The main motivation to preparing these guidelines was to provide a minimum, current and recognised cross-sectorial best practices oversight to conduct investigations of accidents. At the same time, this set of practices provides the foundation for further work to harmonise investigative practices within the European countries. Hence, the primary aim of these guidelines is to share knowledge and experience about methodologies and principles for accident investigation across different sectors and application areas.

The development of these guidelines follows ESReDA "Accident Investigation" Working Group (WGAI) *study on investigative practices in Europe (2003)* where we noted certain deficiencies, in particular a lack of use of formal methodologies and a lack of proper investigation management. This fact motivated the work that resulted in the ESReDA book on *Shaping public safety investigations of accidents in Europe* (2005), which focused on the political and organisational axis (at societal level) of accident investigation as well as on a methodological and organisational axis (at managerial level) with the preparation of these guidelines.

Consequently, these guidelines are intended to give both practical and theoretical advice appropriate to each stage of accident investigation, and by this contribute to the improvement of investigations performed within companies and by public authorities. Such advice is directed both to the investigators and to those who order and specify what shall be investigated.

Safety investigation of accidents is a field that is currently improving and expanding. The ambition behind these guidelines is to reflect the state of the art as well as addressing future challenges. By formulating these considerations into the guidelines, the intent is to support a learning process across sectors, and to enhance improvement in the quality of investigations.

1.2 Scope of the Guidelines

The general scope of these guidelines is to cover investigations of accidents and incidents aimed at learning, in order to improve safety, prevent and prepare for future accidents. Investigations are seen as important sources of safety information, as they demonstrate how and why things go wrong or could have gone wrong. Investigations can be a good knowledge base for improving safety in production systems and public governance organisations. They can help to develop knowledge and also learn about knowledge deficiencies. By choosing the term "safety investigation," this aspect is emphasised.

The scale of severity is considerably wide, ranging from minor injuries to major disasters and natural catastrophes with many fatalities. However, natural catastrophes would be subject to comprehensive investigations by various relevant specialist investigators. The focus in these guidelines is somewhere in between the extremes. The term "accident investigation" is generally used in the guidelines, but it can also be applied to the study of near-accidents and other events indicating safety problems.

The guidelines could also be applied across a wide industry spectrum. They are generic and cover, in large part, most types of activities and systems in which accidents can occur. The principles are meant to be generic and could as well be applied in non-profit-organisations (such as community services). In a number of industrial branches, specific guidelines have been developed to which references are given.

These guidelines are mainly based on a system perspective, including how technical and organisational systems interplay or malfunction. Specialities like forensic techniques, technical investigations, interviewing techniques,... are less pronounced here. However, there is a large literature available which covers these subjects.

<u>There are different target groups for this publication:</u>

- People who conduct the practical investigations; it could be practitioners in companies, authorities or consultants. These are the main target group. However, they are not the only actors who shape the context in which investigations are performed;
- In reality, there is always someone who orders an investigation, giving more or less clear instructions and quality demands;
- In addition, responsible persons who are supposed to learn from the investigation, and consider and decide about the measures proposed. This in turn will influence other actors such as managers, designers, consultants;
- There is often also a more common interest in the results of investigations. The guidelines might be useful also for external reviewers to find out what can be considered as good practice and high quality;
- Victims at an accident and other directly affected persons or organisations have an interest in a fair and correct investigation. They could use the guidelines to find out what is considered as good practice for an investigation;
- Also researchers in accident investigation and safety may find interesting insights from this cross-sectorial best practices oversight.

1.3 Disclaimer

It should be noted that issues of terminology and definitions will not be addressed in these guidelines as it is rather specific to the various sectors (e.g. the meaning of ‘casualty’ refers to the loss of a vessel in the maritime sector, while it is understood as a fatality in the road safety arena).

To this extent a disclaimer is noticed. These guidelines use the most commonly applied notions as developed in the medical metaphor depicted in Haddon’s “agent-host-environment” model which was based upon the research of Gordon and Gibson. The “Swiss Cheese” metaphor, as developed by James Reason, refers to this medical model and reflects Reason’s school of thinking on hazards, defences, triggering events, proximate and remote causal factors and linear sequencing of events.

Although these models could be criticised for their oversimplification of a complex reality, they reflect the state of the art for investigating the majority of frequent accidents and incidents with an emphasis on human error and/or organisational failure.

On the copyrights issue, we have done our best and get specific agreements where necessary.

2 PRINCIPLES AND APPROACHES FOR ACCIDENT INVESTIGATIONS

2.1 Event, accident causation model: what is an event?

In-depth analyses of accidents, incidents and crises clearly showed that any event is generated by direct and/or immediate causes (technical failure and/or "human error"). Nevertheless their occurrence and/or their development are considered to be induced, facilitated or accelerated by underlying organisational conditions (complex factors).

A vast majority of events can be seen as the ending point of a process of safety degradation. An event is very rarely an "unexpected combination of circumstances" or an "act of God". Indeed, an accident happens at the end of an incubation period (Turner 1978), during which some events and signals (weak or strong) occur, but they are not perceived and/or not treated appropriately according to their potential threat to safety.

Every industrial system is coping with factors that impact safety, both positively and adversely. Life of an industrial system, from a safety standpoint, can be seen as continuous tension between resilient organisational factors (ROF) and pathogenic organisational factors (POF). An accident occurs when POFs overtake ROFs. Figure 1 below portrays how events can be seen (with the medical metaphor) as symptoms of prevailing conditions.

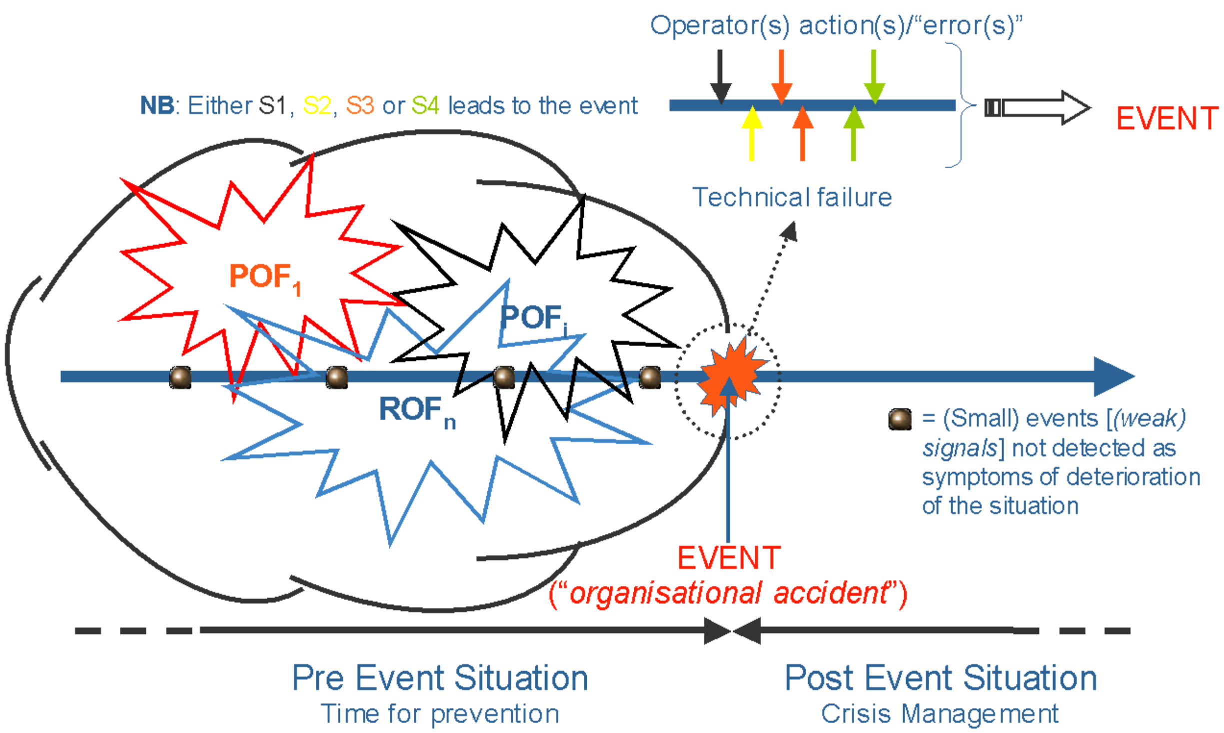

Figure 1: *Event development model (Y. Dien, 2006)*

An investigation can be triggered by the observation of visible effects (i.e. from near misses to disasters). However, an analysis (i.e. an audit or a review) can also be triggered by a change of perspective, or faith, or degree of reliance on the safety status, or its dynamics, by an expert of the system—even in the absence of an event.

“Event” and “accident” have many definitions. An accident or an event is a materialised risk. But what is important to remember is that they are characterised by many parameters (e.g. organisational, procedural, spatial, temporal). It is also important to bear in mind that an event is usually interlinked with other events and is merely a point in a timeline when symptoms of prevailing conditions become observable. According to Barry Turner, it is this moment when we understand that what we saw as safe was wrong (Turner 1978).

As a reminder, in some sectors, event and accident definitions are provided in procedures or regulations along with investigation triggering criteria.

2.2 Basic concepts and theories

Introduction

The knowledge on safety has evolved in the past century from an approach oriented towards technology to an approach that includes the human as well as the social dimensions of an accident. Accidents are indeed not only the result of technological breakdowns but also the result of human actions, within various (social) contexts. In 1998, Wilpert and Fahlbruch suggested that our awareness and the one of the research communities had moved to gradually consider multiple dimensions of these contexts (see Figure 2).

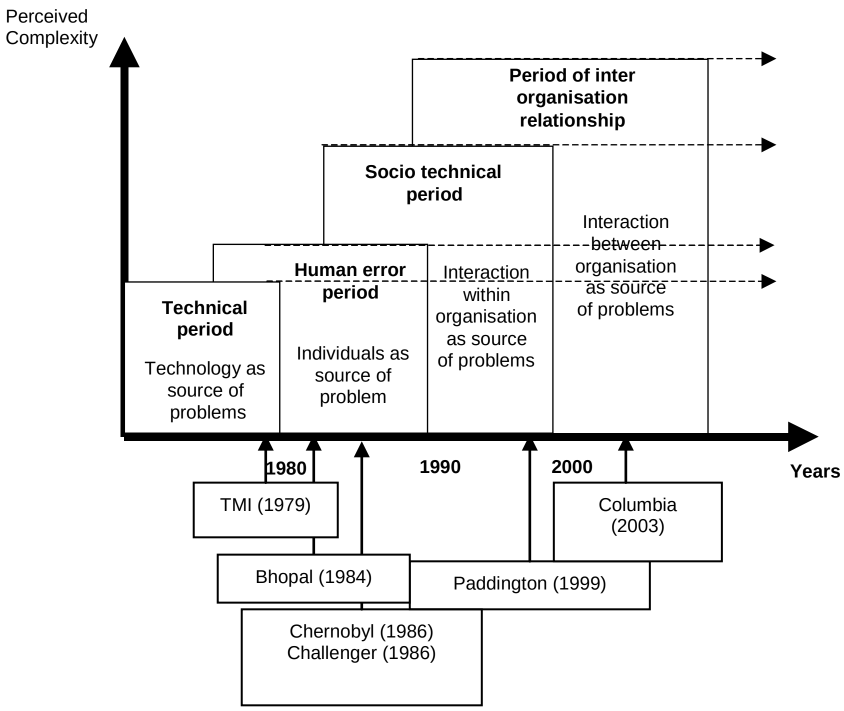

Figure 2: *Research trend in safety for the last 40 years (modified from B. Wilpert & B. Fahlbruch, 1998, Pergamon-Elsevier ©)*

A timeline was added to the original figure along with key major accidents, each time providing new insights to our understanding of accidents, following the investigation commission or specific social scientists' work.

The investigation conclusions of accidents at Tenerife (1977) and Three-Mile Island (1979) emphasised the human error dimension of the events (although in some work of that time the organisational aspects were already clearly stated by social scientists like Perrow and La Porte).

With Bhopal (1984), Chernobyl (1986) and Challenger (1986), it was clear that the organisational dimension had played a key role in the genesis of the accidents.

And more recently, trains collision at Paddington (1999), loss of the space shuttle Columbia (2003) and explosion in a refinery at Texas City (2005) stressed the importance of the institutional and organisational context. The detention fire at Schiphol Airport (2005) expanded the scope of the organisational dimension even further towards public safety, crisis management and governance issues.

All the dimensions portrayed in Figure 2 are important in understanding the behaviour of a socio-technical system and should be taken into consideration when starting an investigation.

System and accident models useful for investigation

<u>General statement</u>

Today the accident investigation process relies on the knowledge developed through years of scientific, as well as practical development in safety science. From the perspective of the natural and social sciences (i.e. from the technical-analytical, psycho-cognitive approaches and including the psychosocial and the sociological perspectives) as well as the practical safety management approach (extracted from companies' best practices in safety-related activities), the sources for supporting investigation and providing models are wide.

They provide the underlying models that are necessary not only for making sense of the data collected, but also for indicating where to look at. Our ability to understand is indeed a subtle relationship between what we know (our available reference model) and our creativity and ability to "see" what we do not know—and therefore, generate new assumptions and new models that differ from the existing ones.

Most of the investigative methods rely on existing models for an examination of the events, as it is not intended to generate a theory for each accident. The use of models is meant to imply the use of logic based on comparisons (analogical reasoning) and will consecutively raise the question of the level of understanding in order for it to be adequately handled as a support in the interpretation of events.

<u>Useful modelling principles</u>

A systemic approach to modelling provides a good basis for introducing the level of openness of the system that is chosen, and the related scientific disciplines to be associated at each level. Rasmussen (1997) represented the various disciplines applied against a column showing the main organisational levels and external stresses to be expected. This socio-technical system can be seen in Figure 3.

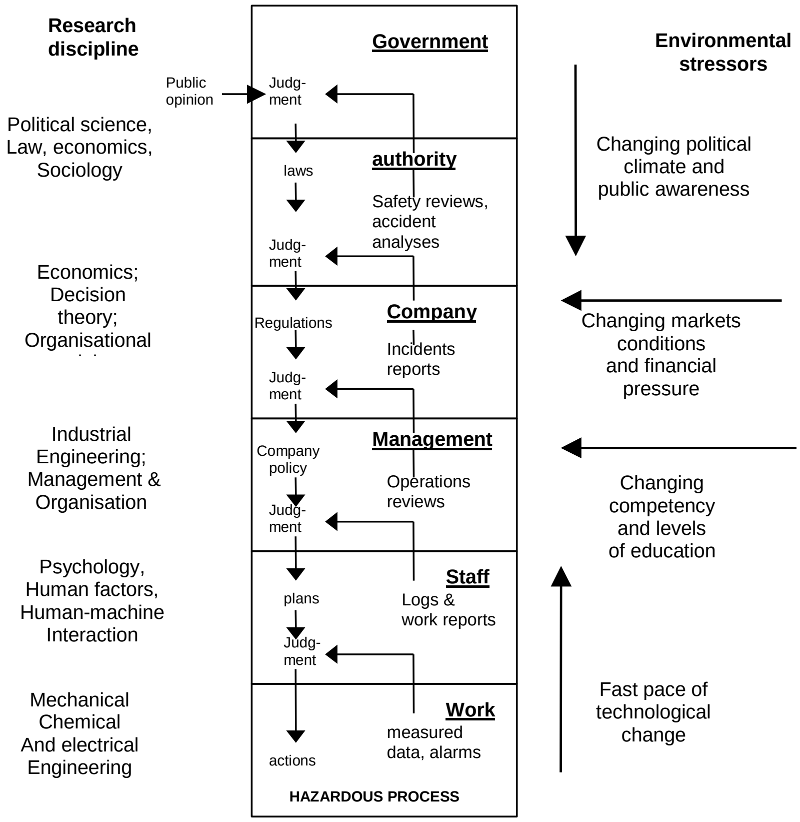

Figure 3: *Socio-technical system (Rasmussen, 1997, with the courtesy of I. Svedung from Svedung and Rasmussen, 2002)*

Causalities

Another interesting and important dimension of modelling accidents is the nature of causality in human and social systems compared to causalities in technical systems. Technical risk assessments rely on predictive behaviour of installations (such as pressure, heat,…) in response to external causes, while human and social systems introduce the systems' purpose(s) and circular causalities. These two types of causalities can be represented as shown in Figure 4.

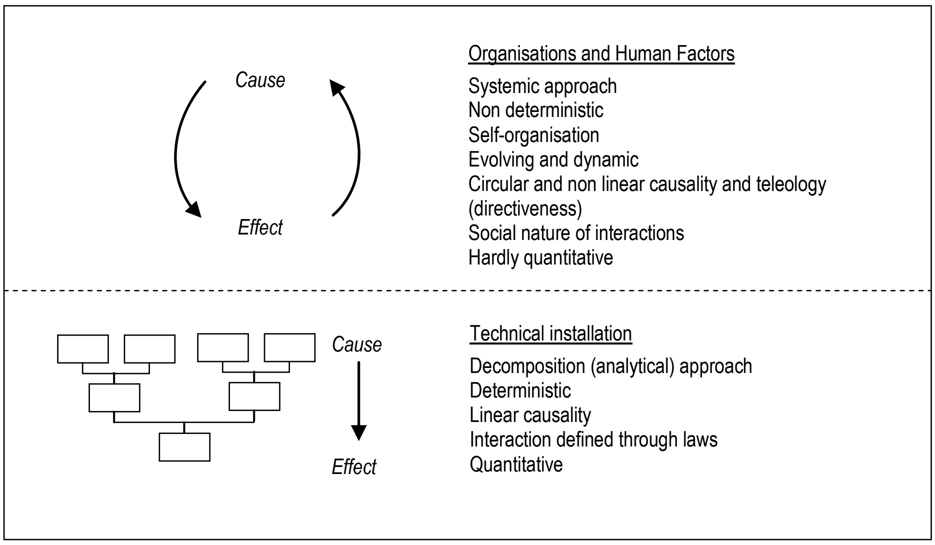

Figure 4: *Organisation, human factors and technical interface (J.C. Lecoze, 2005)*

Difficulties in predicting behaviour in human and social systems are generated through feedback loops, increasing, stabilising or decreasing effects. The resulting dynamical properties of systems are highly unpredictable and complex. As stated by Rasmussen (1997), "*Often we found that attempts to improve the safety of a system from models of local features were complicated by people adapting to the change in an unpredicted way*".

Preliminary requirements for investigating events in those socio-technical systems and network of organisations

From the discussion of the previous and present sub-sections, it can be highlighted that the investigation of an event in such socio-technical systems and/or networked organisations would have to be addressed along three main dimensions (see Figure 5) with the following characterisations:

(1) The <u>Historical</u> dimension:

- To go back in time to comprehend and analyse processes and trends that led to the event/situation;
- Meticulous examination of past events (post-event analysis);
- Check of repetitive phenomena that increase risks.

(2) The <u>Transversal</u> dimension: across the inter-organisational network:

- Connections and interaction between "entities" involved;
- Network covers entities beyond one company;
- Network is 'constructed' simultaneously as the investigation/analysis develops;
- Network accommodates clear interactions that allow the unaffected part of the organisation(s) to be ignored;
- Organisational network is not an organisational chart.

(3) The <u>Vertical</u> dimension: within the intra-organisational network:

- Interactions between hierarchical levels;
- Focus on:
  - Mode of cooperation;
  - Mode of communication;
  - Information flows;
  - Different visions of the world;
  - Relations between "field operators" and management;
  - Modus operandi deteriorated leading to decreased level of safety.

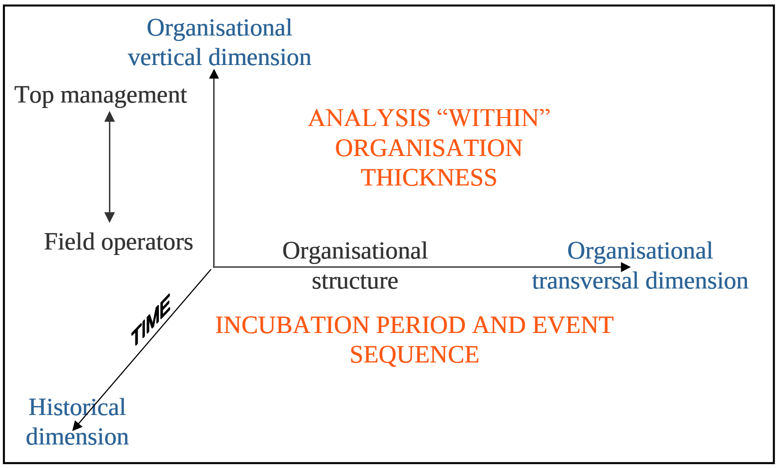

Figure 5: *Three dimensions to investigate (Y. Dien, 2006)*

2.3 Different aims for accident investigation

Accident investigations can be performed for various reasons and objectives. Each investigation depends on the stakeholders and their perspectives.

Table 1 is an example of the numerous stakeholders that can be interested in performing an accident investigation. Their investigations will often be managed simultaneously and independently. This may lead to conflicts in performing the investigation (such as access to the accident scene and to witnesses, the collection of facts, the preservation of evidence) or may compromise the results of the investigation (such as the investigation's findings, the communication of the findings,...).

Some regulations in some countries try to specify these contexts and cooperation principles, in particular, between Safety authorities and Justice (see ESReDA publication *Shaping Public Safety Investigations of Accidents in Europe*, 2005).

Table 1 *: A general classification of accident investigation stakeholders*

Type of stakeholders		
A) The Companies	**B) The Authorities**	**C) The Public Parties**
• The company and the group; • The Health, Safety and Occupational Conditions departments; • The insurers, • The sub-contractors or clients.	• The local control authorities; • The control authorities of local control authorities; • The police and justice, • The labour inspectorate; • The fire and rescue services; • National control authorities, Ministries and Government	• The Health, Safety and Occupational Conditions committees; • The third party-expert; • The independent investigation board; • The victims associations; • The Parliament and political parties; • The mass media; • The Non Governmental Organisations.

In addition to the stakeholder standpoint, Rasmussen et al. (1994) have identified several perspectives on investigating human errors, such as:

1. Explaining an unusual event: the *common sense perspective*;
2. Understanding human behaviour (or organizational behaviour): the *scientist's perspective*;
3. Evaluating human performance (or organizational performance): the *reliability analyst's perspective*;
4. Improving human performance (or organizational performance): the *therapist's perspective*;
5. Finding somebody to punish: the *attorney's perspective*;
6. Improving system (organization) configuration: the *designer's perspective*.

These guidelines focus more on safety investigations of accidents and may be governed by perspectives 2, 4 and 6. In a same investigation, stakeholders may use several 'hats' (such as 4 and 6). These guidelines will be of interest to the different stakeholders (A, B and C) for their own investigative purposes, in particular for the understanding of the accident and the insights they provide on safety lessons to implement.

It is essential to take stock of all these perspectives when carrying out an accident investigation, as all stakeholders involved will be associated with special interests and view the event from a particular angle. Thus, this could assist in a better perceiving and understanding of others and provide insight on how to better communicate with them.

Such a position may contribute to the credibility of the investigator as an independent and qualified expert, able to take a more independent position irrespective of an individual stakeholder's interest or objectives.

2.4 Different requirements and frameworks for accident investigations

As outlined above, different stakeholders have different aims for investigations. Achieving an effective and credible investigation relies on recognition of these different requirements and frameworks:

- Participation in an investigation will be affected by individuals' and companies' perceptions of the investigation and its goals;
- Corporate requirements will be to protect company reputation and liability;
- Political requirements will be to satisfy key stakeholders without attracting blame to senior figures or recommendations which prove to be politically unattractive or excessively costly to implement;
- Societal requirements will be to find someone (individual or company or both) responsible who will take action to ensure "*it can never happen again*";
- All will require the investigation to be thorough, to find out what happened and to be transparent;
- All will require the output to be perceived to be independent and seen by all as highly credible and as an authoritative statement.

2.5 General principles for accident investigations

The illustration of the different levels, approaches, disciplines, and environmental stressors in the socio-technical system (seen in Figure 3) clearly shows that, in order to address the multiple causes of event occurrence, several factors can influence the investigation process of an accident and that the various levels, approaches, disciplines,... could each play a role in the entire process. This hierarchic model also indicates the type of information that exists between the levels and the factors that can influence the process of investigation. It also indicates the way to adapt changes and demonstrates the need for a multidisciplinary approach. This model provides a vision and an understanding of the complexity and process dynamics which should be tackled and revealed by the investigation.

Although accident investigation is a complicated process, it is necessary to pay particular attention to the following principles:

a. Basic assumption

An investigation should be a fact-finding activity to learn from the experience of the accident, not an exercise designed to allocate blame or liability. The emphasis in conducting investigations should be on identifying the underlying causes in a chain of events leading to an accident, the lessons to be learned, and ways to prevent and mitigate similar accidents in the future.

b. Protocols

Protocols should be established for conducting investigations. These protocols should identify the roles and responsibilities of the individuals involved in the investigation, specify the steps to be taken in the investigative process and establish a common terminology to be used in preparing investigation reports in order to facilitate sharing information related to investigations. Caution should be taken regarding “anonymity” (e.g. persons interviewed, victims, organisations). Decision regarding this issue has to be made at a very early stage of the investigation process, and this decision has to be communicated to the participants and the stakeholders.

c. Coordination

As there can be more than one body with the authority to investigate an accident, efforts should be made to co-ordinate the investigations to avoid duplication, improve effectiveness and help ensure access to all relevant evidence.

d. Competence

A team should be established and should consist of participants from different disciplines, with different skills, including those with knowledge of the specific installation and work practices (operators, engineers, managers) subject to the investigation. All members of the investigation team should have the appropriate knowledge, competency and experience to carry out investigations. They should comply with the professional criteria of independence and objectivity.

e. Data and evidence

Investigations should take account of the various types of information/evidence that might be available, including testimony from people (e.g. witnesses, experts) collected by face-to-face interviews or by hearings, relevant data, documentation and physical evidence.

Evidence should be protected in order to facilitate the investigation process. There should be clear identification of who has responsibility for evidence and who can release evidence. Caution should be taken to ensure that all involved parties agree about the correct procedure for handling all collected material.

f. Reporting

Investigation reports should include a factual chronology of the events leading up to the accident/near-miss, a statement of the underlying causes and contributing causes, and recommendations for follow-up actions. The recommendations should be specific, so that they can lead to adaptations (expected improvements) of technology and management systems. The objective should be to seek optimum solutions under the given circumstances, recognising that it might not be possible to achieve perfect solutions.

g. Follow-up of investigations

When following up an investigation, there should be a review of the investigative process to help ensure that it has been effective, that there has been appropriate communication of its findings and to learn for future investigations. Efforts should be made to improve sharing experience related to the methodologies and approaches used in investigations of incidents.

h. Communication

All communications concerning the investigation should be as transparent as possible without compromising the investigative process.

2.6 Phases of accident investigation and background knowledge

Accident investigation includes several main phases or tasks:

- Data collection;
- Hypotheses generation;
- Analysis;
- Findings;
- Recommendations.

Each of these phases/tasks is presented in more detail below.

Relative importance of phases along the investigation process

The allocation of efforts and resources to various phases may vary throughout the working progress of the investigation (e.g. collecting data load is decreasing through time, although the workload for drafting recommendations is increasing). This relationship can be seen in Figure 6.

Furthermore, each phase is connected with other phases. This means that all along the investigation, several phases can interact and will have to be managed in parallel.

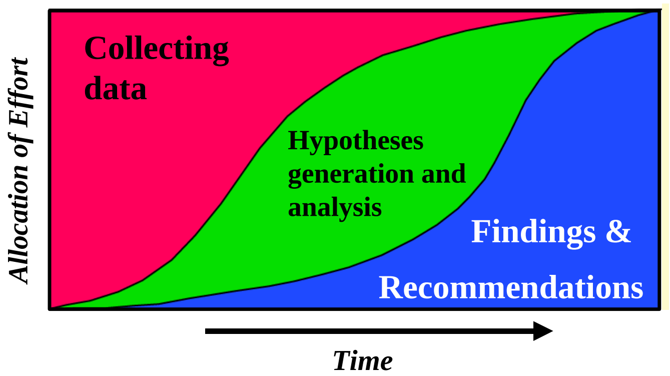

Figure 6: *Progressive allocation of effort to investigation phases (adapted from US DOE, source NRI Foundation)*

<u>Phase I : "Data collection"</u>

Data to be collected could be objective (chronological record of events, parameters and/or values, status of systems involved, written reports), subjective (feelings about a situation, explanation about relationships with other people) or mixed, i.e. "objective phenomena" described/rationalised by a person (such as an explanation of actions, description of situations,...).

Every fact that seems relevant to the analyst(s) for explanation and/or understanding of the event has to be collected.

Data to be collected is not only "linked" with field personnel and/or line operators in the workplace, or only related to the direct (immediate) cause of an event. This means that in particular, history related data and managers' actions (e.g. decision makings) have to be taken into account, as well.

<u>Phase II : “Hypotheses generation”</u>

First set of data collected allows to defining assumptions concerning causes of the accident. Hypotheses can reflect several standpoints: for example, technical, human, organisational and cultural causes. Assumptions shape analysis and lead to other data to be collected so that they may be challenged. At the end of the investigation, hypotheses can either be confirmed or denied.

<u>Phase III : “Analysis”</u>

Analysis is the stage during which assumptions can be challenged. This means that they can be proven—either as relevant or as non pertinent—thus requiring some new hypotheses to be defined (and processed in the same manner as were earlier hypotheses).

<u>Phase IV : “Findings”</u>

At the end of the analysis phase, the analyst is left with a set of proven[2] hypotheses. They represent causes (direct and root) of the accident. Findings are a synthesis of accident explanation, i.e. they mainly deal with the causes that led to the accident. Findings also deal with phenomena that did not contribute to the accident itself but are discovered during the process of the investigation.

<u>Phase V : “Recommendations”</u>

Once these causes (technical, human, organisational, societal and cultural) have been established, corrective measures must be defined, tested, implemented[3] and validated in operation in order to ensure that this type of accident does not recur.

Background knowledge

Every analyst acquires skills and know-how, so accident investigation is influenced by ‘initial knowledge’ (i.e. *a priori* knowledge or reference models from the analyst’s earlier experiences). Additionally, connections between investigation phases are not a linear process, but rather an iterative one. This iterative process and the relationships between the various phases can be seen in Figure 7.

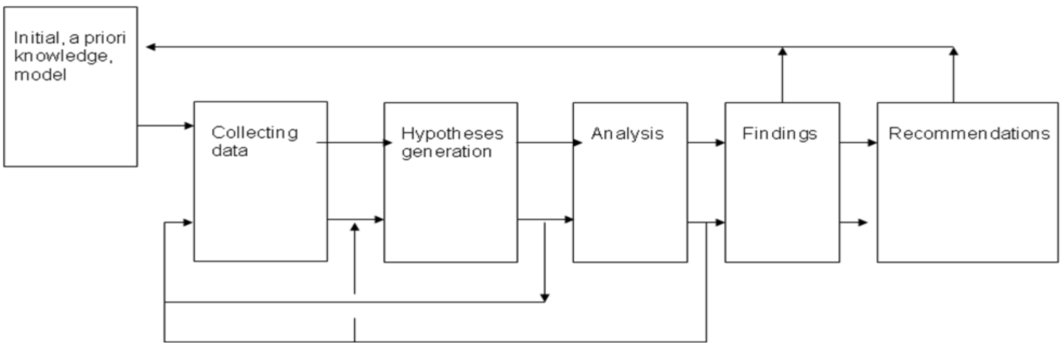

Figure 7: *Initial knowledge and accident investigation*

[2] “Proven” as used here means valid, but especially from the viewpoint of the persons involved in the accident and in the investigation.
[3] What are limits of scope of investigation ?

Indeed, an analyst or an investigation team member is not naïve regarding event analysis. He/she has a set of knowledge -- previously acquired -- and related to:

- Methodologies for fact-finding regarding technical, human and organisational factors;
- A set of chief findings and lessons learned from other accident or incident investigations;
- Techniques that can be used to identify certain root causes or to uncover facts "hidden" in the past or by the situation.

This body of knowledge helps the analyst to set up hypotheses that make up the skeletal framework for the analysis, i.e. to establish a general framework for (field) analysis guided by the principle that, *"You can only find what you are looking for.*" As a result of analysis, hypotheses will be confirmed or discredited. In the same way, this knowledge is useful for producing a synthesis for drawing conclusions and for developing recommendations.

Thus, an accident investigation is part of an iterative process of continuous improvement: i.e. it is fed by and benefits from the set of knowledge the analyst acquired from previous investigations and lessons learned, which in turn contributes to the skill set and experience that become the analyst's *improved* set of knowledge to be applied in future investigations.

It is especially necessary that the analyst focus on acquiring the knowledge of day-to-day (routine or standardized) operations, which form part of the background knowledge required for carrying out an accident investigation (deviations from the routine or standardized processes become items of interest in an accident investigation).

2.7 Models and methodologies for investigating accidents

When carrying out an accident investigation, an accident model is needed (see sections 2.1 and 2.2). The general principle of accident causation models encompasses all aspects ranging from consequence(s) to cause(s).

When starting the investigation, the entrance gate to the investigation process is the unwanted consequence (near-miss, incident, accident, disaster).

An investigation, in industrial sectors, addresses 4 main levels (see Figure 8 below):

- The main elements of an event (in the rectangular block) that are produced by the 3 next levels;
- The person (unsafe act);
- The workplace (error-provoking conditions);
- The organisation.

The upward-directed thin arrows in Figure 8 indicate the direction of causality and the downward-directed thick arrows indicate the investigative steps

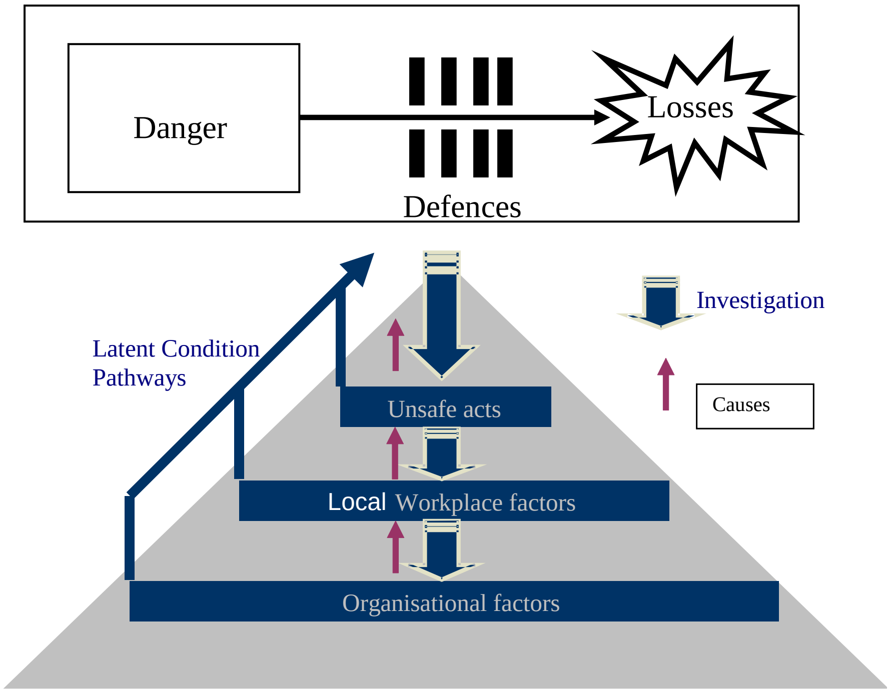

Figure 8: *Stages in the development and investigation of an organisational accident (from Reason, 1997, ©Ashgate)*

Accident investigations have several purposes. Their conclusions are about what happened, why it happened and what is recommended to prevent the recurrence of similar accidents.

Different types of approaches are available: some are more quantitative or more qualitative; some enable an explanation via use of an underlying model (data that should fit the model); and, some are comprehensive (model that should fit the data).

Methods may be constructed based on different forms of logic or process characteristics (such as deductive, inductive, morphological or non-system oriented). (For additional description, please see Sklet 2003).

Another important characteristic is the underlying model of an accident that may have influenced the methodological design. This underlying model influences the view of the accident causation. Several models have been suggested as examples of the main accident models in use: Causal-sequence model; process model; energy model; logical tree model; SHE-management models (Sklet, 2003, Kjellen 2000). Accident models can also be categorized based on other criteria (Hollnagel 1994)[4].

Table 2 summarises some of the various parameters and main characteristics that influence the methodologies used in accident investigation.

[4] Hollnagel suggested that models could be classified in three groups, ranging from: 1) Deterministic models (cause-and-effect models, anchored in a technical view of the accident); 2) Pathological models (searching for elimination of errors or as a set of indicators of the health of the system); and 3) Systemic models (or ecological and dynamic models, that try to manage errors as intrinsic features of complex systems and try to understand causal mechanisms, such as underlying drifts and deviations of organisations).

Table 2 : *Example of criteria to classify methodologies*

Purposes of the investigation and its conclusions are about	**Levels and/or phenomena to be addressed; type of data,**	**Phases of the investigation; tasks to be performed**	**Type of approach**	**Methods employ different forms of logic or processes**	**Underlying accident model**
- What happened - Why it happened - What is recommended to prevent the recurrence of similar accidents	-The main elements of an event (in the rectangular block) that are produced by the 3 next levels: - The person; - The workplace; - The organisation.	- Data collection - Hypotheses generation - Analysis - Findings - Recommenda-tions	- Quantitative - Qualitative, - "Data that should fit the model" - "Model that should fit the data"	- Deductive - Inductive - Morphological - Non-system oriented	- Causal-sequence model - Process model - Energy model - Logical tree model - SHE-management models

Several methodologies have been described and classified according to most of the characteristics seen in Table 2. (For additional discussion please see Sklet 2003, Frei et al. 2003, Energy Institute, 2008). Another interesting classification of investigation methodologies and tools was provided by Frei et al. (2003) that combined three separate criteria of characteristics: phases of investigation, scale of investigation (severity of event) and level of abstraction.

To conclude, the main point is that a variety of methodologies and tools are available to investigators. They should be chosen according to the context of their use (which is discussed more fully in section 3.4).

2.8 Investigator(s) and investigation

The investigator (or team of investigators) cannot be regarded as neutral to the investigation outputs. There are—at least—two aspects regarding investigators that could make an impact on the investigation results:

- Position of investigators towards the event;
- Role of investigators regarding investigation results.

Results (report) of an investigation have to be read and interpreted with the knowledge of the position and role of the investigator(s).

Position of investigators

Investigators can belong to one of three different schematic layers of an organisation. They could be:

- Part of the company where the event occurred and also part of the operational facility and/or plant;
- Part of the company where the event occurred but attached to another organisational layer (such as the corporate headquarters), rather than the facility and/or plant itself;

- From outside the company where the event occurred (e.g. they might belong to the Safety Administration or to a consulting company specialised in event investigations).

One goal of investigators is to detect and to take account of the entire set of possible event causes; in other words, to gain a global picture of the event. Some accidents (e.g. the loss of the space shuttle *Columbia*) showed that some root causes of the event were beyond the strict organisational boundaries of where the event occurred. If investigators are “too close” to the event, then some root causes can be “hidden” (or disregarded for investigation) because investigators may not have the authority and/or perspective (i.e. the possibility) to investigate beyond the boundaries of the organisation to which they belong. Another issue is that a “culture of efficiency” could lead investigators to emphasise the controllable and manageable causes for which corrective measures exist within the organisational boundaries available to the investigator(s).

So, the position of the investigator(s) with respect to the organisation influences their view of the situation and, therefore, their analysis. In order to comprehend an event in its broadest scope, investigators must be in a position that enables them to grasp the “big picture” of the event as well as the comprehensive situation that preceded it.

Role of investigators

It is very rare that an event investigation is launched based on an initiative of the investigator(s) themselves. Either the investigation is requested by someone in authority (such as part of management or administration) or it is part of a procedure to be applied after an event occurs. As a consequence, the results of an investigation are not under the full control of the investigator(s) and the results may be screened before (public) release of the investigative report. Therefore, the information in a report might only be a part of the data gathered and results obtained by the investigator(s).

Clearly, the more independent an investigator is from the authority that ordered the investigation, the more likely it is that more information will be released in the final (public) report. Investigative reports issued by independent boards (e.g. the Columbia Accident Investigation Board/CAIB or the US Chemical Safety Board) are expected to more accurately reflect the investigation findings.

3 PROCEDURES AND PREPAREDNESS

Bearing in mind the general principles of accident investigation (as described in Chapter 2), this chapter aims at discussing issues to be clarified within an organisation before the (next) investigation is started.

3.1 Clarifying investigation needs: planning, training and preparedness to investigate

It should be kept in mind that the scale of needs, risks, stakes, resources, applications, et al. is wide (ranging from small to medium-sized enterprises/SMEs to High Risk Industries).

In practice, developing operational readiness for any function means creating an organisation that: places the right people, in the right places, at the right times, working with the right hardware (tools), according to the right procedures and management controls (Kingston et al. 2005). Kingston et al. describe such a programme including several steps or actions to be developed to maintain readiness to investigate:

- Develop willingness to investigate among participants and stakeholders;
- Define requirements and criteria (such as a policy for learning from experience, codes of conduct and standards) as guidelines for an investigation;
- Prepare an incident response plan (notification of event, need to preserve evidence during the emergency and rescue actions);
- Identify basic elements of the investigation response and prepare an investigation activation plan (with potential participants and stakeholders, investigator's toolkit, and the establishment of an activation procedure);
- Achieve the level of readiness for initiating an investigation (rapid implementation of advance plans, ready to specify the investigation's terms of reference, ready to consult the stakeholders, ready to appoint the investigation team);
- Develop readiness to manage the investigation (i.e. to manage activities, to manage data collection and its preservation, to perform analysis);
- Verify readiness to investigate.

The participants of an investigation should be appointed according to their competencies. They should be trained in the field they will be responsible to investigate in order to bring expertise to particular tasks that form part of the investigative process (such as assessing damages, interviewing, reconstructing a chronology, performing a causation analysis, analysing human, organisational, societal factors).

Usually few people are trained internally on all of these investigative skills and external expertise is often requested. An investigation facilitator or mediator might be useful to assist the internal staff in conducting an investigation.

3.2 Procedure for accident investigation

Procedures are often just the "tip of the iceberg" in terms of investigation preparedness. Written protocols and guidelines provide a framework of how the investigation's objectives can be fulfilled and specify the main requirements (such as defining chronology, identifying causes). Based on the different phases of an investigation, the guidelines should – at a minimum - provide the basic principles and at best, the practical suggestions and tools of how the various tasks should be performed.

The design and contents of the guidelines should be worked out by the participants of the investigation with a goal to strike a balance between principles and practical details, between very short and general, and between very precise and very long explanations and recommendations. In practice, it's often the case that the main principles of investigation are found in the main part of the guidelines while practical checklists are found in the annex (such as for interviewing, collecting and preserving evidence, conducting a public hearing). Developing guidelines with potential participants in an investigation is a good way to develop competencies among the investigative team, to promote and implement the approach to users and to maintain readiness.

3.3 Defining the aim of accident investigation : the Terms of Reference(ToR)

At the start of any accident investigation, it is essential to define and agree on its aim. This is best achieved with the involvement of stakeholders throughout the development of a formal statement (sometimes referred to as the *Terms of Reference*/ToR or the *Remit*). The Remit should build on a general common basis to identify the safety lessons without apportioning blame or liability. At a minimum, it needs to include:

- Scope of the investigation;
- Requirement to identify immediate and underlying causes;
- Timescales;
- Requirement to issue an immediate safety notice on any safety matter identified that requires urgent action;
- Requirements for a report;
- Audience for the report.

The time spent on refining the Remit and taking account of stakeholders' views is likely to lead to the investigation report being more readily and widely accepted.

3.4 Choice of approach and methodology

The main idea is to choose the accident investigation methodologies according to their context of use. (For additional discussion, please see "*Tools in context*", Frei et al. 2003). In Section 2.7, methodologies were analysed and categorized according to various dimensions.

The context is determined by the Terms of Reference (described in Section 3.3) of the accident investigation agreed upon between the parties, which defines the scope of the investigation (direct and root causes), the requirements for the report and urgent recommendations, the timescales and the audience.

Indeed, it therefore implies, according to the stakes involved in the accident and expected results of the investigation, several levels of resources that are usually provided to the investigation. Constraints may be placed upon the investigation, as well. The choice of people and skills required in the investigation team ranges from those with general knowledge to specialist experts, all helping to understand and make sense of the phenomena (from physical, to human, organisational and societal aspects). The choice of methodologies will depend upon the resources, time constraints and the expertise needed to use the investigation tool (meaning that a novice can use the tool or meaning that it needs a specialist or an expert in the particular methodology).

To assist in these decisions, some basic "*do's and don'ts*" are suggested:

- Tools and methodologies are 'servants' and not 'masters';
- Organisations that want to increase their potential to learn from opportunities such as incidents, should have already trained some investigators beforehand to use a set of relevant tools;
- Apply the "stop rule" : this rule leads to usually stop an investigation with a goal that can be managed; Investigators have a tendency to limit themselves in their investigation; so it's not necessary to be too strict in the framing of an investigation.

4 CONDUCTING THE INVESTIGATION

When notification of an accident has been received and the decision to start an investigation has been taken, the work with the actual investigation is just commencing. In this chapter, several aspects related to this set of tasks are outlined in detail.

4.1 Conducting and managing an investigation

Since these guidelines are intended to provide a general approach in accident investigations suitable for nearly all industries, the guidelines remain generic in nature.

Main objectives of an investigation

As discussed in Chapter 3 the aim of an investigation must be defined within an agreed Terms of Reference. The fundamental objectives of an investigation are to answer the following questions:

- WHAT happened? In particular the chronology of events;
- HOW did it happen? In particular, explaining the causal relationships (mostly mechanistic with regard to this objective with so-called direct causes) between events;
- WHY did it happen? In particular, understanding, making sense and recognising a rationale for actors' actions, decisions, operations, design of systems and organisation, in order to identify and highlight the complex causal relationships with the so-called root causes.

In order to do this, facts and information must be collected and analysed at several levels of the socio-technical system and at differing proximities to the risk and to the events (i.e. range from the 'sharp end' to the 'blunt end'). In order to render such advice implies that the investigation produces intermediate products that enable a thorough analysis and obtain reliable findings:

- At the operational level, the goal is to construct a narrative description of the event;
- At the tactical level, the goal is to identify the contextual factors (both before and after the event);
- At the strategic level, the goal is to provide information on systemic and knowledge-based deficiencies in previous events and past performance of the system.

Basic requirements in order to conduct and manage the investigative process

Conducting and managing a high quality investigation is influenced by the following criteria:

- *Preparation of the investigation* should include an inventory of necessary assets and equipment, protection of the investigators' working conditions, identification of site specific hazards, drafting a work plan, procedures, documentation and identifying communication facilities;
- *Scrupulous conduct of an investigation* should include the completion of a comprehensive site overview, preservation of volatile and/or perishable evidence, timely collection and documentation of on-site information and recorded data;

- *Efficiency and control of the work processes* is achieved by: applying ‘stop rules’ for information collection and data recovery and employing a structured search strategy; balancing the investigation activities so as to include stakeholders, while addressing a thorough examination of system components and operational conditions;
- *Transparency in the decision making processes during the investigation* is facilitated by verifying the criticality of information deficiencies, assessing the required level of data collection and applying a structured search strategy with respect to gaining oversight of the event, ‘zooming in’ on uncertainties and peculiarities while working toward a synchronisation of events and actions;
- *Maintaining high ethical standards* is a prerequisite throughout the investigation with regard to impartiality, independence, credibility, fairness, objectivity and a respectful attitude towards victims and their relatives.

Conducting an investigation: what is the rationale?

The *rationale* in accident investigations consists of diagnosing unknown situations through an iterative reasoning cycle in which a temporary and conditional adaptation of the hypothesis under investigation takes place. One way of looking at the investigation is that it is about reducing uncertainty about what happened, why it happened and what should be done about it by applying the knowledge available to the investigator(s) based on the evidence obtained during the investigation. In that sense, management of the investigative process can best be described as:

- Structuring known facts and findings;
- Structuring unknown information that will require further collection or analysis.

Finally, throughout the investigative process, a cyclic decision making process takes place, covering perception, analysis, decision-making and action. In particular where information deficiencies occur due to lack of evidence or data, exploring additional ways of collecting data is mandatory.

Basic competencies needed for conducting an investigation

In order to increase the likelihood of the investigation’s success, certain competencies are particularly helpful:

- Familiarity with a broad range of disciplines;
- Ability to pursue several lines of investigation simultaneously.

The investigative process can be seen as being conducted at three different levels of investigators’ expertise:

- At a skill-based level: based on training and learning by doing;
- At a rule-based level: by applying (to the degree possible) established steps, procedures and protocols in the investigative process;
- At a knowledge-based level: by using cognitive decision-making methodologies and techniques when selecting investigative strategies, setting priorities during the investigation and assigning the optimal choice of methods and techniques to specific issues that may emerge during the conduct of an investigation.

The accident investigation process may use formal protocols – such as the International Civil Aviation Organisation (ICAO) and International Maritime Organisation (IMO) investigation manuals and codes – and may call on qualified experts representing expertise from multiple disciplines and from a variety of scientific domains, as well as operational areas, in order to compensate for knowledge deficiencies that may turn up during the investigation.

Managing the investigation also requires information transfer to occur between various phases of the investigation as well as communication with experts and stakeholders within and outside the investigative team. The investigation management should provide a structure to support such information and communication needs.

Ultimately, one important objective of the investigation is to *render advisory opinions* to assist in *the resolution of disputes* affecting life or property.

4.2 Starting up the investigation

Consequently, before initiating an investigation into a specific domain or accident situation, each investigator should: establish the objectives; identify the goal and scope of the investigation; declare his/her formal position as an investigator, including mandate, competencies, available codes of conduct and qualifications. Such an assessment should clarify the necessary resources, responsibilities, codes of conduct, operating environment, public exposure and complexity of the event. In doing so, an investigator will proactively assure his/her credibility, ethical standards, professional judgement and quality of personal performance.

When the first contacts are undertaken between the investigator (internal and/or external) and the client of the investigation, several initial steps should be taken:

- Gather all initial information concerning the accident;
- Establish which factors will need investigating;
- Determine which skills will be needed to thoroughly examine those factors;
- Establish which companies are involved;
- Appoint an appropriately-skilled and independent person to lead the investigation;
- Draft and agree on the terms of reference for the investigation;
- Establish a senior single point of contact in each involved company.

4.3 Collecting data: the fact finding phase

Principles of the fact finding phase

After the decision has been made to start an investigation, the fact-finding phase of the investigation starts. This phase discriminates between an on-site phase and a post-scene phase. During the on-site phase, facts are collected which provide insights into WHAT happened and HOW the event happened. After the closure of the on-site phase, further information is collected through the post-scene fact-finding activities. This particular fact-finding phase is a prerequisite for the analysis phase that establishes WHY the event could happen, and the recommendation phase that establishes WHAT can be done and by WHOM to prevent recurrence of such events. Although all these phases are interlocked and processed cyclic several times during an investigation as a result, the choice of appropriate methodologies and techniques vary considerably. (Please see Section 2.6 for additional description).

The primary objective of the fact-finding phase is to provide data to enable a reconstruction of the accident—much like pieces in a jigsaw puzzle—by determining the set of (intervening) intermediate events. Below is a schema that locates the fact-finding phase throughout the overall investigative process.

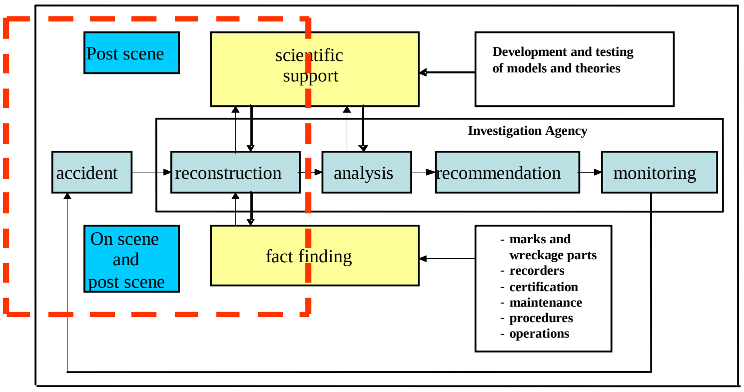

Figure 9: *Positioning the fact finding phase*

Data collection - first phase

In order to structure the fact-finding phase, the on-scene as well as the post-scene investigation applies a systems perspective, scrutinising different types of data at different levels of the socio-technical system:

- All actors and all components in the system are elements of the investigation. Actors include operators, managers, customers, shareholders and victims; components include technical means and assets, infrastructure, traffic control and management, operational and managerial controls, rules, regulations and qualifications;
- The system state before, during and after the event; especially with regard to the established set of operating envelope as well as both the actual performance and the expected operating parameters;
- The operating conditions and constraints, the system mode and operating environment. With respect to the accident site, specific constraints are established such as site accessibility, physical environment, other parties involved. Specific conditions are taken into account, such as contamination, toxic substances and impairment to safe operation;

Based on a frequently used underlying model of energy transfer (originating from the medical metaphor), two main paths of data collection can be followed in order to reconstruct the origination of the accident:

- The causal part before the damage was produced, i.e. the energy source: dealing with system state information, operating constraints, chronology of actions, decisions taken, etc;
- The consequences (damages, effects) and their origins: characterisations of the damage pattern and energy transfer, gathering information about potential vulnerability of the stakes, assets and targets related to a given hazard and an indication of the survivability of the activity/system following the event.

These two paths will cross at the time of event reconstruction and analysis, when generating hypotheses about the causal relationships of events.

In order to provide the investigator with a more comprehensive awareness of the situation during the on-site investigation, an assessment should be carried out with respect to:

- Complexity of the event, its scale and magnitude;
- Volatility of the information;
- Necessary documentation of the accident site's (physical, environmental) state regarding imprints, vectors, headings and forces;
- Final state after the event from a technical, medical and psychological perspective;
- Parameters of actual operating characteristics and operating conditions, the expected performance according to standards and related constraints;
- Condition of the event site.

Methodology in collecting and applying data

All available techniques should be applied based on the investigator's decision regarding the relevance of additional information to be collected.

The techniques should be used in an iterative manner. An analysis for criticality can be used both for achieving consensus about the actual sequence of events as well as for generating hypotheses.

For the on-scene and post-scene investigation phase, a wide variety of data collection techniques are available for the investigation team.

<u>At the tactical level, specific dedicated techniques exist:</u>

- Technical reconstruction;
- Witness interviewing;
- Simulations and tests;
- Physical reconstruction of wreckage;
- Identifying operating conditions;
- Read-outs from data recording devices.

<u>At the strategic level, a variety of data sources of a formal and informal nature are available:</u>

- Trend and pattern recognition;
- Design requirements;
- Rules and regulations;
- Training and certification;
- Transfer of information and knowledge/expertise;
- Motives and decisions that may have impacted performance.

The two main techniques used at upper levels (i.e. actors and organisational levels) are to collect all types of information transfer (e.g. documents about the formal organisation of activities; letters, memos and emails; informal conversations) and through interviews to describe actors' beliefs, perceptions and rationales for their decisions and actions.

Data collection – complementary to production of 'derived data'

In addition to the initial data and facts collected about the system state (such as operational details, data from recorders, damage assessments, testimony from the various actors, etc…), a secondary set of data is produced by analysing the initial data using a variety of different (filtering) techniques. With the help of these techniques, the initial facts are critically assessed in order to derive new findings from their analysis and to eventually iteratively restate the hypotheses generated via the fact-finding activities.

Information on the technical performance/failure can be obtained by applying:

- Forensic techniques;
- Matching patterns;
- Pair wise comparisons;
- Calculations and mathematical modelling;
- Testing the operational status of the system components;
- Simulation operational performance;
- Component reconstruction;
- Timeline analysis;
- Change analysis;
- Graphical representation;
- Interviewing witnesses, participants, stakeholders;
- Document analysis;
- Historical review.

Information on the human elements of performance/failure can be derived by application of:

- Reconstruction of emotions and rationales of decisions and actions,
- Sequence of decision making;
- Information flows and communication;
- Training and skills;
- Analyses and reconstruction of lines of sight, prevailing conditions of visibility, ergonomics, perception, sensory and locomotor skills, tactile feedback.

A description of a decision-making sequence is a construct based on a hindsight view. It will most likely depict the development along a timeline and in a sequential manner.

To capture the forward-oriented actions that were occurring at the time of the event and the cognitive processes used by the operators to rationalise, one has to find out: if the situation was recognised as normal or not, and on what grounds; and if actions other than normal procedures were considered in order to maintain control over the situation. Such a reconstruction of the actors' decision making should provide the investigators with insight as to WHY the decision and actions seemed reasonable and logical at the time of the event.

Information on the organisational, social, cultural and historical dimensions can be obtained from:

- Interviewing people from inside the organisation; and interviewing those from outside, but connected with the organisation (such as subcontractors, lenders and financing entities, control authorities, regulators, the general public, customers, etc…);
- Identifying and finding relevant written documents (written memos about risks, reports from whistle-blowers, strategic policies from top management, records of planned and performed maintenance, risk analysis charts, etc…);
- Analysis of risk management activities (such as learning from experience, risk analysis, management of change, etc…);
- Consideration of other organisationally-related dimensions (such as conflicts, formal lines of authority and informal power, decision making, governance issues, etc…) and historical changes (organisational, governance, technological, competencies, safety practices and production, availability and reliability requirements).

Information on the system state, its condition and operating environment can be determined by data collection and review of documentation on:

- Geographical information;
- Travel and data recordings;
- Graphic and visual site representation;
- Dimensions and operating parameters;
- Interview recordings;
- Timeline documentation;
- Damage assessment;
- Identification of witnesses, victims, event participants.

4.4 Generating hypothesis

Principles

After the on-site fact-finding phase, the process of generating hypotheses begins; reflecting and drawing upon initial findings in order to eventually establish the sequence of events. During this phase a verification of findings takes place, but also—and even more importantly—elimination begins of facts that are disproved by the findings as being contributing or intervening factors in the event. This hypothesizing process serves the dual purpose of selecting the necessary and sufficient (causal) factors and to establish the analytical proof of their involvement in the chain of events.

While it’s possible for only one investigator to conduct an on-site investigation, the hypothesizing process requires teamwork to ensure an objective and unbiased focus. The team consists of the lead investigator – the Investigator in Charge – with additional experts from appropriate domains and disciplines. Together they strive to achieve consensus on the facts and findings in order to establish a satisfactory sequence of events. However, if a lack of information hampers a consensus or conflicting interpretations remain due to differences of opinion, the discourse may be settled later by additional data collection. It is also possible to leave the opportunity open for more than one probable accident scenario. Eventually, similar accidents may provide a satisfactory explanation, based on additional analyses.

This hypothesizing process requires an open mind, while impartiality and objectivity are preconditions for a credible and trustworthy explanation of the accident. Establishing a consensus on the sequence of events is a precondition for communication with the outside world. The rationale for such hypothesizing is based on factual findings, not on speculations, and requires a logical line of reasoning that is easily able to deal with causal and temporal events. The investigation team should be flexible and open-minded, while each team player should be capable of precise and accurate reasoning. If involvement of experts with different backgrounds is requested, it needs to be recognized that there is likely to be more than one type of logic employed, with each type originating from the scientific domain or discipline each expert represents.

In such a case, a strict adherence to causality might have to take secondary importance in favour of the ‘contributing influences’ of higher systems levels and ‘remote factors’ of a more indirect nature.

Some frequently observed concerns are expressed in the list below regarding such remote influences and distant causes ; the concerns arise in comparison with the focus on more proximal factors:

- They have little causal specificity;
- Some are outside the control of system managers;
- Their impact is shared by many systems;
- The more exhaustive the inquiry, the more likely it is to identify remote factors;
- Their presence does not discriminate between normal states and accidents.

This is why such concerns require specific analysis from experts in the fields of human and social sciences to explain and understand these phenomena. They also require insights from accident experts who have the experience of many accident cases as a basis for their judgment about the causality of those factors. They can base their judgment on similarities and patterns, much as a physician would in the diagnosis of the present pathogenic factors that would have caused the disease. Indeed, the recent major accident investigations (such as Columbia and Texas City) have explicitly involved experts from human and social science to help to track, recognise and judge the effects of these remote factors as possible root causes in the causality of the accidents.

Available techniques

Examples of techniques available for hypothesis generation are as follows:

- Brainstorming in teams;
- Expert opinion/pattern recognition;
- Characterisation of systemic design and operational deficiencies;
- Common failure mechanisms;
- Matching facts and findings;
- Building a timeline of events;
- Event reconstruction;

- Scenario generation;
- System decomposition;
- Criticality analysis.

These tools help to share facts, presumptions and beliefs between the investigation team members. They are used to build up the presumed sequence of events. Some tools do help to test causal relationships between events. Some tools are able to both simulate the sequence of events as well as test the causal relationships. Depending on the type of methods used, hypothesis formation can be made systematic and transparent; thus, giving more confidence to investigators and observers alike.

Intermediate products

A full event description is required in order to establish a clear timeline about WHAT happened and HOW it happened. In the next phase of the investigation this description serves as input for the analysis of WHY the event occurred.

The fact-finding phase should produce the following intermediate products for further elaboration:

- Establishing the sequence of events;
- Identifying potential accident scenarios;
- Identifying deficiencies in facts and/or knowledge;
- Definition of additional investigation issues;
- Priority-ranking for the continued course of the investigation.

Fact-finding and analysis provide the potential means for explaining the identification and validation of recommendations and measures to be taken during the next phase of the investigation.

Pitfalls and errors during fact-finding

During the fact-finding phase, several pitfalls and errors may occur:

- Errors in perception of facts
  - Preconceived notions may deliver a perception by expectation due to proximity, similarity, continuity and/or consistency;
  - Underestimation or simplification due to adherence to initial observations;
  - Contextual confusion of the situation, event or system state.
- Analytical errors
  - At the skill-based level due to a lack of routine, conventions, or interference and competition;
  - At the rule-based level due to (preconceived) expectations, experience, confirmation, protocols and biases;
  - At the knowledge-based level due to preoccupation with certain aspects, inappropriate use of analogies and other deficiencies.
- Decision-making errors

  - Scenario preferences that jeopardize objectivity and selectivity while possibly introducing added complexity;
  - Group decision making deficiencies due to tunnel vision and/or groupthink;
  - In establishing indications, counter-indications or non-indications.
- Action errors
  - Multiple allocation of resources that limit the physical, medical, visual, verbal and observational aspects of data collection and analysis;
  - Deficient assessments due to lack of knowledge.

4.5 Analysis of direct and root causes, testing of hypothesis

For a good understanding of the investigative process, several phases and steps are delineated. Such phrasing (phases and steps) might suggest a linear process, but essentially the fact-finding and analysis phases are interconnected by the iterative processing of facts, findings and analysis (see Chapter 2).

Figure 10 is a schema that locates the analysis phase throughout the overall investigative process.

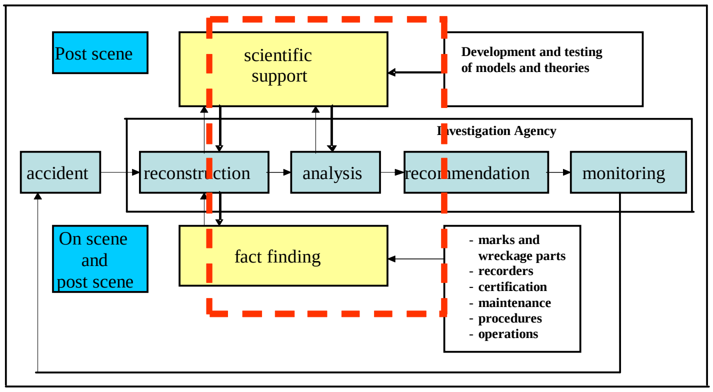

Figure 10: *Positioning the analytical phase*

Principles

There are two major goals that drive the steps to be taken in the analysis:

- To validate WHAT happened and HOW it happened: implies an assessment of the plausibility (proving or invalidating) of hypotheses generated based upon the sequence of events, to challenge the various scenarios with available evidence, to validate the most probable scenario taken from observed consequences and traced back to its direct causes;
- To answer WHY the accident could occur: requires identifying root causes, and asking WHY it was not prevented.

The question of WHAT happened should be answered in a structured manner and carefully guided in order to achieve credible and "objective[5]" conclusions as a basis for consensus about an evidence-based explanation of the event.

[5] An absolute objectivity does not exist in our socially construct world

Preliminary outcomes of this process could be:

- A decision to collect more factual information;
- To generate additional hypotheses;
- To render the investigation as ‘inconclusive’ due to the lack of a satisfactory explanation.

In general, the intermediate product of this investigative phase (challenging the hypotheses generated) can be one, or more, accident scenarios in which a consensus may be reached as an acceptable explanation of the event under investigation.

As soon as the most probable scenario is identified, the analysis of root causes can start, on the basis of direct causes and search of safety measures that could have prevented the accident.

The analysis lies at the heart of the investigative process: between the fact-finding phase and drawing up recommendations. Analysis is an iterative process, clarifying needs for collecting additional information as well as changing the content of the recommendations. Analysis has two aims: structuring what we know and structuring what we do not know. Analysis occurs throughout the investigative tasks and forms the basis for the investigation’s management decisions on performance efficiency and resource allocation. Analysis has no prescriptive rules, but essentially relies on informed judgement under uncertainty.

The use of formal tools may help to provide a more methodical approach, increased transparency and allow people to challenge the analyses or to have more confidence in the investigation’s results because they can see how the conclusions were reached.

Models required

During the analysis phase, two types of models are required in order to link the event to the systems’ performance. First, accident models are required to structure the sequence of events to reflect their temporal and sequential nature and to allocate causal factors to the chain of events. Secondly, systems models are necessary to link accident causation factors to the systems in which the accidents occur. During this linkage process, a transition takes place from explanatory factors towards systems change factors, facilitating adaptation of the system to its new state and configuration.

Accident models:

- Provide structure and transparency in the dynamics and complexity of the event;
- Allocate factors and actors to the sequence of events;
- Clarify relations and interactions between factors, actions and decisions.

These models, though, may contain generic pitfalls:

- They represent metaphors that should not be interpreted as depicting models of an accident (such as Heinrich’ Iceberg, Reason’ Swiss Cheese model);
- Only very few models can be considered as systems-oriented (such as AcciMap or STEP).

Systems models:

- Should cover the overall systems architecture: its structure, culture, context and including the life cycles for the design and operation of the primary systems;
- Should incorporate systems complexity and dynamics;

- Should facilitate identification of systems and knowledge deficiencies;
- Should facilitate the transition from explanation to systems change.

These models also may contain pitfalls, as they:

- May take a static, prescriptive form;
- May adopt a perspective from a specific discipline (such as technical, behavioural, cognitive, organisational or institutional);
- May be overly simplistic, focusing only on accident causation, explanatory variables, and not on systemic deficiencies and control variables.

Systems models should take into account the various dimensions that are characteristic of a systems approach:

- The various life cycle phases (such as design, development, construction and operations);
- The various systems levels (such as practice, management, policy making and governance);
- The various design levels (such as the conceptual, functional and physical form levels).
- These types of systems models can be seen in Figure 11 of the Design, Control and Practice diagram. The diagram shows how the systems models facilitate the representation of possible accident scenarios and system adaptations.

These systems models can be depicted in the following Design, Control and Practice diagram (Figure 11) through which accident scenarios and system adaptations can be related:

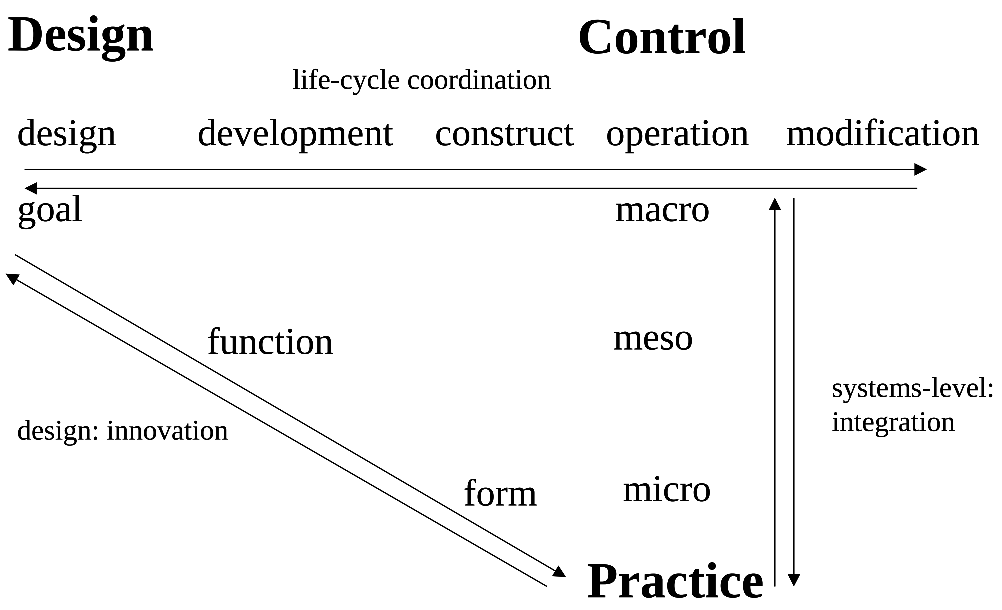

Figure 11: *Design, Control and Practice diagram (Stoop, 1996)*

Pitfalls in analysis

Pitfalls in systems modelling

Several pitfalls exist in applying systems models for representing complex and dynamic socio-technical environments. Such systems may be decomposed in a structural manner and take static, prescriptive form (such as the ICAO Annex 13 investigation protocol from 1951, with several updated editions since then). Such systems modelling may adopt the perspective of a specific discipline (technical, behavioural, cognitive, organisational or institutional).

The modelling may be overly simplistic (such as the SHEL model -Software, Hardware, Environment, and Liveware), focusing only on accident causation and explanatory variables—not on systemic deficiencies and control variables. Thus, it is important to be aware of the perspective from which the modelling is being carried out and the assumptions made in order to incorporate the desired aspects in the communication of results that lead to the decision-making process.

Fallacies in analytic reasoning

Analytical reasoning may contain several fallacies that may hamper the quality of the conclusions. The level of analysis may restrict itself to either technical failure or individual actions, thereby excluding higher systems levels. The arguments may consequently be based on assumptions instead of evidence, creating uncertainty in the likelihood of findings. The reasoning may contain fallacies of a suggestive, restrictive nature and may be based on ignorance of significant factors. The reasoning may not be representative, and rather based on exclusion and a false analogy, or may focus on correlation instead of cause. The reasoning may be ambiguous and appeal to popularity and focus on affirmation without denial (or false presumption) as an option.

Finally, biases may exist due to the manner in which groups process information (such as confirmation, groupthink, risky shift, tunnel vision, hindsight and pigeon holing).

Specificity of root causes analysis

The problems of identifying root causes pose additional challenges to investigators. The first is to identify those remote causal factors and the second is to assess their causal influence to the event generation. The aim is to link general factors (such as human, organisational, cultural) to specific conditions that directly influenced decisions, actions and event sequence.

It must be acknowledged that identifying and qualifying root causes requires additional competencies from the human and social sciences. These last types of competencies are traditionally very rare in a world of technicians and engineers and even amongst managers of those socio-technical systems. Recent major accident investigations, such the one conducted for the Columbia space shuttle accident, have explicitly involved researchers from the human and social sciences. Furthermore, they advocate a methodological posture referring to organisational analysis of the accident (see Chapters 6 and 7). This posture was then used as a reference by the US CSB when conducting the Texas City 2005 accident investigation.

One way to identify and link the root causes to direct causes is to look for safety controls and barriers that have not or could have had prevented the event. This implies that investigators should look for standards that are often applied in working procedures but may have not been met within the context of the accident. Such methodologies and tools were called "Norms, Novelties and Deviations” by Frei et al. in 2003. Therefore, there is a need to question whether or not the controls or barriers should have been in place (as an industry standard), or perhaps they might have been imagined.

Root cause analysis tools exist (such as MORT, Cause Control Change Analysis, Tripod,…) that help to structure the questioning process (WHY did it happen) in a systematic way. They rely on models of risk management that have their own limitations. This point implies a normative vision of what should have been the risk management practices and is helpful for systematic recommendations. But, as a reminder, tools are ‘servants’ not ‘masters.’

In addition, these tools do have limits in highlighting the rationale behind actions, decisions, beliefs and strategies of actors. Comprehensive (with empathy as defined in psychology) approaches are therefore required to address these particular dimensions of human and social systems. Descriptive approaches (based on social sciences models and theories) provide alternative perspectives (but are also complementary to normative models) given the complexity of systems involved.

The specificity of the causal nature requires precautions for formulating judgements. The validity of the root causes can be tackled. Validation of root causes relies on expert judgements and cannot be tested in the same manner as the direct causes (i.e. via simulation, tests, etc...). One way of testing the validity of the findings concerning root causes is to test the analyses regarding the actors implicated in the accident.

4.6 Formulating findings

The findings must express the conclusions of the causal investigation process. They should highlight the major factors that contributed to the event sequence. The pre-findings have been assessed in the analysis phase and some conclusions (the preliminary findings) were reached.

They can be facts that have been verified, presumptions that have been proven to be true or false (based on the available facts or analysis), or judgements beyond reasonable doubt when dealing with human and organisational factors.

A summary of the event sequence and major causes helps to understand quickly WHAT happened, HOW it happened and WHY it happened.

4.7 Communication during investigation

Context and types of communication

Communication is not a linear process. In our information society communication implies many interactions and often subject to multiple dimensions—such as cognitive (transmitter and receiver’s rationale), psychological (meaning of message) and social (perception, acceptability, amplification).

In the exchange of information within the investigative process, every stakeholder will have their own scope of communication and own objectives, which may not necessarily coincide with one another. Furthermore, several key aspects of the investigation should be kept in mind:

- Main investigation steps (WHEN does communication happen ?): range from event notification and include several investigative phases, and finally conclude by communication of findings and recommendations;
- Multi-actor process with various expectations and roles (WHO communicates and with WHOM ?): investigators, victims, witnesses, the public, lessons learners and stakeholders in the socio-technical system;
- Objectives defined (On WHAT is the communication?): provide status of actions, collect information, communicate findings and results, etc…;
- Constraints identified: timing, regulatory, social pressure, budget, etc…;

- Stakes and risks of communication: vulnerability of stakeholders, and political, financial and/or technical risks, etc…

Communication has to deal with two major groups of stakeholders:

- Professional colleagues who are taking part in the investigation or performing a parallel investigation of the same event;
- Stakeholders who are interested in the findings of the investigation. Special attention should be paid to the interests of the media, the victims and their relatives.

As a summary and in this Guideline, safety investigation actors have the following main communication scopes:

- Notification of the event (see paragraph "*Notification of the event*" below);
- Internal communication within the investigative team and process (see paragraph "*Communication inside the investigation…*" below);
- External communication of the facts and findings to the (external) stakeholders (see Section 5.4);
- Providing lessons to be learned and recommendations to be implemented (see Chapter 6).

The communication and information flows and channels of an investigation team will depend on its organisational form, structure and procedures, which in turn are related to the size and severity of the event, nature of the phenomenon, expertise needed, risks/damages and stakeholders involved and investigation characteristics (actors, scope, objectives,...).

Notification of the event

When an event occurs, it is essential to launch the notification process (alarm, signal, phone call, safety-alert e-mail, etc…) ensuring that the relevant management layer is immediately informed. Once extracts of information are available, management's responsibility will be to communicate to (multiple) stakeholders about actions taken to investigate, to restart operations, to inform authorities, to communicate with victims, the public and the media (on a "need to know" basis versus "want to know"). Notification and communication plans should be incorporated into the safety management system of the company and coordinated with the emergency response and crisis management plans.

Communication inside the investigation team and main actors of investigation process

The safety investigation team is similar to a project team whose goal is:

- To explain the event and find the various causes and propose corrective measures to prevent recurrence of such events, and/or;
- To identify systemic and knowledge deficiencies which should be addressed in order to enhance the future safety performance of the socio-technical system.

Communication within the investigation team and with the main actors (witnesses, victims, and people interviewed, etc…) involved in the investigative process occurs according to different types of scope and various objectives:

- At the level of management of the investigation, the flow of information and communication is more *top-down* (roles and responsibilities, rules, safety issues, debriefings, informing victims, etc);

- At the level of the event's investigation, information and communication are more *bottom-up* (information collecting, interviewing, feedback and reporting, etc…).

The nature of messages will vary from management actions to information collection, sharing and reporting. For feedback and analysis, the channels used to send the messages to receivers can be *informal* (mostly oral), *formal* (via oral briefings) or written (procedures, memos and field notes, etc…).

Key points to focus: do's and don'ts

Most examples provided here below have been extracted from investigation procedures such as NTSB's :

- It is essential to immediately set up communication facilities (to provide emails, telephone, fax, meeting room for briefings) at or near the location of the event. If the damages are severe, backup plans (including a plan B and a plan C) may be necessary to ensure uninterrupted communications during the investigation;
- The dissemination of information during the course of an investigation should follow a fundamental and necessary rule, i.e. that no individual or group should withhold information;
- The investigator in charge should share and discuss all information and developments with the authorized stakeholder representative(s). Subsequently, the authorized stakeholder representative(s) are expected to share all relevant factual information with their advisers and stakeholders. The scope and depth of the investigation are dictated by the exchange of information amongst the technical members of the authorized representative's advisory team and any resulting feedback to the investigator in charge;
- Stakeholder representatives may forward information to their respective organisations, provided the information is factual and is presented in the proper perspective. This information should be transmitted on a "need to know" basis for purposes of accident prevention, remedial action, or other similar reasons, and is not for public release;
- Beware of biases in information collected, such as in testimonies (facts versus opinions) where the investigator's protocol, behaviour and questions could influence the information provided;
- On-site progress meetings are held daily to disseminate information obtained during the day's activities and to discuss plans for subsequent investigative activities. Progress meetings should not be used to discuss accident causation;
- Beware of biases (due to groupthink) when generating hypotheses for investigation. Dissenting opinions should be welcomed and formalised for analysis, as needed;
- The use of tools and explicit models for collecting, analysing and interpreting data can facilitate communication in the investigative process (e.g. use of graphic tools describing chronology and causal presumptions). These types of models and tools help to share information, to communicate the facts and to engender a transparent process for generating causal hypotheses. It helps to structure known facts and to identify the "unknowns" that will require further investigation;
- For severe events, the communication and cooperation between investigators is a key factor for the success of the investigation itself. Roles and protocols for information sharing should preferably be defined at the outset (for example, in a Memorandum of Understanding) if no legal obligations and mandates exist that provide a communication

strategy (e.g. see regulations for safety boards). However, keep in mind that facts and information collected will vary according to the objective (conflicting interests in fact-finding, access to and secrecy of data, freedom to disseminate intermediate findings) and skills of other investigators;

- Any issues arising with stakeholders involved in the investigation that cannot be resolved through consensus should be raised to the next level of authority. Failure to follow this chain of command can lead to unnecessary misunderstandings and poor communication within the investigation team.

4.8 Code of conduct and ethics

In order to maintain the necessary moral authority, integrity, independence and credibility, accident investigators should provide an example of what constitutes professional behaviour. Several professional investigative societies have drafted Codes of Conduct for their members.

A code of conduct and ethics is different from general codes of investigation of causalities and incidents as well as codes of practices. A code of conduct and ethics guides individuals in the field in both, avoiding misconduct and promoting sound attitudes, behaviour and representing basic values in accident investigation.

The expectations to follow specific norms for expected conduct and ethical principles are not limited to investigators or members of an accident investigation team. All stakeholders who are involved in an investigation should feel responsibility toward and follow such norms in their behaviour. The code should be monitored, and violations should be subject to sanctions.

A general framework for accident investigation based on broad consensus may include:

- Strict adherence to the objective of investigation for the prevention of accidents and incidents to enhance safety—not to apportion blame or liability;
- The necessity and duty to investigate all major accidents and important near-accidents in order to learn lessons and take corrective actions;
- Allocation of resources for the investigation in proportion to the scale and complexity of the incident and potential to learn;
- Formulation of and follow-up of recommendations with the aim of reducing the relevant risk factors involved.
- Examples of the ethical principles that a code should include are seen in Table 3. The principles included in Table 3 are partly based on the *Code of ethics and conduct* of the International Society of Air Safety Investigators (ISASI, October 1983). Several associations within the accident investigation field have now developed their own codes of ethics, some with slightly different core values.

Table 3 : *Examples of principles for codes of conduct*

Integrity	At all times the activities should be in accordance with the high standards of integrity required of the role, profession or position held by the individual.
Objectivity	While collecting, analysing, describing or communicating facts, the main emphasis should be on objectivity.
Logic	Facts should be applied in a logical manner.
Prevention	Facts and analysis should be used to develop findings and recommendations that will improve safety.
Independence	The investigative body, its investigators and staff should be independent of the national judicial system, other authorities and of all other actors and parties involved.

The investigators should possess several qualities and capabilities, including a high standard of competence and knowledge, professional behaviour, a strong commitment to the objectives of the investigation, impartiality and thorough training in the disciplines aimed at safety promotion and risk control/management.

5 THE INVESTIGATION REPORT AND PROTOCOL

The use of investigation reports is one of the main tools for communication and dissemination of information and findings from the accident investigation. The investigation team is often flooded with huge amounts of information and their challenge is to provide one or more reports with clear-cut messages and recommendations. This chapter gives some advice on how to prepare and disseminate the investigation report, and provides some information about the format and content while at the same time assuring that all relevant parties are given the opportunity to give input.

5.1 Preparation of the report

The access to information from the main actors (such as relevant authorities and/or companies) may be defined in national legislation. National legislation that concerns the rights of the public to documents relating to the authorities' activities defines just how public or confidential the accident reports are. If the documents are in the public domain, the relevant authority decides how actively they will publicise the accident investigation reports. Some authorities present accident investigation reports as separate publications or post them on their website(s).

The final content and layout of the report depends largely on how the accident investigation is organised and conducted. Specifically, this concerns the category of the investigation as seen:

- Public accident investigation (required by Parliamentary, Government, Directorate/Control authority, or a separate accident investigation commission);
- Corporate investigation (in-house – especially in large companies), or;
- Consultancy investigation on behalf of company.

At the outset, the guidelines for preparing the investigation report need to be decided (based on the level of severity, distribution, availability and archiving of the report). It is important to distinguish between who is to receive the preliminary report (possibly during a hearing process) and those parties who will receive the final report. (Please see Section 5.3).

The actual writing of the report and recording of information also needs to start at the very beginning of the investigation. Information and findings should be added to the report along with the progress of the investigative work. This will keep the investigation team members updated with all available information and it will simplify the report's writing and improve the efficiency of the process. It is always very important to document and systematise information being collected (such as interviews and notes) throughout the entire investigative work.

In every phase of the investigation and report writing, it is each team member's responsibility to assure high quality performance. In some cases, or if proven necessary, special quality assurance (QA) procedures should be considered.

Writing a high quality investigation report is of utmost importance, because it may serve as an important tool for changes in design and/or operational features, safety and risk management, public safety assessment and identification of knowledge deficiencies. In addition, the only visible product for several stakeholders, as a result of the investigation, is the report.

5.2 Report contents

In many cases, the scope of the investigation and the complexity of the accident itself will dictate the report's size/volume, depth and content. Based on a number of international sources, the main chapters in the report should be based on the following headings:

1. Summary;
2. Background and purpose;
3. Organisation and mandate;
4. Factual information (e.g. chain of events, consequences);
5. Analysis/method used;
6. Results (e.g. findings, direct and root causes);
7. Conclusions (e.g. most probable scenario);
8. Urgent recommendations to immediate measures;
9. Safety recommendations;

Appendices (to supplement the content and information of the main report).

What is to be included under the various headings will largely depend on the particular accident being investigated. The investigation team should ensure that all information to be documented in the report is included under each appropriate heading.

Special considerations :

Care should be taken when preparing the title of the report. The title should clearly indicate the subject of the investigation. Preferably, it should also contain specific information about the accident. This may ease the retrieval of the report in the future.

Regarding the Summary: Its main purpose is to give a reader unfamiliar with the event quick access to the most significant and necessary information about the event. The Summary should not exceed more than a couple of pages. Furthermore, it should be possible to read and understand the information in the Summary without necessarily having access to the rest of the report. The Summary should contain key information about the event itself (e.g. chain of events), an overview of the causal relationships and recommended risk reduction measures.

If the investigating authority is also a surveillance authority it may be necessary to differentiate between safety recommendations and possible mandatory decisions that must be made in connection with the report.

5.3 Dissemination of the report

The process governing dissemination of the draft and/or intermediate report(s) and the final report(s), as well as their content and layout, largely depends on how the investigation is organised and conducted. In addition, there may be different procedures for the draft and final versions of the report.

Through a hearing process, every participant is given the opportunity to read draft versions of the report(s) and then give their feedback to the investigation team. The basic principle should always be to invite and involve every relevant party in a hearing; and the investigation team should subsequently evaluate and incorporate the input provided into the final report(s). It should be noted that, in some cases, several draft sub-reports might be issued during the investigation process, as well.

Preliminary report

When the preliminary report is ready for distribution, it should be sent to the establishment or facility where the accident occurred or to other involved parties for comments. All parties can be asked to make corrections concerning any aspect of the accident, and to also mark all confidential information that should not be made public. The time limit for responding may vary from weeks to months, depending on the legal mandate of the investigation authority. Information that is regarded as confidential may be defined in national legislation. Confidential information is especially likely to concern facts about business operations or trade secrets, and particularly if such information may cause financial harm to the enterprise in question. Names of involved persons, witnesses and organisations may also be considered as confidential information or may be kept restricted by regulation. Interested parties may also be asked to comment on the recommendations made in the report.

When considering public accident investigations, the official authorities have to ascertain that the interested parties can attend an accident hearing before making any decisions related to the report. The interested parties can, at that point, present any views on the accident investigation, the causes of the accident and so forth.

During the period from the issuance of the draft report(s) to the start of implementing comments from the parties that were invited to comment, it is important that the team keeps careful track of versions and/or revision numbers; logs are usually maintained for this purpose.

After closing the process of gathering comments and a possible hearing, the final report should be completed without delay.

Final report

In the interest of accident prevention, the investigation team should release the Final report(s) as soon as possible after receiving and incorporating the input from the hearing process.

The investigation team is only responsible for submitting its signed reports to the body/entity having ordered the investigation. Proper archiving, further distribution, presentations, etc. are the responsibility of the ordering entity.

5.4 External communication and communicating findings when writing the report

Main principles

The general objectives of external communication (i.e. from the investigation team to the outside) are to disseminate information (facts and findings) to enable understanding of the event (by those who need to know and others that want to know), to enable victims to organise their mourning and to enable lessons to be learned.

All communications concerning the investigation should be as transparent as possible without compromising the investigation process or the privacy of individuals. In some countries, the obligation to provide information about the accident investigation with access to information and public participation are defined in regulations such as the Aarhus Convention (EU) and the Freedom of Information Act (USA). However, some restrictions may apply if the investigation were to be compromised in any way. Some dimensions of communications might be affected by the code of conduct and ethics for the investigators (see Section 4.8). In addition, national regulations may be relevant.

It is important to define a communication strategy, especially when addressing major accidents. The procedure to be used and format for external communication (addressing WHAT, HOW, WHEN, and to WHOM) should be established, including identification of potential communication risks.

When communicating externally, the timing of communication (along with its scope and constraints) is crucial:

- *Right after the event*: often related to crisis management and communicating the decision of when to investigate;
- *During the investigation*: communication of facts and progress may be held as meetings or press briefings;
- *At the end of the investigation*: communication of final findings, final report and further steps to be taken.

The main principles for external communication are:

- Contact with the news media should be maintained by one representative;
- Preview of investigation progress should be provided to invited parties and stakeholders' representatives before release to the media;
- Communication of significant information.

There are several often used means and/or channels for communication of facts and findings: notes for attendees (in press briefings), website with summaries and latest developments, reports (ranging from intermediate to final), slides, videos, press briefings, public hearings, etc... Content should be designed and written to be easily read and understood by any participant.

During an investigation, two main patterns of external communication are frequently observed:

- Communication is limited to the end of the investigative process. Different perspectives of the event from the point of view of all stakeholders may become visible at a hearing to present the preliminary results of the investigation. This offers an opportunity for stakeholders to criticise the draft investigation report;
- Communication throughout the investigation process: frequent communication may garner support for the eventual conclusions and recommendations that should be implemented. This is especially important when several stakeholders are involved. All parties should be convinced by the evidence presented and the opportunities provided to them to change the system accordingly.

Key points to focus: do's and don'ts

Most examples provided here below have been extracted from investigation procedures such as NTSB's :

- It's better to communicate earlier than later. Often, the first (expert) speaker is the one believed. Incorrect information and rumours may circulate quickly and have adverse effects. A relationship based on trust must be established immediately after the event (and even better, before any event);

- The listeners/readers have different expectations (e.g. those that need to know, those who want to know and/or those that need to learn). Their perception of information and rationalisation will vary accordingly;
- Public hearings allow the public to learn more about an accident investigation. Public hearings are sometimes used to collect additional information from victims, witnesses and the general public (e.g. during natural hazards and events with an impact on public health) as well as new insights for investigators' models, experiences, etc.
- At times, keeping the public and the media informed about investigation constraints, difficulties and delays can limit possible harsh treatment from them;
- When organizing hearings, invite and involve all relevant actors. Explain the investigation's objectives, set deadlines, solicit the victims' expectations, and sometimes allocate roles for them (such as helping with information collection);
- The release of information during the field investigation, particularly at the accident scene, should be limited to factual developments until the full story is known;
- The investigator or the appointed representative responsible for communication (e.g. press briefings) should have prepared a memo of the latest facts found during the investigation and a summary for the investigator in charge;
- Identifying the appropriate spokesperson is not as simple as it might seem. In theory, it should be the most credible (i.e. independent, trustworthy and objective) organisation and person. It could be the investigator in charge, but more usually the candidates might be: the plant manager, the plant's or corporate communication services, a safety board member. These individuals are usually trained to communicate in crisis situations and already have defined procedures for doing so;
- Beware that one or more parties to the investigation could be adversely affected by the release of factual information. This situation is often unavoidable but is sometimes resented by the affected party. Such concerns should be raised promptly at progress meetings with all parties, and especially before any news media briefings. Unilateral press briefings or formal "clarifications" by any participants to an investigation should be prohibited;
- Procedures regarding the release of information gathered during an investigation should be designed to prevent parties with vested interests from "leaking" or releasing information that would reflect adversely on other parties. It is also necessary to maintain the procedure agreed by the parties to prevent unnecessary conflicts between investigation team members and stakeholders;
- A situation may arise where the police and judicial authorities or litigants ask other authorities not to publish their findings before the investigation is closed. The reasons for such requests should be in accordance with legislation;
- Parties to the investigation may want to relay to their respective organisations information necessary for purposes of prevention or remedial action. However, it is necessary to first consult and obtain approval from the investigator in charge before any accident information is released;
- Coordinators acting on behalf of the various parties are authorised to allow their public affairs representatives to release general background information about their organisation to the news media during the on-scene phase of the investigation. A good rule of thumb is

that any information that could have been released before the accident is acceptable for release during the on-scene phase;

- The final report should maintain the record of investigative facts, findings and work provided by investigators. It may be the most comprehensive and important record of the event reconstruction and the analysis. Although usually less complete, other channels of information dissemination and communication (such as summary notes, slides and videos) are very important to widen dissemination of the investigation findings. These channels are commonly used in industry to disseminate key information and lessons to be learned. Formats that are increasingly used with success are videos which are developed by some companies for training purposes and by safety boards to communicate their findings.

5.5 Reactions to the final report

The accident investigation commission, either official (public safety accident investigation board) or internal (corporate-based investigation group), must foresee possible reactions to the final report and make plans for how different scenarios should be handled. The content of the final report, the facts found, the analysis, the safety recommendations, etc… may all be used—or misused—by different stakeholders to promote their own interests. The investigation team should have already developed and agreed upon a common approach and behaviour before such situations arise.

It should also be recognised that public safety authorities depend on a form of confidence of consensus among all major stakeholders towards the main conclusions and recommendations in an accident investigation report. Otherwise, mistrust and doubt may linger resulting in widespread discontent that eventually forces the public authorities to reopen the investigation.

In some national legislation, the emergence of new facts about the accident in question may constitute the legal basis for starting a new accident investigation process—usually executed by a new investigation team.

6 LEARNING THE LESSONS

6.1 Who wants to know: who needs to learn?

Every accident investigation is an opportunity to learn and increase the cumulative knowledge available to improve safety and accident management; in particular to further accident prevention, mitigation, preparedness and response to future events. Before sharing lessons and issuing recommendations, it is essential to be aware of the roles of participants and stakeholders (who may have different priorities and agendas) concerning the learning process. Some may want to know and learn, but are they the same as those who need to learn?

- Many different audiences want to know about what happened (e.g. the bereaved, public, police) but these are not always the same as the ones who need (and hopefully want) to learn the safety lessons. For example, after some accidents the police will want to know what happened and who was to blame. Their main goal is not necessarily to learn the safety lessons to be applied to the system. Others will need to learn why and how it happened in order to identify improvements in the way the risks are controlled;
- Those who truly need to learn the lessons are those who are in a position to make improvements and changes (i.e. turning the lessons into actions) to the systems (i.e. organisational and technical processes) for controlling risks. However, there are many layers and levels of learning. According to the layer and level, there will be corresponding stakeholders involved;
- Controlling risks is not just in the hands of experts and the system managers. In some circumstances changes in public behaviour is a key aspect of controlling the risks;
- Many will claim they want to learn the safety lessons: politicians, safety professionals, senior managers and workers, for example. However, it is paramount that they follow through with their claims by putting the lessons into actions;
- It is of utmost importance that lessons are communicated in ‘the right way and at the right time to the right people’ in a manner that they can understand. (Please see Section 3.1 for additional discussion). Depending on the scale of the accident, a communication plan to be used during the investigation can be beneficial.

6.2 Turning findings into recommendations

Recommendations should flow directly from the analysis and findings and contain applicable corrective action(s). Corrective actions (safety measures) may be categorized according to:

- Their position with regard to the risky phenomenon: from preventing the occurrence of the hazard (via detection, monitoring and preventive measures) to reducing the vulnerability (via protection and emergency response measures) for those people, systems or environments at risk;
- Their position with regard to the socio-technical level: re-engineering the process, redesigning the human-machine interface, reorganizing the work on the shop-floor and at the management level(s), redesigning organisational and power relationships, changing regulations and procedures.

As mentioned previously regarding the socio-technical system view, the definition of different types of recommendations requires various types of expertise (Rasmussen 1997).

Turning findings into recommendations can be interpreted simply as analysing the learning experiences of those involved and transforming them into meaningful recommendations. During this process it is important to bear in mind the following:

- Making meaningful recommendations requires a thorough understanding of the system;
- Once accident causes have been identified, it is helpful to refer to a model of the system in order to develop recommendations;
- It is essential to involve and communicate with appropriate stakeholders (those controlling the risks in the system) whilst developing recommendations. This process (of discussing options) leads to more credible recommendations and greater understanding of what needs to be done by the stakeholders;
- When findings are complete and the time has come to move to recommendations, they should be formulated to address the following goals to:
    - Prevent such accidents/events from happening again;
    - Mitigate the consequences should such an event happen again in the future;
    - Address knowledge deficiencies revealed during the investigation;
    - Identify weaknesses in the processes (human, technical or managerial) with special focus on the interfaces (human-technical, human-managerial, technical-managerial), as these potentially could be the weaker parts of the processes within the system;
    - Focus on strengthening these weaknesses;
    - Propose special processes as an early-warning system to quickly address potential breakdowns within critical processes with a potential to trigger cascading effects.
- It may be appropriate to include a reasonable time limit for responding to a recommendation if this is not already mandatory by regulation or law. This may be seen as a way to indicate the investigator’s ranking of priorities, however skill and caution is needed if this technique is used. It must be remembered that recommendations are just that—good proposals or ideas based on the evidence provided during the investigation. They are not mandatory, except in the instances when a safety authority turns them into directives of what must be done.

Please note that some independent investigation safety boards have developed a specific team and set of procedures to deal with recommendations; Indeed, the process is not as simple as it might appear.

In general, two principal strategies are available for drafting recommendations:

- Coping with deviations from a normative level of performance based on optimal operating conditions, and restoring the situation and/or system state to what it was before the disruptive event. This strategy deals with ‘resilience’, i.e. the ability of a system to return to its normative level of performance following an overload. In this scenario, the system will be brought back into the original set of operating parameters;
- Coping with deficiencies in the system’s design and operation. Safety enhancement can be achieved by timely adaptation of the system characteristics and primary working

processes. The system will adapt its operating parameters to enable changes in the operating environment.

6.3 Applying the recommendations

Essentially, recommendations are statements of the lessons drawn from the investigation by the investigators. Learning the lessons means taking some actions and implementing some changes. The role of those with authority to implement the recommendations can be considered against the following guidelines:

- It is for those with responsibility for the activities affected by the recommendations to take them into account and follow-through with appropriate action;
- In determining their response (to either accept or reject) the recommendations, the responsible party should consider all information relevant to manage and/or control the risk(s) involved;
- Responses to recommendations should be recorded: any rejected recommendations should be supported by a justification or rationale; any accepted recommendations should be accompanied by an action plan;
- Actions taken in response to recommendations should be tracked through to their completion;
- Formal steps should be taken to preserve the 'lessons learned' in the corporate memory (such as a database of recommendations and actions, a record of why changes are made to systems, etc.). Similarly, steps should be taken to ensure lessons are learnt across the industry sector and that its memory is also preserved;
- Lessons must not rest only with individuals but with systems' change and mechanisms to ensure the lessons are not lost;
- A key challenge is in the proactive use of databases of lessons and/or recommendations. Only through the continual use of these databases to challenge safety management systems and develop refinements, will the full potential of the investigative process be realised. The goal is a 'living memory' that constantly informs of actions to be taken rather than a dormant listing residing in a rarely used "black box."

6.4 Codes of good practice

The following codes of good practice should be respected and practised:

- Recommendations need to be clear and unambiguous;
- The accident investigation report needs to clearly set out the reasoning applied, based on evidence of what happened, and forming the basis of the recommendations;
- Consultation with system owners (i.e. involved parties) on draft recommendations before publication leads to more practicable recommendations and a better likelihood of a more positive response;
- The integrity and credibility of investigators is crucial to securing acceptability of their findings. This is mainly achieved by professional reputation based on actual behaviour. Codes of conduct covering such matters can be especially helpful, though, at the start of an investigation to provide assurance to stakeholders in the absence of knowledge about the individual investigator(s).

6.5 Learning from several investigations

There are several advantages to integrating lessons learned from other similar investigations:

- Added value can come from reviewing the output of several investigations to identify system deficiencies which were not identified by any one single investigation;
- A series of similar incidents (near misses) can be investigated to reveal important safety lessons;
- The regular analysis of investigation reports and recommendations can reveal recurring problems and system deficiencies and assist in the prioritisation of actions.

6.6 Learning from the investigation itself

It is important to bear in mind that during the accident investigation process, stakeholders do not only learn about the accident itself, but they also have an opportunity to improve the accident investigation process. Some benefits of lessons learned that could be applied to the investigative process are:

- The lessons can lead to recommendations for improved techniques in evidence collection and preservation, more robust retention of information, the interviewing of witnesses, and other accident investigation processes;
- The lessons may provide new insights and lead to the revision of existing accident causation models and consequence models or serve to challenge previously held views.

6.7 Improving the link between the accident investigation and the risk analysis processes

Accident investigation is an *a posteriori* analysis in the aftermath of an event carried out to identify direct and root causes of the accident, as well as contributing to lessons to be learned. Risk assessment is an a priori analysis carried out to identify potential unwanted events that may occur and whose results are used to devise preventive and mitigating actions and accident management preparation and response plans. Knowledge of these actions is very important to the accident investigator. Thus, accident investigation and risk analysis are intricately part of the same process of increasing the resilience and coping capacity of systems in the face of potential hazards. Experience has shown that there is a natural relationship between accident investigation and risk assessment, and there are several advantages for having an active cooperation between them. (Please see Annex 2 for additional discussion).

An important question then becomes: How can this crucial link be improved? Some practical suggestions are made here (and in Annex 2):

- It would be essential to ensure that when risk assessment is carried out, past accident investigation results and lessons learned are also taken into account. Additionally, when accident investigation is carried out, risk assessment scenarios with similar characteristics as the accident should also be taken into consideration;
- It would be useful to have a risk analyst in the accident investigation team and vice versa, an accident investigator could assist in the risk assessment process. In principle, both actors are contributing to improving safety in a given situation, but are coming from different angles. The potential for mutually learning and sharing one another's

methodologies would foster increases in the quality and credibility of both, coupled with more efficient use of time and allocated resources;

- It would be important to promote training of staff on risk assessment and accident investigation, in order to increase awareness of the interconnectedness between the two disciplines and to better support a culture of safety.

6.8 Positioning accident investigation in a systems framework

In enhancing the safety performance of a system, two major strategies exist: a reactive approach (i.e. investigating events after they have occurred) and a proactive approach (i.e. anticipating events before they occur). In discussing a preference for either accident investigations or safety management, the terms 'obsolete' and 'modern' are sometimes used for accident investigation and safety management systems, respectively. Both terms are incorrect because these two strategies are complementary to each other, rather than replacements for one for another. They are, however, fundamentally different. A reactive approach is based on the feedback of knowledge and insights learned from identifying systems' and knowledge deficiencies found in functioning systems. A proactive approach applies safety management, rescue and emergency management and design principles in order to prevent occurrences by taking appropriate measures beforehand. Combining these two strategies provides feedback learning as well as an opportunity for 'feedforward learning' (i.e. learning based on anticipated results of effects) applied to a functioning system.

This also implies that we do not only learn from accidents as performance indicators, but also from other safety performance indicators such as incidents, safety perception, rescue and emergency operations or social/public safety issues. This learning process enables the identification of not only system deficiencies, but also knowledge deficiencies that can either be implemented to prevent the next accident or to recover from a potentially dangerous situation, by allowing the system to adapt itself by changing its characteristics.

This complementary nature of feedback and feedforward learning can be seen in the positioning of accident investigation as part of a systems model that combines both reactive and proactive feedback loops (see Figure 12 next page).

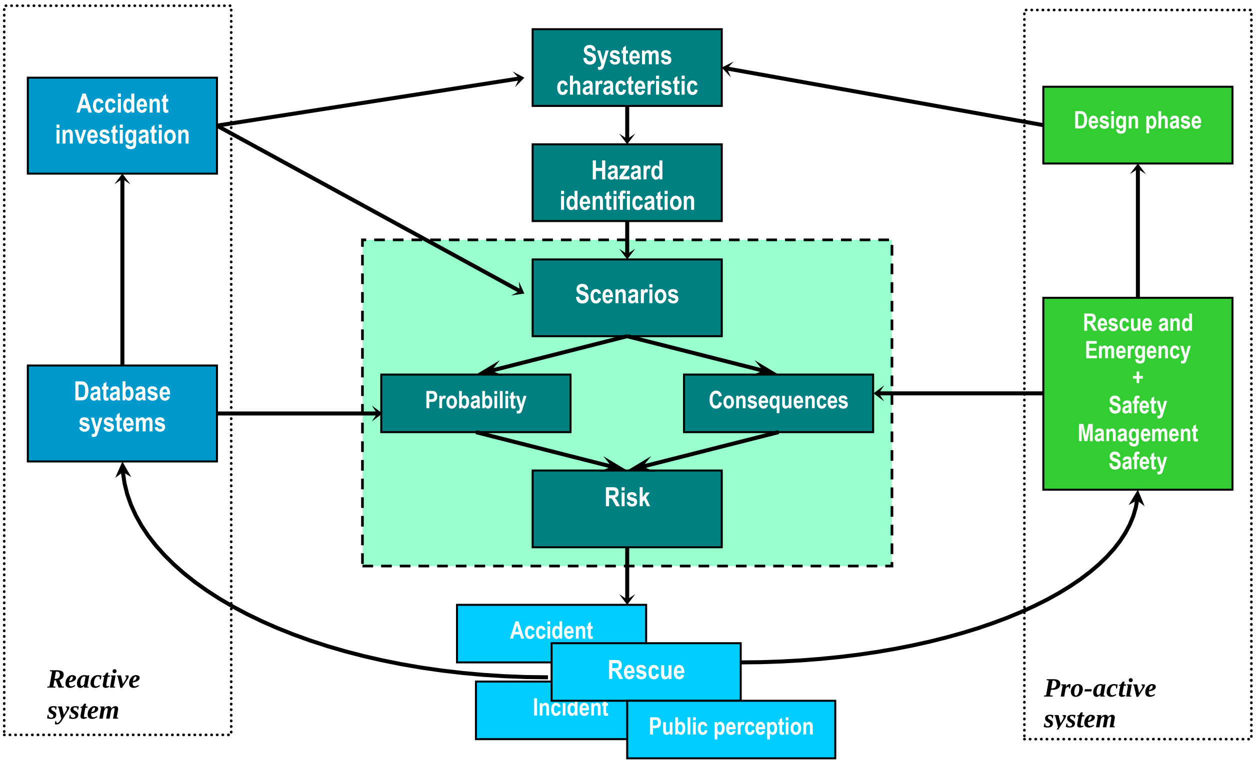

Figure 12: *Proactive and reactive system safety enhancement (Stoop, 2001)*

6.9 Towards a lessons learning culture

How can a learning culture be promoted? First of all, it is essential to be aware that everyone involved in an investigation process has different interests and different standpoints, resulting in different perceptions and learning processes. Against this backdrop, there is a need for a socio-technical, pluralistic and participatory dialogue to be implemented in order to achieve convergence in both learning from an event (*a posteriori* analysis) and creating new knowledge that can be used to improve existing human, technical and managerial safety/risk processes (*a priori* analysis). In order to nurture a learning culture, the following recommendations are proposed:

- It is important to integrate lessons learned from practical experience into all procedures involving safety/risk management;
- It is of utmost importance that everyone at all levels (i.e. individual, corporate, sectoral) take ownership of the learning process during the investigation and carries out his/her part in disseminating not only the knowledge gained from the interactive experience, but also spreads the practice via interactive communication processes in various formats (training, targeted seminars, discussion forums, blogs, portals);
- Furthermore, these communication processes should be negotiated and established by consensus amongst all stakeholders. They should also be regularly updated and go through quality assurance procedures. Actors must feel engaged in this learning process for it to evolve into a culture of perpetual learning;
- Investigations provide the opportunity to make recommendations about management of knowledge deficiencies and organisational issues. It is therefore essential to capture the subjective experiences as carefully as the more objective technical information. Both

should be systematically collected in a knowledge-based format, accessible to all involved parties. Procedures should also be created to ensure that the knowledge base can be constructively exploited by all the interested parties (e.g. customised sections targeted to specific user groups with user-friendly graphical user interfaces). Allowing access to information (such as via a web portal) does not necessarily mean that stakeholders will be able to actively use the knowledge base. Organisational and managerial issues must be established in combination with knowledge management and vice versa. This provides a chance for change to take place and also improves safety and risk management;

- Establishing a learning culture implies promoting the desire of stakeholders to learn the (transferable) lessons found in other investigations elsewhere. We live in a complex and interconnected world where accidents can transcend conventional boundaries and require a mindset that can address interdisciplinary and multi-sectoral aspects. Lessons learned from investigations in one sector can be transferred to another sector. It is therefore necessary that facilitating processes and platforms be put in place for this cross-fertilisation to take place. Only through a collective and systematic effort including all the above suggestions can momentum be built towards creating an effective learning culture.

6.10 Some barriers to learn lessons

Usually, the investigation of an event (i.e. accident, incident or crisis) is carried out within the framework of an operational feedback system that assumes “we learn from our mistakes.” The goal is to understand the event -- and especially the causes that led to it -- in order to define and to introduce corrective measures within the socio-technical system. As a result, the level of safety increases.

High-risk industries have devoted considerable resources for dealing with operational feedback systems and especially with event investigation and analysis. Despite these substantial efforts, many managers and experts share the view that the same types of events reoccur with the same type of causes.

So everything is happening as if it were difficult to fully learn lessons from past events and errors.

Several “barriers” have been identified that could explain difficulties in assimilating the lessons that could be learned and in invigorating them (Dechy and Dien 2007, Dechy et al, 2008). It should be noted that these barriers are (more or less strongly) in correlation with one another :

- The first barrier refers to the “quality” of lessons drawn from events due to the “quality” of investigations themselves. The Columbia Accident Investigation Board stated this issue very clearly, “*Many accident investigations do not go far enough. They identify the technical cause of the accident, and then connect it to a variant of “operator error” – the line worker who forgot to insert the bolt, the engineer who miscalculated the stress, or the manager who made the wrong decision. But this is seldom the entire issue. When the determinations of the causal chain are limited to the technical flaw and individual failure, typically the actions taken to prevent a similar event in the future are also limited: fix the technical problem and replace or retrain the individual responsible*. **Putting these corrections in place leads to another mistake – the belief that the problem is solved.”**[6] In other words, as many accident investigations do not go deep enough in researching causes, they stay at the surface—thus leaving room for the same type of events to recur.

[6] Emphasis added.

Furthermore, weaknesses in investigation could block the capability of finding both generic characteristics from the analysis of the event and other characteristics of interconnected events;

- A second barrier is the difficulty in learning from others (Dien and Llory 2004). For example, the NASA (Columbia) disaster and the Texas City BP refinery explosion–were both events in which the effects of production pressures and of flaws in Control Authorities were identified;
- A third barrier is related to the loss of the collective 'organisational memory.' For example, "*Echoes of Challenger*" describes how in the Columbia space shuttle accident this loss of memory was already noticed only ten years after the Challenger disaster. Another example is the occurrence of vessel head corrosion at the Davis-Besse nuclear power plant (NPP) in 2002 despite considerable experience gained by the French NPPs in the 1980's. (This example could be considered a mix between the second and the third barriers);
- A fourth barrier is the gap between proposals of change resulting from analysis of accident causation and those changes derived from a thorough analysis of systems' variables conducted in order to propose changes. Both approaches are important and are interconnected. (Please see Section 6.7 for additional discussion). In reality, there seems to be an observed decoupling between issuing findings from AI and issuing recommendations from risk assessment. Addressing this gap would overcome this fourth barrier;
- A fifth barrier is the lack of institutional (corporate/management) commitment and functional design to foster accident investigation and a learning culture (see Section 6.8). A major lesson learned at this level of overcoming barriers is to organise the learning processes at appropriate levels. This would most likely occur at the sectoral or societal level in establishing a learning agent at the institutional level by harmonising investigation protocols, supporting open dissemination of reports and findings, identifying knowledge deficiencies, establishing independent investigation agencies with legal mandates, missions and resources and a mandatory feedback on their recommendations.

7 FUTURE CHALLENGES

Investigation bodies, national control authorities, safety agencies and private enterprises will all face different challenges within accident prevention and accident investigation.

Advancements in technology will lead to a change of risk characteristics, magnitude and related uncertainties. Furthermore, political, economic, social and institutional alterations at the global level, as well as on national, regional and local levels will shape new conditions for safety promotion. Some of the major challenges are discussed in the following sections.

7.1 Definition of scope

In the near future, the problems within four main areas will be perceived as urgent and in need of common and harmonised solutions:

1. The problem of **definition of scope** is itself multifaceted: (i) Should the scope be limited to the category of accident (e.g. severe or major, and include near-misses or events with a high-risk potential), or broadened to include phenomena such as disasters and catastrophes (also natural), crises and security events? What would the impacts be on investigation methodology when natural hazards, security events and similar catastrophic events are addressed? Which changes would need to be made if the scope were more generic? (ii) Furthermore, when the term “accident investigation” is used, there is an implicit indication that it is about a *man-made disaster*. This further implies a clear distinction with a *natural disaster*. This traditional frontier was probably appropriate in earlier use but does not seem adequate anymore. Indeed, over time, natural disasters and climate change integrate the effects of man-made activities. Likewise, technological systems are developed within environmental boundaries (or constraints) that can be challenged for some events and others will be challenged in the future.
2. The **problem of purpose** is still in many instances characterised by the classical split between a safety investigation (a “no blame”-investigation or “what can we learn from accident?”) and a regulatory investigation (a legal investigation, usually conducted by the police and “are we able to find the persons responsible?”).
3. The main problem in **making generalisations** about accidents is the fact that precisely the same accident will never happen again. But in order to prevent similar future accidents, some kinds of generalisations are still necessary. Information about comparable accidents may add valuable experience, and these accidents can be drawn from the same sphere at local or national levels, or the sphere may be expanded to include regional or even global levels. The use of a wide perspective is often necessary because accidents of a specific type are rare at local and national levels. However, this scalability (either outward or inward) of experiences introduces uncertainties that need to be acknowledged and addressed.
4. The **problematic transition** from the notion of an ‘accident’ toward the concept of ‘systems change’: accident investigations have focused on the causation of accidents and on their prevention. A major challenge in the near future will be to tackle in parallel both the explanatory variables of accident causation, as well as the ‘change variables’ (i.e. those factors that cope with adaptation of the system itself). Such adaptations however, require sophisticated systems modelling, change management strategies and monitoring methods of implemented recommendations – most of which are not readily available or

not commonly applied in the investigation process. Measuring the effect of investigations cannot be based on the sheer reduction of accident numbers alone. Indicators should be developed to assess the safety of a system as an emerging entity, comparable with other systems (such as the environment, the economy or sustainability).

7.2 Integration of past experiences and future risks

In the future, safety recommendations must combine two approaches: they must include both: the necessary proposed safety measures as a consequence of lessons learned from single accidents or from safety studies of similar accidents (reactive approach); and, the proactive integration of risks identified from different future-oriented methodologies (proactive approach), such as the use of risk assessments, scenarios, forecasts, modelling and other techniques designed to increase reliability (see Sections 6.7 and 6.9).

7.3 In-case-studies or generic studies

In-depth studies of a single accident may add valuable and unique insight into accident mechanisms, event chains, organisational failures and identification of adequate prevention measures. However, the value of safety analysis and preventive recommendations may be substantially strengthened by adding relevant accident and safety knowledge from comparable accidents, within the same sector or adjoining sectors, at national or international levels (see Sections 6.8 and 6.9). Such types of generic studies, though, presuppose new types of national and international harmonisation and co-operation.

Examples of successful harmonisation and co-operation can be gathered from other industries. In particular, the "fast-track sectors" (i.e. the financial, clinical/medical, IT industries) serve as examples where the degree of interconnectedness, partnering, complexity and pace of technology are high. The rapid pace in these industries results in a higher density of events taking place; these sectors are the potential harbingers of the (lessons) learning culture (Vetere Arellano, 2007). Through comparative analyses of events in these sectors with those of the High Risk Industries, these examples could also help to improve risk control and management through the identification of potential risks and uncertainties, not yet identified in the High Risk Industries. This in turn would help to improve accident management and investigation of the related potential adverse impacts of such risks.

7.4 The need for independent investigations

When all is considered, the final outcome of an investigation depends on the stakeholders' confidence in the investigation, which to a certain degree is linked to the objectivity, the integrity and competence of the investigative body. The need for an independent investigation commission, without vested interests to any involved parties (such as control authorities, certification bodies, or commercial partners), has increasingly been recognised for its contribution to the overall quality of the investigation, and has gained strength in recent years. Such a commission would also be able to give better protection to witnesses and could exercise normative power. Appointment of members for this type of commission would have to find the right trade-off between expertise (i.e. experts that know the field and its culture, technical evolution and latest modifications, but possibly present a risk of a poor level of independence) and independence (members who have no link with the field, but present a risk of poor levels of expertise). Most of these principles are valuable for internal investigations.

7.5 Investigating root causes: towards organisational analysis?

The investigation methodologies issue is facing a central question: Will investigations continue to remain fixed to the analysis of direct and immediate causes of events or will they also address root causes, such as organisational factors connected to the event?

Unfortunately, although the concept of 'organisational accident' is already familiar to scholars, it has appeared more recently in industry; and so, not applied. Indeed, this factor was noted by the explicit reference to an organisational vision of the accident with the Columbia Accident Investigation Board (CAIB) stating that, "*We are convinced that the management practices overseeing the Space Shuttle Program were as much a cause of the accident as the foam that struck the left wing" (CAIB 2003).* Furthermore, the CAIB investigation explicitly referred to the organisational, institutional and historical character of the accident: "*The Board recognized early on that the accident was probably not an anomalous, random event, but rather likely rooted to some degree in NASA's history and the human space flight program's culture. Accordingly, the Board broadened its mandate at the outset to include an investigation of a wide range of historical and organizational issues, including political and budgetary considerations, compromises, and changing priorities over the life of the Space Shuttle Program. The Board's conviction regarding the importance of these factors strengthened as the investigation progressed...* "[7] The CAIB investigation has had a strong impact not only for its findings but also for its methodological developments as stated by US CSB when investigating the BP Texas City refinery March 2005 accident: *"This investigation was conducted in a manner similar to that used by the CAIB in its probe of the loss of the space shuttle. Using the CAIB model, the CSB examined both the technical and organizational causes of the incident at Texas City".*

7.6 Follow-up of corrective measures

Too many events are still occurring because recommendations resulting from previous investigations (of previous accidents and events) were not (yet) implemented. In addition to cost considerations or budgetary constraints used to postpone or cancel changes, it seems that very often there is a lag in the operational feedback process, between the analysts in charge of investigation and the operational workforce in charge of updating and upgrading. A potential improvement to the recommendations from the accident investigation occurs when each recommendation goes through a 're-appraisal' during the overall process of implementation and operational feedback.

7.7 Guidelines: Dynamic versus static

The need for flexible and dynamic guidelines, easily reflecting changes in all sorts of developments, including advances in dynamic systems investigation concepts, practices and outputs (see Benner), will certainly be superior to today's guidelines that are more static. Future challenges will also include topics such as the necessity of publishing interim safety recommendations, the possibility of reopening an investigation in certain cases, the necessity of having updated previous recommendations, broad competence among the investigation staff, the power of implementing recommendations and the question of using sanctions. Moreover, the transparency of the investigative process and the free access to the final report will be a very important question for many stakeholders, especially the public. Promoting free access to investigations results could allow progress to be made in the field of generic studies.

[7] In addition to the CAIB quote already mentioned in section 6.9 "investigations do not go far enough…"

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Accident Investigation Guidelines and protocols

ICAO Annex 13: Annex 13 to the Convention on International Civil Aviation. Aircraft Accident and Incident Investigation, International Civil Aviation organization.

IMO Code : International Standards and Recommended Practices for a Safety Investigation into a Marine casualty or Marine Incident. International Maritime Organisation IMO.

ISIM : Integrated Safety Investigation Methodology, Transportation Safety Board of Canada/Bureau de la Securite des Transports du Canada, ISIM Reference Manual.

ATSB Safety Investigation: Safety Investigation Guidelines Manual, Guidelines-Analysis, Australian Transport Safety Bureau. Australian Government. Version 1.02.

ANNEX 1: ESReDA, Goals – Membership – Seminars – Reports

ESReDA aims and goals

- Focus the European experience in the fields of security, safety, reliability, maintainability, lifetime and management of technological and human risks
- Harmonize and facilitate European R & D on these techniques;
- Promote the setting-up, development, operation and maintenance of data banks concerning these techniques;
- Provide expert opinion in these fields, to the European Commission and other national, European or international organisms;
- Improve the communication between researchers, industry, university, databanks owners and users, and government bodies;
- Contribute to Safety & Reliability education, its integration with engineering disciplines and in arriving at international definitions, methods and norms;
- Contribute to national, European and international efforts in field of standardization and methodological guides' elaboration;

ESReDA Membership

Effective Members are legal entity or individuals. They have the right to vote and are eligible for the various functions of the Association. They pay an annual membership fee or render services, conform with the internal rules, to the Association.

Associate Members can be legal entity or individuals. They participate to the project groups and are invited to join the General Assembly as mere observers. They are not entitled to voting rights and are not eligible.

Sponsoring Members can be legal entity or individuals. Sponsoring Members are expected to contribute to the funds of the Association with free services or assets. They may attend General Assembly as mere observers. They are not entitled to voting rights and are not eligible.

ESReDA Seminars

All ESReDA proceedings are available from:

Dr. Giacomo G.M. Cojazzi
JRC/IPSC, T.P. 210
I-21020 Ispra (VA)
Italy
Phone: +39-0332-785085
Fax: +39-0332-785748
e-mail: giacomo.cojazzi@jrc.it

1. London (UK), October 1991: *The use of expert systems in safety assessment and management*;
2. Amsterdam (NL), April 1992: *Safety of systems relying on computers*;
3. Chamonix (FR), October 1992: *Equipment ageing and maintenance*;
4. Huddersfield (UK), April 1993: *Safety in transport systems*;
5. Lyon (FR), October 1993: *Operational safety*;

6. Chamonix (FR), April 1994: *Maintenance and system effectiveness*;
7. Ispra (IT), October 1994: *Accident analysis*;
8. Espoo (FI), May 1995: *Reliability data analysis and use*;
9. Erlangen (G), November 1995: *Learning from accidents investigations and emergency responses*;
10. Chamonix (FR), April 1996: *Rotating machinery reliability and maintenance*;
11. Oxford (UK), October 1996: *Communicating safety*;
12. Espoo (FI), May 1997: *Decision analysis and its applications in safety and reliability*;
13. Paris (FR), October 1997: *Industrial applications of structural reliability theory*;
14. Stockholm (SW), May 1998: *Quality of reliability data*;
15. Antwerpen (BE), November 1998: *Accident databases as a management tool*;
16. Oslo (NO), May 1999: *Safety and reliability in transport*;
17. Garching (GE), September 1999: *Work & Results from ESReDA Working Groups*;
18. Karlstad (SW), June 2000: *Risk Management and Human Reliability in Social Context*;
19. Lyon (FR), October 2000: *Operation Feedback Data & Knowledge Management for New Design*;
20. Rome (IT), May 2001: *Decision Analysis*;
21. Erlangen (GE), November 2001: *Lifetime Management*;
22. Madrid (SP), May 2002: *Maintenance Management & Optimization*;
23. Delft (NL), November 2002: *Decision Analysis; Methodology & Applications for Safety of Transportation and Process Industries*;
24. Petten (NL), May 2003: *Safety Investigations of Accidents*;
25. Paris (FR), November 2003: *Lifetime management of structures*;
26. Tampere (FI), May 2004: *Lifetime management of industrial systems*;
27. Glasgow (UK), November 2004: *Assembling evidence of reliability*;
28. Karlstad (SW), June 2005: *On The Geographical Component of Safety Management: Combining Risk, Planning and Stakeholder Perspectives*;
29. Ispra (IT), October 2005: *System Analysis for More Secure World: Application of system analysis and RAMS to security of complex systems*;
30. Trondheim (NO), June 2006: *Reliability of Safety-Critical Systems*;
31. Smolenice (SL), November 2006: *Ageing*;
32. Alghero (IT): May, 2007: *Maintenance Modeling and Applications*;
33. Ispra (IT), November 2007: *Future challenges of accident investigation*;
34. San Sebastian (SP), May 2008: *Supporting Technologies for Advanced Maintenance*.
35. Marseille (FR), November 2008: *Uncertainty in industrial practice – Generic best practices in uncertainty treatment*;
36. Coimbra (PO), June 2009: *Lessons learned from accident investigations*;

ESReDA Working Group Publications

ESReDA publications are available from:
http://webshop.dnv.com/global/category.asp?c0=2631&c1=2632

Communicating Safety (1996).

Guidebook on the Effective Use of Safety and Reliability Data (1996).

Directory of Accident Databases (1997).

Industrial Application of Structural Reliability Theory (1998).

Handbook of Safety and Reliability Data (1999).

Guidance Document for Design, Operation, and Use of Safety, Health, and Environment (SHE) Databases (2001).

Handbook on Maintenance Management (2001).

Accident Investigation Practices – Results from a European Study (2003).

Decision Analysis for Reliability Assessment (2004).

Lifetime Management of Structures (2005).

Shaping Public Safety Investigations of Accidents in Europe (2005).

Ageing of Components and Systems (2006).

Uncertainty in Industrial Practice : A Guide to Quantitative Uncertainty Management (2008).

ANNEX 2: Relationships between accident investigation and risk analysis

Harms-Ringdahl (2004) showed that there is a web of relationships between Accident Investigation (AI) and Risk Analysis (RA), and concluded that there are several advantages to having an active cooperation between AI and RA.

In the early stages of an AI there are issues that should be raised, related to RA. For example:

- Has this type of event been studied earlier in an RA?
- If the event was addressed in an RA;
    - Did the analysis propose implementation of specific risk-reducing measures? The AI should check whether or not these measures had been implemented as recommended at the time of the event;
    - Were the sequence of events and consequences as predicted?
    - The AI can make use of information gathered as part of the RA's preparatory phase with regard to aspects such as system descriptions, organisation/management, environment, infrastructure, and so forth.
- Personnel having conducted the RA could be an important source of assistance or information for the AI;
- AI should utilise RA methodologies in its processes (e.g. to reveal whether the accident could occur as a result of a combination and sequence of other factors and circumstances;
- A conclusion from the AI could be to recommend that an RA be conducted for a particular system or situation related to the event being investigated.

From the RA perspective, there are aspects such as:

- Data and knowledge from AI provide important input to future RAs, (e.g. causal factors, chain of events, extent of consequences);
- Findings in an AI could initiate updating an existing RA and accident database(s);
- Reveal whether the premises and assumptions made for the RA were correct;
- Use of RA methods to assess the effects of implementing recommended measures and actions proposed in the AI report;
- Following an AI, and in order to improve safety management, an RA of the AI process and further use of the AI report could be performed. This could encompass issues like:
    - Were some aspects not investigated properly or missing?
    - Were wrong conclusions made?
    - Were results from available sources not used?
    - Were conclusions and recommendations in the AI report not followed up and/or implemented?

Both AI and RA serve as important tools for risk prevention and mitigation, both at a company/industry level and for society in general. By utilising the potential for cross-learning and mutually sharing methodologies, the quality and credibility of both disciplines may be increased and time and resources may be saved. In addition, developing such relationships could improve the understanding and efficiency between teams doing RA and AI respectively.

An important question is then: "*How can this crucial link be improved?*"

The crucial link between an *a posteriori* and an *a priori* approach is in the mutual ability to learn from experience and to implement knowledge in the system performance, management and control strategies. In order to make the transition from rule-based compliance—and hence, a culture of 'blame and responsibility'—toward a knowledge-based change in the systems' functioning and performance, there are four requirements:

- Replace prescriptive and procedural decision making by a goal-setting behaviour: upgrading from a rule-based to the knowledge-based level of decision making;
- Provide transparency on the functionalities to be incorporated in the system's common goal setting: achieve consensus among the actors;
- Provide feedback at all managerial levels to facilitate information exchange: encourage vertical integration of information exchange;
- Deal with the multi-actor complexity and dynamic decision-making environment: foster horizontal integration of information exchange (Stoop 2007).

Safety evaluations and risk assessments are both part of any safety management programme (as seen in Figure 13).

Figure 13: *The safety management process (from DETEC, the National Aerospace Laboratory NLR and Van der Geest et al., 2003)*

ANNEX 3: Some internet addresses related to accident investigation

Some European Institutions and Organisations	
http://europa.eu/	Gateway to the European Union
http://www.esreda.org/	European Safety, Reliability and Data Association
http://www.etsc.be/	European Transport Safety Council
http://www.fevr.org/	European Federation of Road Traffic Victims
http://mahbsrv.jrc.it/	Major Accident Hazards Bureau
http://ec.europa.eu	EC – Joint Research Centre
Some international or national institutions / companies and organisations	
http://www.fafonline.org/	Family Assistance Foundation
http://estonia.kajen.com/	The Estonia Foundation (in Swedish)
http://www.imo.org/	International Maritime Organisation
http://www.ieee.org/	Institute of Electrical and Electronics Engineers
http://www.icao.int/	International Civil Aviation Organization
http://www.isasi.org/	International Society of Air Safety Investigators
http://www.itsasafety.org/	International Transportation Safety Association
http://www.iprr.org/	The Investigation Process Research Resources
http://www.planesafe.org/	National Air Disaster Alliance / Foundation
http://www.skagerrak.org/	The Norwegian Skagerrak Foundation (Norwegian)
Some Accident Investigation Safety Boards in Europe	
http://www.hcl.dk/	Accident Investigation Board Denmark
http://www.onnettomuustutkinta.fi/	Accident Investigation Board Finland
http://www.aibn.no/	Accident Investigation Board Norway
http://www.aaib.dft.gov.uk/	Air Accidents Investigation Branch England
http://www.aaiu.ie/	Air Accident Investigation Unit Ireland
http://www.bfu.admin.ch/	Aircraft Accident Investigation Bureau Switzerland

http://www.bea-fr.org	Civil Aviation Accidents – France
http://www.bea-tt.equipement.gouv.fr/	Civil Ground Transportation Accidents – France
http://www.beamer-france.org/	Marine Accident Investigation Office – France
http://www.casb.hu/	Transportation Safety Bureau – Hungary
http://www.safetyboard.nl/	Dutch Safety Board – Holland
http://www.bfu-web.de/	Federal Bureau of Aircraft Accidents Investigation – Germany
http://www.ansv.it/	National Agency for Safety Flight – Italy
http://www.fomento.es/ciaiac/	Civil Aviation Accidents – Spain
http://www.maib.dft.gov.uk/	Marine Accidents Investigation Branch – England
http://www.havkom.se/	Accident Investigation Board – Sweden
Some Other Accident Investigation Agencies in the World	
http://www.atsb.gov.au/	Transport Safety Bureau – Australia
http://www.tsb.gc.ca/	Transportation Safety Bureau – Canada
http://www.taic.org.nz/	Transport Accident Investigation Commission – New Zealand
http://www.araic.assistmicro.co.jp	Aviation and Railway Accident Investigation – Japan
http://www.ntsb.gov/	National Transportation Safety Board – the USA
http://www.csb.gov/	Chemical Safety and Hazard Investigation Board – the USA
http://www.hss.energy.gov/csa/	OHSS – Corporate Safety Analysis – the USA
http://www.colorado.edu/hazards/	University of Colorado : Natural Hazards Center – the USA
Some Other relevant website resources mentioned in the Guidelines	
http://www.iprr.org/ http://www.investigationcatalyst.com/index.shtml	Investigation Process Research Resources site, and Software resources to help structuring data
http://www.nri.eu.com	NRI Foundation : Investigation methods, manuals and preparedness guidelines