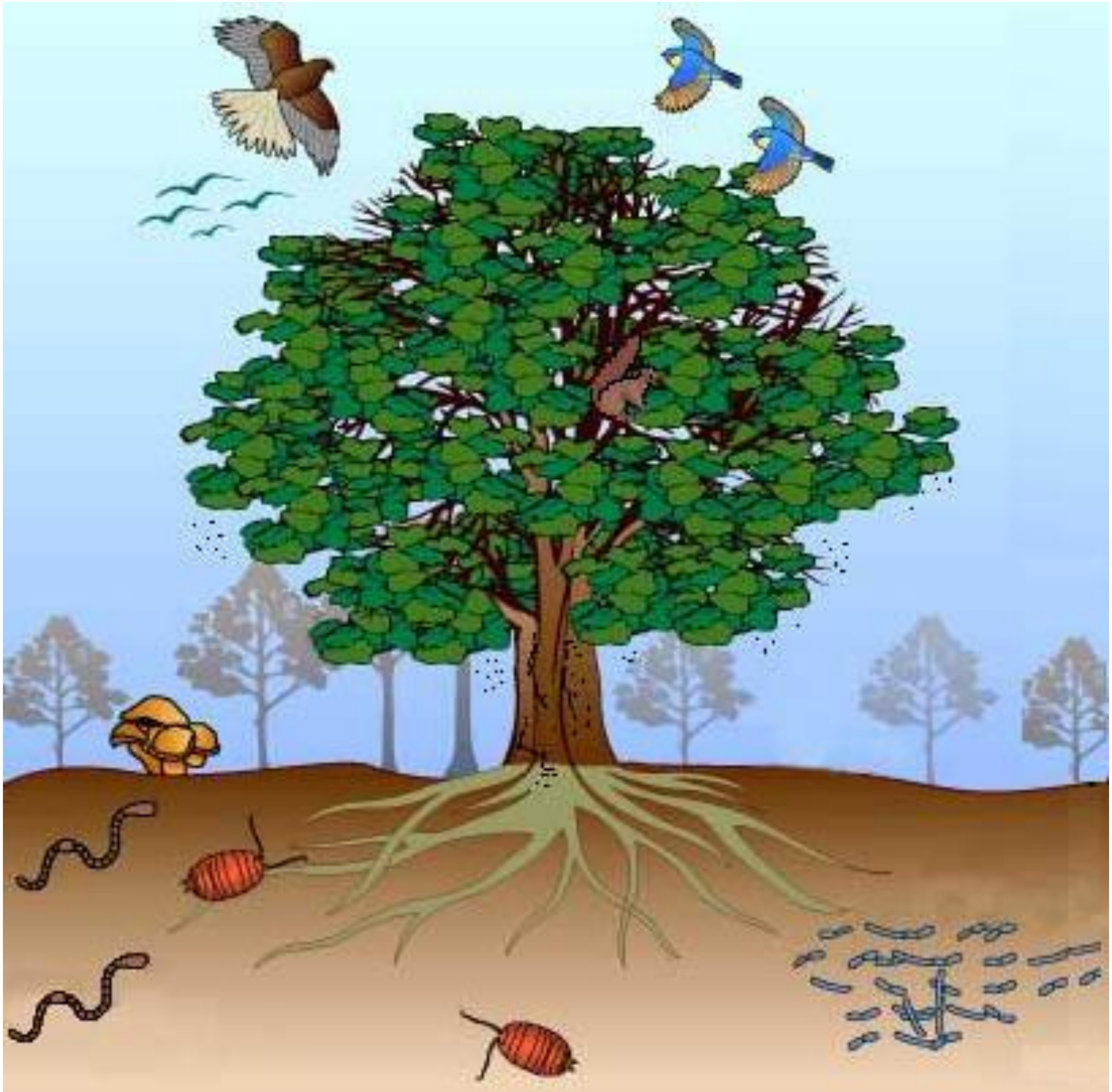
BEYOND
Traditional Accident Investigation



Searching for Extra-Organisational Factors

Kirsten N.R. van Schaardenburgh-Verhoeve, *MA, 2008*

Preface

This thesis was written as a conclusion of the Masters of Public Safety. This Masters is developed by Delft TopTech, in joint effort with Delft University and the National Institute of Physical Safety (NIFV).

The research for this thesis is closely connected to my work as Sr. advisor Research and Development at the Dutch Safety Board. The research on extra-organisational factors is not finished with this thesis, and I look forward continuing this research.

I would like to thank all who have been patient with me the last couple of months, accepting I had less time to spend with them. I would like to thank Menno: as my mentor you gave me ideas and challenged me in the approach. Next, I would like to thank Paul: you gave me detailed feedback on the structure and text in my thesis, which was very helpful. The Barbera Aurigo Pavia is well deserved! I also would like to thank some colleagues in particular: John - for helping with the search on which methods are used by Transport safety Boards and our own organisation, Einar – for challenging me on my thoughts of which methods to use, and the Dutch Safety Board – for offering me the opportunity to develop myself and innovate our investigation approach.

Last (but not…!), I would like to thank Pepijn: thanks for being there, challenging me and sharing the table when we were both working. Since I have finished my Masters now, you can work less too….

Kirsten van Schaardenburgh – Verhoeve
Eindhoven, september 2008

Contents

Summary

The objective of this thesis was to find an answer to the question: *How to extend traditional accident investigation, in order to identify extra-organisational factors?*

This question is relevant since today's accidents occur in socio-technical systems, involving multiple organisations. Traditional accident models and methods appear to

- provide little guidance what factors - outside the organisation in which the accident took place – should be searched for
- provide no guidance which actors (organisations) to include
- lack a structure to (inter)connect contributions of these (f)actors

To be able to answer the main question, four other questions had to be answered:

1. *What is traditional accident investigation?*
2. *What theories can be possibly of use, aiming to identify extra-organisational factors?*
3. *What methods can be possibly of use, aiming to identify extra-organisational factors?*
4. *What is the added value of these theories and methods, compared to traditional accident investigation?*

In general, traditional accident investigation consists of sequencing models -aimed at technical and human factors - and epidemiological models - aimed at organisational factors that make them more vulnerable to accidents. All traditional accidents models are linear, although some are a bit more complex, and all models are static. Traditional accident models focuses on intra-organisational factors. Figure 1 represents this traditional focus: sequencing models focus on the green part of the tree, epidemiological models focus on the brown part as well: the roots of the tree as well.

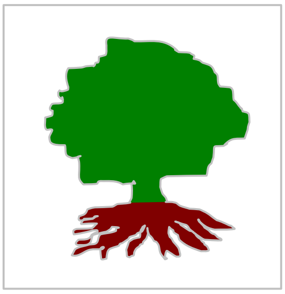


Figure 1 Graphical representation of traditional accident investigation

Traditional accident investigation at the Dutch Safety Board consists of the use of the traditional sequencing method STEP and epidemiological method Tripod, and assessment frameworks for compulsory regulations, voluntary regulations, and individual responsibility.

The theory of Perrow's (1984) on system characteristics - distinguishing interactiveness and coupling - can be of help to determine the kind of system an accident has taken place in. The theory of Wildavsky (1988) - on risk strategy - can be of use to determine the applied risk strategies in this system. The results of both theories can be combined, determining whether the best risk strategy was followed, or improvements can be made.

The methods Accimap, STAMP, FRAM, and IPIC RAM all include the system in one way or

another. All methods, except the Backward and Forward mapping of De Bruijn, can include multiple actors. Accimap, STAMP and IPIC RAM focus explicitly on information flows between actors. Accimap and IPIC RAM explicitly focus on capabilities of the (external) decision makers. STAMP focuses on control loops within the complete system, and FRAM focuses on normal variability between system components.

Backward and Forward mapping emphasizes to review the consequences of actions and events in a broader perspective (complete system) as well as both the negative and positive ones.

In general, traditional accident investigation is not identifying the system characteristics and risk strategy as meant by Perrow (1984) and Wildavsky (1988). Neither is traditional accident investigation identifying the extra-organisational factors, as meant by Accimap, STAMP, FRAM and IPIC RAM. Therefore, it can be concluded that these theories and methods have an added value the traditional accidents investigation.

The following themes are not explicitly included in the Dutch Safety Board's traditional accident investigation approach:

- Opportunity risks versus opportunity benefits
- Boundaries of the safe envelope
- Control structure
- Functional resonance
- System dynamics
- Generalising findings

It can be concluded that traditional accident investigation focuses on intra-organisational factors in a static environment. Extension of this traditional approach should include the system, which the organisation is part of, and its dynamic interactions. Figure 2 represents this. Accidents do not only have to be investigated for it's leafs and roots, but also for the dynamic system it is positioned in. The surroundings of the organisation (system characteristics), the threats and benefits, and the applied strategies must be investigated. Extra-organisational factors like the designed process of the complete system, the actual processes in this system and the capabilities of all those involved have to be investigated.

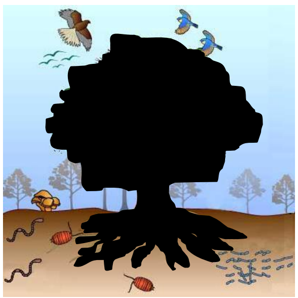


Figure 2 Graphical representation of the extension of traditional accident investigation

The main question, however, ***how** to extend traditional accident investigation, in order to identify extra-organisational factors,* has not been answered. This thesis provides details on what factors to include in the extension, and some practical solutions to extend current investigation approach. But which methods can be used best, and what added value these methods have in enhancing safety, still has to be investigated.

1 Introduction

This chapter describes the motive for the search for extra-organisational factors. It introduces challenges of accident investigation in current society, especially for the Dutch Safety Board. Clarification is given on what is meant by extra-organisational factors.

The research question and partitive questions for this thesis are defined. Finally, some guidance is given on how to read this thesis.

1.1 Accident investigation

Learning from things that went wrong is of all ages. Formal accident investigation however has started from the beginning of 1900. The domino theory of Heinrich (1930's) is the first model on accident causation. Since then, several models and methods have been developed to analyse and understand accidents.

However, now more than in earlier days, technology changes rapidly, introducing new hazardous sources in all domains. Today's systems are highly integrated and coupled, and not limited to one organisation. These systems, sometimes referred to as socio-technical systems, are connecting multiple organisations. Decisions of one organisation can rapidly have effect on others (Rasmussen, 2000).

Traditional accident modelling and analysis appears to be inadequate for accidents in modern socio-technical systems (Qureshi, 2007). Understanding and managing the dynamic interaction among various levels of society is of increasing importance in improving safety. Therefore, accident investigation should no longer be limited to isolated organisations, but include this dynamic system and relevant actors, horizontally as well as vertically (Svedung & Rasmussen, 2002). In order to understand the multidimensional aspects of socio-technical system accidents, researchers have to step outside their traditional boundaries (Qureshi, 2007).

1.2 Accident investigation by the Dutch Safety Board

The Dutch Safety Board, founded in 2005, is a statutorily established autonomous agency, responsible for independent investigation of causes and possible consequences of disasters, serious accidents and incidents. The Dutch Safety Board can investigate accidents in all domains, from transport domains, like aviation, rail, and shipping, to all types of industry, services, healthcare and crisis management & aid provision. The Dutch Safety Board is free to choose its methods for investigation, can issue recommendations to all parties involved in public safety, and can monitor implementation of these recommendations. The main objective for the Dutch Safety Board is to identify structural safety deficiencies as a starting point to enhance public safety in the Netherlands (Dutch Safety Board, 2008).

The Dutch Safety Board is confronted with the changes in society. Today's accidents occur in socio-technical systems involving multiple organisations. The Dutch Safety Board experiences the shortcomings of traditional accident models and methods. Traditional accident models and methods were developed to control the controllable (Groeneweg,2002) and stop at the boundaries of organisations. Basically, the experienced shortcomings are:

Traditional accident models and methods

- Provide little guidance what factors - outside the organisation in which the accident took place – should be searched for
- Provide no guidance which actors (organisations) to include
- Lack a structure to (inter)connect contributions of these (f)actors

These shortcomings have been experienced when the investigation went beyond technical, human and organisational factors. Recent examples of such investigations are for instance the excessive high mortality rate in a hospital, and multiple derailments after putting a revised rail system into use. Investigation of these (type of) accidents should include the dynamic system and all relevant actors.

The Dutch Safety Board is in need of extending their accident investigation in a structured, valid and reliable manner, to identify extra-organisational factors influencing public safety.

1.3 Research question

Considering the aim of the Dutch Safety Board to improve public safety by learning from accidents, considering the changing society and change in hazardous sources, and considering the identified shortcomings of traditional accident models, the main research question of this thesis is:

How to extend traditional accident investigation in order to identify extra-organisational factors?

In order to attempt to answer this question, the following four partitive questions have to be answered:

(I) What is traditional accident investigation?

(II) What theories can be possibly of use, aiming to identify extra-organisational factors?

(III) What methods can be possibly of use, aiming to identify extra-organisational factors?

(IV) What is the added value of these theories and methods, compared to traditional accident investigation?

1.4 Context of this research

The Dutch Safety Board is the successor of the Dutch Transport Safety Board, in which only transport related accidents were investigated. With the foundation of the Dutch Safety Board, four at that time new domains were added to the field of investigation. New and different expertise was added to the Dutch Safety Board: three new Board members and an extension of the Bureau with almost 40 percent. In hindsight, (some of) these changes have been a renewed motive to develop and innovate methodologies for investigation.

Illustrative for these changes is the extension of the amount of analysts – those responsible for application of accident analysis methods - from one to three full-time employments in 2005. Next, in 2008 the function changed from (sr.) Analyst to (sr.) Advisors Research & Development, now being responsible for application of accident analysis methods, the training of investigators in these methods, exploration and development of methods for accident analysis and other instruments to improve quality, and innovation of the accident investigation process. With this change, innovation in the accident investigation process is formalized.

This thesis supports the objective of the Dutch Safety Board to apply state of the art methods for accident investigation and analysis. It is a step in the process towards new accident models and methods, in order to capture the dynamic system in which accidents take place and enhance public safety. It identifies additional questions to be answered and directions to be explored. Therefore, although this thesis is the end of the Masters of Public Safety, it is not the end of my research on extra-organisational factors or contribution to innovation at the Dutch Safety Board.

1.5 How to read this thesis

How to read this thesis depends on what the reader's aim is. Before guidance is given per possible aim of the reader, the content of each chapter is briefly described.

Chapter 2 describes the methodology how the main research question and its partitive questions have been attempted to answer. The design of the methodology and the adjustments made during the research are described.

In Chapter 3 the definition of traditional accident investigation is searched for. First, traditional accident investigation is framed, based on a literature search. Next, the results of a search on applied methods by Transport Safety Boards are presented. Third, accident investigation of the Dutch Safety Board is described and the used methods are analysed. These three parts result in a definition of traditional accident investigation.

Chapter 4 presents the results of the search for theories possibly of use to identify extra-organisational factors. It summarizes the theories of Wildavsky (anticipation and resilience), Perrow (interactions and coupling), and others (boundaries of safe operation and organisational drift). The chapter concludes with an analysis of the theories presented and their contribution to identify extra-organisational factors.

Chapter 5 presents the identified methods possibly of use to identify extra-organisational factors: Rasmussen's Accimap, Leveson's STAMP, Hollnagel's FRAM, Groeneweg & Verhoeve's IPIC RAM, and De Bruijn's Backward- & Forward mapping. The chapter concludes with an analysis of the methods presented and their contribution to identify extra-organisational factors.

In Chapter 5 traditional accident investigation of the Dutch Safety Board is assessed. The chapter starts with the developed analysis framework, based on the identified theories and methods. Next, a theoretical assessment is presented: the generic approach of the Dutch Safety Board is assessed against the framework. Then a practical assessment is presented: an assessment of the results of an investigation of the Dutch Safety Board. The chapter concludes with an analysis of the added value of the theories and methods – measures by assessing against the developed framework- to the Dutch Safety Board's traditional accident investigation.

Chapter 6 presents the conclusions to the main research question and partitive questions. Finally, chapter 7 discusses the limitations of this thesis, the relevance of accident investigation in general, and the relevance of identifying extra-organisational factors. The chapter concludes with directions for future research.

Those interested in how to improve accident investigation to include system factors, the reading of chapter four, five and six is recommended, as well as Appendix I and Appendix II. Who's interested in the methods used by Safety Boards, chapter three provides information. Those who would like to learn more from the theories and methods which are used for the analysis framework, the applicable appendices are recommended. These appendices provide a summary of the most relevant books and articles on each subject.

2 Methods

In order to answer the main research question and partitive questions, several steps have been taken. The structure of these steps has been defined in advance, defining the objectives of each part. During the research - while executing these steps - choices had to be made, more details on the steps could be defined and sometimes additional steps or deviations were taken. The approach had features of both a project-approach (i.e. structured, goals specified, tight timing of delivery), as well as a process-approach (not everything was pre-determined, and even research questions were adjusted slightly during the research).

This chapter describes the methodology: the up-front designed methodology and the operational additions and deviations.

2.1 Definition of traditional accident investigation

Since the aim of this thesis was to go *beyond* traditional accident investigation, the first step was to define traditional accident investigation. In order to define traditional accident investigation, three parts of research were defined:

(I) Literature search on traditional accident investigation
(II) Research on methods used at other Transport Safety Boards
(III) Research on methods used at the Dutch Safety Board

For each of the parts, the execution is described below.

(I) Literature search on traditional accident investigation

Searching for information on (traditional) accident models and methods, one could easily get lost. A 'Google search' on "accident investigation" results in more than 1 million hits. Fortunately, summaries and comparisons of traditional accident investigation (models and methods) have been made. Based on some recent summaries and comparisons, information on traditional accident investigation models and methods was identified.

(II) Research on methods used at other Transport Safety Boards

The International Transport Safety Association (ITSA) is a global association of Transport Safety Boards. Based on the information *on the websites* of each member – 14 in total – an overview was created of the methods used by each member. Next, the list of methods used, has been checked with the knowledge available at the Research and Development department of the Dutch Safety Board and – if necessary – adjusted and completed. Finally, these methods were categorized according to the chosen categorisation in (I).

The result is information on the (categories) of methods, claimed to be used by safety boards on their websites.

(III) Research on methods used at the Dutch Safety Board

The Dutch Safety Boards possesses a "Knowledge Base" with all (results and) publications of accident investigations executed by the Dutch Safety Board since 1999. Based on these publications – which are public – the methods used have been identified. The list of publications and methods used was divided in minor and major investigation reports. Minor reports are those resulting from limited investigation, while major reports are those resulting from extensive investigation.

Next, the list of major publications and methods used, have been checked internally with the knowledge available at the Research and Development Department, and – if necessary – adjusted and completed of the Dutch Safety Board. This was the case for three publications: one shipping, one defence and one aviation report.

The result is information on the (amount and type of) methods used at the Dutch Safety Board during the past 8 years.

Based on the results of these three parts, traditional accident investigation – including models and methods – have been defined. Directions for extending traditional accident investigation (theories and methods) are given.

2.2 Identification of theories for extra-organisational factors

Based on the research question, and the research executed for defining traditional accident investigation, theories were searched for. The aim was to identify theories that could facilitate identification extra-organisational factors. The factors identified should facilitate the understanding of the appearance of accidents.

Two paths were chosen to identify potential applicable theories:
(I) Expertise in network
(II) Literature search
For each of the paths, the execution is described below.

(I) Expertise in network

Discussing the initial research question with my mentor, he advised to look into Wildavsky (searching for safety), and Perrow (Normal Accident Theory; NAT). To pursue a certain amount of completeness, the identified theories have been discussed with my co-students of the Master of Public Safety and my colleague advisors Research & Development.

(II) Literature search

Reading Wildavsky and Perrow, terms like system, linear and complex interactions, anticipation and resilience popped up. Wildavsky's and Perrow's books and literature triggered the search for other/ extended theories and methods, like for instance Hollnagel and Dekker.

The theories have been summarized in detail in the appendices, while the most relevant information has been summarized in chapter 4. The theories have been analysed for their ability to identify system and/or extra-organisational factors.

2.3 Identification of methods for extra-organisational factors

Based on the research question, and the research executed for defining traditional accident investigation, and the identified theories possibly of use to identify extra-organisational factors, methods were searched for. The aim was to identify methods that could facilitate identification extra-organisational factors. The factors identified should facilitate the understanding of the appearance of accidents.

Three paths were chosen to identify potential applicable methods:
(I) Expertise at the Dutch Safety Board
(II) Expertise in network
(III) Literature search
For each of the paths, the execution is described below.

(I) Expertise at the Dutch Safety Board

Since 2006, the Dutch Safety Board is developing an extension of traditional methods with Leiden University. This project resulted in development of a – preliminary - instrument: IPIC RAM. Accimap and STAMP were methods which were identified in this project.

FRAM was identified by a board member, as well as Backward and Forward mapping of Hans de Bruijn. De Bruijn used one of our accident investigations to demonstrate how accident investigation could be improved. The Dutch Safety Board used his essay as an opportunity to discuss the approach for investigation and analysis.

(II) Expertise in network

To pursue a certain amount of completeness, the identified methods have been discussed with my mentor, my co-students of the Master of Public Safety, my colleague advisors Research & Development, and the participants in the research project of Leiden Univerity and TNO.

(III) "Google search"

To pursue completeness and prevent tunnelvision of me and my network, finally a Google search was performed. For this search I used (combinations of) words like accidents, analysis, organisation, system, method, risk. This search results in generic information an accident models (most of which, in hindsight, can be called traditional models), traffic accident information, and a generic site on resilience engineering.

The methods have been summarized in detail in the appendices, while the most relevant information has been summarized in chapter 5. The methods have been analysed for their ability to identify system, dynamic and extra-organisational factors.

2.4 Assessment of traditional accident investigation

Next, traditional accident investigation was assessed against the factors identified by the theories and methods. This consisted of three parts:

(I) Development of assessment framework

The identified theories and methods appeared to be partial overlapping and partial adding up. Based on the objectives and relevant factors to the different theories and methods, an assessment framework was generated. The assessment framework consists of two parts:

a. A checklist based on the identified theories
   This checklists consists of factors for system characteristics and risk strategy: the S &RS framework (system & Risk strategy)
b. A questionnaire based on the factors identified by the identified methods, structured in four categories: the EOF framework (extra-organisational factors)

(II) Theoretical assessment

The traditional investigation approach of the Dutch Safety Board has been assessed using the S&RS and EOF framework. For each factor was estimated to what extend this could be identified with the traditional investigation approach. This was done for each element of the traditional approach. The estimation had to be one of the following values:

Legenda	Explanation
- -	(nearly) impossible to identify
-	not suited, but with explicit effort possible to identify
0	migth occasionally be identified
+	(partially) suited to identify, some innate tendency
++	developed to identify, innate tendency, could hardly be missed

Figure 3 Possible values for theoretical assessment

(III) Practical assessment

The practical assessment consisted of assessment of a case study: the results of an investigation performed by the Dutch Safety Board. The case study was an investigation on an explosion of a tank, filled with hydrocarbons and water. As a result of this explosion, two persons died and one was injured. This investigation followed the traditional accident investigation approach of the Dutch Safety Board, i.e. all traditional elements were part of the investigation. The results were assessed with the S&RS and EOF framework. For each factor of the assessment framework it was estimated to what extend the information was identified. The estimation had to be one of the following values:

Legenda	Explanation
- -	No relevant aspects identified (0%)
-	Few relevant aspects identified (25%)
0	some relevant aspects identified (50%)
+	A lot of relevant aspects identified (75%)
++	all relevant aspects identified (100%)

Figure 4 Possible values for practical assessment

The results of the theoretical and practical assessment have been analysed. The range, the average, and the maximum value have been identified, as well as factors that might be identified using the traditional approach. Finally, factor have been identified that will not be identified by the traditional approach.

3 Results: traditional accident investigation

In this chapter traditional accident investigation will be searched for. A tradition can be defined as a set of habits or customs, practiced by a certain group during a longer period of time, and taught by one generation to the next. Traditional accident investigation can thus be defined as the set of approaches and methods commonly used to investigate accidents, by Safety Boards in particular.

3.1 Models and methods

Learning from things that went wrong is of all ages. Formal accident investigation however has started from the beginning of 1900. The domino theory of Heinrich around 1930 is the first model on accident causation. Since then, several models and methods have been developed to analyse and understand accidents.

Accident models aim to conceptualize the characteristics of the accident. Methods facilitate identification of factors relevant to the model it is based on. Accident models and methods can be distinguished in different ways. One way to discriminate between accident models and methods is to their ability to identify technical, human, organisational, and system failures. Methods that have their focus on technical factors are for instance Fault Tree Analysis (FTA) and Failure Mode & Effect Analysis. Tripod and the Human Factors Analysis and Classification System (HFACS) were specially developed to take human factors into account. Organisational factors are identified by methods like Tripod and MORT. Methods that focus on the system are for example Accimap and STAMP.

This classification is not exclusive and some methods are easier to classify within this classification system than others. STEP and CCA for instance, were developed to identify the chain of events, which can consist of both technical as human factors. Tripod was originally developed to deal with the human factor, but in the end mainly focuses on the organisation. Fault Tree Analysis was developed to identify technical failures, but can also identify human and organisational failures.

Models that have their focus on technical, human and organisational factors all were developed (far) before the year 2000. Accident models with a focus on the system are fairly new and are being developed since the beginning of the 21st century.

Another way is to classify models and methods is to discriminate between sequencing, epidemiological, and system models and methods (Hollnagel, 2006; 2008). Sequencing models are based on the theory that an accident is a chain of discrete events occurring in a particular temporal order. The Domino Theory of Heinrich is one of the earliest sequencing models. Other sequencing methods are for instance Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Failure Mode and Effect Analysis (FMEA), One-dimensional timeline analysis, multiple-dimensional timeline analysis like Sequentially Timed Events Plotting (STEP), and Cause Consequence Analysis (CCA). All these methods can be classified as deterministic: an event is caused by the preceding unbroken chain of events. For accidents in relative simple systems, caused by physical system of human failures, these methods work well. Figure 5 presents a simple model of a sequencing accident model.

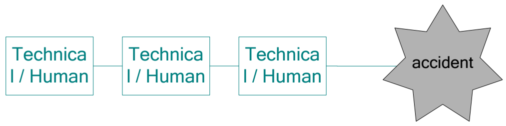


Figure 5 Prototype of sequencing accident model

When investigating accidents resulting from failures in more complex systems, sequencing models appeared to be of limited use. This resulted in the development in epidemiological models in the 1980's (Hollnagel, 2004). Epidemiology is the scientific approach to prevent existence and spreading of diseases by identifying whom will be diseased and what factors make them disease-prone. In other words: what are the weakening characteristics that makes some more vulnerable than others. In epidemiological accident models, accidents are the result of combination of both manifest (direct) and latent (indirect, hidden, and weakening) factors. Latent failures decrease the resilience of organisations and increase the vulnerability to accidents. The Swiss Cheese Model of Defences (Reason, 1990), in which accidents are the result of failed defences on operational as well as management and organisational level, can be seen as the start of the development of several epidemiological accident models. Reason introduced the concept of organisational accidents. Dimensions like sharp-versus-blunt end, and proximal-versus-distal factors were introduced.

Relations between events, failures, and hidden factors are much more complex than in sequencing models. However, the relation remains linear and static. Examples of these methods are Tripod and Management Oversight Risk Trees (MORT).Figure 6 presents a prototype of an epidemiological accident model.

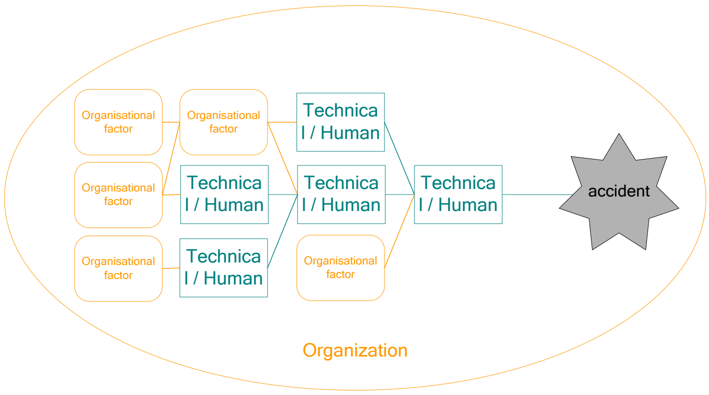


Figure 6 Prototype of epidemiological accident model

The third category consists of (dynamic) system models. System (or systemic) accident models acknowledge the complex and interconnected network in which accidents take place (Qureshi, 2008). Examples of such models are the hierarchical socio-technical framework and the accompanying method Accimap (Rasmussen, 1997, 2000) and STAMP (Leveson, 2003, 2004).

Table 1 provides an overview of the two presented classification methods and some examples of methods.

Classification I	**Technical**	**Human**	**Organisational**	**System**
Examples of methods	*Fault Tree Analysis (FTA)* *Failure Mode & Effect Analysis (FMEA)*	*Tripod* *Human Factors Analysis and Classification System (HFACS)*	*Tripod* *MORT*	*ACCIMAP*

Classification II	**Sequencing**	**Epidemiological**	**System**
Examples of methods	*Fault Tree Analysis (FTA)* *Event Tree Analysis (ETA)* *Cause-Consequence Analysis (CCA)* *Sequentially Timed Events Plotting (STEP)*	*Swiss cheese model* *Tripod* *MORT*	*ACCIMAP* *STAMP*

Table 1 *Overview of two classification systems and examples of models / methods*

Besides these two classification systems, other criteria to discriminate between models and methods are used. One of them is the distinction between linear models, complex linear models and dynamic models (Hollnagel, 2008). All sequencing methods can be seen as linear: discrete events occurring in a particular temporal order and are caused by one or more preceding events. Complex linear models are featured by more complex relations between causal factors. Relations can be both deterministic as probabilistic, but are still linear. Dynamic models acknowledge interconnections between (f)actors, which can result in inhibiting and stimulating loops.

The use of the term *dynamic*, suggests however an antipole *static.* This implies that linear and complex linear methods assume staticallity. For the identified linear and complex linear methods, this is indeed the case (see also Table 2
Table 2). The question however is whether all system models can be classified as dynamic.

Classification III	**Sequencing / linear**	**Epidemiological / complex linear**	**System / dynamic**
Examples of methods	*Fault Tree Analysis (FTA)* *Event Tree Analysis (ETA)* *Cause-Consequence Analysis (CCA)* *Sequentially Timed Events Plotting (STEP)* *Failure Mode & Effect Analysis (FMEA)* *Human Factors Analysis and Classification System (HFACS)*	*Tripod* *MORT*	*System models?*
	◄──── **Static** ────►		◄── **Dynamic** ──►

Table 2 Classification sequencing/ linear, epidemiological/ complex linear and system/dynamic models

Traditionally, accident prevention was a matter of preventing component failures, including a proper design and construction (Perrow, 1984). According to Dekker (2005), traditional accident investigation mainly consists of error-counting. Accidents are explained by - for instance - operator error, faulty design or equipment, lack of attention, inadequately trained personnel, and failure to use the most advanced technology. Qureshi (2007) states that traditional accident models are based on sequential models. These models focus mainly on the relation between causes and effects (Dekker, 2005; Qureshi, 2007), which all can be explained by technical, human, or organisational malfunctioning (Hollnagel, 2008)

Traditional investigation makes use of a mechanistic vocabulary, using words like events, effects, barriers or defences, failures, and causes. One-dimensional parameters like sharp- versus blunt end, and blame- versus safety culture are used. Traditional accident investigation is event-driven, searching for holes in the layers of defences, and unsafe acts causing these holes (Dekker, 2005). However, some accidents can be the result from failures from a (larger) system: system accidents (Perrow, 1984), and traditional accident models are not adequate to predict accidents in complex modern socio-technical systems (Qureshi, 2007).

3.2 Transport Safety Boards

The International Transport Safety Association (ITSA) is a global association of Transport Safety Boards, with a mission to improve safety in each member country by learning from experiences of others. One of the objectives formulated is to exchange information on safety deficiencies, safety studies, safety recommendations, accident data and accident investigation techniques and methodologies (ITSA, 2008).

Currently, fourteen Transport Safety Boards are member of this association. Based on the information on the websites of each member, an overview of the accident investigation methodologies was generated. In Appendix VI a tabulated overview of the methods used can be found. The methods have been categorized using the following categorization:

(I) fact finding methods
(II) sequencing / linear methods
(III) epidemiological / complex linear methods
(IV) system / dynamic methods

As can be seen in Figure 7, twelve of the fourteen members mention a fact-finding method (86%). In all cases, this was the method interviewing.

Methods in the sequencing / linear category were mentioned by nine out of twelve members (64%). Most of these nine members use a timeline analysis method (of which a quarter uses the multidimensional timeline analysis STEP), almost half of the group use Root Cause Analysis or Fault Tree Analysis. Six out of fourteen use epidemiological / complex linear methods (43%). Three of these six use the Reason Model. Other methods used are TEM, SHELL, Tripod and Mort. Tripod is only used by the Dutch Safety Board. Finally, three Transport Safety Boards mention the use of system / dynamic models: Accimap is mentioned by the Canadian, Australian and Dutch Safety Board.

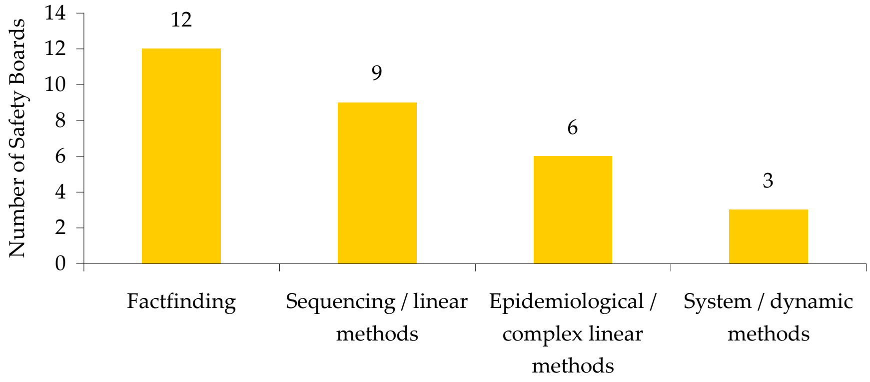


Figure 7 Number of Transport Safety Boards mentioning use of certain methods (DSB included).

3.3 Dutch Safety Board

The Dutch Safety Board can investigate accidents in all domains, from transport domains like aviation, rail, and shipping, to all types of industry, services, healthcare and crisis management & aid provision. The Dutch Safety Board is free to choose the methods for investigation. In this paragraph the current process of accident investigation of the Dutch Safety Board will be described. The assessment frameworks will be explained. The paragraph concludes with an analysis of the methods used by the Dutch (Transport) Safety Board from the years 2000 to 2008.

3.2.1 Primary process

Each investigation starts with an event. This event is assessed on several criteria, for instance (potential) severity, frequency of (prior) similar events, societal turbulence and possibility to identify structural safety deficiencies. Information on events that potentially might induce further investigation is immediately taken charge of. The Board decides whether the event will be investigated.

When the event will be investigated, an investigation team is formed. This team will identify possible aspects for investigation, formulate hypothesis to be tested, and execute further investigation and analysis. The initial approach is stated in a project plan and approved by the Board. To improve the quality of the end results, several approaches are used, like the application of structured methods, brainstorm sessions, cooperative working, formal factual checks with those involved in the event, peer reviews by colleagues from different angles, and reviewing by the Board (Van Schaardenburgh-Verhoeve, 2006). Finally, the report for publication is written, and recommendations are formulated and appointed. The Dutch Safety Board strives to publish this report within twelve months after the event took place or the investigation started.

The Safety Board also monitors the follow up of the recommendations issued. Governmental organisations have to respond to their Minister within six months after the publication what they will or have done with the recommendation. Other organisations have to respond within one year.

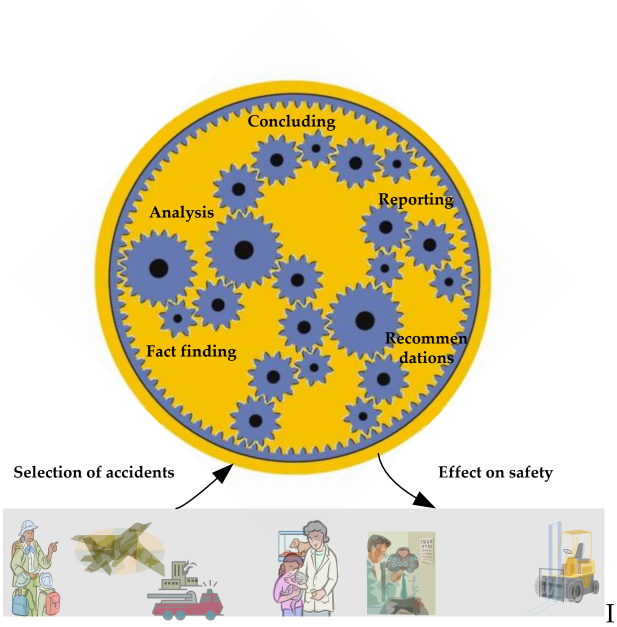


Figure 8 Visual overview of the primary process of the Dutch Safety Board. When staring at this picture, the radars start moving, visualizing the iterative process in which the parts are connected.

3.2.2 *Methods*

The approach of the investigation and analysis process depends on for instance the type of event, the scope of the investigation and the expertise in the team. Investigation and analysis can consist of a wide range of fact-finding techniques, including forensic techniques and interviewing, and a wide range of analysis methods, like simulations, timeline analysis, fault tree analysis, and Tripod.

Based on the accident investigation reports published since 1999 by the Dutch (Transport) Safety Board, an analysis of the methods used is made. Methods that were mentioned in the report or its appendices are taken into account. Initially, 132 reports have been included in the analysis. 50 of them have been removed from the analysis, since these were all minor investigations, consisting of only a couple of pages without explanation of the investigation process. The methods in the remaining reports – the major investigations - have been categorized using the same categorisation as in paragraph 3.2. An overview of the 82 major reports and the identified methods used can be found in Appendix V.

As can be seen in Figure 9, most major investigation reports mention the use of a fact-finding method (77%). Less then 20 percent of the major investigation reports mention the use of a sequencing / linear method, like timeline-analysis. Almost 40 percent of all major investigation reports used and mentioned an epidemiological / complex linear method. Nearly all of this 40 percent used Tripod. Less then one percent - 1 investigation report - mentioned the use of a system / dynamic method (Accimap).

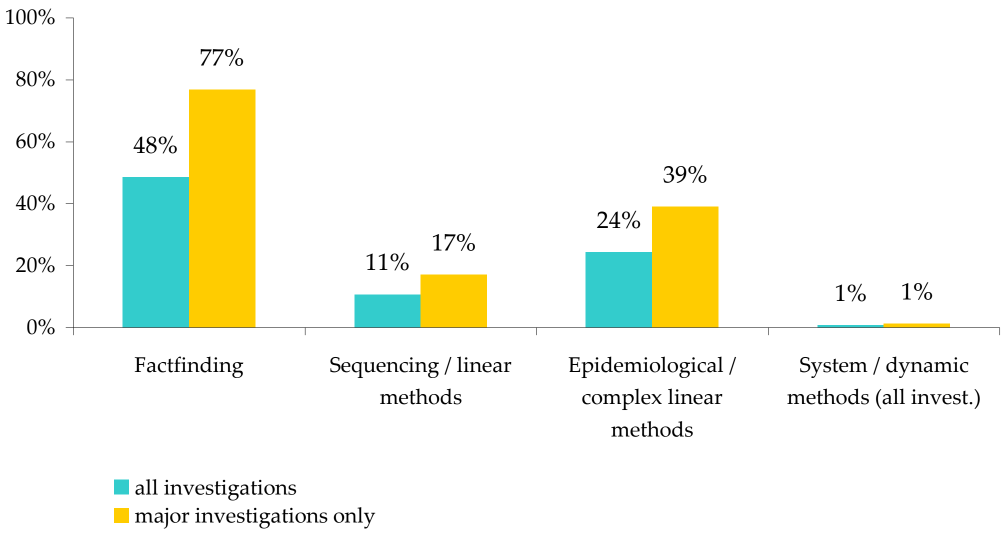


Figure 9 Percentage of published reports mentioning (use of) method. Number all investigations = 132; number full investigations = 82

The above mentioned percentages are based on all major reports published in the past eight years. Interesting is to see whether the application of methods changed over the years. This is represented in Figure 10. In general, the application of - all types of - methods has increased since 2003. Of all major investigation reports published in 2007 (the last completed year), all reports mentioned use of the fact-finding method interviewing; over 40 percent mentioned the use of sequencing / linear method, and almost 80 percent used an epidemiological / complex linear method. System / dynamic methods were not mentioned. The proportion of popularity of the different types of methods over the years remained the same: fact-finding is most popular, then the epidemiological / complex linear methods, then the sequencing / linear methods. System / dynamic methods have been used only once, very recently (2008).

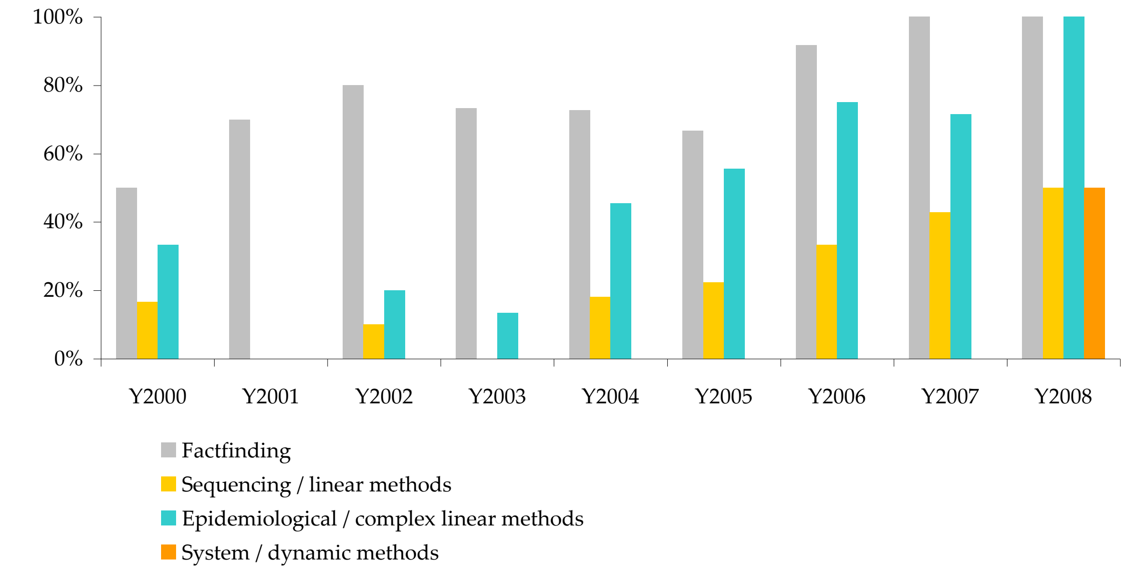


Figure 10 Percentage of published reports mentioning (use of) method - per year. 82 full investigations included. Y2008 includes two reports.

To identify whether the use of methods is domain-related, Figure 11 has been included. As can be seen, investigation reports of road accidents only mention the use of fact-finding methods. Also remarkable is the little use of sequencing / linear methods and epidemiological / complex linear method in shipping accidents. The new domains, in which only 1 or 2 reports have been published, all use fact-finding- , sequencing / linear – and epidemiological / complex linear methods.

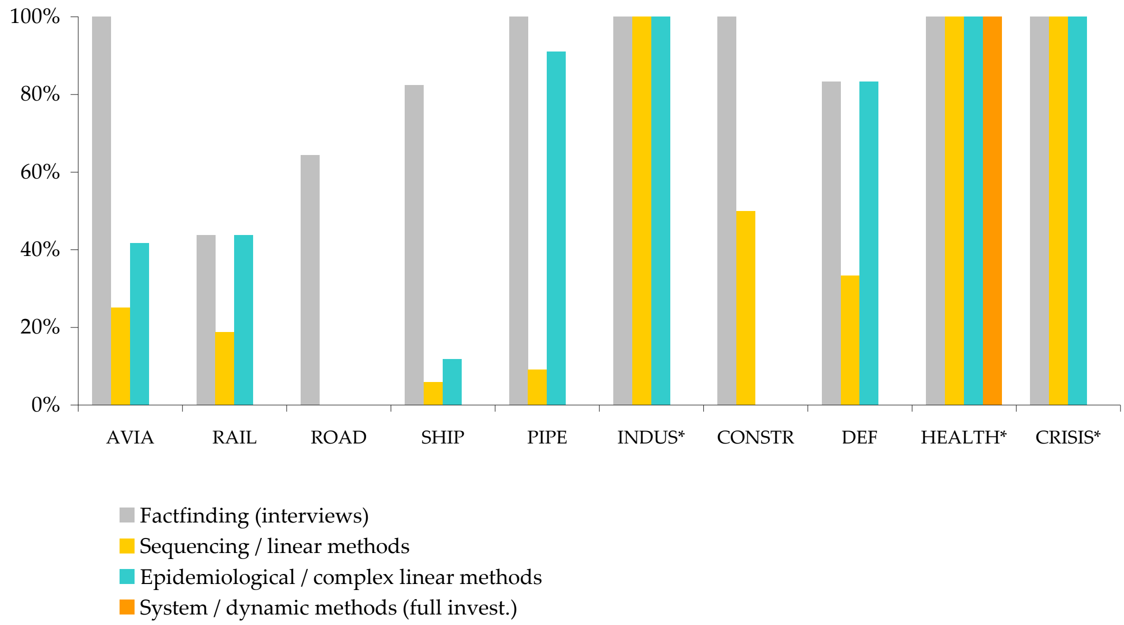


Figure 11 Percentage of published reports mentioning (use of) method - per domain. * includes one investigation only.

3.2.3 *Assessment frameworks*

Part of the Dutch Safety Board's investigation and analysis, is the assessment of the findings against certain standards. The Dutch Safety Board distinguishes an assessment framework consisting of:

1. Law and regulations
    a. compulsory regulations, like legislation
    b. voluntary regulations, like domain or company specific standards
2. Individual responsibility for safety
   Individual responsibility is defined using the following generic principles of Safety Management:
   (I) Understanding risks as a basis for a safety policy
   (II) A demonstrable and realistic safety policy
   (III) Implementing and sustaining the safety policy
   (IV) Tightening the safety policy
   (V) Management, involvement and communication

More information on each principle can be found in Appendix VII.

Derivative of these two parts of assessment are the responsibilities of the staff and organisations involved. The events, preconditions, and factors contributing to the accident are assessed against the regulations and responsibilities. This can be seen as a comparison between the process-as-designed and the actual process, with the remark that the Boards individual responsibility can also be seen as the process-as-desired.

3.4 Conclusion

Traditional accident investigation is the set of commonly used approaches, accident models and methods to investigate accidents. These models and methods can be categorized in different ways. One way is to discriminate between sequencing (linear), epidemiological (complex linear) and system (dynamic) models, as introduced in this chapter.

Based on the identified literature on accident investigation, traditional accident investigation consists of error counting, by focusing on failures. In general, it consists of at least linear, sequencing models. Some evidence is found that traditional accident investigation also includes complex linear, epidemiological models. All traditional models are static. System and dynamic models are seen as the modern approach for accident investigation.

These conclusions are largely supported by empirical data from the methods used at Transport Safety Boards. Apart from fact-finding methods, which are used by almost all Transport Safety Boards, sequencing / linear methods are used by more than 60% of the Transport Safety Boards. Over 40% of the Transport Safety Boards uses epidemiological / complex linear methods, and less then 25 % of the Transport Safety Boards use system / dynamic methods. The (Transport) Safety Boards of Canada, Australia and the Netherlands are front runners in application of such methods.

Traditional accident investigation at the Dutch Safety Board consists of a team- & project approach, using methods, and an assessment against regulations and Individual Responsibility. The traditionally used methods consist of the fact-finding method interviewing, the sequencing / linear method STEP, and the epidemiological / complex linear method Tripod.

System / dynamic models, which cannot be called traditional and which acknowledge the complexity of current society, and its dynamic interactions, might be the next step forward in learning form accidents and improving public safety. Figure 12 positions the sequencing / linear – and epidemiological / complex linear models in this dynamic system.

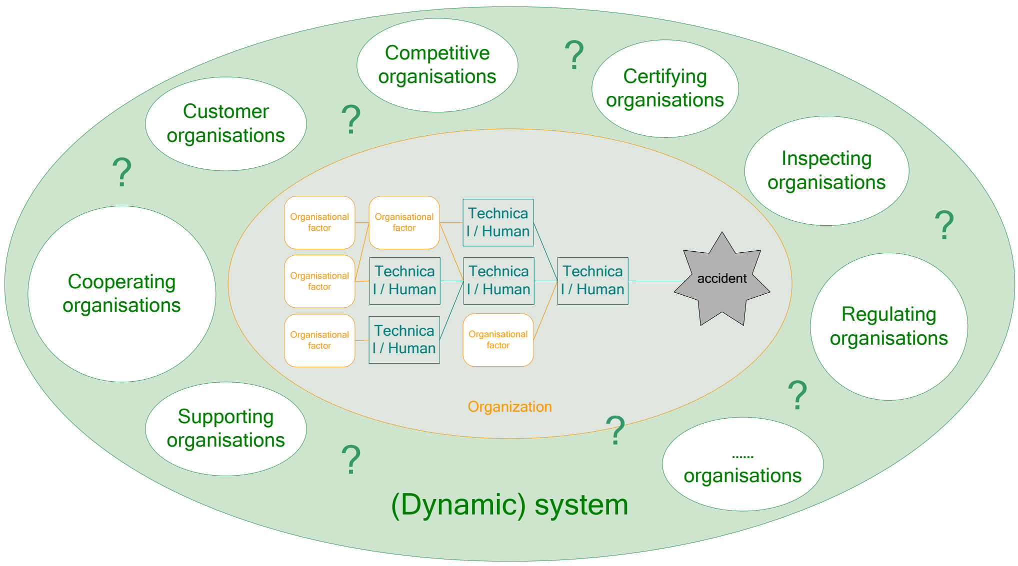


Figure 12 Complex linear accident model in system of surrounding organisations

The next chapters will focus on identifying theories and methods which can facilitate the identification of the system and the extra-organisational factors. Table 3 provides some initial guidance on what factors to include.

Direct factors	**Intra-organisational factors**	**Extra-organisational factors**
Static	***Dynamic***	
Linear	*Complex linear & dynamic*	
Technical & Human	*Organisational & System*	
Proximal	*Distal*	
Sharp end	*Blunt end*	
Failures	*Failures and successes*	

Table 3 Schematic overview of extra-organisational factors in relation to accident models

4 Results: theories for extra-organisational factors

Based on the previous chapter in which traditional accident investigation was defined, the search of extra-organisational factors should include identification of the actors and systems involved. Factors can be the integration of the system, and the relationships and interactions between the actors involved (Rasmussen, 2002; Dekker, 2005). This chapter consists of a summary of the main theories identified as possibly relevant for the search of extra-organisational factors, amplified to the relevance for accident investigation.

4.1 Systems

As mentioned in the introduction, technology changes rapidly and systems become more intergraded and coupled. Nowadays, modern society as a whole can also be seen as a socio-technical system, with its complex infrastructures and multiple actors. Socio-technical systems are those systems in which technology and people interact. The technical system includes for instance machinery, processes, and procedures. The social system consists of the people, their habitual attitudes, values, behavioural styles and relationships. According to Trist (1950's) system performance is determined by interconnections, rather than individual elements. Therefore, more information on system characteristics was searched for.

According to Perrow (1984), systems can be divided into four levels: units, parts, subsystems and the complete system. According to his definition, accidents involve damage to the system or subsystem, affecting safety on people. When just parts or units are involved, or safety has not been affected, he speaks of incidents. Accidents can be divided into two categories: component failure accidents, which involve one or more components failures, linked by an anticipated sequence; and system accidents, which involve multiple components failures, linked by an unanticipated interaction (see
Figure 13).

	type of failures	Component failures with anticipated interaction	Multiple component failures with unanticipated interaction
Failures in	units		
	parts		
	subsystem	**accidents**	
	system		

Figure 13 Accidents according to Perrow (1984)

Systems can be open, meaning the system is highly affected by its environment (Qureshi, 2008). When accidents take place in these systems, the interactions and interrelationships between technical, human, social and organisational aspects (and components) of the system have to be understood. The system must be treated as an integrated whole, and its aspects should be considered simultaneously (Qureshi, 2007). Figure 14 presents the socio technical system according to Rasmussen (1997).

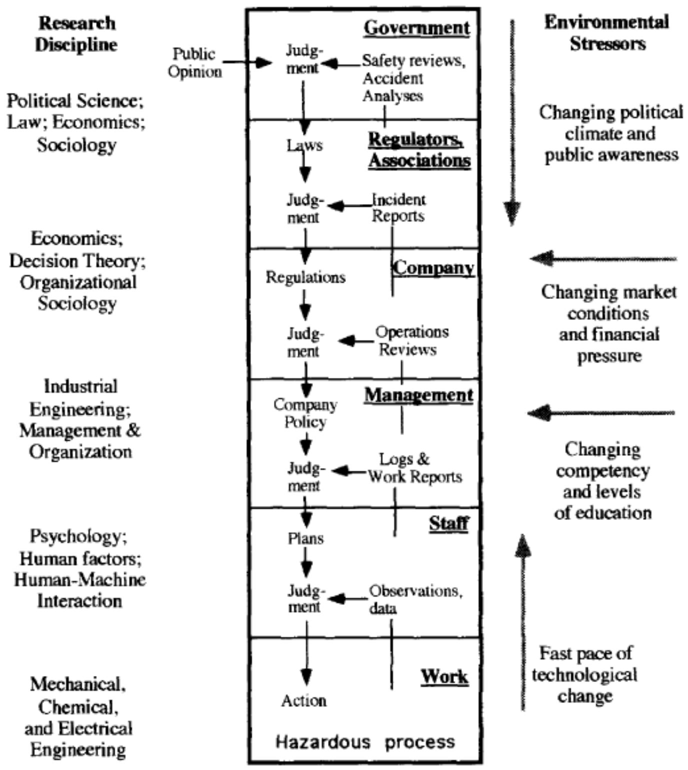


Figure 14 Socio technical System according to Rasmussen (1997)

4.2 Interactiveness & coupling

Perrow (1984) distinguishes two main features of systems, influencing the proneness of a system to accidents.

The first feature is the kind and amount of *interactiveness*. Interactions are linear, when a component in the DEPOSE system (Design, Equipment, Procedures, Operators, Supplies & materials, and Environment) interacts with one or more components, that precede or follow it immediate in the sequence of production. Linear interactions are often familiar to those involved and can be expected. Since these interactions are quite visible, even unplanned interactions are easy to recognize.

Interactions are complex, when a component can interact with one or more components outside the normal sequence of production. Complex interactions are unfamiliar, or have unplanned and unexpected sequences. These interactions are less visible and not immediately comprehensible.

Systems have not either linear or complex interactions. All systems mainly consist of linear interactions, but some have more complex interactions than others. Systems therefore should be characterized in terms of the degree of either quality. Linear systems have a very few complex interactions. Complex systems have more complex interactions than linear systems, but are still in the minority compared to linear interactions.

The more complex a system is, the less transparent it becomes. In such systems, foreseeing, detecting and comprehending deviations from the intended process are difficult. But from a production efficiency point of view - neglecting accident hazards - complex systems are more efficient than linear systems: there is less slack, less underutilized space, less tolerance of low quality performance and more multifunction components.
Table 4 presents a summary of the differences between linear and complex systems.

	Linear systems	Complex systems
Subsystems	Segregated	Interconnected
Connections	Dedicated	Common-mode
Production steps	Segregated	Proximity
Feedback loops	Few	Unfamiliar, unintended
Isolation of failures	Easy	Limited
Substitutions	Easy	Limited
Controls	Single purpose, segregated	Multiple, interacting
Information	Direct	Indirect, interferential
Equipment	Spread out	Tight spacing
Personnel	Less specialization Extensive understanding	Specialization limits awareness of interdependencies Limited understanding

Table 4 Summary of features of linear and complex systems

The second feature is the amount of *coupling*. Coupling is called tight when there is only one way to achieve the production goal, in a predetermined sequence of processes. Buffers and redundancies must be designed and thought of in advance, and delays are not possible without disturbing the process. Tightly coupled systems will respond more quickly to perturbations, although the response may be disastrous.

Coupling is called loose, when the way to achieve the production goal is multivariate and not predetermined. Buffers and redundancies are in generic form available, though must be made specific for the situation. Loosely coupled systems can incorporate shocks, failures and pressures for change without destabilization.
Table 5 summarizes the main differences between tight and loose coupling.

	Tight coupling	Loose coupling
Achieving goals	One method	Multivariate methods
Sequences	Invariant	Order can be changes
Delays	Not possible	Possible
Buffer and redundancies	Designed in, deliberate	Fortuitously available
Substitutions	Designed in, limited	Fortuitously available
Resources	Little slack	Slack

Table 5 Summary of features of tight and loose coupling

Perrow argues that the applicable management structure depends on these two dimensions. Linear and tightly coupled systems are best centralized, while complex but loosely coupled systems are best decentralized. Linear and loosely coupled systems can be either. Complex and tightly coupled systems can be neither and are inherently dangerous. Figure 15 presents the two main dimensions, combined with the dimension centralisation versus decentralisation. Appendix VIII provides more detail on Perrow's interactiveness and coupling dimensions.

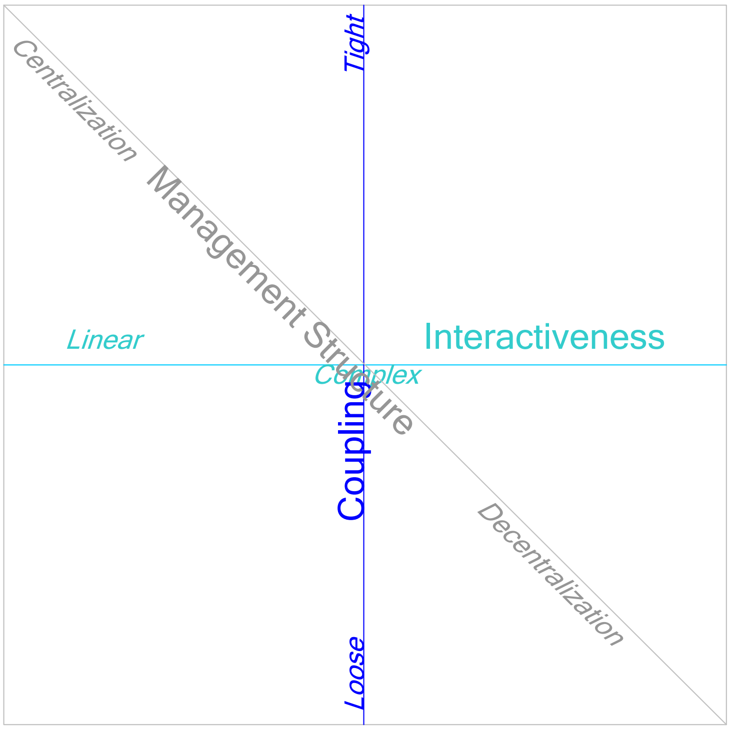


Figure 15 Interactiveness, coupling and management structure

4.3 Anticipation & Resilience

Wildavsky (1988) distinguished two main risk strategies: anticipation and resilience. He emphasises we are living in a world with uncertainties. Predicting accidents, in a qualitative as well as a quantitative way, has appeared to be very difficult. Since we will always be faced with unplanned and unpredicted accidents, both in qualitative and quantitative way, we should possess a sufficient amount of *resilience* to cope with these accidents. Resilience is a capacity, a skill of the system and its components, to recognize, comprehend and react to dangers that have become manifest. In order to gain this capacity, one has to be able to learn from errors.

Trial and error is a strategy that comes with resilience. Trial and error does not mean to put people unnecessary or irresponsible at risk. By establishing a policy where possible consequences should be (quite) modest, execute this policy, observe the effects, correct for the effects, observe again, and so on, errors are permitted and improvements can be made. This approach fits in a risk-taking approach, where opportunity risks (i.e. dangers of trials) and opportunity benefits (i.e. gains / possible benefits from trials) are both considered, for short term as well as long term, for individuals (micro level) as well as society as a whole (macro level). A resilient organisation will be flexible in its response, and by that more apt to deal with surprises than an organisation based on anticipation strategies.

Wildavsky (1988) defines resilience as the dominant strategy, since it has the possibility to learn from errors and by that learn strategies to best react to surprises and to find new ways to improve safety. The main limitation of resilience is its potential for catastrophe. Table 6 presents an overview of the main differences.

	Anticipation	Resilience
Applicable to	Predictable accidents Stable / static systems	Unpredictable accidents Dynamic systems
Prerequisites	Certainty about probability, effects, who will be harmed	Uncertainty about probability, effects, who will be harmed
Drive	Fear of regret	Recovery is better than prevention
Risk strategy	Risk averse Enhance stability Trial without error	Risk taking Enhance variability Trial and error
by	Investment in safety defences Safety drills, protocols	Resources available for repression Sampling in small doses and diverse ways Redundancy Expanding general knowledge and technical facility
Underlying assumption	Doing nothing is better than doing something that harms people (But: inaction is a sure strategy for allowing more people to remain hurt, who by trial and error would have been helped.)	Doing something of which more people benefit, and less get hurt than previous is better than doing nothing Sacrifices on micro-level for gains on macro-level (rule of sacrifice)
Focus on	Mostly hazards Risks of changes (Opportunity risks) Components, parts (specification, measuring added value for safety)	Hazards and benefits Benefits of changes (Opportunity benefits) System as a whole (specification, measuring added value for safety)
Results in	Micro-safety	Macro-safety Innovations Adaptability
Risks	Rigidity Overspending on useless defences Decreased safety (by missing benefits of risks)	Potential catastrophe

Table 6 Summary of the anticipation and resilience strategies

However, today's society has adopted the strategy of anticipation. Anticipation puts all efforts on predicting and preventing potential danger. Errors are not permitted, trials are only allowed with a guarantee of absence of adverse events. Putting a small number at risk, to protect the majority, is not accepted. This is the characteristic approach of risk averseness. In risk averse approaches, protection of each part against failure is pursued. Resources will be spent on safety devices and redundancy, achieving reliability of each part. Anticipation seeks to preserve stability.

However, stable systems are less flexible and less apt to react to surprises, reliability of each part is not necessarily leading to increase in safety, fear of failure inhibits learning, and risk averseness overlooks the opportunity benefits. Therefore, anticipation strategies not necessarily increase safety, but can decrease safety.

Wildavsky states that resilience and anticipation have their own conditions under which they work best. The two dimensions involved to decide which is best, are knowledge on how to react to dangers, and predictability of change (see also Figure 16). When dangers are known and one knows how to act to these dangers, and changes to the system can be predicted, anticipation is the preferred strategy. When dangers are unknown and uncertain, and changes to the system are hard to predict, resilience is to be preferred.

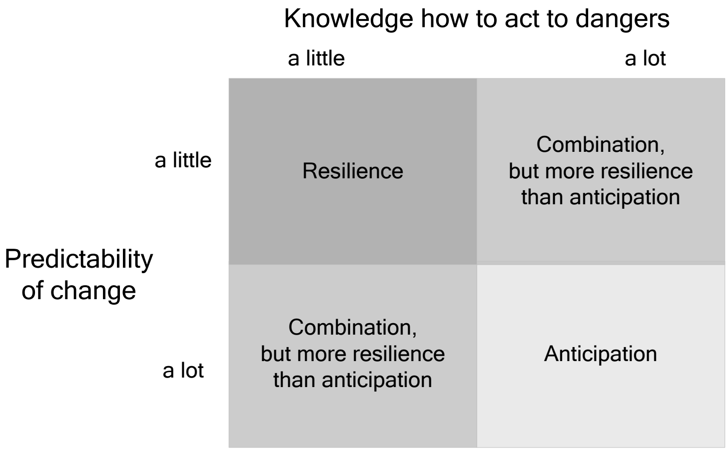


Figure 16 Application of anticipation and/or resilience

Nowadays society is over-focussed on anticipation: public sees damage as equivalent to negligence. Regulators and jurisdiction stimulate risk averseness. In the end it can be counterproductive to its goal: increasing safety. Wildavsky pleads for a different strategy. Safety is not absolute and static, but relative and degrades. Safety should be actively searched for. Appendix IX provides more detail on Wildavsky's view on the search for safety.

Where Wildavsky defines resilience as the capability to deal with unexpected dangers after they have become manifest, Hollnagel et al (2006) pleads for extending resilience to the left side of the Bow Tie (see Figure 17 and Figure 18), defining resilience as the ability of the system (and its components) to anticipate the changing shape of risk before failures and harm can occur. Resilience then becomes the ability to maintain control in order to stay outside the accident region and thus inside the safe area. This brings us to the next paragraph: the boundaries where safety ends and accidents begin.

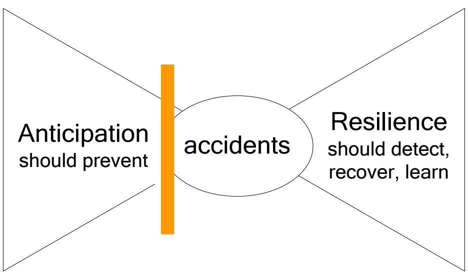


Figure 17 Wildavsky's Anticipation and Resilience in Bow Tie

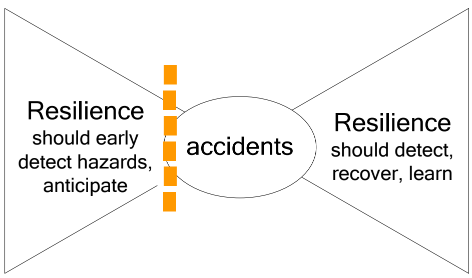


Figure 18 Hollnagel et al's Resilience in Bow Tie

4.4 Drift & boundaries

Accidents in complex systems frequently involve a migration of the system toward a state where a small deviation can lead to catastrophe (Leveson, 2003). Dekker (2005) calls this organisational drift. This drift is characterized by an incremental move towards the boundaries of the safety envelope.

In order to remain within the safety envelope, the boundaries have to be defined, made visible, and adjusted over time. Rasmussen (1997) distinguishes three boundaries: individual unacceptable workload, financial and economic constraints, and safety regulations and procedures (see Figure 19).

Drift is the process towards the boundaries of the safe space of performance. Drift is normal to all open systems and is the result of sequential decisions made by different actors which in isolation and in their time and place made sense for the decision makers. It appears difficult to recognize drift, by decision makers involved in this drift as well as by regulators and inspectorates (Dekker, 2005). Processes of decision-making play an important role in remaining within the boundaries of the safety envelope and should be taken into account in increasing safety.

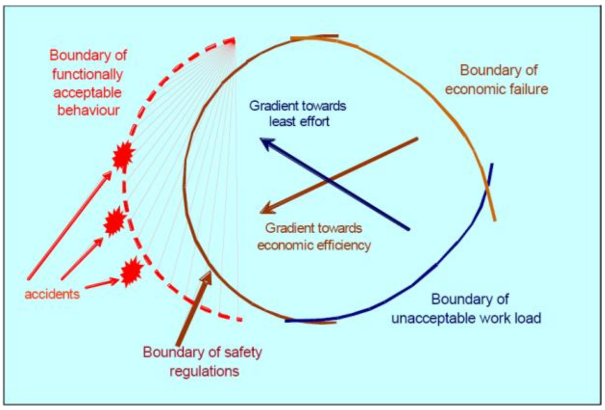


Figure 19 The operating boundaries according to Rasmussen (1997)

Appendix X provides more detail on Rasmussen's view on boundaries of safe operating and companying method Accimap (see also par. 5.1)

4.5 Conclusion

The identified theories focus on the system in which accidents take place, the appropriate risk strategy and the challenge to stay within the safe envelope. Perrow states that accidents are those events affecting safety of people, and resulting from failures of subsystems and systems. He distinguishes between linear and complex interactions, and tight and loose coupling.

Wildavsky identifies two risk strategies which are complementary. Anticipation is the strategy aiming to predict incidents and accidents, in order to prevent them form happening. Resilience is the strategy acknowledging uncertainty, and preparing for recognition, comprehension and reaction to incidents and accidents. There appears to be a relation between Perrow's interactiveness and coupling, and Wildavsky's risk strategies. The more linear interactions are, the more predictable the hazards and accidents, the more effective and thus appropriate anticipation as risk strategy. The more complex the interactions are, the less predictable the hazards and accidents, and the more essential resilience becomes. More complex interactions go well with loose coupling, providing time for recognition, comprehension and reaction. Figure 20 illustrates this relation.

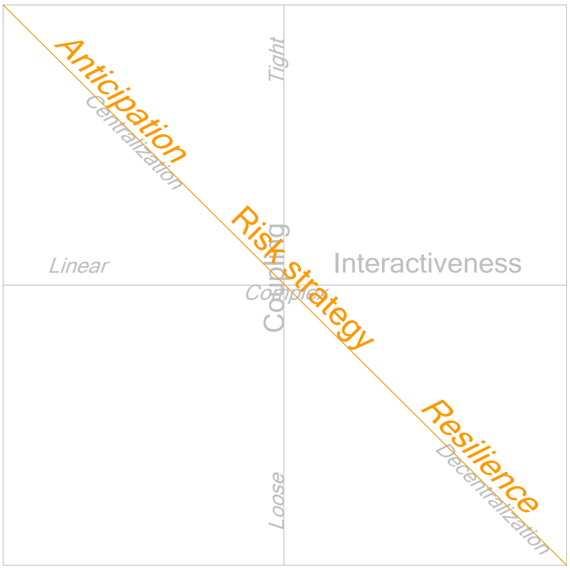


Figure 20 Theories of Perrow and Wildavsky combined

Modern scientists extend resilience to the left side of the Bow Tie, by stating that resilience is also anticipating to changes in society and new dangers before the become manifest in accidents.

All identified theories take extra-organisational factors into account. The systems theory of Perrow might facilitate identification of interactiveness and coupling between the different actors and system components. The theory on risk strategy of Wildavsky might be of use to identify the applicable risk strategy, when taking extra-organisational hazards and opportunities into account. Finally, drift and boundaries of the safe envelope might be extended to the complete system that organisations are operating in nowadays. Table 7 summarises the extra-organisational factors possibly identified by the theories.

Method	Features / aspects	Extra-organisational aspects
Systems	Technical system *(units, parts, subsystems, system)*	Multi-technical system: combination of technical systems; Complex technical system: technical system involving multiple organisations
	Socio-technical system *(human & technique)*	Multi-socio-technical system: combination of socio-technical systems; Complex socio-technical system: socio-technical system involving multiple organisations
Interactiveness & Coupling	Interactiveness *(linear to complex)*	The kind and amount of interactions between (socio-) technical systems and organisations
	Coupling *(tight to loose)*	The amount of coupling between (socio-)technical systems and organisations
Anticipation & Resilience	Anticipation	Applicable to predictable accidents, predictable hazards resulting from the multi (socio-)technical system and organisations involved (stable / static system)
	Resilience	Applicable to unpredictable accidents, unpredictable hazards resulting from the multi (socio-)technical system and organisations involved (dynamic system)

Table 7 Overview of the identified theories and the extra-organisational factors they take into account

5 Results: methods for extra-organisational factors

This section describes identified methods that can be of use searching for extra-organisational factors of accidents. Accimap (Rasmussen) and STAMP (Leveson) are two notable systemic modelling approaches. Functional Resonance Accident Model (FRAM) has been developed based on the principles of cognitive systems engineering (Qureshi, 2007). IPIC RAM has been developed for the Dutch Safety Board in order to facilitate interactions between actors. Backward and Forward mapping is an approach described bij De Bruijn in order to improve accident investigations by national committees.

5.1 Accimap

Rasmussen, originator of the socio-technical system in Figure 14, and Svedung (2000, 2002) describe a way to proactively manage risk in the present dynamic and technological rapidly changing society. This dynamic society consists of multiple actors, mutually influencing each others processes, in tightly coupled systems and in an aggressive, competitive environment. Management structures, safety legislation and safety regulation will always lag compared to changes in technology and their accompanying risks.
To adequately manage risks, an adaptive, closed loop feedback control strategy is needed. Features of such a control strategy are:

1. Clear goals to achieve, transparent for actors involved
2. Adequate knowledge on current state of affairs
3. Known, visible and safe design-envelope: boundaries must be clear to everyone
4. Counteraction of pressures on decision-makers operating towards the boundaries of the design envelope.

These features are premises for decision-makers involved in and creating the dynamic system.

An adaptive, closed loop feedback control strategy is needed for both the organisations involved in the process towards an accident, as well as the emergency and rescue organisations involved in the process starting from the accident. This implicates that accident investigation should include investigation of the decision making process. A study of decision-making cannot be separated from a simultaneous study of the social context and value system in which it takes place and the dynamic work process it is intended to control (Rasmussen & Svedung, 2000)

Accident investigation is one of the ways to retrieve information about the dynamic society, identify risks and identify ways to improve safety. Accident investigation should not be limited to the one organisation, but should identify opportunities for all relevant actors to improve safety (Rasmussen & Svedung, 2000). The following steps in accident investigation can be distinguished:

1. <u>Identify the potential accident pattern</u> (Cause Consequent Diagram)
2. <u>Identify the relevant actors</u> (Actor map). The actor map distinguishes:
   - Government policy & budgeting
   - Regulatory bodies & associations
   - Local area government / company management
   - Technical & operational management
   - Physical processes & actor activities
   - Equipment & surroundings

3. Identify the context for the relevant actors:
   - Information flow (use of infoflow map)
   - Conflicts (use of map of conflicts)
4. Identify the events / decisions / influence of relevant actors in the accident pattern (use of Accimap)
5. Generalize the findings by plotting results of multiple accidents (use of generic Accimap)

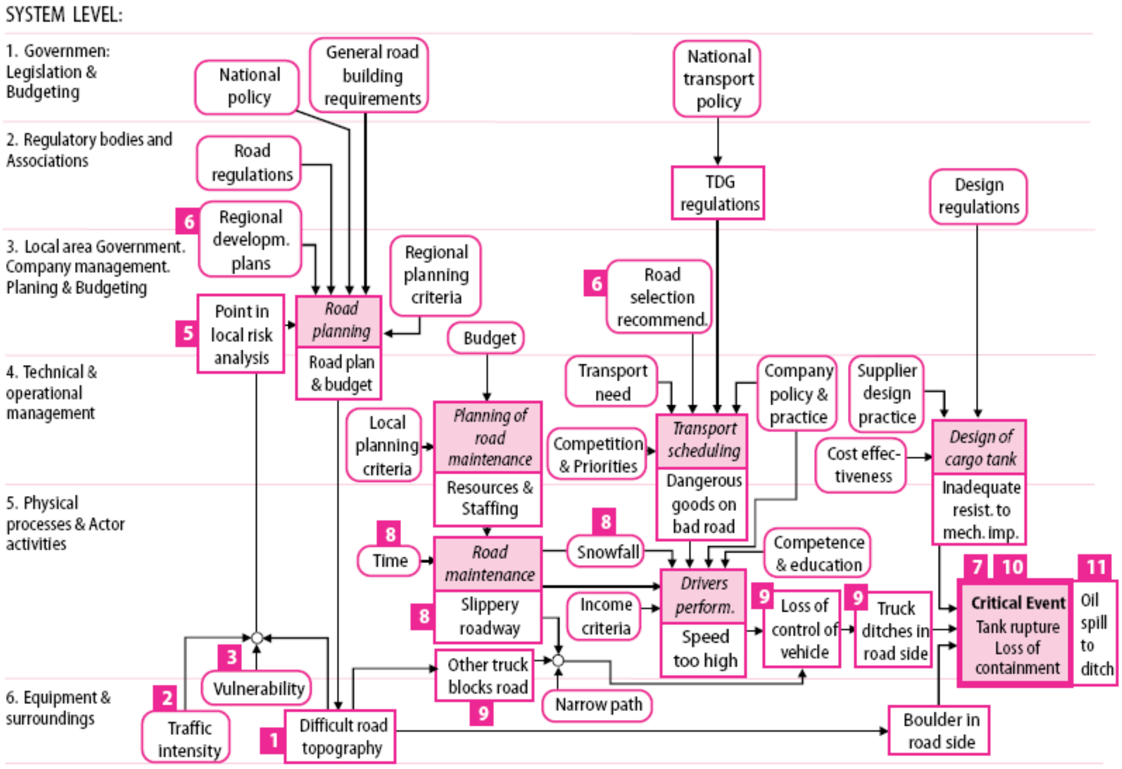


Figure 21 Example of an Accimap (tank rupture)

On the Y-as the different system levels are positioned. The boxes represent events, decisions and influences by different actors, all influencing /leading to the critical event.

Appendix X provides more detail on Accimap, including some examples and possible investigation questions.

5.2 STAMP

Accidents occur when external disturbances or dysfunctional interactions among system components are not adequately handled by the control system (Qureshi, 2007). Therefore, accidents are a control problem, and safety should be managed by a control structure (Leveson, 2004). Systems are viewed as hierarchical structures, and each level imposes constraints on the level beneath.

STAMP has been developed to consider technical, human and organisational factors in complex socio-technical systems. It is based on Rasmussen's (1997) hierarchical model of the socio technical system in Figure 14 (Qureshi, 2008), and based on Hollnagel et al's (2006) renewed views on resilience, stating organisations should stay in control and within the safe boundaries.

STAMP is constructed from three basic concepts: constraints, hierarchical levels of control and process models. The most basic concept is the constraint (Leveson, 2003). Accidents are the result of interactions between system components that violate the system safety constraints. Constraints should be designed to limit system behaviour to safe changes and adaptations.

The hierarchical levels of control consist of two steams of information: a downward reference channel with information on the constraints, and an upstream measuring channel to provide feedback about the effectively of the constraints.

The process models aim to identify the processes as designed originally, as the processes actual were and the process state at the time of the accident. System accidents frequently result form inconsistencies between the process model used by controllers, and the actual process state. When two or more controllers control the same process, problems can occur. In boundary and overlap areas, independently made decisions can be prone to ambiguity and conflicts.

A STAMP analysis can be divided in two stages:

1. Identification of constraints en controls:
    a. system hazards and system safety constraints
    b. control structure in place (as designed, see Figure 43 in Appendix XI; and actual state, see Figure 22)

2. Classification and Analyse Flawed Control, consisting of
    a. Classification of causal factors:
        1. inadequate constraints
        2. inadequate execution of constraints
        3. inadequate or missing feedback
    b. Reasons for flawed control and dysfunctional interactions

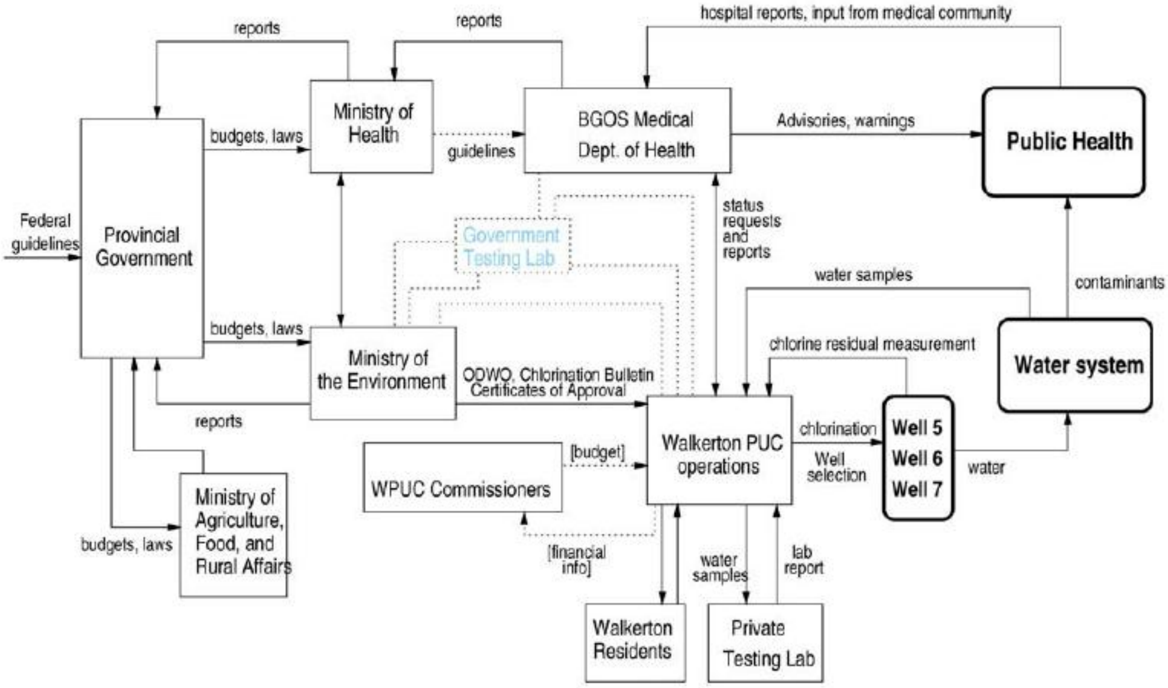


Figure 22 Example of a degraded control structure (water contamination)

The boxes represent actors or system components having a role in this system. Arrows which connect boxes represent connections between these actors/system components. The dotted lines are control loops which were originally designed, but have degraded over time.

For more details on the classification of control flaws, see Figure 44 in Appendix XI. This appendix also provides more detail on STAMP, including some examples and possible investigation questions.

Leveson emphasises the dynamic complexity of systems. Constraints and controls degrade over time, and one should consider reasons for the (directions) of change. In complex systems, two main forces on directions can be discriminated: positive (reinforcing) and negative (balancing). Directions can be reinforced or balanced directions by endogenous and exogenous influences (read: actors). When safety controls are degrading, balancing forces should overcome the negative influence.

5.3 FRAM

FRAM aims to describe resonance of system components, creating hazards that can run out of control (Qureshi, 2007). FRAM is a qualitative model to investigate how the combination of a normal variability of individual, technical and organisational performance may lead to an adverse outcome (Hollnagel et al, 2007). These variabilities – individually - all are normal, and even useful to get the work done, but the combination can be disastrous. The aim is to identify the elements and their interrelationship. FRAM is based on four principles:

i. *The principle of equivalence of successes and failures*
   Failures represent the flip side of necessary adaptations
ii. *The principle of approximate adjustments*
   Situations are never completely identical; adjustments never completely match the situation
iii. *The principle of emergence*
   Variability of multiple functions may combine in unexpected ways
iv. *The principle of functional resonance*
   The variability of multiple functions may resonate i.e. reinforce each other and thereby exceed normal limits

The following steps have to be followed, to investigate accidents:

1. <u>Identify essential system functions</u>
   Each function should be characterized for
   a. Input (I)
   b. Output (O)
   c. Preconditions (P)
   d. Resources (R)
   e. Time (T)
   f. Control (C)

2. <u>Characterise the observed variability</u>
   Describe both actual and potential variability

3. <u>Identify and describe functional resonance</u>
   This results in an overall description how functions were linked or coupled.

4. <u>Identify barriers for variability and specify required performance monitoring</u>
   Barriers can be systems and functions.

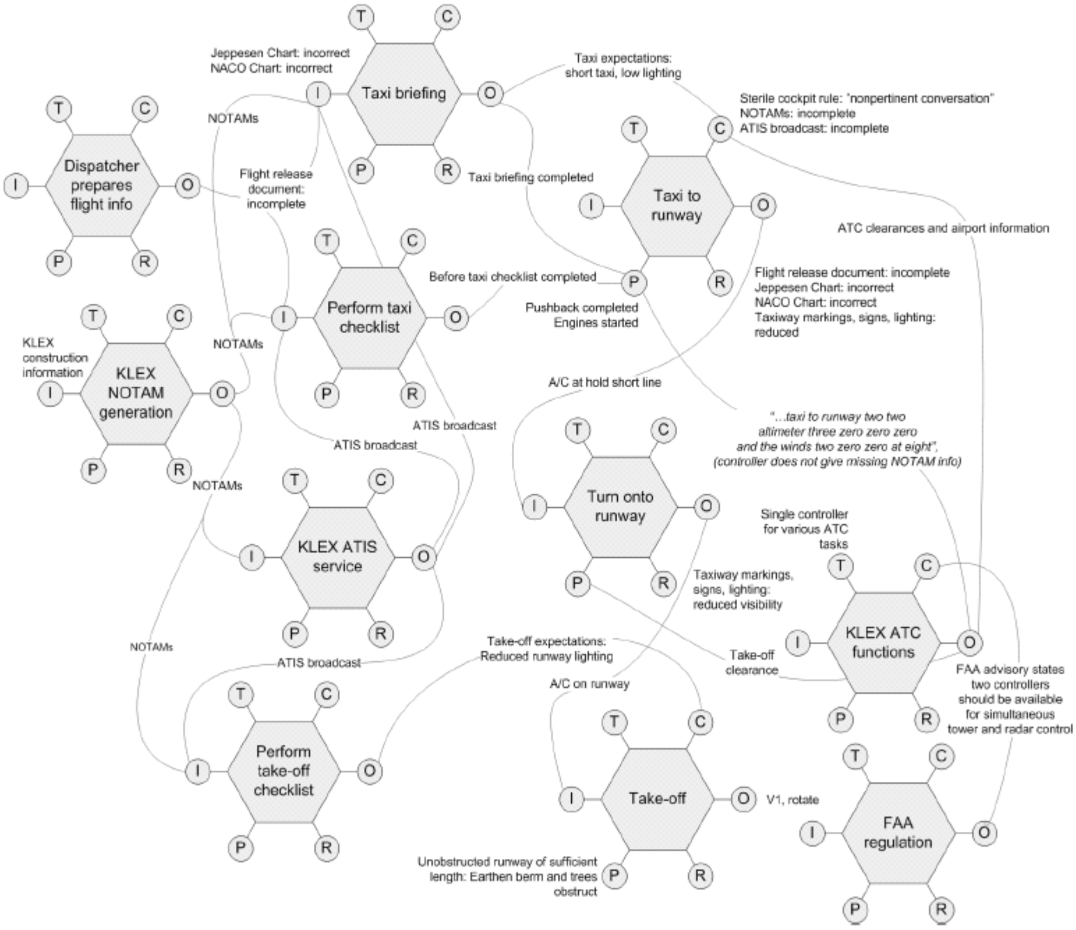


Figure 23 Example of an FRAM analysis (airplane)

Each hexagon represents a system component. Each hexagon has six characterisations. System components are connected to one another through one of these characterisations.

5.4 IPIC RAM

IPIC RAM is an instrument developed to facilitate accident investigators to identify contributing factors outside the traditional boundaries of the organisation. The development started as a reaction to faced shortcomings of existing methods. These methods, STEP and Tripod, were unable to guide identification of underlying causes outside the organisation in a structured manner.

A model was developed distinguishing between situational organisations – those organisations actively or directly involved in the occurrence of the accident- and influencing organisations – those organisations passively involved or indirectly influencing the occurrence of the accident. This can be seen as proximal and distal actors, as mentioned in chapter 3. These actors can influence each others processes, by decisions or non- decisions which are not taken into account. This (fallible) decision making has to be identified for all relevant actors.

In order to facilitate identification this decision-making and the underlying causes, IPIC RAM was developed. IPIC RAM is an acronym for

Information (in)
Process
Information (out)
Comply

Responsibility
Authority
Means

Underlying factors identified with epidemiological / complex linear methods are the starting point for IPIC RAM. For each relevant actor, one have to question whether:
1. they were aware of this situation; if so
2. they have taken action on this situation (changes, standards, training etc); if so
3. they have informed the relevant parties of this action; if so
4. the relevant parties have complied with this action (and is effective).

When one of above mentioned situations is not the case, for instance the actor knew of the situation, but did not take action, one have to question whether this was because the actor:
1. was/ felt not (in)formally responsible (to take action)
2. did not have or feel the authority (to take action)
3. (felt they) did not have the means (to take action)

The findings identified with the RAM-part, can be a starting point for another IPIC RAM session with other relevant actors. This way, IPIC RAM offers the possibility to identify interactions between different actors.

5.5 Backward & Forward mapping

Backward and Forward mapping is an approach, emphasised by De Bruijn (2007) as an improvement for public investigation committees. He identifies huge differences between conclusions of public investigation committees, which could easily have been identical, using an identical approach.

One approach is what he calls a *causal case-study* investigation, in which, based on a single case, unambiguous and hard conclusions are drawn on what was wrong and who is responsible. Causal factors are linear connected, reasoning backward from the accident. The main booby trap in this reasoning pattern is hindsight bias.

The other approach is *contextually comparative* investigation. On one hand the context is identified in which the accident and errors (in hindsight) took place. On the other hand comparative investigation is executed to identify other, possibly positive, outcomes of these erroneous activities. This part is the reasoning forward again.

Both approaches have their pros and cons. The advantage of the causal case study is that since conclusions are unambiguous and clear, society will be shocked and societal pressures will force changes. However, since a linear causal reasoning pattern is followed, this approach can lead to omissions in contributing factors. Context is overlooked, possibly ordering impossible or counterproductive recommendations. Besides, the - in general - positive effects of what is identified as erroneous in this case might be lost. This is one of the advantages of contextually comparative investigation. By using forward mapping, the existence of such apparent erroneous factors is compared to other situations, weighing its dangers and its benefits. Identifying the context in which these occur into account, makes that additional (reinforcing or balancing) factors can be identified, Recommendations can be defined to remedy both causal and contextual factors, and will take the context into account. The biggest disadvantage of this approach is that it might legitimate the accident. Identifying the context, in which the accident could occur, makes it difficult to appoint the ones to blame. There will be no shock effect to force changes.

De Bruijn concludes that both reasoning patterns should be used, and that depending on the impact of the accident, the centre of gravity can be decided. The more impact an accident has, the less societal acceptance of contextual comparative forward mapping. The less impact an accident has, the more societal allowance of contextual comparative forward mapping.

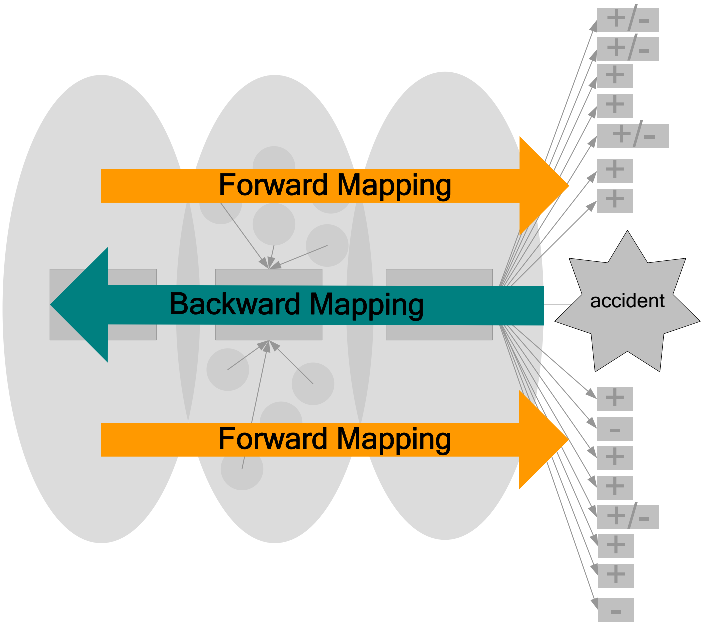


Figure 24 Backward and forward mapping in causal-case study and contextual comparative reasoning

5.6 Conclusion

The studied methods all include the system in one way or another. The identified system theories are fundaments for the methods. Accimap aims to identify all actors that could have influenced with decisions, the information flows and conflicts between actors. Accimap also identifies the decisions made and the context in which they took place. STAMP aims to identify how the control on the system was flawed. STAMP identifies first the system hazards and safety constraints, including the accompanying control structure. Next, it aims to identify the flawed control: inadequate constraints, inadequate executing of constraints, or inadequate or missing feedback, and the underlying reasons. FRAM identifies normal variability between all system components involved, in order to identify unwanted resonance. In order to do so, the variance for all individual system components have to be identified. IPIC RAM identifies interactions between actors involved, questioning why external actors have not taken appropriate action. Actors can lack information, can lack in taking action, can lack in feeding back information and can lack in measuring the compliance with their standards. This can be the result of inadequate responsibilities, authority (power) or means. Backward and Forward mapping is more an approach than a formal method. It states that not only case studies should be investigated, and causal relations should be searched for. Accident investigation should include thematic studies, consisting of contextual investigation (in what environment were decisions made) and comparative investigation (in how many other situation this decision lead to negative / positive outcome).

All methods, except the Backward and Forward mapping of De Bruijn, can include multiple actors. Accimap, STAMP and IPIC RAM focus explicitly on information flows between actors. Accimap and IPIC RAM explicitly focus on capabilities of the (external) decision makers. STAMP focuses on control loops within the complete system, and FRAM focuses on normal variability between system components. Backward and Forward mapping emphasizes to review the consequences of actions and events in a broader perspective (complete system) as well as both the negative and positive ones. Table 8 summarises the extra-organisational factors possibly identified by the methods.

Method	System aspects	Dynamic aspects	Extra-organisational aspects
ACCIMAP	6 levels: from physical surroundings and activities, to (levels of) management, to regulatory bodies and government	*(none explicit found)*	Multiple actors; information flow between actors; conflicts between actors; capabilities of (external)
STAMP	Actors involved in control of processes;	Change over time; reinforcing and balancing influences	Multiple actors; information flow between actors; control loops between actors;
FRAM	(functions of) System components	Normal variability	Multiple actors when system components are part of different organisations; normal variability of each component and (potential) influence on other components (actors)
IPIC RAM	Actors causing or influencing latent failures in other organisations	*(none explicit found)*	Multiple actors; information flow between actors; capabilities/possibilities of actors
Backward & Forward mapping	*(none explicit found)*	*(none explicit found)*	Negative and positive consequences in a broader perspective

Table 8 Overview of the identified methods and the system and dynamic aspects an extra-organisational factors they take into account

6 Results: assessment of traditional accident investigation

In this chapter the identified theories and methods will be compared to the traditional accident investigation process of the Dutch Safety Board, using an assessment framework based on these theories and methods. In paragraph 6.1 the assessment framework is presented. In paragraph 6.2 the results of the theoretical assessment of the traditional investigation approach are summarized. In paragraph 6.3 the results of the assessment of a case study of the Dutch Safety Board are presented. Finally, conclusions will be drawn on the added value of the theories and methods presented in chapter 4 and 5 compared to the traditional accident investigation approach of the Dutch Safety Board.

6.1 Assessment Framework

In order to apply the theories and methods identified in chapter 4 and 5 to traditional accident investigation, an assessment framework has been composed.

The first part of the assessment framework is based on the theories of chapter 4: the System and Risk Strategy (S&RS) Assessment Framework. This framework is set up as a decision diagram and consists of aspects to identify. The structure is as follows:

1. Define Accident (y/n)
2. Define type of system
3. Define actual risk strategy
4. Compare results of step 2 and 3 with the proposed risk strategy

The second part of the assessment framework is mainly based on the methods of chapter 5, added with some features of Wildavsky's theory. This Extra-Organisational Factor (EOF) Assessment Framework is set up as a structured questionnaire, aiming to identify specific extra-organisational factors. The questions are categorized using an adjusted version of Rasmussen's classification, which resulted in four categories:

1. Risk (-strategy)
2. Process as designed
3. Actual state of affairs / actual process
4. Capability (context) of decision-makers

More information on the Assessment Framework can be found in Appendix I on page 64 (System and Risk Strategy) and Appendix II on page 68 (Extra-Organisational Factors).

6.2 Theoretical assessment

In this paragraph the traditional investigation approach of the Dutch Safety Board will be theoretically assessed using the developed assessment framework. For the extra-organisational factors, per factor has been assessed whether it can be identified, using a categorisation as specified in Table 9. For the meta-analysis, to determine to what extent each category is identified, the categorisation of Table 10 is used.

Legenda	Explanation
- -	(nearly) impossible to identify
-	not suited, but with explicit effort possible to identify
0	migth occasionally be identified
+	(partially) suited to identify, some innate tendency
++	developed to identify, innate tendency, could hardly be missed

Table 9 Categorisation of amount in which each factor can be identified

Legenda	Explanation
- -	(nearly) impossible to identify
-	not suited, but with explicit effort some aspects possible to identify
0	some aspects migth (occasionally) be identified
+	partially suited to identify most aspects, some innate tendency
++	developed to identify, innate tendency, could hardly be missed

Table 10 Categorisation of amount in which each category can be identified

6.2.1 *Theoretical approach*

The traditional accident investigation approach of the Dutch Safety Board has been described in paragraph 3.2.1 . For the assessment of the traditional approach against the identified theories and methods, the focus will be on the following elements:

1. Methods to identify the accident process and the context
2. Assessment Framework for law & regulation
3. Assessment Framework for individual responsibility

Each element will be discussed below.

6.2.2 *Assessment of Methods*

As can be seen from paragraph 3.2 the Dutch Safety Board traditionally uses methods for fact-finding (interviews), linear methods to identify the sequence of events (STEP), and complex linear methods to identify the context (Tripod).

Each of these methods has been assessed for their ability to identify the system characteristics and risk strategy using the assessment framework in Appendix I. These results can be found in Table 21 in Appendix III. The methods also have been assessed on their natural tendency to provide answers to the Extra-organisational factor assessment framework, as specified in Appendix II. These results can be found in Table 22 in Appendix III. All detailed results can be found in Table 27 in Appendix III. The main results from these assessments are presented below.

It can be concluded that the traditional methods have limited capacity to identify system characteristics and risk strategy.

Interviews can be used to obtain and check information, but have no specific purpose or structure to identify system characteristics. The linear method STEP could be of some use to identify the amount of interactiveness and coupling in the system. Interactiveness in information flow, production steps and feedback loops, and coupling in sequences, timing and redundant pathways could be identified. However, these are not the complete set relevant aspects of interactiveness and coupling. Besides, the aim of the method is to identify the causal sequence of events, which represent only a small part of the system. The complex linear method Tripod has no added value in identifying system characteristics as meant by Perrow, and is limited in it's ability to identify the chosen risk strategy. The method itself appears to favour the anticipatory risk strategy over the resilient strategy. Tripod focuses on latent failures which should be remedied, without explicitly asking what the possible positive consequences can be, like for instance innovation (which can increase safety on long term), or increased resilience (of the organisation or of those involved). A summary of the ability per method to identify information for each S &RS category can be found in Table 11.

	METHODS		
S & RS assessment	**interview**	**step**	**tripod**
Interactions	-	0	-
Coupling	-	0	-
Risk strategy	-	- -	0

Table 11 Overview of the possibility to identify certain aspects with methods. For the legend, see Table 10

The traditional methods STEP and Tripod can be used to identify extra-organisational factors to some extent, although STEP can only identify very specific information on a few aspects.

With regard to the questions about risk(-strategy) it can be concluded that only Tripod provides some answers. It identifies the hazards that contributed to the accident scenario, might identify ignorance of safety risks of proposed remedies and ignorance of displacement of risks onto other people. The aspects Tripod identifies are generally anticipatory factors. With regard to the process as designed, both STEP and Tripod identify some aspects. STEP facilitates identification of actors involved. Tripod identifies safety constraints as far as it concerns barriers related to the accident process, and it identifies the auditing system. Certain parts of the actual state of affairs can be identified with Tripod. Tripod has been developed to identify the actual state of affairs, and can identify available information, actual safety constraints, actual auditing system and conflicts. STEP can identify a few aspects, for instance the actual information flow – as long as relevant to the accident process – and occasionally the actual safety constraints and feedback loops. Capabilities of decision makers can be identified using Tripod, in relation to their knowledge and skills. The natural tendency is limited to the decision makers in their isolated organisation. A summary of the ability per method to identify information for each EOF category can be found in Table 14.

	METHODS		
EOF assessment	**interview**	**step**	**tripod**
Risk (-strategy)	-	-	0
Process as Designed	-	- -	0
Actual state of affiars / process	-	-	0
Capability of decision makers	-	- -	0

Table 12 Overview of the possibility to identify EOF factors with traditional methods. For the legend, see Table 10

6.2.3 *Assessment of Law & regulation*

As described in paragraph 3.2.3, assessment against law and regulation consists of two parts and includes assessment of legal responsibilities per actor involved:

a. compulsory regulations, like legislation
b. voluntary regulations, like domain or company specific standards

Each type of regulation has been assessed for their ability to identify the system characteristics and risk strategy - by assessing the accident process against the regulations - using the assessment framework in Appendix I. The results can be found in Table 23 in Appendix III. The two types of regulation also have been assessed on their natural tendency to provide answers to the in the Extra-organisational Factor assessment framework - by assessing the accident process against the regulations. These results can be found in Table 24 in Appendix III. All detailed results can be found in Table 27 in Appendix III. The main results from these assessments are presented below.

It can be concluded that assessment against compulsory regulations have limited capacity to identify system characteristics and risk strategy. Compulsory regulations itself can be checked for the innate applied risk strategy. By this, anticipatory or resilient forces on the system can be identified. Compulsory regulations are nowadays descriptive, and as a result they lack details on interactiveness and coupling in the system.

Voluntary regulations, like company's internal guidelines and procedures provide more details. They can provide some information on interactiveness and coupling. They probably will not provide information on the applied risk strategy. A summary of the ability per type of regulation to identify information for each S&RS category can be found in Table 14.

	REGULATIONS	
S & RS assessment	**compulsory**	**voluntary**
Interactions	-	0
Coupling	- -	0
Risk strategy	-	-

Table 13 Overview of the possibility to identify S&RS factors with regulations. For the legend, see Table 10

Extra-organisational factors can be identified to some extend, especially when the voluntary regulations are used. Voluntary regulations, like industry standards, can provide guidance on the completeness of risk (-assessment and strategy) performed by individual companies. The process as designed is likely to be identified by investigating the company's guidelines and procedures.

Compulsory regulations are less useful, although they might provide some information on the constraints of the process as designed and formal responsibilities and authority. A summary of the ability per type of regulation to identify information for each EOF category can be found in Table 15.

	REGULATIONS	
EOF assessment	**compulsory**	**voluntary**
Risk (-strategy)	-	+
Process as Designed	-	+
Actual state of affiars / process	- -	- -
Capability of decision makers	-	0

Table 14 Overview of the possibility to identify EOF factorss with regulations. For the legend, see Table 10

6.2.4 *Assessment of Individual responsibility*

As described in paragraph 3.2.3, individual responsibility is defined using the following generic principles of Safety Management:

- (I) Understanding risks as a basis for a safety policy
- (II) A demonstrable and realistic safety policy
- (III) Implementing and sustaining the safety policy
- (IV) Tightening the safety policy
- (V) Management, involvement and communication

These principles have been assessed for their ability to identify the system characteristics and risk strategy - when assessing the accident process against these principles. The framework used for System and Risk Strategy factors can be found in Appendix I. The detailed assessment can be found in Table 25 in Appendix III.

The principles of safety management also have been assessed on their natural tendency to provide answers to questions in the Extra-organisational factor assessment framework - when assessing the accident process against the principles. This assessment can be found in Table 26 in Appendix III. All detailed results can be found in Table 27 in Appendix III. The main results from these assessments are presented below.

It can be concluded that the safety management principles can be used to reveal (indirect) information the applied risk strategy. Mainly based on – by the organisation's identified-risks, & preventive and repressive measures (Principle I), the safety approach (Principle II) and the management control (Principle V), the applied risk strategy can be constructed.

Information on system characteristics is not likely to be identified assessing against the principles of safety management. Although the first principle mentions "exploration of the entire system", no guidance on this exploration is found. The risk analyses which are part of the fourth principle could provide some information on risks associated with interactiveness and coupling or counter-measures. The other principles provide no guidance whatsoever to identify system characteristics. A summary of the ability per method to identify information for each category can be found in Table 15.

	INDIVIDUAL RESPONSIBILITY				
S & RS assessment	**I**	**II**	**III**	**IV**	**V**
Interactions	-	- -	- -	0	- -
Coupling	-	- -	- -	0	- -
Risk strategy	+	+	0	0	+

Table 15 Overview of the possibility to identify S&RS factors with individual responsibility. For the legend, see Table 10

Extra-organisational factors which can be identified are especially the risks (-strategies) and some aspects of the processes as designed. Risk aspects which are likely to be identified are system hazards, ignorance of risks associated with safety remedies and displacement of risks onto other people. Ignorance of large benefits, ignorance of effects of economic costs of safety and ignorance of trade off between errors of commission and omission are not likely to be identified.

With regard to the processes as designed, it is likely to identify actors involved, some safety constraints and the designed existence of an auditing system. Other aspects are not likely to be identified.

EOF assessment	INDIVIDUAL RESPONSIBILITY				
	I	II	III	IV	V
Risk (-strategy)	+	+	-	+	-
Process as Designed	-	0	-	+	-
Actual state of affairs / process	- -	- -	-	0	-
Capability of decision makers	- -	- -	-	-	- -

Table 16 Overview of the possibility to identify EOF factors with individual responsibility. For the legend, see Table 10

6.3 Practical assessment

In this paragraph the practical results of one investigation of the Dutch Safety Board will be assessed using the developed assessment framework (Appendix I and Appendix II). For the extra-organisational factors, per factor has been assessed how much can be identified, using a categorisation as specified in Table 17. For the meta-analysis, to determine to what extend each category is identified, the average of all factors per category has been taken.

Legenda	Explanation
- -	No relevant aspects identified (0%)
-	Few relevant aspects identified (25%)
0	some relevant aspects identified (50%)
+	A lot of relevant aspects identified (75%)
++	all relevant aspects identified (100%)

Table 17 Categorisation of amount in which each factor can be identified

6.3.1 Practical results: Case-study

In 2007 the Dutch Safety Board published a report on an explosion of a tank, filled with hydrocarbons and water. As a result of this explosion, two persons died and one was injured.

The accident was investigated with a team of investigators of the Dutch Safety Board. The investigation results of the companies involved, the inspectorates and public prosecutor were used. Amongst others, interviews, STEP and Tripod were used as methods for investigation and analysis. Besides, IPIC RAM was used to identify factors between organisations. The structure of the report was as follows:

1. Introduction and scope of investigation
2. Factual information:
    a. the sequence of events
    b. people (functions) involved
    c. effects
3. Assessment frameworks:
    a. compulsory regulations
    b. voluntary regulations
    c. individual responsibility
4. Actors involved and their responsibilities
5. Analysis
    a. Failed barriers
    b. Underlying causes
6. Generalization to principal company as whole
7. Conclusions
8. Recommendations

X Several appendices

The complete report (in Dutch) can be downloaded from the website of the Dutch Safety Board (Onderzoeksraad, 2008).

6.2.5 *Identification of System and Risk Strategy Factors*

The results in the report have been assessed to what extend they identified the system characteristics and risk strategy, using the assessment framework in Appendix I. The detailed results can be found in Appendix IV. The main results from these assessments are presented below.

The report identified on average few relevant factors for interactiveness and risk strategy, and some relevant factors for coupling.

The few relevant factors identified for interactiveness are related to information loops, equipment and personnel. Based on the information in the report it is difficult to determine to what amount the system was linear and complex. The few relevant factors identified for risk strategy are related to for instance hazards, components, and safety drills, indicating anticipatory strategies. The applied risk strategies are not explicitly mentioned or investigated. Some relevant factors identified for the amount of coupling are based on information on sequences, substitutions, recourses and possibility of delays. Based on this information, it is not yet possible to determine the kind of coupling. A summary per System and Risk strategy category can be found in Table 18.

S & RS assessment	**CASE STUDY**
Interactions	-
Coupling	0
Risk strategy	-

Table 18 Overview of the amount of relevant identified S &RS factors.

6.2.6 *Identification of Extra-Organisational Factors*

The results in the report have been assessed to what extend they identified Extra-organisational factors, as specified in Appendix II. The detailed results can be found in Figure 27 in Appendix IV. The main results from these assessments are presented below.

The report identified on average some relevant extra-organisational factors for risk (-strategy), process as designed and actual state of affairs. It identified a few relevant factors for the capability of decision makers.

The report identified for instance ignorance of the safety risk associated with a proposed remedy: the risks of not cleaning a tank but working with work permits, not allowing "hot work" instead (risk(-strategy) factor). The report also identified most relevant actors involved in the system: the principal organisation, the parent organisation, the contractors, two inspectorates and the ministry (process as designed factor). Inadequate (execution of) constraints, inadequate or missing feedback and the auditing function in place are examples of identified actual state of affairs – factors. With respect to the capability of decision makers, only some relevant factors for the capability of control and knowledge on current state of affairs, and the (in)formal responsibility to receive information, take action and check compliance have been identified. A summary per Extra-organisational category can be found in Table 19.

EOF assessment	CASE STUDY
Risk (-strategy)	0
Process as Designed	0
Actual state of affiars / process	0
Capability of decision makers	-

Table 19 Overview of the amount of relevant identified EOF factors.

6.4 Conclusion

Conclusions can be drawn on two aspects:

1. to what extend the traditional investigation approach of the Dutch Safety Board identifies System and Extra-organisational factors, and
2. which method or assessment identifies these factors

In general, the traditional accident investigation approach of the Dutch Safety Board is not able to identify system characteristics like interactiveness and coupling, nor is it able to identify the systems actual state of affairs and the capabilities of the decision makers. This is supported by both the theoretical assessment as well as the results from the case study, although the case study identifies slightly more aspects of the actual state of affairs than expected by the theoretical assessment.

Theoretically seen, risk and risk strategy factors and the process as designed can be identified with the traditional accident investigation approach, by assessing against voluntary regulations and individual responsibility. In the case study these factors were however not identified.

The traditional accident methods are not naturally identifying the system characteristics and risk strategy, and the extra organisational factors. Both the theoretical assessment of the traditional methods, as well as the results of the assessed case study support this conclusion.

Assessment against compulsory regulations has no added value when aiming to identify system characteristics and risk strategy, and extra organisational factors. Assessment against voluntary regulations can however have added value to identify information on the extra organisational categories risk(strategy) and process as designed. The case study shows however that in practice this is not always the case.

Assessment against Individual Responsibility can have added value to identify the risk strategy (factors of both the S &RS and EOF framework), and the extra organisational category process as designed.

	METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY							CASE STUDY
S & RS assessment	interview	step	tripod	compulsory	voluntary	I	II	III	IV	V	*Average*	*Max*	
Interactions	-	0	-	-	0	-	- -	- -	0	- -	-	0	-
Coupling	-	0	-	- -	0	-	- -	- -	0	- -	-	0	0
Risk strategy	-	- -	0	-	-	+	+	0	0	+	0	+	-

	METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY							CASE STUDY
EOF assessment	interview	step	tripod	compulsory	voluntary	I	II	III	IV	V	*Average*	*Max*	
Risk (-strategy)	-	-	0	-	+	+	+	-	+	-	0	+	0
Process as Designed	-	- -	0	-	+	-	0	-	+	-	0	+	0
Actual state of affiars / process	-	-	0	- -	- -	- -	- -	-	0	-	-	-	0
Capability of decision makers	-	- -	0	-	0	- -	- -	-	-	- -	-	-	-

Table 20 Overview of the meta-analysis of the theoretical and practical assessment

Analysing the individual aspects of the EOF framework, it can be concluded that some questions will not be answered following the traditional accident approach of the Dutch Safety Board. This concerns the following themes:

- Opportunity risks versus opportunity benefits
- Boundaries of the safe envelope
- Control structure
- Functional resonance
- System dynamics
- Generalising findings

An overview of the specific factors which will not be identified following the traditional approach can be found in Table 28 in Appendix III.

It can also be concluded that eleven individual questions might only be identified with one instrument or assessment framework (only one instrument +). Five of these can be identified assessing against the Individual Responsibility, three with Tripod, two assessing against voluntary regulations and one with STEP. An overview of these factors can be found in Table 29.

7 Conclusion

In this chapter conclusions based on this thesis are drawn. First the partitive questions will be answered, based on the results of previous chapters. Finally the main question will be attempted to answer.

7.1 Traditional accident investigation

Traditional accident investigation is the set of commonly used approaches, accident models and methods to investigate accidents. Distinction can be made between traditional accident investigation in general, and traditional accident investigation by the Dutch Safety Board.

In general, traditional accident investigation consists of the use of sequencing models and methods, aimed at technical and human factors. Models and methods aimed at organisational factors, with an epidemiological philosophy, have been developed more recently that the sequencing models, and are less frequent used. Still, they can be seen as traditional accident investigation. All traditional accidents models are linear, although some are a bit more complex, and all models are static. System and dynamic models cannot be defined as traditional, but have to be seen as a modern approach for accident investigation. Traditional accident models focus on intra-organisational factors. Figure 25 represents this traditional focus. Sequencing linear models and methods focus on the green part of the tree. Epidemiological, complex linear models and methods also focus on the roots of the tree (brown).

Figure 25 Graphical representation of traditional accident investigation

Traditional accident investigation at the Dutch Safety Board consists of the use of methods and assessment frameworks. Traditional methods are STEP - a sequencing method -, and Tripod - an epidemiological method focused at the organisation. Assessment frameworks are used to assess against compulsory and voluntary regulations, identifying responsibilities of those involved, and assessing against the principles of safety management in order to identify the realisation of individual responsibility.

7.2 Theories facilitating identification of extra-organisational factors

Perrow's (1984) defines accidents as the result of (multiple) components failures in (sub)systems, affecting safety of people. Systems can be characterized using two main dimensions: interactiveness and coupling. His theory on accidents and systems can be applied to the system in which accidents take place. This way, interactiveness and coupling for the complete system, including multiple actors should be identified.

Wildavsky (1988) identifies two risk strategies which are complementary. Anticipation is the strategy aiming to predict incidents and accidents, in order to prevent them from happening. Resilience is the strategy acknowledging uncertainty, and preparing for recognition, comprehension and reaction to incidents and accidents.

There appears to be a relation between Perrow's interactiveness and coupling, and Wildavsky's risk strategies. The more linear interactions, the more predictable the hazards and accidents, the more effective and thus appropriate anticipation as risk strategy. The more complex the interactions, the less predictable the hazards and accidents, and the more essential resilience becomes. More complex interactions go well with loose coupling, providing time for recognition, comprehension and reaction.

7.3 Methods on extra-organisational factors

The studied methods all include the system in one way or another. The identified system theories are fundaments for the methods.

Accimap aims to identify all actors that could have influenced decisions, the decisions made and the context in which they took place, information flows, and conflicts between actors. STAMP aims to identify how the control on the system was flawed. It focuses on system hazards, safety constraints, the accompanying control structure, and the flawed control including inadequate constraints, inadequate executing of constraints, or inadequate or missing feedback, and the underlying reasons. FRAM identifies normal variability between all system components involved, in order to identify unwanted resonance. IPIC RAM focuses on interactions between actors involved. It aims to identify, why external actors have not taken appropriate action, whether they lacked information, lacked taking action, lacked feeding back information or lacked in measuring the compliance with their standards. This can be the result of inadequate responsibilities, authority (power) or means. Backward and Forward mapping is more an approach than a formal method. It states that accident investigation should include thematic studies, consisting of contextual investigation (in what environment were decisions made) and comparative investigation (in how many other situation this decision lead to negative / positive outcome).

All methods, except the Backward and Forward mapping of De Bruijn, can include multiple actors of the system. Accimap, STAMP and IPIC RAM focus explicitly on information flows between actors. Accimap and IPIC RAM explicitly focus on capabilities of the (external) decision makers. STAMP focuses on control loops within he complete system, and FRAM focuses on normal variability between system components. Backward and Forward mapping emphasizes to review the consequences of actions and events in a broader perspective (complete system) as well as both the negative and positive ones.

7.4 Added value to traditional accident investigation

As concluded on paragraph 7.1, traditional accident investigation can de defined in general – specifying the methods used - and specific for the Dutch Safety Board – specifying the methods and the assessment frameworks.

In general, traditional accident methods are not identifying the system characteristics and risk strategy, and the extra-organisational factors, as the – for this thesis identified - theories and methods do. It can be concluded therefore that these theories and methods have an added value the traditional accidents methods.

The traditional accident investigation approach of the Dutch Safety Board can - theoretically seen - identify risk and risk strategy factors, and the process as designed. This can be done by assessing against voluntary regulations and individual responsibility. In the case study however, these factors were not identified. System characteristics like interactiveness and coupling, the systems actual state of affairs and the capabilities of the decision makers are not identified by the traditional accident investigation approach of the Dutch Safety Board.

The following themes of the identified methods are not explicitly identified by the Dutch Safety Board's traditional accident investigation approach:

- Opportunity risks versus opportunity benefits
- Boundaries of the safe envelope
- Control structure
- Functional resonance
- System dynamics
- Generalising findings

7.5 How to extend traditional accident investigation

In general, it can be concluded that traditional accident investigation focuses on intra-organisational factors in a static environment. Extension of this traditional approach is to include the system, which the organisation is part of, and its dynamic interactions. Figure 26 represents this. Accidents not only have to be investigated for it's leafs and roots, but also for the dynamic system it is positioned in. The surrounding of the organisation (system characteristics), the threats and benefits, and the applied strategy must be investigated. Extra-organisational factors like the designed process of the system as a whole, the actual processes in this system and the capabilities of all those involved have to be investigated.

Figure 26 Graphical representation of the extension of traditional accident investigation

Based on the assessment of traditional accident investigation against the identified theories and methods, practical directions for extension of traditional accident investigation can be given. The traditional approach can be extended in two ways:

1. by warranting and extending the use of currently used methods and assessment frameworks
2. by extending the arsenal of methods, assessment frameworks and other instruments

The traditionally used methods and assessment frameworks are able to identify some aspects of the System & Risk Strategy- and Extra-organisational Factors Framework. Some factors are identified by only one method or framework, and some factors are theoretically likely to be identified but have not been identified in the case study. This emphasizes the need to use the methods and frameworks to it's full extend and to check against the factors in the S&RS and EOF framework. The assessment against voluntary regulations – for instance company procedures and handbooks – and Individual Responsibility – especially the first, second and fourth principle – appear not to be used to it's full extend.

Some factors will however not be identified using one of the traditional methods or frameworks. The traditional accident investigation has to be extended to identify these themes. The main question, however, ***how** to extend traditional accident investigation, in order to identify extra-organisational factors,* has not been answered. For the time being, the S&RS and the EOF Framework can be used to guide investigation.

Discussion

In this chapter the research and results of this thesis will be discussed. First, the limitations of the research will be discussed. Next the relevance of accident investigation and identification of extra-organisational factors are discussed. Finally, some directions for future research will be given.

8.1 Limitations of this thesis

As any research, the research for this thesis is limited. The quality of this research could have been higher, when additional research was performed. The available time and resources however, limited the research.

For chapter 3, a literature search was performed on accident models, a web search was performed to identify the used methods at other (transport) Safety Boards, and a document search was performed to identify the used methods at the Dutch Safety Board.

The web search could have been extended with a verification of the identified methods by each (transport) Safety Board. The benefit would be that the inventory would be more complete, the hazard would be that all Safety Boards would add methods not actually used, to have a better performance.

The same goes for the methods used at the Dutch Safety Board. Measurement of the methods used, is mixed with the transparency in the publications on which methods have been used. Verifying the information with the investigators-in-charge, this list might be extended with desired methods, with similar benefits and hazards as the other (transport) Safety Boards.

For the purpose of this chapter: to define traditional accident investigation – these shortcomings probably have no effect. Traditional accident investigation is defined on the complete set of the findings, not the parts. Conclusions on the parts however, should be drawn with care.

For chapter 4, theories have been identified which can facilitate extra-organisational factors. These theories are limited to the imagination of the author and the network surrounding the author. The two main theories (Perrow and Wildavsky) were developed in the 1980's and might be somewhat outdated. The more recent theories however - for instance described in Hollnagel (2006) - are operationalisations or adaptations of these two basic theories. Therefore, the two first theories have served as basis.

These two theories are familiar in the domain of safety. It might be possible that other domains could have offered additional theories, which can be of use to identify extra-organisational factors. These theories have not been identified in this thesis.

For chapter 5, methods have been identified which facilitate identification of extra-organisational factors. These are all methods developed to enhance safety. There might however be methods in other domains - not specifically developed to enhance safety - which focus on extra-organisational factors.

All identified methods (de Bruijn excluded) are developed by psychologists (Rasmussen, Leveson, Hollnagel, Groeneweg & Verhoeve). This might be seen as a limitation of the identified methods. Other scientists might have complementary or contradictory views.

Also, one might question some of the assumptions in the methods: Can all constraints been known? (STAMP); are accident caused by variability of normal situations instead of deviations /failures? (FRAM); and is the world really such different than in previous years? (for instance: Rasmussen, 2000)

Finally, practical examples of accidents in (complex) multi actor systems analysed with these methods, is still limited. System theories to accident modelling are rather new, and they still have to demonstrate that they are more effective in improving safety than traditional accident models (Qureshi, 2008). Coming years, the methods have to be applied to accidents including multiple actors, proving its value and being developed to be of practical use.

To determine the added value of the identified theories and methods to traditional accident investigation (chapter 6), a theoretical and practical assessment of traditional accident investigation has been performed. This assessment was structured with the S&RS and EOF assessment frameworks, and values ranging from - - to + + were assigned. This way, completeness and objectivity was pursued. Still, this assessment was performed by the author only, and the actual assignment of - - to ++ can be arbitrary.

For the practical assessment one published report was used. This report is limited to what the Dutch Safety Board wanted to communicate. It might be possible that more factors have been identified during investigation, but have not been taken up in the report. Besides, it was only one case-study. Other reports might have included different factors. Although the theoretical and practical assessment is pointing in the same direction, including multiple cases might have enriched the analysis and conclusions.

8.2 Relevance of including extra-organisational factors

Identifying extra-organisational factors, like multiple actors, their influence and the system dynamics, appears to be a modern approach of accident investigation. The question however, is what the added value is of including these factors in accident investigation.

One opportunity risk is that focus on extra-organisational factors limits the attention to intra-organisational factors. This is supported by Qureshi (2007), who states that the current emphasis on organisational and systemic factors tends to overlook technical aspects of accidents. Another opportunity risk might be that by focusing on the complete system, responsibilities can be shifted away by the different actors, or the processes become so understandable, that the accident is legitimated (De Bruijn, 2007). As a result, (public) forces on actors to change or improve are mitigated. On the other hand, not including these factors might lead to limited or even contra-productive conclusions. Recommendations might be formulated “a contrario” (de Bruijn, 2007), not taking into account the context and the opportunity risks and benefits.

The question then is: should all accident investigations include extra-organisational factors? Following Rasmussen’s “stop-rule”, one might argue that only if the remedies to prevent the accident can not be found intra-organisational, extra-organisational factors should be identified. However, this stop-rule decends from the period of (complex) linear and static models. To investigate whether this rule still holds, additional research should be conducted.

8.3 Relevance of accident investigation

Veenhoven (2004) reveals a relation between happiness of citizens and the absence of accidents. Seen from a utilitarian perspective, prevention of accidents should have priority.

But following the theory that we live in a dynamic, fast changing society, and acknowledging that accidents result from a combination of factors which are hard to detect and even harder to predict (Amalberti, 2001), one might question whether accident investigation might help us to enhance safety and prevent the next accident. Proactive safety management becomes more and more important (Rasmussen, 2000) and accident reporting becomes less relevant in predicting major disasters (Amalberti, 2001).

The question is thus to what extent, and by investigation what kind of accidents, accident investigation can facilitate us preventing accidents from happening. In line with this question, it is justified to ask what effect the accident investigations of the Dutch Safety Board have on public safety.

8.4 Future research

Based on the conclusions in chapter 7 and the discussions in the previous paragraphs, several questions for future research have been identified, for instance:

- To what extent are nowadays systems complex and dynamic, and to what extent do they differ from previous days?
- What is the added value of accident investigation?
- What is the added value of identifying extra-organisational factors?
- When should extra-organisational factors be identified?
- How can extra-organisational factors best be identified?
- What extra-organisational factors are relevant in improving public safety?

One aspect that hasn't been explicitly discussed so far, but was identified as by-catch is the assessment against regulations. As can be seen from chapter 6, assessment against compulsory regulations has no added value in identifying system characteristics and risk strategy factors, nor extra-organisational factors. Voluntary regulations facilitate identification of some aspects, especially aspects concerning the process as designed. However, assessment against regulations is limited and some problems may occur. Rules can never be completely specific. A task description or an instruction is an unreliable model for judging behavior during actual work, as found in dynamic society (Rasmussen, 2000). Always following all rules is unworkable, considering the effect of "working to rule" (Hollnagel, 2008). Since management structures and safety regulations will always lag to the risks introduced by the rapidly changing dynamic society (Svedung & Rasmussen, 2002) accidents cannot be prevented by compliance with regulations only. Besides, regulations are nowadays based on anticipatory strategies, being risk avers and focusing on micro safety. Assessment against regulations might enhance this defensive strategy by those assessed.

Further research should identify the limitations of the Dutch Safety Boards assessment against regulations, and how this assessment can be used in a way optimising added value to accident investigation and enhancing public safety.

Finally, we have to keep in mind that, searching for ways to extend traditional accident investigation, and optimising ways to enhance public safety, there will never be one single solution. It is unlikely that one single language or model can capture all factors relevant to accidents (Burns, in Qureshi, 2007).

References

Amalberti, R. *The paradoxes of almost totally safe transportation systems*. Safety Science, 37, 109-126. (2001)

Bruijn, H. de, *Een gemakkelijke waarheid - waarom we niet leren van onderzoekscommissies* (2007)

Dekker, S., *Why we need new accident models*. Technical Report 2005-02

Dutch Safety Board, www.safetyboard.nl (2008)

Dutch Safety Board, *FIRE AT THE DETENTION CENTRE SCHIPHOL OOST, 26th October 2005*, Publication (2006)

Groeneweg, J. *Controlling the Controllable, the management of safety,* 5th revised edition, Leiden: Global Safety Group (2002)

Groeneweg, J., Van Schaardenburgh-Verhoeve, K. N .R., Corver, S., Lancioni, G. E. & Knudsen, T. (2007) *Accident investigation beyond the boundaries of organisational control*. In: Aven T. and Vinnem J.E. (eds). Risk, Reliability and Societal Safety. Proceedings of the ESREL 2007 Conference, June 25 - 27 2007, Stavanger, 2007,Taylor and Francis, 929 – 936.

Groeneweg, J. Verhoeve, K.N.R. & Corver, S. (2006) *A model-based approach to facilitate the identification of (non-) governmental factors in accidents* . Leiden University: Report prepared for the Dutch Safety Board.

Groeneweg, J. Verhoeve, K.N.R. & Corver, S. (2006). *Tripod outside the organisation*. Leiden University: Report prepared for the Dutch Safety Board.

Hollnagel, E., Woods, D., Leveson, N., *Resilience Engineering*: *Concepts and Precepts* (2006)

Hollnagel, E., Pruchnicki, S. , Woltjer, R., Etcher, S. *Analysis of comair flight 5191 with the Functional Resonance Accident Model.* Proceedings of the 8th International Symposium of the Australian Aviation Psychology Association, (2008)

Hollnagel, E., *Presentation on Resilience,* the Netherlands, (2008)

ITSA., *Objectives*, http://www.itsasafety.org/organisation/objectives/index.html, (2008)

Leveson, N. Daouk, M, Dulac, N. Marais, K. *Applying STAMP in Accident Analysis* (2003).

Leveson, N. *A New Accident Model for Engineering Safer Systems.* Safety Science, 42(4): 237-270. (2004)

Onderzoeksraad, *EXPLOSIE AARDGASCONDENSAATTANK Bij de Nederlandse Aardolie Maatschappij te Warffum d.d. 31 mei, 2005*, http://www.onderzoeksraad.nl/publicaties/ovv/rapport_explosie_opslagtank.pdf, (2008)

Perrow,C., *Normal Accident. Living with High Risk Technologies* (1984)

Qureshi, Z., *A Review of Accident Modelling Approaches for Complex Socio-Technical Systems.* Conferences in Research and Practice in Information Technology, Vol.86 (2006)

Qureshi, Z., *A Review of Accident Modelling Approaches for Complex Critical Sociotechnical Systems.* Command, Control, Communications and Intelligence Division 1, Defence Science and Technology Organisation (2008)

Rasmussen, J. *Risk management in a dynamic society: A modelling problem.* Safety Science, 27(2/3), 183-213 (1997)

Rasmussen, J. & Svedung, I., *Proactive Risk Management in a Dynamic Society* (2000)

Reason, J.T., *Human Error*. Cambridge: Cambridge University Press. (1990)

Roelofsma, P.H.M.P., Steeg, M. van der, Vlies, M. van der, Grimbergen, T.W.M., Kloet, R.W. *De kwaliteit van de organisatie van veiligheid in de stralingshygiëne. Een vergelijkend onderzoek naar de validiteit van de Tripod Delta methode in het domein van de stralingshygiëne.* In: Tijdschrift voor toegepaste Arbowetenschap (2007) nr 3 & 4

Trist, E. *The Social Engagement of Social Science, Volume II: The Socio-Technical Systems Perspective* http://www.moderntimesworkplace.com/archives/archives.html (2008)

Svedung, I. & Rasmussen, J., *Graphical representation of accident scenario's: mapping system structure and the causation of accidents*. In: Safety Science, 40, 397-417 (2002)

Van Schaardenburgh-Verhoeve, K. N. R., & Riemersma, S. *How to manage my incident investigation?* Working on Safety (2006)

Veenhoven, R. In: V*eiligheid; studies over inhoud, organisatie & maatregelen*. (2004)

Wildavsky, A., Se*arching for Safety* (1988)

Appendices

Appendix I System and Risk Strategy Framework

First, the (type of) system and strategy needs to be investigated. Step I to V are based on the identified theories. These steps force to choose between A or B, and can be seen as a nominal instrument.

I	Decide accident Yes / no		
	type of failures	Component failures with anticipated interaction	Multiple component failures with unanticipated interaction
Failures in	units		
	parts		
	subsystem	**accidents**	
	system		
IIa	Decide interactions		
	Interactions	visible	unvisible
		familiar	unfamiliar
		anticipated	unanticipated
	Subsystems	Segregated	Interconnected
	Connections	Dedicated	Common-mode
	Production steps	Segregated	Proximity
	Feedback loops	Few	Unfamiliar, unintended
	Isolation of failures	Easy	limited
	Substitutions	Easy	limited
	Controls	Single purpose, segregated	Multiple, interacting
	Information	Direct	Indirect, interferential
	Equipment	Spread out	Tight spacing
	Personnel	Less specialization	Specialization limits awareness of interdependencies
		Extensive understanding	Limited understanding
	Interactveness	Linear	Complex

IIb Decide amount of coupling

Achieving goals	One method	Alternative methods
Sequences	Invariant	Order can be changes
Delays	Not possible	Possible
Buffer and redundancies	Designed in, deliberate	Fortuitously available
Substitutions	Designed in, limited	Fortuitously available
Resources	Little slack	Slack

Coupling	**Tight coupling**	**Loose coupling**

IIc Point out the system in which the accident took place

		Interactiveness	
		Linear	Complex
Coupling	Tight		
	Loose		

III Decide type of strategy applied in system

Drive	Fear of regret	Recovery is better than prevention
Risk strategy	Risk averse	Risk taking
	Enhance stability	Enhance variability
	Trial without error	Trial and error
by	Investment in safety defences	Resources available for repression
	Safety drills, protocols	Sampling in small doses and diverse ways
		Redundancy
		Expanding general knowledge and technical facility
Underlying assumption	Doing nothing is better than doing something that harms people	Doing something of which more people benefit, and less get hurt than previous is better than doing nothing
		Sacrifices on micro-level for gains on macro-level
		(rule of sacrifice)
Focus on	Mostly hazards	Hazards and benefits
	Risks of changes	Benefits of changes
	(Opportunity risks)	(Opportunity benefits)
	Components, parts (specification, measuring added value for safety)	System as a whole (specification, measuring added value for safety)
Results in	Micro-safety	Macro-safety
		Innovations
		Adaptability

risk strategy	**Anticipation**	**Resilience**

IV Compare the position pointed in IIc and the applied risk strategy in III with the matrix below

		Interactiveness: Linear	Interactiveness: Complex
Coupling	Tight	Anticipation	
Coupling	Loose	Anticipation & Resilience	Resilience

Ordinal checklist - based on identified theories

Different then previous step I to V, this checklist offers the possibility to determine "the amount of" and can therefore be seen as an ordinal instrument.

interactions

linaer		**complex**
Segregated	*Subsystems*	Interconnected
Dedicated	*Connections*	Common-mode
Segregated	*Production steps*	Proximity
Few	*Feedback loops*	Unfamiliar, unintended
Easy	*Isolation of failures*	limited
Easy	*Substitutions*	limited
Single purpose, segregated	*Controls*	Multiple, interacting
Direct	*Information*	Indirect, interferential
Spread out	*Equipment*	Tight spacing
Less specialization, Extensive understanding	*Personnel*	Specialization limits awareness of interdependencies, Limited understanding

coupling

tight		**loose**
One method	*Achieving goals*	Alternative methods
Invariant	*Sequences*	Order can be changes
Not possible	*Delays*	Possible
Designed in, deliberate	*Buffer and redundancies*	Fortuitously available
Designed in, limited	*Substitutions*	Fortuitously available
Little slack	*Resources*	Slack

Risk Strategy

anticipation		**resilience**
Predictable accidents	Situation	Unpredictable accidents
Stable / static systems		Dynamic systems
Certainty about probability, effects, who will be harmed		Uncertainty about probability, effects, who will be harmed
Fear of regret	Drive	Recovery is better than prevention
Risk averse	Risk strategy	Risk taking
Enhance stability		Enhance variability
Trial without error		Trial and error
Investment in safety defences	by	Resources available for repression
Safety drills, protocols		Sampling in small doses and diverse ways
		Redundancy
		Expanding general knowledge and technical facility
Doing nothing is better than doing something that harms people	Underlying assumption	Doing something of which more people benefit, and less get hurt than previous is better than doing nothing
		Sacrifices on micro-level for gains on macro-level (rule of sacrifice)
Mostly hazards	Focus on	Hazards and benefits
Risks of changes		Benefits of changes
(Opportunity risks)		(Opportunity benefits)
Components, parts (specification, measuring added value for safety)		System as a whole (specification, measuring added value for safety)
Micro-safety	Results in	Macro-safety
		Innovations
		Adaptability

Appendix II Extra-organisational Factors Framework

Next, specific information regarding the accident process and the context needs to be identified. The following tables provide guidance on what aspects to investigate, categorised in 4 categories:

1. Risk (-strategy)
2. Process as designed
3. Actual state of affairs / actual process
4. Capability (context) of decision-makers

	Risk (-strategy)	
RI1	What are the identified system hazards?	*Leveson*
RI2	Was there ignorance of opportunity benefits?	*Wildavsky*
	How is the relation failure /success in the flip side of a coin? Has both negative as positive consequences been investigated?	*Hollnagel* *De Bruijn*
RI3	Was there ignorance of the safety risk associated with a proposed remedy?	*Wildavsky*
RI4	Was there ignorance of large existing benefits while concentrating on small existing risks?	*Wildavsky*
RI5	Was there ignorance of effects of economic cost of safety?	*Wildavsky*
RI6	Was there ignorance of trade off between errors of commission (type I) and errors of omission (type II)?	*Wildavsky*
RI7	Was there ignorance of displacement of risk onto other people as a consequence of reducing risks for some?	*Wildavsky*

	Process as designed	
DP1	What actors were involved / influencing the process?	*Rasmussen*
DP2	What were the system safety constraints ?	*Leveson*
DP3	What was the originally designed control structure?	*Leveson*
DP4	What were the essential system functions (Input, Output, Preconditions, Resources, Time, Control)	*Hollnagel*
DP5	What variability is normal?	*Hollnagel*
DP6	Were the to be achieved goalsclear to all actors involved? Were objectives formulated by principals in a way such that the interpretation and re-formulation performed by their agents are properly considered?	*Rasmussen* *Rasmussen*
DP7	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*
DP8	How effectively can changes in objectives be communicated downward the organization, and how effectively can changes in local constraints and criteria (e.g., to change of technology) be communicated upward the system to be considered for resource manageme	*Rasmussen*

	Actual state of affairs / process	
AP1	Has the context been investigated?	*De Bruijn*
criteria and boundaries		
AP2	Were boundaries of acceptable performance known or could be observed by actors, agents and/or principals?	*Rasmussen*
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*
AP3	Did controllers (decision-makers) have information about the actual state of the functions within their control domain and was this information compatible with (comparable to) the objectives as interpreted by the agent?	*Rasmussen*
	Could a discrepancy with respect to objectives or performance criteria be observed?	*Rasmussen*
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*
information		
AP5	What was the information flow between the actors like?	*Rasmussen*
AP6	How effectively were changes in objectives communicated downward the organization, and how effectively were changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management	*Rasmussen*
AP7	Were (the relevant) actors aware of (known with) the failure(s) in the organisation?	*Groeneweg & Verhoeve*
control		
AP8	How was the perceived control structure?	*Leveson*
	How was the actual control structure?	*Leveson*
AP9	What were there inadequate constraints ?	*Leveson*
AP10	What were there inadequate execution of constraints?	*Leveson*
AP11	What was there inadequate or missing feedback?	*Leveson*
AP12	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*
miscellaneous		
AP15	Were there conflicts between actors?	*Rasmussen*
AP14	What was the functional resonance (linking, coupling between functions)	*Hollnagel*
AP16	Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?	*Groeneweg & Verhoeve*
AP17	Has the organisation informed relevant departments and organisations about these actions?	*Groeneweg & Verhoeve*
AP18	Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?	*Groeneweg & Verhoeve*
AP19	What were the system dynamics (reinforcing and balancing forces)?	*Leveson*
A20	Have these findings been tried to generalise, using results from multiple accidents?	*Rasmussen*
	Has this context been compared to other situations and have other outcomes been investigated?	*De Bruinn*

	Capability of decision makers	*Rasmussen*
CA1	What were the reasons for flawed control and dysfunctional interactions?	*Leveson*
CA2	Were the decision makers capable of control?	*Rasmussen*
CA3	Did the decision makers have sufficient knowledge of the current state of affiars?	*Rasmussen*
CA4	Was the organisation (in) formally responsible to receive information, take action and check compliance?	*Groeneweg et al*
CA5	Were the decision makers thoroughly familiar with the control requirements of all relevant hazard sources within their work system?	*Rasmussen*
CA6	Has the organisation (in) formally authority to receive information, take action and check compliance?	*Groeneweg et al*
CA7	Has the organisation means to receive information, take action and check compliance?	*Groeneweg et al*
CA8	Did the decision makers know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?	*Rasmussen*
CA9	Could the decisionmakers act without undue time delays?	*Rasmussen*
CA10	What reinforcing and balancing forces were acting upon decision makers? (What) were the system dynamics?	*Leveson* *Leveson*

Appendix III Theoretical Assessment

The theoretical investigation approach of the Dutch Safety Board consists of three parts:

1. Methods to identify the accident process and the context
2. Assessment against law & regulation
3. Assessment of individual responsibility

Each part will be analysed separately. The detailed analysis is to be found in Table 27. In the paragraphs below the detailed analysis is summarized in main features.

1. Methods to identify accident process and context

As can be seen from paragraph 3.2 the Dutch Safety Board generally uses methods for fact-finding (interviews), linear methods to identify the sequence of events (STEP), and complex linear methods to identify the context.

System characteristics and Risk Strategy

A brief check on the system characteristics and risk strategy results in the table below.

	Interviewing	**STEP**	**Tripod**
	Method to obtain and check information from victims, witnesses, parties involved	*Sequencing / linear method to identify events per actor. Actors can be people, parts, components, organisations,….*	*Epidemiological / complex linear method to identify latent failures, responsible for preconditions (context) in which people are tempted to err or violate.*
Interactiveness (linear / complex)	Can be asked for, no guidance	The method itself is (simple) linear. Implicitly it can identify the type of interactiveness for some aspects, for instance for information, production steps, and feedback loops. For other aspects, for instance positions of equipment and specialisation of personnel, this will certainly not be identified using STEP	The method itself is complex linear It does not explicitly identify interactiveness in the system, but for personnel involved it can identify for instance the information available and their expertise.
Coupling	Can be asked for, no guidance	Identifies cause and effect relations, implicitly identifying coupling. Invariant sequences, impossibility of time delays and redundant pathways can be identified.	Apart from identification of slack in resources, Tripod does not explicitly identify coupling.
Risk strategy	Can be asked for, no guidance	No guidance	No explicit guidance, although the method invites to identify a wide range of latent failures, not asking whether identified factors are just hazards or maybe also opportunities in certain situations, and possibilities to learn. The method supports the anticipatory strategy more than the resilient strategy

Table 21 Traditional methods and their natural tendency to identify system characteristics

Extra-organisational Factors

Next, these methods are checked against the questionnaire based on the methods. The results of this check can be found in the table below.

	Interviewing	**STEP**	**Tripod**
	Method to obtain and check information from victims, witnesses, parties involved	*Sequencing / linear method to identify events per actor. Actors can be people, parts, components, organisations,….*	*Epidemiological / complex linear method to identify latent failures, responsible for preconditions (context) in which people are tempted to err or violate.*
Risk (strategy)	Can be asked for, no guidance	STEP does not provide answers to the questions concerning risk (strategy)	Tripod identifies the system hazards related to this accident. Other aspects in this part of the questionnaire might incidentally be answered, like for instance RI7: ignorance of displacement of risk onto other people …
Process as designed	Can be asked for, no guidance	STEP provides guidance to identify actors involved. Other questions regarding the process as designed are not answered	Tripod identifies some safety constraints by identifying barriers that should have been in place but failed, were inadequate or were missing. Some other aspects could be identified when failed/inadequate/missing barriers lead to latent failures in the process as designed, such as auditing systems in place and the designed information flow.
Actual state of affairs / process	Can be asked for, no guidance	STEP provides some answers to the questions on the actual state of affairs, for instance on the information flow, the actual safety constraints and certain feedback loops	Tripod aims to identify the context in which actors were acting. Some aspects from the questionnaire can be identified, for instance available information, the safety constraints which were inadequate or missing, auditing systems and possible conflicts.
Capability of decision makers	Can be asked for, no guidance	STEP does not identify capabilities of decision makers	Tripod can identify the capability of actors to take decisions and their knowledge on the state of affairs. Some other aspects could be identified, but is not a natural tendency

Table 22 Traditional methods and their natural tendency to identify extra-organisational factors

2. Assessment against law & regulation

As described in paragraph 3.2.3, assessment against law and regulation consists of two parts and includes assessment of legal responsibilities per actor involved:

c. compulsory regulations, like legislation
d. voluntary regulations, like domain or company specific standards

System characteristics and Risk Strategy

A brief check on what might assessment against regulations reveal, regarding the system characteristics and risk strategy, results in the table below.

	Compulsory regulations	**Voluntary regulations**
	Compulsory governmental regulation, nowadays mostly descriptive by specifying the aim of the regulation instead of the means	*Voluntary regulations like industry standards, best practices and company specific guidelines and protocols*
Interactiveness (linear / complex)	Limited. In case of high risk industries and available detailed regulations: can provide some information on for instance segregation of systems, feedback loops and controls.	Company's procedures and guidelines can provide some information on interactions, for instance on the subsystems, production steps, and controls.. No innate tendency however.
Coupling	Provides no guidance.	Company procedures can provide some information on coupling, for instance on amount of ways to achieve goal, (invariance) of sequences, and buffers and redundancies. No innate tendency however.
Risk strategy	Can provide some information on the applicable risk strategy forced by compulsory regulation (most of the times risk averse)	Provides no guidance. Background documentation might provide information on risk assessment.

Table 23 Law and regulation and their natural tendency to identify system characteristics

Extra-organisational Factors
Next, the assessment against the two types of regulation is checked against the questionnaire based on the methods. The results of this check can be found in the table below.

	Compulsory regulations	Voluntary regulations
	Compulsory governmental regulation, nowadays mostly descriptive by specifying the aim of the regulation instead of the means	*Voluntary regulations like industry standards, best practices and company specific guidelines and protocols*
Risk (strategy)	(Partially) suited to identify known system hazards and displacement of risk onto other actors. Not suited for identification of other aspects.	(Partially) suited to identify known system hazards, relation failure/success (probabilities), ignorance of safety risks and displacement of risk onto other actors. Other aspects might occasionally be identified.
Process as designed	Only safety constraints defined by compulsory regulations will be naturally identified.	Almost all aspects of the process as designed can be naturally identified using voluntary regulations, especially the safety constraints and the control structure. Only the normal variability is less likely to be identified.
Actual state of affairs / process	Not suited to identify information on the actual state of affairs.	Documentation on the process as designed can be of some use to analyse the effectiveness of the actual process and to use for a comparison of the actual process against the designed process. In itself, it is not suited to identify the actual state of affairs.
Capability of decision makers	Formal responsibilities and authority could be identified to some extend. Other aspects are not likely to identify, and underlying causes and system dynamics cannot be identified.	Formal responsibilities and authority could be identified to some extend. Other aspects are not likely to identify, and underlying causes and system dynamics cannot be identified.

Table 24 Law and regulation and their natural tendency to identify extra-organisational factors

3. Assessment of individual responsibility

Individual responsibility is defined using the following generic principles of Safety Management:

(I) Understanding risks as a basis for a safety policy
(II) A demonstrable and realistic safety policy
(III) Implementing and sustaining the safety policy
(IV) Tightening the safety policy
(V) Management, involvement and communication

System characteristics and Risk Strategy
A brief check on what might assessment against safety management principles reveal, regarding the system characteristics and risk strategy, results in the table below.

	I Understanding risks	II Demonstrable and realistic approach	III Implementing and sustaining	IV Tightening	V Management
	Exploration of the entire system inventory of the corresponding risks management of dangers: preventive and repressive measures	*To prevent and manage undesirable events Based on compulsory and voluntary regulations*	*Descriptive, including objectives transparent in responsibilities, establishing required expertise, coordination of safety activities, drills & testing*	*Risk analysis including: Observations, inspections, audits, accident investigation*	*Clear expectations and ambitions Climate of continuously improvement Communicate findings*
Interactiveness (linear / complex)	"Exploration of entire system" could include interactions, but no guidance is provided	Not applicable	Not applicable	Not suited to identify interactiveness, although risk analyses may reveal some information on interactions or measures to decrease complexity	Not applicable
Coupling	"Exploration of entire system" could include interactions, but no guidance is provided	Not applicable	Not applicable	Not suited to identify coupling, although risk analyses may reveal some information on coupling or measures to decrease tight coupling	Not applicable
Risk strategy	Based on the identified risks and the preventive and repressive measures, an analysis of the applied risk strategy can be done.	The approach to manage safety may provide information on the risk strategy	The execution of safety management may provide information on the actual risk strategy and drives	Information on the tightening structure may reveal some information on the risk strategy. Observations and audits may reveal some information on the actual risk strategies in the organisation(s)	Can provide information on actual risk strategy by management.

Table 25 Safety Management Principles and their natural tendency to identify system characteristics

Extra-organisational Factors

Next, the assessment against Safety Management Principles is checked against the questionnaire based on the methods. The results of this check can be found in the table below.

	I Understanding risks	II Demonstrable and realistic approach	III Implementing and sustaining	IV Tightening	V Management
	Exploration of the entire system inventory of the corresponding risks management of dangers: preventive and repressive measures	*To prevent and manage undesirable events Based on compulsory and voluntary regulations*	*Descriptive, including objectives transparent in responsibilities, establishing required expertise, coordination of safety activities, drills & testing*	*Risk analysis including: Observations, inspections, audits, accident investigation*	*Clear expectations and ambitions Climate of continuously improvement Communicate findings*
Risk (strategy)	Several aspects can be partially identified. System hazards should be identified. Positive and negative effects of risks, possible ignorance of opportunity benefits and displacement of risk can be identified.	Several aspects can be partially identified: system hazards, possible ignorance of opportunity benefits, of safety risks of remedies and displacement of risk	Not likely to identify	Several aspects can be partially identified: system hazards, positive and negative effects of risks, possible ignorance of opportunity benefits, of safety risks of remedies and displacement of risk	Not likely to identify
Process as designed	Less likely to identify. Some actors involved can be identified, as well as perhaps some safety constraints and designed control structure	Partially suited. Can identify some actors involved, safety constraints, control structure and auditing system	Not likely to identify	Partially suited. Can identify some actors involved, safety constraints, and auditing system	Not applicable or likely to identify aspects,, except how objectives were formulated transparently
Actual state of affairs / process	Not applicable	Not applicable	Most aspects are not likely to identify. Aspects that can partially be identified are the inadequate (execution) of constraints, and the existence of an auditing function	Several aspects can be (partially) Identified: whether context has been investigated, information decision makers had, the inadequate (execution) of constraints, the	Not applicable or likely to identify aspects,, except the way how changes have been communicated.

				existence of an auditing function, and what organisations have done with information / compliance	
Capability of decision makers	Not applicable (some aspects maybe with explicit effort)	Not applicable (maybe some formal responsibilities and familiarity of decision makers with control requirements to be occasionally identified	Not likely to identify	Not likely to identify	Not applicable

Table 26 Safety Management Principles and their natural tendency to identify extra-organisational factors

The table below shows the analysis of the parts of the investigation process of the Dutch Safety Board, when checked with the theories- and methods checklist, as described in Appendix I and Appendix II.

Legenda	**Explanation**
- -	(nearly) impossible to identify
-	not suited, but with explicit effort possible to identify
0	migth occasionally be identified
+	(partially) suited to identify, some innate tendency
++	developed to identify, innate tendency, could hardly be missed

Next pages:

Table 27 Detailed theoretical analysis for Extra-organisational Factors:

Risk (-strategy)

			METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY				
			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V
RI1	What are the identified system hazards?	*Leveson*	-	- -	+	+	+	++	+	0	+	-
RI2	Was there ignorance of opportunity benefits?	*Wildavsky*	-	- -	0	- -	0	+	+	0	+	0
	How is the relation failure /success in the flip side of a coin?	*Hollnagel*	-	- -	0	- -	+	+	0	0	0	-
	Has both negative as positive consequences been investigated?	*De Bruijn*	-	- -	0	-	0	+	0	-	+	0
RI3	Was there ignorance of the safety risk associated with a proposed remedy?	*Wildavsky*	-	- -	+	0	+	0	+	0	+	0
RI4	Was there ignorance of large existing benefits while concentrating on small existing risks?	*Wildavsky*	-	- -	-	- -	0	0	0	-	0	-
RI5	Was there ignorance of effects of economic cost of safety?	*Wildavsky*	-	- -	-	- -	0	0	0	-	-	-
RI6	Was there ignorance of trade off between errors of commission (type I) and errors of omission (type II)?	*Wildavsky*	-	- -	-	-	0	0	0	-	0	0
RI7	Was there ignorance of displacement of risk onto other people as a consequence of reducing risks for some?	*Wildavsky*	-	- -	+	+	+	+	+	-	+	0

Process as designed

			METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY				
			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V
DP1	What actors were involved / influencing the process?	*Rasmussen*	-	+	-	0	+	+	+	0	+	- -
DP2	What were the system safety constraints ?	*Leveson*	-	- -	+	+	++	0	+	-	+	-
DP3	What was the originally designed control structure?	*Leveson*	-	- -	0	0	++	0	+	-	0	- -
DP4	What were the essential system functions (Input, Output, Preconditions, Resources, Time, Control)	*Hollnagel*	-	- -	0	-	+	-	0	0	0	- -
DP5	What variability is normal?	*Hollnagel*	-	- -	-	-	0	- -	-	0	0	- -
	Were the to be achieved goals clear to all actors involved?	*Rasmussen*	-	- -	0	- -	+	- -	-	-	0	0
DP6	Were objectives formulated by principals in a way such that the interpretation and re-formulation performed by their agents are properly considered?	*Rasmussen*	-	- -	0	- -	+	- -	0	-	0	+
DP7	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*	-	0	+	0	+	- -	+	-	+	0
DP8	How effectively can changes in objectives be communicated downward the organization, and how effectively can changes in local constraints and criteria (e.g., to change of technology) be communicated upward the system to be considered for resource manageme	*Rasmussen*	-	- -	+	-	+	- -	0	-	0	0

Actual state of affairs / process

	Actual state of affairs / process		METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY				
			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V
AP1	Has the context been investigated?	*De Bruijn*	-	-	+	- -	- -	- -	- -	- -	+	- -
criteria and boundaries												
AP2	Were boundaries of acceptable performance known or could be observed by actors, agents and/or principals?	*Rasmussen*	-	-	0	-	0	- -	-	0	0	0
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*	-	-	0	- -	0	- -	-	0	0	-
AP3	Did controllers (decision-makers) have information about the actual state of the functions within their control domain and was this information compatible with (comparable to) the objectives as interpreted by the agent?	*Rasmussen*	-	-	0	- -	0	- -	-	0	+	-
	Could a discrepancy with respect to objectives or performance criteria be observed?	*Rasmussen*	-	-	0	- -	0	- -	-	0	-	0
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*	-	-	0	- -	0	- -	-	0	-	0
information												
AP4	What was the information flow between the actors like?	*Rasmussen*		+	0	- -	0	- -	-	0	0	0
AP5	How effectively were changes in objectives communicated downward the organization, and how effectively were changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management	*Rasmussen*	-	-	0	- -	0	- -	-	0	0	+
AP6	Were (the relevant) actors aware of (known with) the failure(s) in the organisation?	*Groeneweg & Ver*	-	0	+	- -	0	- -	-	0	+	-
control			-									
AP7	How was the perceived control structure?	*Leveson*	-	-	0	- -	- -	- -	- -	-	0	- -
	How was the actual control structure?	*Leveson*		-	0	- -	0	- -	- -	-	0	- -
AP8	What were the inadequate constraints ?	*Leveson*		-	+	- -	0	- -	- -	+	+	- -
AP9	What were the inadequate execution of constraints?	*Leveson*	-	+	+	-	0	- -	- -	+	+	- -
AP10	What was there inadequate or missing feedback?	*Leveson*	-	+	+	0	0	- -	- -	0		- -
AP11	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*	-	-	+	0	0	- -	- -	+	+	- -
miscellaneous												
AP12	Were there conflicts between actors?	*Rasmussen*	-	0	+	-	0	- -	-	0	0	- -
AP13	What was the functional resonance (linking, coupling between functions)	*Hollnagel*	-	-	-	- -	-	- -	- -	-	-	- -
AP14	Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?	*Groeneweg & Verhoeve*	-	0	0	-	-	- -	- -	0	+	0
AP15	Has the organisation informed relevant departments and organisations about these actions?	*Groeneweg & Verhoeve*	-	0	0	-	-	- -	- -	0	+	0
AP16	Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?	*Groeneweg & Verhoeve*	-	0	0	-	0	- -	- -	0	+	0
AP17	What were the system dynamics (reinforcing and balancing forces)?	*Leveson*	-	-	0	- -	- -	- -	- -	-	-	-
AP18	Have these findings been tried to generalise, using results from multiple accidents?	*Rasmussen*	-	- -	-	- -	- -	- -	- -	- -	0	- -
	Has this context been compared to other situations and have other outcomes been investigated?	*De Bruinn*	-	- -	-	- -	- -	- -	- -	- -	0	- -

	Capability of decision makers	Rasmussen	INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V
			METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY				
CA1	What were the reasons for flawed control and dysfunctional interactions?	Leveson	-	- -	0	- -	0	- -	- -	0	0	- -
CA2	Were the decision makers capable of control?	Rasmussen	-	- -	+	0	0	- -	-	0	0	- -
CA3	Did the decision makers have sufficient knowledge of the current state of affiars?	Rasmussen	-	- -	+	0	0	-	-	0	0	- -
CA4	Was the organisation (in) formally responsible to receive information, take action and check compliance?	Groeneweg & Verhoeve	-	- -	0	+	+	- -	0	-	-	- -
CA5	Were the decision makers thoroughly familiar with the control requirements of all relevant hazard sources within their work system?	Rasmussen	-	- -	0	0	0	-	0	0	0	-
CA6	Has the organisation (in) formally authority to receive information, take action and check compliance?	Groeneweg & Verhoeve	-	- -	-	+	+	- -	-	-	-	-
CA7	Has the organisation means to receive information, take action and check compliance?	Groeneweg & Verhoeve	-	- -	0	-	0	- -	- -	0	0	0
CA8	Did the decision makers know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?	Rasmussen	-	- -	0	0	0	-	-	0	0	-
CA9	Could the decisionmakers act without undue time delays?	Rasmussen	-	- -	-	-	-	- -	- -	0	-	- -
CA10	What reinforcing and balancing forces were acting upon decision makers?	Leveson	-	- -	0	-	0	- -	- -	-	-	- -
	(What) were the system dynamics?	Leveson	-	- -	-	- -	-	- -	- -	- -	-	- -

The next tables provide information on which factors might be identified with the traditional approach, and which not.

Table 27 Analysis for Extra-organisational Factors:Minimum, Maximum, Rang.

Legend

Information on factor not identified (only - - and -)
Information on factor partly identified but only by one "instrument"

Risk (-1strategy)

			min	max	spread	AVE	count 0	count 1	count 2	total 0,1,2
RI1	What are the identified system hazards?	*Leveson*	-2,00	1,00	-3,00	0,13	1,00	5,00	1,00	7,00
RI2	Was there ignorance of opportunity benefits?	*Wildavsky*	-2,00	1,00	-3,00	-0,33	4,00	3,00	0,00	7,00
	How is the relation failure /success in the flip side of a coin?	*Hollnagel*	-2,00	1,00	-3,00	-0,67	4,00	2,00	0,00	6,00
	Has both negative as positive consequences been investigated?	*De Bruijn*	-2,00	1,00	-3,00	-0,50	4,00	2,00	0,00	6,00
RI3	Was there ignorance of the safety risk associated with a proposed remedy?	*Wildavsky*	-2,00	1,00	-3,00	0,17	4,00	4,00	0,00	8,00
RI4	Was there ignorance of large existing benefits while concentrating on small existing risks?	*Wildavsky*	-2,00	-1,00	-1,00	-1,33	4,00	0,00	0,00	4,00
RI5	Was there ignorance of effects of economic cost of safety?	*Wildavsky*	-2,00	-1,00	-1,00	-1,29	3,00	0,00	0,00	3,00
RI6	Was there ignorance of trade off between errors of commission (type I) and errors of omission (type II)?	*Wildavsky*	-2,00	-1,00	-1,00	-1,20	5,00	0,00	0,00	5,00
RI7	Was there ignorance of displacement of risk onto other people as a consequence of reducing risks for some?	*Wildavsky*	-2,00	1,00	-3,00	0,22	1,00	6,00	0,00	7,00
		AVE				-0,29				

Process as designed

			min	max	spread	AVE	count 0	count 1	count 2	total 0,1,2
DP1	What actors were involved / influencing the process?	*Rasmussen*	-2,00	1,00	-3,00	0,13	2,00	5,00	0,00	7,00
DP2	What were the system safety constraints ?	*Leveson*	-2,00	1,00	-3,00	-0,13	1,00	4,00	1,00	6,00
DP3	What was the originally designed control structure?	*Leveson*	-2,00	1,00	-3,00	-1,00	4,00	1,00	1,00	6,00
DP4	What were the essential system functions (Input, Output, Preconditions, Resources, Time, Control)	*Hollnagel*	-2,00	1,00	-3,00	-1,00	4,00	1,00	0,00	5,00
DP5	What variability is normal?	*Hollnagel*	-2,00	-1,00	-1,00	-1,43	3,00	0,00	0,00	3,00
DP6	Were the to be achieved goals clear to all actors involved?	*Rasmussen*	-2,00	1,00	-3,00	-1,14	3,00	1,00	0,00	4,00
	Were objectives formulated by principals in a way such that the interpretation and re-1formulation performed by their agents are properly considered?	*Rasmussen*	-2,00	1,00	-3,00	-0,86	3,00	2,00	0,00	5,00
DP7	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-1technical system?	*Rasmussen*	-2,00	1,00	-3,00	0,00	3,00	4,00	0,00	7,00
DP8	How effectively can changes in objectives be communicated downward the organization, and how effectively can changes in local constraints and criteria (e.g., to change of technology) be communicated upward the system to be considered for resource manageme	*Rasmussen*	-2,00	1,00	-3,00	-0,71	3,00	2,00	0,00	5,00
		AVE				-0,49				

Actual state of affairs / process

				min	max	spread	AVE	count 0	count 1	count 2	total 0,1,2
AP1	Has the context been investigated?	*De Bruijn*		-2,00	1,00	-3,00	-1,20	0,00	2,00	0,00	2,00
criteria and boundaries											
AP2	Were boundaries of acceptable performance known or could be observed by actors, agents and/or principals?	*Rasmussen*		-2,00	-1,00	-1,00	-1,20	5,00	0,00	0,00	5,00
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*		-2,00	-1,00	-1,00	-1,33	4,00	0,00	0,00	4,00
AP3	Did controllers (decision-1makers) have information about the actual state of the functions within their control domain and was this information compatible with (comparable to) the objectives as interpreted by the agent?	*Rasmussen*		-2,00	1,00	-3,00	-1,00	3,00	1,00	0,00	4,00
	Could a discrepancy with respect to objectives or performance criteria be observed?	*Rasmussen*		-2,00	-1,00	-1,00	-1,33	4,00	0,00	0,00	4,00
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*		-2,00	-1,00	-1,00	-1,33	4,00	0,00	0,00	4,00
information											
AP4	What was the information flow between the actors like?	*Rasmussen*		-2,00	1,00	-3,00	-1,00	5,00	1,00	0,00	6,00
AP5	How effectively were changes in objectives communicated downward the organization, and how effectively were changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management	*Rasmussen*		-2,00	1,00	-3,00	-1,00	4,00	1,00	0,00	5,00
AP6	Were (the relevant) actors aware of (known with) the failure(s) in the organisation?	*Groeneweg & Verh*		-2,00	1,00	-3,00	-0,71	3,00	2,00	0,00	5,00
control											
AP7	How was the perceived control structure?	*Leveson*		-2,00	-1,00	-1,00	-1,63	2,00	0,00	0,00	2,00
	How was the actual control structure?	*Leveson*		-2,00	-1,00	-1,00	-1,67	3,00	0,00	0,00	3,00
AP8	What were the inadequate constraints ?	*Leveson*		-2,00	1,00	-3,00	-0,75	1,00	3,00	0,00	4,00
AP9	What were the inadequate execution of constraints?	*Leveson*		-2,00	1,00	-3,00	-0,44	1,00	4,00	0,00	5,00
AP10	What was there inadequate or missing feedback?	*Leveson*		-2,00	1,00	-3,00	-0,83	3,00	2,00	0,00	5,00
AP11	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-1technical system?	*Rasmussen*		-2,00	1,00	-3,00	-0,63	2,00	3,00	0,00	5,00
miscellaneous											
AP12	Were there conflicts between actors?	*Rasmussen*		-2,00	1,00	-3,00	-1,00	4,00	1,00	0,00	5,00
AP13	What was the functional resonance (linking, coupling between functions)	*Hollnagel*		-2,00	-1,00	-1,00	-1,40	0,00	0,00	0,00	0,00
AP14	Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?	*Groeneweg & Verhoeve*		-2,00	1,00	-3,00	-1,00	4,00	1,00	0,00	5,00
AP15	Has the organisation informed relevant departments and organisations about these actions?	*Groeneweg & Verhoeve*		-2,00	1,00	-3,00	-1,00	4,00	1,00	0,00	5,00
AP16	Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?	*Groeneweg & Verhoeve*		-2,00	1,00	-3,00	-1,00	5,00	1,00	0,00	6,00
AP17	What were the system dynamics (reinforcing and balancing forces)?	*Leveson*		-2,00	-1,00	-1,00	-1,44	1,00	0,00	0,00	1,00
AP18	Have these findings been tried to generalise, using results from multiple accidents?	*Rasmussen*		-2,00	-1,00	-1,00	-1,78	1,00	0,00	0,00	1,00
	Has this context been compared to other situations and have other outcomes been investigated?	*De Bruinn*		-2,00	-1,00	-1,00	-1,78	1,00	0,00	0,00	1,00
		AVE					-1,02				

Capability of decision makers

		Rasmussen	min	max	spread	AVE	count 0	count 1	count 2	total 0,1,2
CA1	What were the reasons for flawed control and dysfunctional interactions?	*Leveson*	-2,00	-1,00	-1,00	-1,83	4,00	0,00	0,00	4,00
CA2	Were the decision makers capable of control?	*Rasmussen*	-2,00	1,00	-3,00	-1,17	4,00	1,00	0,00	5,00
CA3	Did the decision makers have sufficient knowledge of the current state of affiars?	*Rasmussen*	-2,00	1,00	-3,00	-1,00	4,00	1,00	0,00	5,00
CA4	Was the organisation (in) formally responsible to receive information, take action and check compliance?	*Groeneweg & Verhoeve*	-2,00	1,00	-3,00	-0,88	2,00	2,00	0,00	4,00
CA5	Were the decision makers thoroughly familiar with the control requirements of all relevant hazard sources within their work system?	*Rasmussen*	-2,00	-1,00	-1,00	-1,25	6,00	0,00	0,00	6,00
CA6	Has the organisation (in) formally authority to receive information, take action and check compliance?	*Groeneweg & Verhoeve*	-2,00	1,00	-3,00	-0,80	0,00	2,00	0,00	2,00
CA7	Has the organisation means to receive information, take action and check compliance?	*Groeneweg & Verhoeve*	-2,00	-1,00	-1,00	-1,60	5,00	0,00	0,00	5,00
CA8	Did the decision makers know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?	*Rasmussen*	-2,00	-1,00	-1,00	-1,20	5,00	0,00	0,00	5,00
CA9	Could the decisionmakers act without undue time delays?	*Rasmussen*	-2,00	-1,00	-1,00	-1,44	1,00	0,00	0,00	1,00
CA10	What reinforcing and balancing forces were acting upon decision makers?	*Leveson*	-2,00	-1,00	-1,00	-1,50	2,00	0,00	0,00	2,00
	(What) were the system dynamics?	*Leveson*	-2,00	-1,00	-1,00	-1,60	0,00	0,00	0,00	0,00
		AVE				-1,11				

	Individual EOF	
AP13	What was the functional resonance (linking, coupling between functions)	*Hollnagel*
AP17	What were the system dynamics (reinforcing and balancing forces)?	*Leveson*
AP18	Have these findings been tried to generalise, using results from multiple accidents?	*Rasmussen*
AP18	Has this context been compared to other situations and have other outcomes been investigated?	*De Bruinn*
AP2	Were boundaries of acceptable performance known or could be observed by actors, agents and/or principals?	*Rasmussen*
AP2	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*
AP3	Could a discrepancy with respect to objectives or performance criteria be observed?	*Rasmussen*
AP3	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*
AP7	How was the perceived control structure?	*Leveson*
AP7	How was the actual control structure?	*Leveson*
CA1	What were the reasons for flawed control and dysfunctional interactions?	*Leveson*
CA10	What reinforcing and balancing forces were acting upon decision makers?	*Leveson*
CA10	(What) were the system dynamics?	*Leveson*
CA5	Were the decision makers thoroughly familiar with the control requirements of all relevant hazard sources within their work system?	*Rasmussen*
CA7	Has the organisation means to receive information, take action and check compliance?	*Groeneweg & Verhoeve*
CA8	Did the decision makers know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?	*Rasmussen*
CA9	Could the decisionmakers act without undue time delays?	*Rasmussen*
DP5	What variability is normal?	*Hollnagel*
RI4	Was there ignorance of large existing benefits while concentrating on small existing risks?	*Wildavsky*
RI5	Was there ignorance of effects of economic cost of safety?	*Wildavsky*
RI6	Was there ignorance of trade off between errors of commission (type I) and errors of omission (type II)?	*Wildavsky*

Table 28 EOF which will nor be identified in the traditional accident investigation approach of the Dutch Safety Board

	Individual EOF		Method / assessment framework
AP12	Were there conflicts between actors?	*Rasmussen*	TRIPOD
AP14	Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?	*Groeneweg & Verhoeve*	Individual responsibility, IV
AP15	Has the organisation informed relevant departments and organisations about these actions?	*Groeneweg & Verhoeve*	Individual responsibility, IV
AP16	Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?	*Groeneweg & Verhoeve*	Individual responsibility, IV
AP3	Did controllers (decision-1makers) have information about the actual state of the functions within their control domain and was this information compatible with (comparable to) the objectives as interpreted by the agent?	*Rasmussen*	Individual responsibility, IV
AP4	What was the information flow between the actors like?	*Rasmussen*	STEP
AP5	How effectively were changes in objectives communicated downward the organization, and how effectively were changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management	*Rasmussen*	Individual responsibility, V
CA2	Were the decision makers capable of control?	*Rasmussen*	TRIPOD
CA3	Did the decision makers have sufficient knowledge of the current state of affiars?	*Rasmussen*	TRIPOD
DP4	What were the essential system functions (Input, Output, Preconditions, Resources, Time, Control)	*Hollnagel*	voluntary REGULATIONS
DP6	Were the to be achieved goals clear to all actors involved?	*Rasmussen*	voluntary REGULATIONS

Table 29 EOF which can be identified by only one method /assessment framework of the traditional accident investigation approach of the Dutch Safety Board

Appendix IV Practical Assessment

The practical assessment consists of the assessmen of the results of a case study. First, the results of the System and Risk Strategy assessment will be presented. Next, the results of the Extra-organisational Factor assessment will be presented.

	System and Risk Strategy factors
Interactiveness (linear / complex)	Not explicitly identified. Some information identified on information loops, equipment and personnel. Difficult to say whether the system was more complex or linear, since it is also relative to other organisations. Tend to say more linear than complex
Coupling	Some implicit information on sequences, substitutions, resources, and delays
Risk strategy	Not explicitly identified, but some information on hazards and components, safety drills, not explicitly mentioned that resilience strategies not adopted.

Next pages:

Figure 27 Detailed analysis of assessment of the case study against the EOF Framework

	Risk (-strategy)		CASE STUDY	explanation
RI1	What are the identified system hazards?	*Leveson*	0	Mainly hazards w.r.t accident process (sequence of events) identified. System hazards could be project structure and scattered responsibilities
RI2	Was there ignorance of opportunity benefits?	*Wildavsky*	- -	Not explicitly identified
	How is the relation failure /success in the flip side of a coin?	*Hollnagel*	-	Not explicitly identified, although it is stated that this incident wasn't an exception
	Has both negative as positive consequences been investigated?	*De Bruijn*	-	Negative effects have been investigated. Positive effects of the "contributing factors"haven't been explicitly investigated. Positive effect of the accident investigation by parties itself have been mentioned
RI3	Was there ignorance of the safety risk associated with a proposed remedy?	*Wildavsky*	+	When the tank wasn't completely cleaned, and it was chosen to use work permits (=proposed remedy), the risks of this choice haven't been completely identified
RI4	Was there ignorance of large existing benefits while concentrating on small existing risks?	*Wildavsky*	0	Focus was on personal safety (small risks) while other risks (process safety) was paid less attention to. Benefits could be gained when focusing on these. But this is not the exacts benefits that Wildavsky meant
RI5	Was there ignorance of effects of economic cost of safety?	*Wildavsky*	-	No ignorance, but maybe the opposite: the costs of safety were were limited. This was identified.
RI6	Was there ignorance of trade off between errors of commission (type I) and errors of omission (type II)?	*Wildavsky*	- -	Not explicitly identified
RI7	Was there ignorance of displacement of risk onto other people as a consequence of reducing risks for some?	*Wildavsky*	+	Working with contractors (project leaders and work man) displaced the risk to them. The responsibilities of the work permits was also displaced.

	Process as designed		CASE STUDY	explanation
DP1	What actors were involved / influencing the process?	*Rasmussen*	+ +	Principal, contractors, two inspectorates
DP2	What were the system safety constraints ?	*Leveson*	+	Compulsory and voluntary regulations, including company specific procedures, especially for the principal actor. The exact constraints of the two inspectorates and the two contractors were not extensively identified
DP3	What was the originally designed control structure?	*Leveson*	0	Research has been done on responsibilities of the different actors: principal and contractors. Orgnanigrams have been investigated. The control structure of the inspectorates has been identified globally. No (visual) representation was made of the complet
DP4	What were the essential system functions (Input, Output, Preconditions, Resources, Time, Control)	*Hollnagel*	-	Some factors identified: what competencies should people have, how to check safety, input needed by one (for instance Permit To Work system), by no complete overview as meant by Hollnagel.
DP5	What variability is normal?	*Hollnagel*	-	Based on audits, some information is received on normal variability, but by no means as complete as meant by Hollnagel
DP6	Were the to be achieved goals clear to all actors involved?	*Rasmussen*	-	Not explicitly identified, although based on interviews some goals were clear to all
	Were objectives formulated by principals in a way such that the interpretation and re-formulation performed by their agents are properly considered?	*Rasmussen*	- -	Not explicitly identified
DP7	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*	0	Audit function was in place, but not for the complete socio technical system. Besides the focus was on compliance, not really interpretation
DP8	How effectively can changes in objectives be communicated downward the organization, and how effectively can changes in local constraints and criteria (e.g., to change of technology) be communicated upward the system to be considered for resource manageme	*Rasmussen*	0	The organigram has been investigated, and some difficulties in the organisational structure of the principal were identified. For other actors not identified

	Actual state of affairs / process		CASE STUDY	explanation
AP1	Has the context been investigated?	*De Bruijn*	+	The context of the principal actor has been investigated intensively. The context of others hardly.
criteria and boundaries				
AP2	Were boundaries of acceptable performance known or could be observed by actors, agents and/or principals?	*Rasmussen*	-	Not explicitly identified. Procedures were partly known, hazards were difficult to identify
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*	-	Not explicitly identified, but the complex project structure made it difficult to monitor
AP3	Did controllers (decision-makers) have information about the actual state of the functions within their control domain and was this information compatible with (comparable to) the objectives as interpreted by the agent?	*Rasmussen*	0	Some decision makers had relevant information on the safety concerns. The situation on the location itself (hydrocarbons in a tank with welding activities) was not widely know, if known at all. Investigation could not reveal who knew about the hydrocarbon
	Could a discrepancy with respect to objectives or performance criteria be observed?	*Rasmussen*	-	Not explicitly identified, although from the audit results a discrepancy was identified. The question is: is this normal variance?
	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*	-	Some deviations could be observed, but elements of process safety were hard to detect. The procedural and organisational boundaries of acceptable performance could - in hindsight - be detected; :"to be observed" could not be said. No explicit investigatio
information				
AP4	What was the information flow between the actors like?	*Rasmussen*	0	Not explicitly identified for all actors and processes. Some elements have been identified
AP5	How effectively were changes in objectives communicated downward the organization, and how effectively were changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management	*Rasmussen*	0	Not explicitly identified for all actors and processes. Some elements have been identified
AP6	Were (the relevant) actors aware of (known with) the failure(s) in the organisation?	*Groeneweg & Verhoeve*	0	Some relevant actors and their information were identified, some actors (contractors) were less investigated

Actual state of affairs / process

			CASE STUDY	explanation
control				
AP7	How was the perceived control structure?	*Leveson*	0	Not explicitly investigated, although context was investigated and some relevant aspects were identified wrt who was in control / in the lead / making decisions
	How was the actual control structure?	*Leveson*	0	Not explicitly investigated, although context was investigated and some relevant aspects were identified wrt who was in control / in the lead / making decisions
AP8	What were the inadequate constraints ?	*Leveson*	+	identified w.r.t. the barriers (detailed and on abstract level)
AP9	What were the inadequate execution of constraints?	*Leveson*	+	identified w.r.t. the barriers (detailed and on abstract level)
AP10	What was there inadequate or missing feedback?	*Leveson*	+	identified w.r.t. the barriers (detailed and on abstract level) and audits
AP11	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*	+	identified, although mainly limited to the principal actor
miscellaneous				
AP12	Were there conflicts between actors?	*Rasmussen*	0	identified wrt financial and personal conflict on the principal and contractor level. Not specifically identified for inspectorates
AP13	What was the functional resonance (linking, coupling between functions)	*Hollnagel*	- -	Not identified
AP14	Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?	*Groeneweg & Verhoeve*	+	for instance identified that the principal organisation identified certain aspects. Not identified for all actors.
AP15	Has the organisation informed relevant departments and organisations about these actions?	*Groeneweg & Verhoeve*	0	Identified to some extend: for the principal organisation and the inspectorate
AP16	Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?	*Groeneweg & Verhoeve*	+	Identified that the principal organisation has not assured compliance and effect. Other actors not explicitly identified
AP17	What were the system dynamics (reinforcing and balancing forces)?	*Leveson*	-	some forces on the contractors were identified, and on people level. Not extensively identified
AP18	Have these findings been tried to generalise, using results from multiple accidents?	*Rasmussen*	0	Have been tried to generalise, but not using multiple accidents but audits and other locations
	Has this context been compared to other situations and have other outcomes been investigated?	*De Bruijn*	-	Not explicitly, positive effects of the identified causes have not been investigated

	Capability of decision makers	Rasmussen	CASE STUDY	explanation
CA1	What were the reasons for flawed control and dysfunctional interactions?	Leveson	-	Not explicitly the flawed control reasons, but some underlying caused have been investigated
CA2	Were the decision makers capable of control?	Rasmussen	0	difficult to define decision makers, but some (non)capability in form of competence was identified
CA3	Did the decision makers have sufficient knowledge of the current state of affairs?	Rasmussen	0	for some decision makers this was identified
CA4	Was the organisation (in) formally responsible to receive information, take action and check compliance?	Groeneweg & Verhoeve	0	some aspects has been identified, in separate chapter responsibilities, but not explicit wrt information
CA5	Were the decision makers thoroughly familiar with the control requirements of all relevant hazard sources within their work system?	Rasmussen	-	identified they weren't familiar with certain hazards and unfamiliar with others. All related to accident. Not generic investigated and not for all decision makers
CA6	Has the organisation (in) formally authority to receive information, take action and check compliance?	Groeneweg & Verhoeve	-	Not explicitly identified,although some factors identified
CA7	Has the organisation means to receive information, take action and check compliance?	Groeneweg & Verhoeve	-	Not explicitly identified,although some factors identified
CA8	Did the decision makers know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?	Rasmussen	- -	Not identified
CA9	Could the decision makers act without undue time delays?	Rasmussen	- -	Not identified
CA10	What reinforcing and balancing forces were acting upon decision makers?	Leveson	-	Some were identified, but to little extend. Forces on inspetcorates not / little identified
	(What) were the system dynamics?	Leveson	- -	Not identified

Next pages:

Figure 28 Comparison of the theoretical and practical assessment of the EOF Framework

			METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY								
			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V	*Min*	*Max*	*Ave*	CASE STUDY
AP1	Has the context been investigated?	*De Bruijn*	-1	-1	1	-2	-2	-2	-2	-2	1	-2	-2	1	-1,20	1
RI2	Has both negative as positive consequences been investigated?	*De Bruijn*	-1	-2	0	-1	0	1	0	-1	1	0	-2	1	-0,50	-1
AP18	Has this context been compared to other situations and have other outcomes been investigated?	*De Bruinn*	-1	-2	-1	-2	-2	-2	-2	-2	0	-2	-2	-1	-1,78	-1
														0,33	-1,16	-0,33

			METHODS			REGULATIONS		INDIVIDUAL RESPONSIBILITY								
			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V	*Min*	*Max*	*Ave*	CASE STUDY
AP14	Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?	*Groeneweg & Verhoeve*	-1	0	0	-1	-1	-2	-2	0	1	0	-2	1	-1,00	1
AP15	Has the organisation informed relevant departments and organisations about these actions?	*Groeneweg & Verhoeve*	-1	0	0	-1	-1	-2	-2	0	1	0	-2	1	-1,00	0
AP16	Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?	*Groeneweg & Verhoeve*	-1	0	0	-1	0	-2	-2	0	1	0	-2	1	-1,00	1
AP6	Were (the relevant) actors aware of (known with) the failure(s) in the organisation?	*Groeneweg & Verh*	-1	0	1	-2	0	-2	-1	0	1	-1	-2	1	-0,71	0
CA4	Was the organisation (in) formally responsible to receive information, take action and check compliance?	*Groeneweg & Verhoeve*	-1	-2	0	1	1	-2	0	-1	-1	-2	-2	1	-0,88	0
CA6	Has the organisation (in) formally authority to receive information, take action and check compliance?	*Groeneweg & Verhoeve*	-1	-2	-1	1	1	-2	-1	-1	-1	-1	-2	1	-0,80	-1
CA7	Has the organisation means to receive information, take action and check compliance?	*Groeneweg & Verhoeve*	-1	-2	0	-1	0	-2	-2	0	0	0	-2	-1	-1,60	-1
														0,71	-1,00	0,00

			INTERVIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V	*Min*	*Max*	*Ave*	CASE STUDY
				METHODS		REGULATIONS		INDIVIDUAL RESPONSIBILITY								
AP13	What was the functional resonance (linking, coupling between functions)	*Hollnagel*	-1	-1	-1	-2	-1	-2	-2	-1	-1	-2	-2	-1	-1,40	-2
DP4	What were the essential system functions (Input, Output, Preconditions, Resources, Time, Control)	*Hollnagel*	-1	-2	0	-1	1	-1	0	0	0	-2	-2	1	-1,00	-1
DP5	What variability is normal?	*Hollnagel*	-1	-2	-1	-1	0	-2	-1	0	0	-2	-2	-1	-1,43	-1
RI2	How is the relation failure /success in the flip side of a coin?	*Hollnagel*	-1	-2	0	-2	1	1	0	0	0	-1	-2	1	-0,67	-1
														0,00	-1,12	-1,25

			INTERVIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V	*Min*	*Max*	*Ave*	CASE STUDY
				METHODS		REGULATIONS		INDIVIDUAL RESPONSIBILITY								
AP10	What was there inadequate or missing feedback?	*Leveson*	-1	1	1	0	0	-2	-2	0		-2	-2	1	-0,83	1
AP17	What were the system dynamics (reinforcing and balancing forces)?	*Leveson*	-1	-1	0	-2	-2	-2	-2	-1	-1	-1	-2	-1	-1,44	-1
AP7	How was the perceived control structure?	*Leveson*	-1	-1	0	-2	-2	-2	-2	-1	0	-2	-2	-1	-1,63	0
AP7	How was the actual control structure?	*Leveson*		-1	0	-2	0	-2	-2	-1	0	-2	-2	-1	-1,67	0
AP8	What were the inadequate constraints ?	*Leveson*		-1	1	-2	0	-2	-2	1	1	-2	-2	1	-0,75	1
AP9	What were the inadequate execution of constraints?	*Leveson*	-1	1	1	-1	0	-2	-2	1	1	-2	-2	1	-0,44	1
CA1	What were the reasons for flawed control and dysfunctional interactions?	*Leveson*	-1	-2	0	-2	0	-2	-2	0	0	-2	-2	-1	-1,83	-1
CA10	What reinforcing and balancing forces were acting upon decision makers?	*Leveson*	-1	-2	0	-1	0	-2	-2	-1	-1	-2	-2	-1	-1,50	-1
CA10	(What) were the system dynamics?	*Leveson*	-1	-2	-1	-2	-1	-2	-2	-2	-1	-2	-2	-1	-1,60	-2
DP2	What were the system safety constraints ?	*Leveson*	-1	-2	1	1	2	0	1	-1	1	-1	-2	1	-0,13	1
DP3	What was the originally designed control structure?	*Leveson*	-1	-2	0	0	2	0	1	-1	0	-2	-2	1	-1,00	0
RI1	What are the identified system hazards?	*Leveson*	-1	-2	1	1	1	2	1	0	1	-1	-2	1	0,13	0
														0,00	-1,06	-0,13

			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V	*Min*	*Max*	*Ave*	CASE STUDY
				METHODS		REGULATIONS		INDIVIDUAL RESPONSIBILITY								
AP11	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*	-1	-1	1	0	0	-2	-2	1	1	-2	-2	1	-0,63	1
AP12	Were there conflicts between actors?	*Rasmussen*	-1	0	1	-1	0	-2	-1	0	0	-2	-2	1	-1,00	0
AP18	Have these findings been tried to generalise, using results from multiple accidents?	*Rasmussen*	-1	-2	-1	-2	-2	-2	-2	-2	0	-2	-2	-1	-1,78	0
AP2	Were boundaries of acceptable performance known or could be observed by actors, agents and/or principals?	*Rasmussen*	-1	-1	0	-1	0	-2	-1	0	0	0	-2	-1	-1,20	-1
AP2	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*	-1	-1	0	-2	0	-2	-1	0	0	-1	-2	-1	-1,33	-1
AP3	Did controllers (decision-makers) have information about the actual state of the functions within their control domain and was this information compatible with (comparable to) the objectives as interpreted by the agent?	*Rasmussen*	-1	-1	0	-2	0	-2	-1	0	1	-1	-2	1	-1,00	0
AP3	Could a discrepancy with respect to objectives or performance criteria be observed?	*Rasmussen*	-1	-1	0	-2	0	-2	-1	0	-1	0	-2	-1	-1,33	-1
AP3	Could the margin to the boundaries of acceptable performance be determined or observed?	*Rasmussen*	-1	-1	0	-2	0	-2	-1	0	-1	0	-2	-1	-1,33	-1
AP4	What was the information flow between the actors like?	*Rasmussen*		1	0	-2	0	-2	-1	0	0	0	-2	1	-1,00	0
AP5	How effectively were changes in objectives communicated downward the organization, and how effectively were changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management	*Rasmussen*	-1	-1	0	-2	0	-2	-1	0	0	1	-2	1	-1,00	0

			INTER VIEW	STEP	TRIPOD	compulsory	voluntary	I	II	III	IV	V				CASE STUDY
				METHODS		REGULATIONS		INDIVIDUAL RESPONSIBILITY					*Min*	*Max*	*Ave*	
CA2	Were the decision makers capable of control?	*Rasmussen*	-1	-2	1	0	0	-2	-1	0	0	-2	-2	1	-1,17	0
CA3	Did the decision makers have sufficient knowledge of the current state of affiars?	*Rasmussen*	-1	-2	1	0	0	-1	-1	0	0	-2	-2	1	-1,00	0
CA5	Were the decision makers thoroughly familiar with the control requirements of all relevant hazard sources within their work system?	*Rasmussen*	-1	-2	0	0	0	-1	0	0	0	-1	-2	-1	-1,25	-1
CA8	Did the decision makers know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?	*Rasmussen*	-1	-2	0	0	0	-1	-1	0	0	-1	-2	-1	-1,20	-2
CA9	Could the decisionmakers act without undue time delays?	*Rasmussen*	-1	-2	-1	-1	-1	-2	-2	0	-1	-2	-2	-1	-1,44	-2
DP1	What actors were involved / influencing the process?	*Rasmussen*	-1	1	-1	0	1	1	1	0	1	-2	-2	1	0,13	2
DP6	Were the to be achieved goals clear to all actors involved?	*Rasmussen*	-1	-2	0	-2	1	-2	-1	-1	0	0	-2	1	-1,14	-1
DP6	Were objectives formulated by principals in a way such that the interpretation and re-formulation performed by their agents are properly considered?	*Rasmussen*	-1	-2	0	-2	1	-2	0	-1	0	1	-2	1	-0,86	-2
DP7	Was an auditing function in place to effectively monitor the propagation and interpretation of objectives within the entire socio-technical system?	*Rasmussen*	-1	0	1	0	1	-2	1	-1	1	0	-2	1	0,00	0
DP8	How effectively can changes in objectives be communicated downward the organization, and how effectively can changes in local constraints and criteria (e.g., to change of technology) be communicated upward the system to be considered for resource manageme	*Rasmussen*	-1	-2	1	-1	1	-2	0	-1	0	0	-2	1	-0,71	0
														0,20	-1,01	-1,10

			INTER VIEW	STEP METHODS	TRIPOD	REGULATIONS compulsory	REGULATIONS voluntary	INDIVIDUAL RESPONSIBILITY I	II	III	IV	V	*Min*	*Max*	*Ave*	CASE STUDY
RI2	Was there ignorance of opportunity benefits?	*Wildavsky*	-1	-2	0	-2	0	1	1	0	1	0	-2	1	-0,33	-2
RI3	Was there ignorance of the safety risk associated with a proposed remedy?	*Wildavsky*	-1	-2	1	0	1	0	1	0	1	0	-2	1	0,17	1
RI4	Was there ignorance of large existing benefits while concentrating on small existing risks?	*Wildavsky*	-1	-2	-1	-2	0	0	0	-1	0	-1	-2	-1	-1,33	0
RI5	Was there ignorance of effects of economic cost of safety?	*Wildavsky*	-1	-2	-1	-2	0	0	0	-1	-1	-1	-2	-1	-1,29	-1
RI6	Was there ignorance of trade off between errors of commission (type I) and errors of omission (type II)?	*Wildavsky*	-1	-2	-1	-1	0	0	0	-1	0	0	-2	-1	-1,20	-2
RI7	Was there ignorance of displacement of risk onto other people as a consequence of reducing risks for some?	*Wildavsky*	-1	-2	1	1	1	1	1	-1	1	0	-2	1	0,22	1
														0,00	-0,63	-0,60

Appendix V Methods used at the Dutch Safety Board

The figures are based on accident investigation report, published by the Dutch Safety Board (and its preceding Transport Safety Board) in the period January 2000 – may 2008. The minor reports are only included in the first chart, but are excluded in all others. In total 132 reports have been published, and 82 major investigations are included in this analysis.

The identification of the methods used during investigation is based on the content of the final publication. The methods used should be described or demonstrated somewhere in the report. Additionally, for the reports in which one of the analysts was involved in, the methods used were added. This was the case in three reports (one aviation, one shipping, one defence).

Distinction per category of method

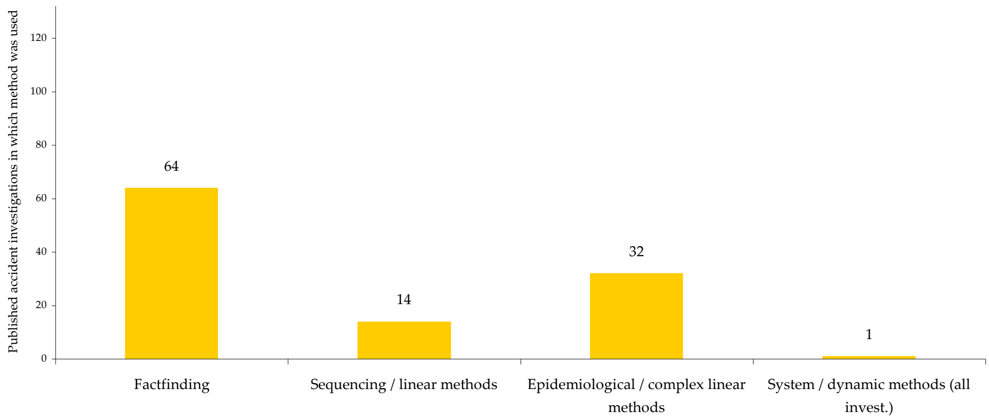


Figure 29 Number of reports in which the different type of methods are mentioned / used. Total number of reports = 132

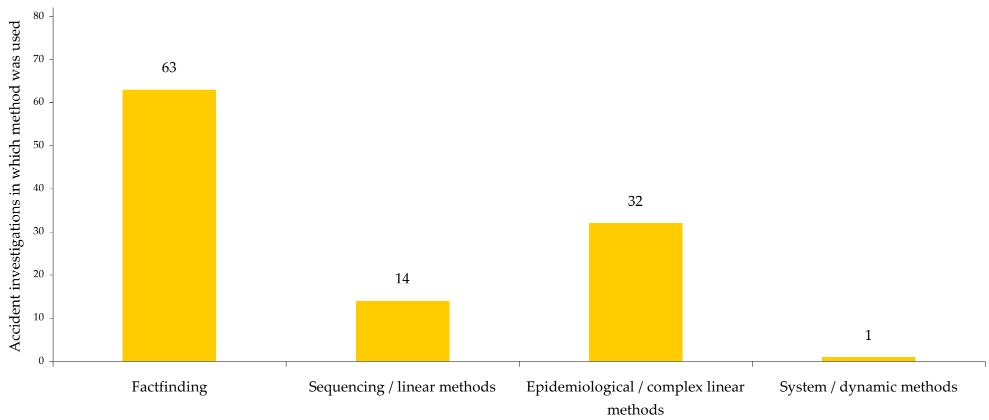


Figure 30 Number of major investigation reports in which the different type of methods are mentioned / used. Total number of reports = 82

Trends in usage of methods over the years

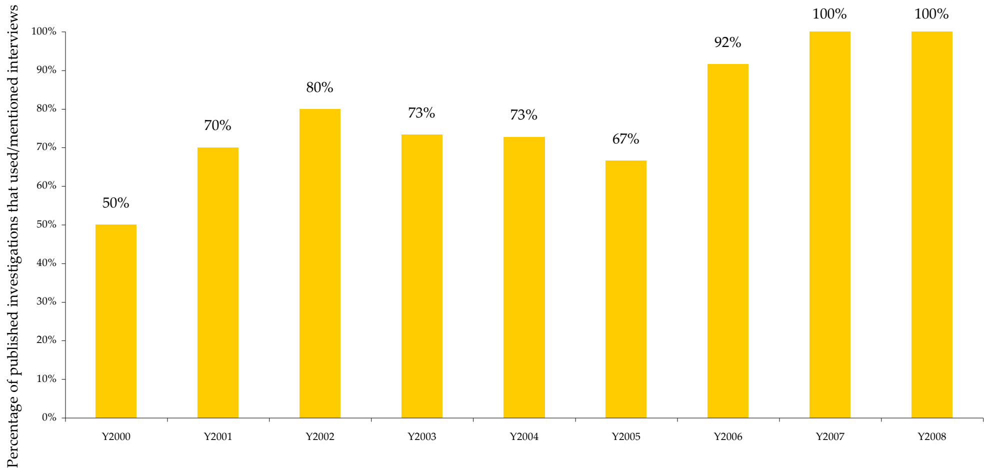


Figure 31 Percentage of major investigation reports in which interviewing as fact-finding method are mentioned / used – per year. Total number of reports = 82. Y2008 are two reports only.

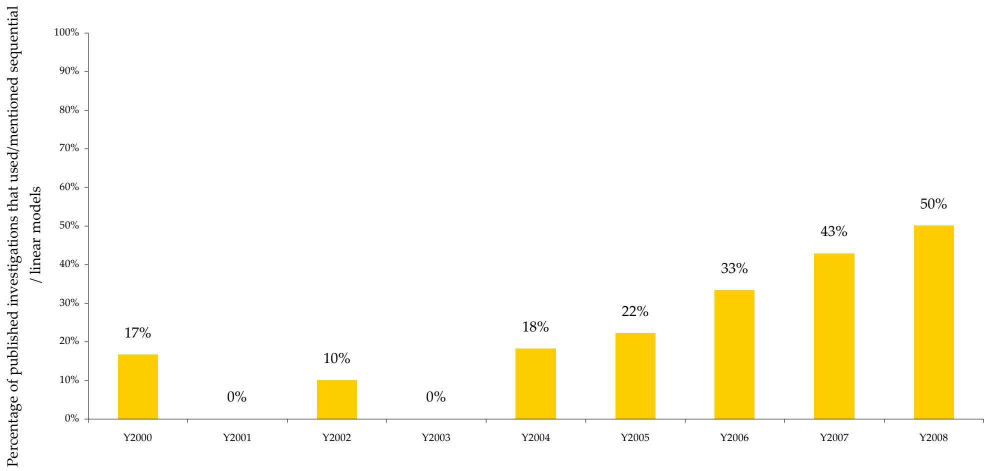


Figure 32 Percentage of major investigation reports in which sequential / linear methods (FTA, timeline-analysis, barrier-analysis and DOVO) are mentioned / used – per year. Total number of reports = 82. Y2008 are two reports only.

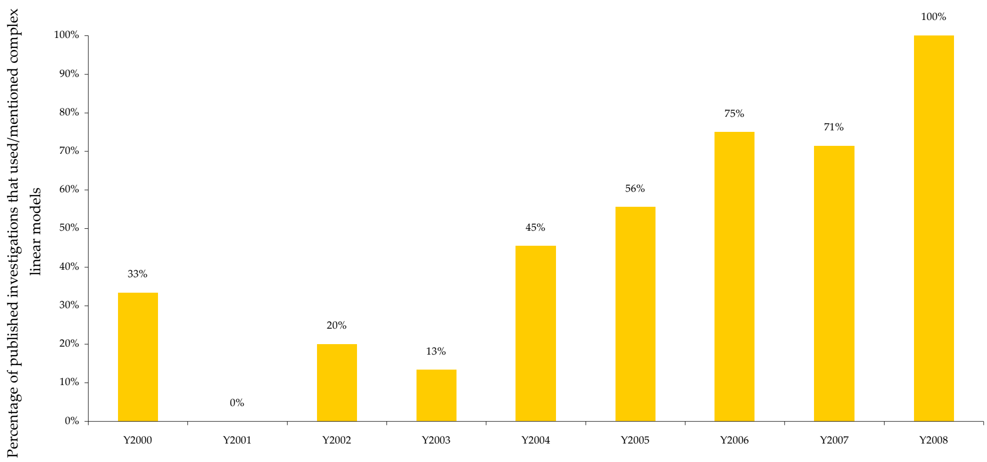


Figure 33 Percentage of major investigation reports in which complex linear methods (Tripod, MORT) are mentioned / used – per year. Total number of reports = 82. Y2008 are two reports only.

Usage of methods per domain

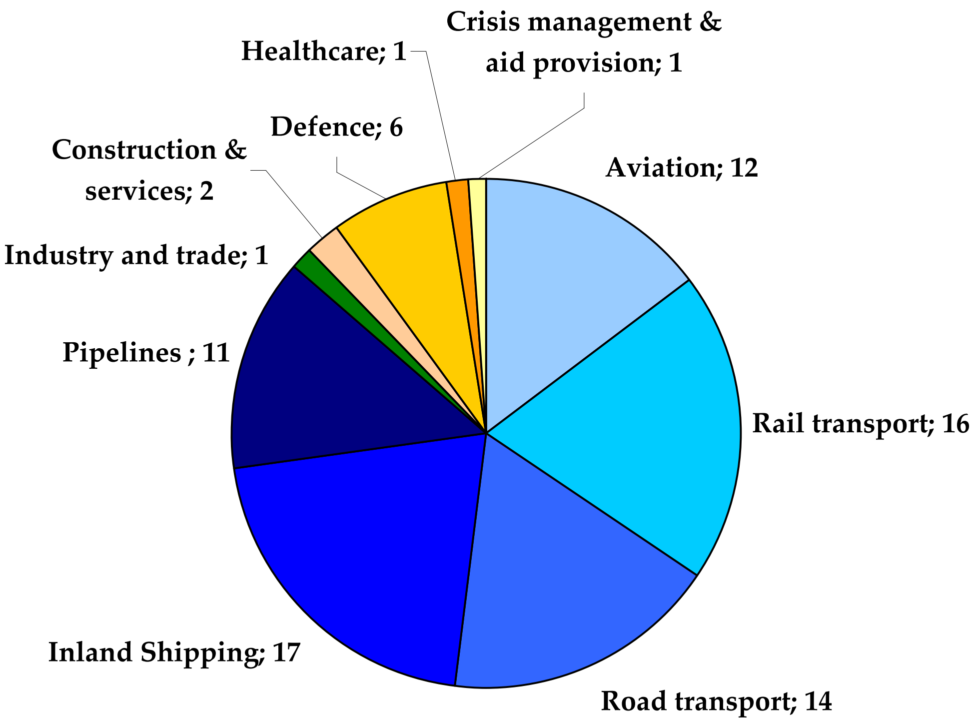


Figure 34 Major investigation reports per domain. Total number of reports = 82

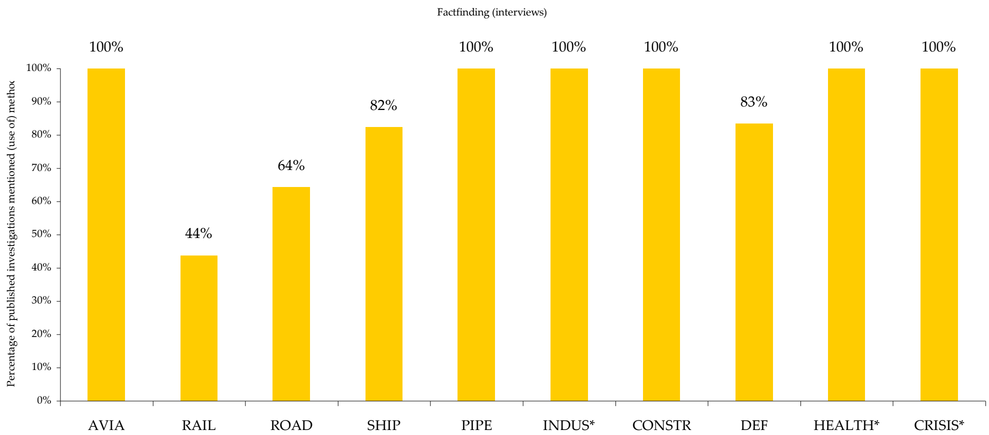


Figure 35 Percentage of major investigation reports in which interviewing as fact-finding method are mentioned / used – per domain. Total number of reports = 82. * Only one published report included.

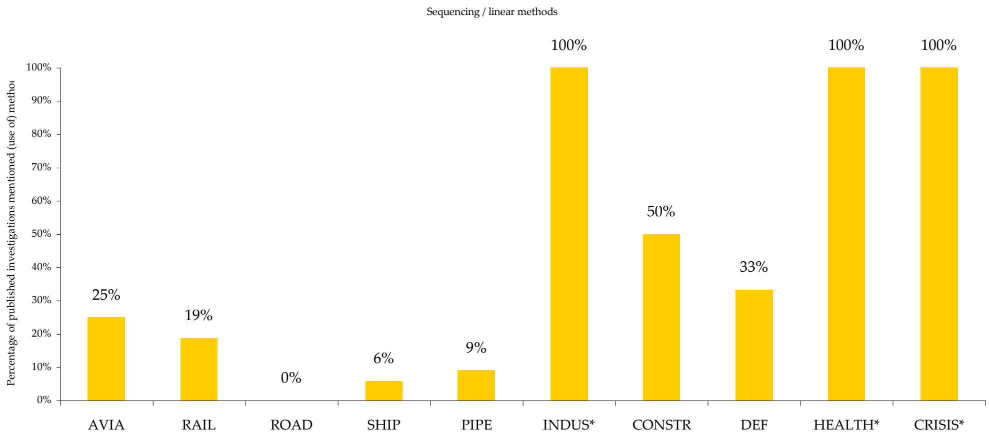


Figure 36 Percentage of major investigation reports in which sequential / linear methods (FTA, timeline-analysis, barrier-analysis and DOVO) are mentioned / used – per domain. Total number of reports = 82. * Only one published report included.

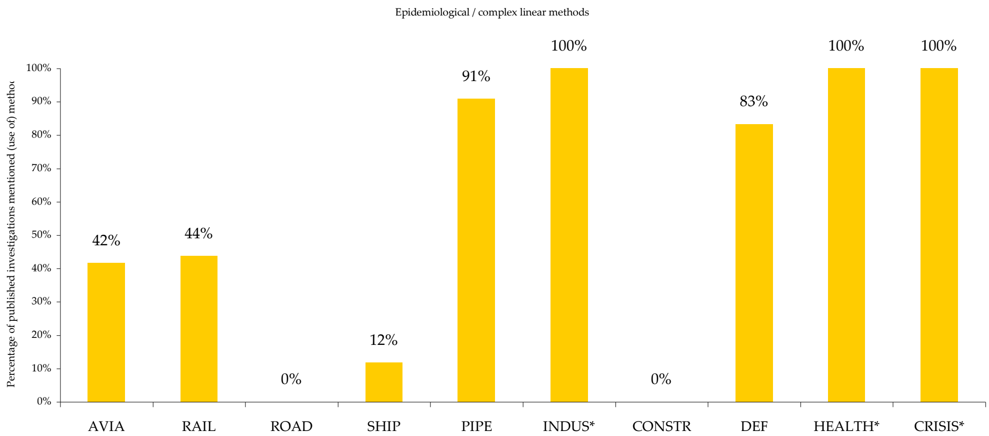


Figure 37 Percentage of major investigation reports in which complex linear methods (Tripod, MORT) are mentioned / used – per domain. Total number of reports = 82. * Only one published report included

Next pages: 82 included major reports and the methods applied.

						Factfinding		Sequencing / linear methods				Epidemiological / complex linear methods		System / dynamic methods		
	Date of accident	Publishing date	Publication title as stored in Knowledge-base	Domain	ID number	Interview	simulation	FTA	Timeline	Barrier analysis	DOVO	Tripod	MORT	IPIC RAM	FRAM	accimap
1	15-07-96	17-12-02	Hercules Ramp Eindhoven	Defence	M1996DE0715-01	1			1							
2	24-01-97	23-10-03	Mistongeval op de A9 bij Badhoevedorp (1997)	Road transport	M1997WV0124-01											
3	20-12-97	10-02-00	Helikopter te water, 97-74/A-25 PH-KHB, Sikorsky S-76B	Aviation	M1997LV1220-01	1										
4	12-03-99	20-12-01	Verlies van remcapaciteit met de Iberworld Airbus A320-214	Aviation	M1999LV0312-01	1										
5	3-07-99	12-06-01	Aanvaring tussen een snelle motorboot met waterskiër en een zeilplank	Inland Shipping	M1999SV0703-01	1										
6	12-07-99	20-07-00	Brand in sneltram in het ondergrondse metrostation Weesperplein in A'dam	Rail transport	M1999RV0712-01							1				
7	21-07-99	16-01-01	Botsing met tegenligger op de N31 bij Harlingen op 21 juli 1999	Road transport	M1999WV0721-01	1										
8	27-07-99	16-08-00	Dodelijk ongeval met een sportboot op de Waddenzee	Inland Shipping	M1999SV0727-01	1										
9	20-08-99	29-09-00	Rangeerder onder rangeerdeel te Rotterdam Waalhaven	Rail transport	M1999RV0820-01											
10	20-08-99	12-10-00	Ontsporing reizigerstrein bij Baarn	Rail transport	M1999RV0820-02							1				
11	5-09-99	13-05-01	Taxibus botst op obstakelbeveiliger in wegwerkzaamheden A17, Zevenbergen	Road transport	M1999WV0905-01	1										
12	11-11-99	8-11-01	Aanrijding van een personenbusje door een reizigerstrein in Breda	Rail transport	M1999RV1111-01											
13	13-11-99	19-06-01	Gronding van de veerboot mps. Prins Johan Friso op 13 november 1999	Inland Shipping	M1999SV1113-01											
14	28-11-99	25-06-01	Botsing tussen twee reizigerstreinen in Dordrecht 28 november 1999	Rail transport	M1999RV1128-01											
15	10-12-99	25-07-02	Scheepvaartongeval met dodelijke afloop op het Keeten	Inland Shipping	M1999SV1210-01	1										
16	20-12-99	13-01-05	Tweerichtingsverkeer in één tunnelbuis tijdens geplande werkzaamheden	Road transport	M1999WV1220-01	1										
17	28-01-00	14-03-02	Ontsporing metro doorverlies motor in de tunnel onder de oude Maas regio Rotterdam 28 januari 2000	Rail transport	M2000RV0128-01											
18	8-06-00	5-06-03	Botsing in de lucht tussen de vliegtuigen PH-BWC en PH-BWD	Aviation	M2000LV0608-01	1										
19	16-06-00	27-02-03	Overwegbotsing te Voorst 16 juni 2000	Rail transport	S2000RV0616-01											
20	23-06-00	20-12-01	Vrachtwagen gaat door vangrail Ketelbrug en valt in Ijsselmeer	Road transport	M2000WV0623-01	1										
21	9-08-00	5-12-02	Explosie aan boord van de duw-/sleepboot Jannie-B op 9 augustus 2000	Inland Shipping	M2000SV0809-01	1										
22	19-08-00	6-03-03	Lekstabiliteit van beunschepen	Inland Shipping	M2000SV0819-01	1										
23	30-11-00	13-03-03	Fataal ongeval in de ladingtank van een chemicaliëntanker	Inland Shipping	M2000SV1130-02	1										
24	9-03-01	21-12-06	Het toezicht op in Nederland gestationeerde i.h.buitenland gereg.luchtvaartuigen	Aviation	M2001LV0309-01	1										

						Factfinding		Sequencing / linear methods				Epidemiological / complex linear methods		System / dynamic methods		
	Date of accident	Publishing date	Publication title as stored in Knowledge-base	Domain	ID number	Interview	simulation	FTA	Timeline	Barrier analysis	DOVO	Tripod	MORT	IPIC RAM	FRAM	accimap
25	23-03-01	5-12-02	Aanvaring op het Amsterdam-Rijnkanaal tussen drie motorschepen	Inland Shipping	M2001SV0323-01											
26	11-05-01	22-01-04	In aanraking gekomen met propeller tijdens het opstarten	Aviation	M2001LV0511-01	1										
27	14-05-01	21-11-06	Tankautobranden met gevaarlijke stoffen	Road transport	M2001WV0514-01											
28	12-06-01	22-02-02	Ongeval, asfaltfreesmachine raakt gasdistributieleiding	Pipelines	M2001BL0612-01	1						1				
29	11-07-01	11-12-03	Brand in de Schipholtunnel 11 juli 2001	Rail transport	M2001RV0711-01	1										
30	15-08-01	11-10-02	Breuk van gasdistributieleiding Amsterdam	Pipelines	M2001BL0815-01	1						1				
31	26-09-01	1-08-03	Stroefheidsproblemen bij niet-afgestrooid asfaltbeton	Road transport	S2001WV0926-01											
32	9-11-01	20-03-03	Storing gasmengstation	Pipelines	M2001BL1109-01	1										
33	5-12-01	21-10-03	Verontreiniging drinkwater Leidsche Rijn	Pipelines	M2001BL1205-01	1						1				
34	24-04-02	8-04-04	Botsing in de Lucht F-16B en Ultralight	Aviation	M2002LV0424-01	1			1			1				
35	2-06-02	28-10-03	Lekkage van gasolie nabij de Oude Maas	Pipelines	M2002BL0602-01	1						1				
36	14-08-02	14-11-02	Ongeval tijdens een trainingsvlucht	Aviation	M2002LV0814-01	1										
37	20-08-02	16-09-04	Lekkage acrylnitril station Amersfoort 20 augustus 2002	Rail transport	M2002RV0820-01	1		1		1		1				
38	31-10-02	22-03-05	Overweg te Veenendaal	Rail transport	M2002RV1031-01	1						1				
39	17-12-02	15-05-03	Gasexplosie Hierden	Pipelines	M2002BL1217-01	1										
40	12-01-03	9-11-06	Tail strike tijdens de start	Aviation	M2003LV0112-01	1						1				
41	15-01-03	4-03-05	Duikongeval op 15 januari 2003 op de Waddenzee	Defence	M2003DE0115-01			1				1	1			
42	27-03-03	16-06-04	Gasuitstroming na breuk afsluiter hogedruk gasdistributieleiding	Pipelines	M2003BL0327-01	1						1				
43	30-04-03	24-03-05	Ontsporing goederentrein bij Apeldoorn op 30 april 2003	Rail transport	M2003RV0430-01	1										
44	17-06-03	20-04-06	Van startbaan geraakt na afbreken start van de Onur Air MD-88	Aviation	M2003LV0617-02	1						1				
45	17-06-03	16-01-04	Botsing YPR met trein nabij Assen op 17 juni 2003	Defence	M2003DE0617-01	1						1				
46	18-08-03	28-08-07	Verlies van controle over besturing tijdens het oppikken reclamesleepnet	Aviation	M2003LV0818-01	1										
47	29-08-03	7-10-04	Ongevallen met vrachtauto's die afneembare laadbakken vervoeren	Road transport	M2003WV0829-01											
48	30-08-03	25-11-04	Gasexplosie op 30 augustus 2003 in Bergschenhoek	Pipelines	M2003BL0830-01	1						1				
49	18-10-03	23-06-05	Fast Ferry Voskhod 605 op 18 oktober 2003 te Amsterdam	Inland Shipping	M2003SV1018-01	1										
50	22-12-03	23-03-06	Verlies van besturing op een gladde rijbaan van de EasyJet Boeing B737-700	Aviation	M2003LV1222-01	1			1			1				
51	27-01-04	4-10-05	Leidingbreuk te Stein	Pipelines	M2004BL0127-01	1			1			1				
52	11-03-04	25-01-06	Gasexplosie Schijndel als gevolg van falen koppeling distributieleiding	Pipelines	M2004BL0311-01	1						1				
53	21-05-04	5-07-05	Door Rood op Amsterdam CS	Rail transport	M2004RV0521-01							1				
54	5-07-04	4-07-06	Plooien en gedeeltelijk zinken van een beunschip op 5 juli 2004 in de Middensluis van Ijmuiden	Inland Shipping	M2004SV0705-01	1			1			1				
55	30-09-04	19-10-06	Assen, arbeidsongeval bij herstel van gaslekkage op 30 september 2004	Pipelines	M2004BL0930-01	1						1				

						Factfinding		Sequencing / linear methods				Epidemiological / complex linear methods		System / dynamic methods		
	Date of accident	Publishing date	Publication title as stored in Knowledge-base	Domain	ID number	Interview	simulation	FTA	Timeline	Barrier analysis	DOVO	Tripod	MORT	IPIC RAM	FRAM	accimap
56	30-11-04	30-08-07	Onbedoeld hoogteverlies tijdens de nadering Sikorsky	Aviation	M2004LV1130-01	1			1			1				
57	15-05-05	16-02-07	Brand disco Kingdom Venue, 15 mei	Construction & services	S2005BD0515-04	1			1							
58	31-05-05	13-09-07	Explosie Aardgascondensaattank	Industry and trade	M2005BL0531-03	1			1			1				
59	4-07-05	6-06-06	Den Helder, chloorgasbedwelming in de averijmoot de "Bever"op 4 juli 2005	Defence	M2005DE0704-01	1						1				
60	15-08-05	20-12-07	Ontsporing Amsterdam Centraal, 15 augustus 2005	Rail transport	M2005RV0815-04	1	1					1				
61	29-09-05	28-04-08	Een onvolledig bestuurlijk proces: hartchirurgie in UMC St. Radboud	Healthcare	S2005GZ0929-03	1			1			1		1	1	1
62	26-10-05	21-09-06	Brand cellencomplex Schiphol-Oost	Crisis management & aid provision	S2005CH1026-02	1			1			1				
63	26-04-06	3-05-07	Curaçao, gewonden door gebruik van rookhandgranaat WP, 26 april 2006	Defence	M2006DE0426-01	1						1				
64	8-06-06	16-08-07	Explosie aan boord van een tweemastklipper te Medemblik tweemastklipper te Medemblik, 8 juni 2006	Inland Shipping	M2006SV0608-02	1						1				
65	2-06-07	8-03-08	Voorval met abseilen tijdens landmachtdagen. Wezep, 2 juni 2007.	Defence	M2007DE0602-01	1						1				
66	thematical	23-11-06	Veiligheidsproblemen met gevelbekleding	Construction & services	T2006BD0711-01	1										
67	thematical	13-11-01	scheepvaartongevallen op het Marker- en Ijsselmeer	Inland Shipping	T2005SV0824-02	1										
68	thematical	22-11-01	Onderzoek naar veiligheidsaspecten van hefbare stuurhuizen in de binnenvaart	Inland Shipping	T2005SV0824-01	1										
69	thematical	9-09-03	Onderzoek naar de dode hoek aan boord van binnenvaartschepen	Inland Shipping	T2005SV0816-02	1										
70	thematical	27-10-03	Zeventien grondingen in de overnachtingshaven bij Haaften	Inland Shipping	T2005SV0815-02	1										
71	thematical	2-09-04	De stabiliteitsrisico's van binnenschepen en drijvende werktuigen	Inland Shipping	T2005SV0811-02	1										
72	thematical	29-11-04	Themastudie naar roeruitval op binnenschepen	Inland Shipping	T2005SV0811-01											
73	thematical	31-01-05	Buisleidingenongevallen en – incidenten a.g.v.(graaf)werkzaamheden derden	Pipelines	T2005BL0809-01							1				
74	thematical	13-09-00	Veiligheidsrisico's van de Nederlandse stadstram	Rail transport	T2005RV0830-01	1					1					
75	thematical	2-10-03	De vrije trambaan	Rail transport	T2005RV0816-03											
76	thematical	30-11-06	Ontsporingen op Amsterdam Centraal, 6 en 10 juni 2005	Rail transport	T2007RV0717-01	1			1			1				
77	thematical	5-12-02	Ongevallen met manoeuvrerende vrachtauto's bij duisternis	Road transport	T2000WV1122-01	1										
78	thematical	19-12-02	Auto te water: ontsnappingsproblemen	Road transport	T2005WV0816-04	1										
79	thematical	30-10-03	Ongevallen op de vluchtstrook Veiligheidsstudie	Road transport	T2005WV0816-01	1										
80	thematical	7-09-04	Bus/trein-botsingen op overweg bij Nootdorp	Road transport	T2005WV0815-01	1										
81	thematical	2-12-04	Botsveiligheid Geluidsschermen	Road transport	T2003WV0619-01											
82	thematical	30-06-05	Langdurige onveilige regionale hoofdwegen	Road transport	T2005WV0809-02	1										

Appendix VI Methods used at the other Safety Boards

The International Transport Safety Association (ITSA) is a global association of (Transport) Safety Boards. The ITSA has 14 members:

Australia – Australian Transport Safety Bureau (ATSB)
Canada – Transportation Safety Board of Canada (CTSB)
Interstate Aviation Committee (IAC)
Finland – Accident Investigation Board (FAIB)
India – Commission of Railway Safety (CRS)
Japan – Aircraft and Railway Accidents Investigation Commission (ARAIC)
Republic of Korea – Aviation and Railway Accident Investigation Board (ARAIB)
The Netherlands – Dutch Safety Board (DSB)
New Zealand – Transport Accident Investigation Commission (TAIC)
Norway – Accident Investigation Board Norway (AIBN)
Sweden – Swedish Accident Investigation Board (SAIB)
Chinese Taipei – Aviation Safety Council (ASC)
United Kingdom - Board of Transport Accident Investigators (BTAI)
United States – National Transportation Safety Board (NTSB)

Based on a website search of the websites of the members, adjusted and completed with the knowledge available at the Research and Investigation department of the Dutch Safety Board, the following methods used have been identified.

	Factfinding	Sequencing / linear methods					Epidemiological / complex linear methods						System / dynamic methods			
	Interviews	Timeline analysis	STEP	Fault Tree	Root Cause analysis	1 or more sequencing / linear method	Reason model	TEM model	SHELL model	Tripod	MORT	1 or more epidemiological / complex linear method	Accimap	Stamp	IPIC RAM	1 or more system / dynamic methods
Australia – Australian Transport Safety Bureau (ATSB)	X	X	X	X		Y	X	X	X			Y	X			Y
Canada – Transportation Safety Board of Canada (CTSB)	X	X		X	X	Y	?	X				Y	X			Y
Interstate Aviation Committee (IAC)																
Finland – Accident Investigation Board (FAIB)	X	X				Y										
India – Commission of Railway Safety (CRS)																
Japan – Aircraft and Railway Accidents Investigation Commission (ARAIC)	X	?														
Republic of Korea – Aviation and Railway Accident Investigation Board (ARAIB)	X	X				Y										
The Netherlands – Dutch Safety Board (DSB)	X	X	X			Y				X		Y	X		X	Y
New Zealand – Transport Accident Investigation Commisssion (TAIC)	X						X					Y				
Norway – Accident Investigation Board Norway (AIBN)	X	X	X			Y					X	Y				
Sweden – Swedish Accident Investigation Board(SAIB)	X															
Chinese Taipei – Aviation Safety Council (ASC)	X			X	X	Y	X	?	X			Y				
United Kingdom - Board of Transport Accident Investigators (BTAI)	X	X				Y										
United States – National Transportation Safety Board (NTSB)	X	X		X	X	Y										
Sum	12	8	3	4	3	9	3	2	2	1	1	6	3	0	1	3
percentage	86%	57%	21%	29%	21%	64%	21%	14%	14%	7%	7%	43%	21%	0%	7%	21%

Figure 38 Overview of the methods used per International Transport Safety Board member, categorized.

Appendix VII Framework of individual responsibility

The Board has sent a letter the Minister of the Interior and Kingdom Relations to inform him about this. The Board employs the priorities referred to below in all of its investigations (Dutch Safety Board, 2006).

1. **Acquiring demonstrable insight into the risks relating to safety as the foundation for the approach to safety:**
   The starting point for achieving the required level of safety is:
   - an exploration of the entire system and
   - an inventory of the corresponding risks.

   The dangers that should be managed and the preventive and repressive measures that are necessary in that regard will be established on the basis of this.

2. **A demonstrable and realistic approach to safety:**
   A realistic and practically applicable approach to safety (or safety policy) must be established to prevent and manage undesirable events.
   This approach to safety is based on:
   - relevant, current legislation and regulations (Section 4.2);
   - available standards, directives and best practices from the sector, the organisation's own insights and experiences, and the safety objectives specifically compiled for the organisation.

3. **Execution and enforcement of the approach to safety:**
   Execution and enforcement of the approach to safety and management of the risks identified is done by means of:
   - a description of the way in which the employed approach to safety is to be executed with a focus on the specific objectives and including the preventive and repressive measures arising from it;
   - transparent, unambiguous and universally accessible division of responsibilities in respect of safety in the workplace as far as the execution and enforcement of safety plans and measures are concerned;
   - clearly establishing the required deployment of personnel and expertise for the various tasks;
   - the clear and active centralised coordination of safety activities;
   - realistic drills and testing of the approach to safety.

4. **Fine-tuning the approach to safety:**
   The approach to safety should be subject to continual evaluation and fine-tuning on the basis of:
   - conducting (risk) analyses on the subjects of safety, observations, inspections and audits (pre-emptive approach) periodically or, at least, in the event of every change to the underlying principles;
   - a system of monitoring and investigation of near accidents in the complex and an expert analysis of these (reactive approach). Evaluations will be carried out and points for improvement will be brought to light on the basis of this on which action can be taken.

5. **Management control, involvement and communication:**
   The management of the parties/organisation involved should:

- ensure internally that expectations are clear and realistic in respect of safety ambitions, ensure there is a climate of continual improvement of safety in the workplace;
- communicate clearly externally about general working practices, the way in which they are tested, procedures in the event of anomalies, etc. on the basis of clear and established arrangements with the environment.

Appendix VIII Theory: Perrow's Normal Accidents

Name	Normal Accidents
Author(s)	Charles Perrow
Year	1984
M/T	Theories
Aim	To emphasize and convince that we create systems – organisations and the organisation of organisations – that increase risks, and that in some type of organisations - no matter how effective safety devices are - accidents are inevitable.
Keywords	Coupling (tight or loose) Complexity : linear and complex interactions

Description

Context

It is the potential for the unexpected interactions of small failures in a system, which makes it prone to the system accident.

Additional background information

The term "normal accident" is meant to signal that, given the system characteristics, multiple and unexpected interactions of failures are inevitable. A normal accident is equivalent for system accident.

The system can be divided in four levels:

Parts

Units

Subsystems

System

Accidents affect safety and the third and fourth level of the system. By this, an accident can be defined as a failure

Victims can be divided in four categories:

first party victims (i.e. operators; part of system, with influence)

second party victims (i.e. visitors, passengers; part of system without influence)

third party victims (i.e. innocent bystanders; not part of system)

fourth party victims (i.e. foetuses and future generations; long term consequences)

We should focus on third and fourth party victims, where fourth party victims potentially constitute the most serious class of victims.

To determine the accident proneness of a system, two dimensions are important:

Interactiveness, which can be confusing

Coupling, which could prevent speedy recovery

Interactiveness

Three indications of interactiveness are:

Common-mode failures

Proximity

Indirect information sources

Complex and linear interactions are distinguished. Complex interactions are featured by branching paths, feedback loops, jumps from one linear sequence to another because of proximity. Connections are not just serial, but can multiply. Complex interactions will generally be those not intended in the design. Complex interactions may be unintended ones, or ones that are intended but unfamiliar. Linear interactions are more common, and are featured by simplicity and comprehensibility. Linear interactions are visible and can be expected.
Linear interactions predominate in all systems. But some systems have more complex interactions than others, and by that, can be complex systems.
The following table gives an overview of the differences between complex and linear systems.

	Linear systems	**Complex systems**
Subsystems	Segregated	Interconnected
Connections	Dedicated	Common-mode
Production steps	Segregated	Proximity
Feedback loops	Few	Unfamiliar, unintended
Isolation of failures	Easy	limited
Substitutions	Easy	limited
Controls	Single purpose, segregated	Multiple, interacting
Information	Direct	Indirect, interferential
Equipment	Spread out	Tight spacing
Personnel	Less specialization Extensive understanding	Specialization limits awareness of interdependencies Limited understanding

The second dimension is coupling: from tight to loosely coupling. Both types of systems have their virtues and vices.

In tight coupled systems, there are more time dependent processes and the sequences are more invariant. Also there is one way to reach the production goal. Tight coupling means there is no slack or buffer or give between two items. Tightly coupled systems will respond more quickly to perturbations, but the response may be disastrous. Buffers and redundancies must be designed and thought of in advance.

Loosely coupled systems tend to have ambiguous or flexible performance standards. It would be a mistake to call loosely coupled systems inefficient. Loosely coupled systems can incorporate shocks and failures and pressures for change without destabilization.

	Tight coupling	**Loose coupling**
Achieving goals	One method	Alternative methods
Sequences	Invariant	Order can be changes

Delays	Not possible	Possible
Buffer and redundancies	Designed in, deliberate	Fortuitously available
Substitutions	Designed in, limited	Fortuitously available
Resources	Little slack	Slack

If the system is linear interactive, tight coupling appears to be the optimum mode of organisation.

We have not had more serious accident of the scope of Three Mile Island simply because we have not given them enough time to appear.

Main References

Perrow,C., *Normal Accident. Living with High Risk Technologies* (1984)

Appendix IX Theory: Wildavsky's Searching for Safety

Name	Searching for Safety (Book)
Author(s)	Aaron Wildavsky
Year	1988
M/T	Theories
Aim	To emphasize and convince resilience is the superior strategy over (the more popular strategy of) anticipation in the search of safety.
Keywords	Resilience & anticipation (U)certainty & (un)predictability Risk taking & risk aversion Trial and error & trial without error Multi-dimensional view on risk, net safety Competition, wealth, experience, resources
Description	
Context	We are living in a world with uncertainties. Predicting accidents, both qualitative and quantitative appears difficult. Safety Is not about avoiding danger, but an active search to receive more of the good and less of the bad Is relative, not absolute Is not static, but is rather a dynamic product of learning from error over time Degrades: unless safety is continuously re-accomplished, it will decline.
Risk management	Risk management is thinking about risks in both dangers as opportunities, searching for less of the bad and more of the good. There are two bedrock approaches to managing risk: trial and error, and trial without error. These interconnect with the universal strategies anticipation and resilience. Since it is impossible to anticipate for all dangers, the potential decrease of safety by using the trial without error strategy, resilience should be the more dominant strategy.
Challenges	Think about how to think about risk, and by that: how to act. Use risk to get more of the good and less of the bad. Move away from a passive prevention of harm to an active search for safety. Deal with a society that becomes more and more risk averse, not accepting errors and focussing on anticipatory measures.
Accident investigation	No specific framework for accident investigation is given. Accidents are opportunities to learn
Specific features	Applicable to systems with uncertainty, change, unpredictability,
Additional	Risk is an inevitable mixed phenomenon from which considerable good as

background information

well as harm is derived. Safety and danger coexist in the same objects and practices. Over-concentration on danger has lead to neglect of safety.

Anticipation and resilience

Anticipation and Resilience are universal strategies. Anticipation is aimed at preventing expected risks become manifest. Efforts are made to predict and prevent potential dangers. Anticipation seeks to preserve stability: the less fluctuation, the better.

Resilience is the capacity to cope with unanticipated dangers after they have become manifest. Resilience accommodates variability. Resilience depends on numerous participants interacting at great speed, sending out and receiving different signals along a variety of channels.

Anticipation and resilience is well suited to different conditions. Under substantial certainty, anticipation makes sense. Effects have to be known and probabilities have to be reliable. Resilience is an inferior strategy under those conditions. But only following the anticipation-strategy is impossible because:

Inherent uncertainty about future low probably events

Need to keep some of the limited resources for dealing with surprises

Acceptation of risk is sometimes necessary to gain long term safety

Under a considerable amount of uncertainty, resilience is preferred.

The main limitation of resilience is the potential for catastrophe: knowledge is incomplete and uncertainty inherent, especially concerning low probability events.

Going to extremes: all resilience and no anticipation, or vice versa, would be destructive. By allowing resilience (and thus errors), information on probabilities can be gathered, feeding anticipatory strategies.

Vital knowledge can only be gained though trail and error. A loss of variability due to anticipatory policies leads to a decline of resilience.

The human body places only limited emphasis on anticipatory mechanisms; most is based on resilient strategies.

Anticipatory strategies have a rhetorical advantage: they can claim they aim directly at safety by prevent expected harm. Adherents of resilience face a rhetorical disadvantage: by encouraging risk taking they are apparently opposed to safety. Besides: You don't miss what you don't know.

Trial without error (anticipation) versus Trial and Error (resilience)

An approach compliant with the anticipation strategy is "*Trial without error*". In relation to this approach, the following can be mentioned:

Focuses on risks with terribly low probabilities, and awfully terrible events. Reduce the scope of unforeseen errors (necessary for anticipation).

Risk averse strategy.

But without errors, there can be no new learning.

The other approach, compliant with the resilience strategy is "*Trial and error*". In relation to this approach, the following can be mentioned:

Basic loop: Establish a policy, observe the effects, correct for undesired effects, observe the effects of the correction, correct again….

Prerequisites: possible consequences should be quite modest. This is however difficult to predict.

Emphasis is on discovering dangerous errors and correcting them.
Trial and error leads to increased wealth, increased knowledge and increased coping mechanisms. The source of improvement in safety lies in the opportunity benefits of the discoveries encouraged by trial and error.
Fear of failure inhibits learning. Failures lead to greater safety margins and hence new periods of success.

Risk aversion (anticipation) versus Risk taking(resilience)
Risk aversion seeks to protect each part against failure. Risk aversion generates incrementalism. Small steps, apparently taking small risks. But a lot of small risks add up too. Risk aversion does not consider the lost benefits by not taking larger steps. However if no new risks are assumed, no new benefits can be gained.
Risk aversion has infiltrated in the whole area of public life. Mostly government policies are risk averse.
Both risk taking and risk aversion are potentially dangerous.

Stability versus flexibility
Stable systems are less flexible. Standing still, you are less capable of dealing with an unexpected push. While moving, it is more easy to react to unexpected pushes.

Prevention versus recovery
Cure may well be better than prevention if the former is feasible and the latter is not, or if cure increases flexibility in dealing with future dangers. Prevention may induce rigidity.

Safety measures
Introducing safety measures can increase and decrease safety. There is a bias to believe safety measures enhance safety. But no safety measure comes without a price. A few safety devices tend to increase safety, but multiplying them decreases safety, the safety devises themselves become causes of new failures. On the other hand, acts that do not intentionally consider safety, may sometimes actually increase it.
Redundancy works, as long as the failure of any single part is independent of the failure of its backup up, because it divides risks.
However, the relationship between safety and safety devices might not be linear. Defensive strategies that only limit damage are not sufficient to achieve health and safety.
Safety precautions may lower small risks while increasing more major risks
The most seductive form of playing it safe is prudential conservatism: why be half safe? When in doubt, add margins of safety. This can lead to less safety, by misdirecting public concern and scarce agency resources.

Opportunity benefits
Opportunity benefits are those opportunities to reduce existing harms that society forgoes when it decides to delay or deny the introduction of a new substance or technology. Net benefit is the difference between the dangers reduced and the dangers created.
Opportunity risks are the dangers coming with the opportunities.

Anticipatory strategies will focus on the (sometimes small, or only for a small group (micro)) risks instead of the opportunities. When "playing safe", avoiding risks, possible opportunities are not taken. Regulators who ignore opportunity benefits, deny responsible use of such products by people in need. To ignore opportunity benefits, is to raise risk. Accepting risks may increase safety, because of the opportunities they come with.
In public opinion man creates new dangers, more than nature does. But looking at net safety, man is bringing a lot of opportunity benefits, which nature does not bring.

Parts (anticipation) versus whole(resilience)
There is a tendency to prove safety of the system by proving the parts are safe. This leads to specification of the parts instead of the system. General policies leave a wide area of discretion, and allows for variation and slow evolution of regulatory strategies.

Competition
Countries lacking a strong economy and a well-developed infrastructure suffer far more from natural disasters because they have fewer ways of protecting their population. Slow economic growth reduces the rate of new trials, thus reducing possible increase in safety.
Market competition increases sharing of new technologies, and efficient use of resources. Thereby it fosters resilience.
The more decentralized, dispersed, variegated and competitive markets become, the more likely it is that there ill be more different kinds of search, and therefore, more safety, especially against the unforeseen.

About coupling
Given tight coupling and positive feedback between system elements, the larger the number of elements, the more unstable the system will become. Tight coupling makes it important for actions to be based on correct information. Overlap (redundancy) is essential in order to permit adaptability.

Four trends have produces disincentives for risk reduction, causing anticipation to replace resilience:
strict liability standards
restrictive regulations (out of fear from regulators to be responsible for accidents)
changes in tort law (damage = negligence)
movement towards strict liability kept new products off the market

Some definitions
<u>Certaint</u>y: the ability to predict accurately the consequences of actions
<u>Uncertainty</u>: knowing the kind or class of events but not the probability.
It appears that predicting the effects and probabilities can be quite difficult.
Unexpected risks can surprise in both qualitative and quantitative way.
<u>Error of commission</u> (type I): falsely raising alarm, when no hazard exists
<u>Error of omission</u> (type II): falsely ignoring a hazard, that is real.

Possible questions / aspects for investigation	Six categories of errors are defined, that might directly be applicable to accident investigation: Ignorance of opportunity benefits Ignorance of the safety risk associated with a proposed remedy Ignorance of large existing benefits while concentrating on small existing risks Ignorance of effects of economic cost of safety Ignorance of trade off between errors of commission (type I) and errors of omission (type II) Ignorance of displacement of risk onto other people as a consequence of reducing risks for some All these errors result of one dimensional focus.
Science	
Background	Political science
Proof	Examples given of strategy of human body (mainly resilience), effects and possibility of anticipation (tort law, unpredictable accidents), one-dimensional view on risk of current (1988) society)
Domain(s)	
Google search	No results on specific domains, other than nuclear (because of the Three Mile Island example)
Weaknesses	Does not propose how to change current society of hazard averseness, does not take into account psychology (studies on innate to be negative effect averse especially when active handling is involved)
Main References	Wildavsky, A., Se*arching for Safety* (1988)

Appendix X Method: Accimap

Name	Accimap
Author(s)	Jens Rasmussen, Inge Svedung
Year	1997
M/T	Method
Aim	Proactive risk management in a dynamic society by understanding the mechanisms of major accidents in the present dynamic and technological society.
Keywords	Dynamic society with multiple actors (horizontal & vertical), integrated and coupled systems Adaptive, closed loop feedback control strategy Operation within design envelope: set goal, monitor performance, visible boundaries of safe operation, counteract pressures on decisionmakers Decision making and necessary information flow
Description	
Context	We are living in a dynamic environment: hazard sources, their control requirements, and sources of disturbances change frequently. Recent major industrial accidents, however, have not been caused by stochastic coincidence of exotic error types or by mechanisms outside the range of the designed defenses. Most major accidents, including Chernobyl, Bhopal, Zeebrugge, Scandinavian Star, etc., have been caused by organisations operating their systems outside the design envelope under severe pressure toward cost-effectiveness.
Risk management	The pace of change in technology is much faster than the pace of change in management structures and of safety legislation and regulation. The dynamics of change and the interaction between the different levels of society become omportant considerations for development of effective risk management strategies. Risk management must be apply an adaptive, closed loop feedback control strategy, based on a measurement or observation of the level of safety actually present and an explicitly formulated target safety level. Closed-loop feedback control is needed when the system to be controlled is subject to unpredictable disturbances.
Challenges	A key problem is the information flow among the decision-makers at all levels of society: (how) are objectives, values, and operational targets communicated? (how) are the boundaries of safe operation identified and communicated? (how) is operation monitored through routine operational reports and reports from incidents and accidents? What do guidelines look like when an improved, consistent “safety control” must be established from a proactive control point of view?
Accident investigation	Accident investigation is a way to retrieve information on the system, in order to proactively manage risk. Phases are:

	Identify the potential accident pattern (use of Cause Consequent Diagram) Identify the relevant actors (use of Actormap) Identify the context for the relevant actors: Information flow (use of infoflowmap) Conflicts (use of map of conflicts) Identify the events / decisions / influence of relevant actors in the accident pattern (use of Accimap) Generalize the findings by plotting results of multiple accidents (use of generic Accimap)
Specific features	Accident investigation is just part of the proactive risk management method. Distinguishes: Government policy & budgeting Regulatory bodies & associations Local area government / company management Technical & operational management Physical processes & actor activities Equipment & surroundings Cause Consequense Diagram Actormap Accimap Generic Accimap Infoflow maps Besides, Rasmussen distinguishes between the pre critical event and the post critical events (separate maps, separate investigation). Rasmussen states that, just as the process leading to the critical event, also the process starting form the critical event should be more closed loop feedback control. Emergency services should move away from pre-planned command and control management towards a focus on continuity, coordination and cooperation. This since emergency response is changing to a more dynamic organisation as well.
Additional background information	The usual approach to modelling social-technical systems is by decomposition into elements that are modelled separately. A study of decision-making cannot be separated from a simultaneous study of the social context and value system in which it takes place and the dynamic work process it is intended to control. Academic research on proactive risk management should change from multi-disciplinary to a cross-disciplinary approach. Closed-loop feedback control: Metaphor of active target seeking missiles: specify target, reach goal while adjusting to movements of the target. Essentials: capability to manage missile, information on target and safe borders. For decision-makers: must know the goal/target, must know the current performance, must be able to change and must know the safe borders.

Organisations differ in type, for instance:
Military model (communication of orders)
Bureaucratic model (communication of procedures)
Adaptive model (communication of objectives)

Loosely coupled systems may have less redundancy than tightly coupled systems.

Rasmussen distinguishes between skill-, rule- & knowledge based behaviour and introduces cognitive aspects of competence and meta-cognitive aspects of competence. Cognitive aspects are more related to the technical task and content, in isolated form. Meta-cognitive aspects are those related to the complete set of activities, the context and the interests of different actors.

In complex dynamic environments it is difficult to establish procedures for every possible condition. For emergency, high risk and unanticipated situation it is even impossible.

Efforts should not be spent on removal of human error, but on making boundaries visible and irreversible and give decision-makers the opportunity to learn to cope with these boundaries.

Decision making:
Decision-making cannot be studied separate from work context and actor competence.
Experts are deeply emerged in work context and the alternatives for action are intuitively determined by the work context.
Only information necessary to choose among perceived alternatives is consulted.
Managers are running risk, not taking risk, and very likely during non-risk related decisions.

Experts in their normal work situation need only little information to choose among their options for action.
They actively seek the information they need, and they know where to look for it.
Therefore, they don't read messages, they don't think they need.
They don't see messages embedded in text they think they know.
To communicate effectively, you must know the form and content of the operational competence of the actor and not hide important messages in well-known information

Rasmussen also provides ideas on proactive auditing, and a tool for this auditing as well as the accident analysis.

Possible questions for investigation

Objectives & Criteria
- Are objectives formulated by principals in a way such that the interpretation and re-formulation performed by their agents are properly considered?

– Are boundaries of acceptable performance known or can be observed by agents and/or principals?
– Is an auditing function in place that effectively serve to monitor the propagation and interpretation of objectives within the entire socio-technical system?
– How effectively are changes in objectives communicated downward the organisation, and how effectively are changes in local constraints and criteria (e.g., to change of technology) communicated upward the system to be considered for resource management and safety control?

Actual state of affairs

– Do controllers (decision-makers) have information about the actual state of the functions within their control domain and is this information compatible with (comparable to) the objectives as interpreted by the agent?
– Can a discrepancy with respect to objectives or performance criteria be observed?
– Can the margin to the boundaries of acceptable performance be determined or observed?

Capability of decision makers

– Are they capable of control?
– Are they thoroughly familiar with the control requirements of all relevant hazard sources within their work system?
– Do they know the relevant parameters, sensitive to control actions, and the response of the system to various control actions?
– Can they act without undue time delays?

Science	
Background	Psychology
Proof	No proof of reliability and validity (Roelofsma et al, 2007) Three case studies demonstrate - a posteriori - validity of Rasmussen's framework of socio technical system, (Qureshi, 2007, 2008)
Domain(s)	Mainly transport
Google search	"Accimap AND Rasmussen": 75 hits Multiple countries, for example: Australia, Canada, France, Germany, Italy, Netherlands, Norway, United Kingdom. Mostly governmental organisations (methods of inspectorates, safety boards)& universities (scientific papers) No private companies
Weaknesses	Apparent hierarchical structure appears not suitable/applicable to dynamic society. Diagrams are difficult to read, especially when becoming complex with decision makers horizontally ánd vertically No checks for completeness of decision makers

No structure for identifying forces on decision makers and the landscape
No framework for generalization from one to many accidents
Based on experience in transport, mainly shipping
Added value for accident investigation of dynamic system and improvement of safety still to be determined

Main References

Rasmussen, J. *Risk management in a dynamic society: A modelling problem.* Safety Science, 27(2/3), 183-213 (1997)

Rasmussen, J. & Svedung, I., *Proactive Risk Management in a Dynamic Society* (2000)

Svedung, I. & Rasmussen, J., *Graphical representation of accident scenario's: mapping system structure and the causation of accidents*. In: Safety Science, 40, 397-417 (2002)

Supporting graphs

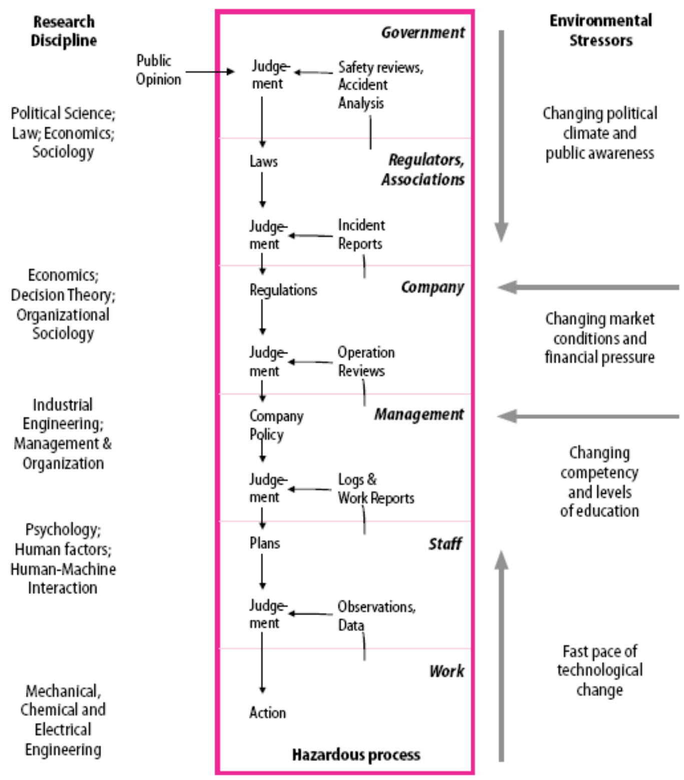


Figure 39 Actormap 1: Many nested levels of decision-making are involved in risk management and regulatory rule making to control hazardous processes

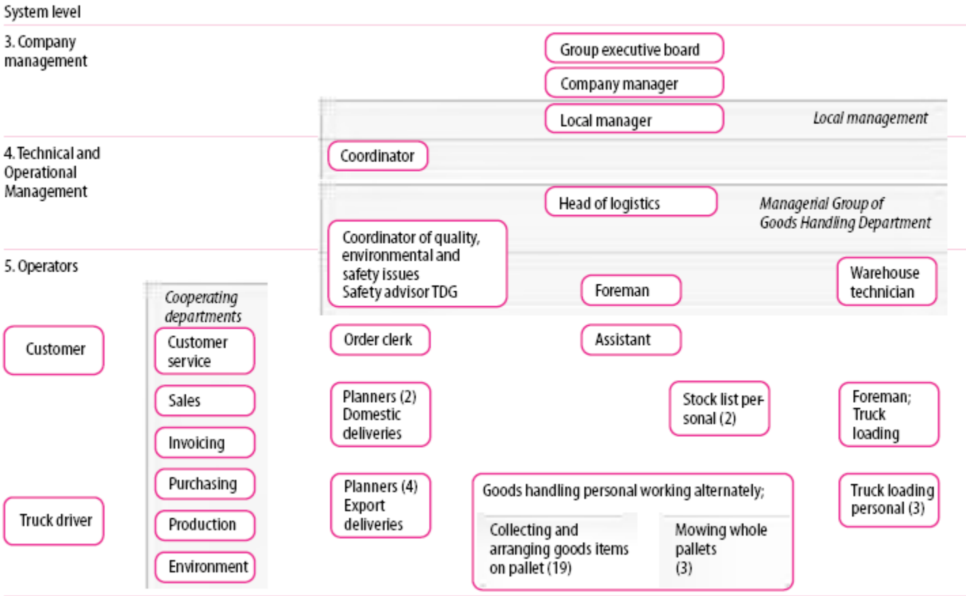


Figure 40 Actormap 2

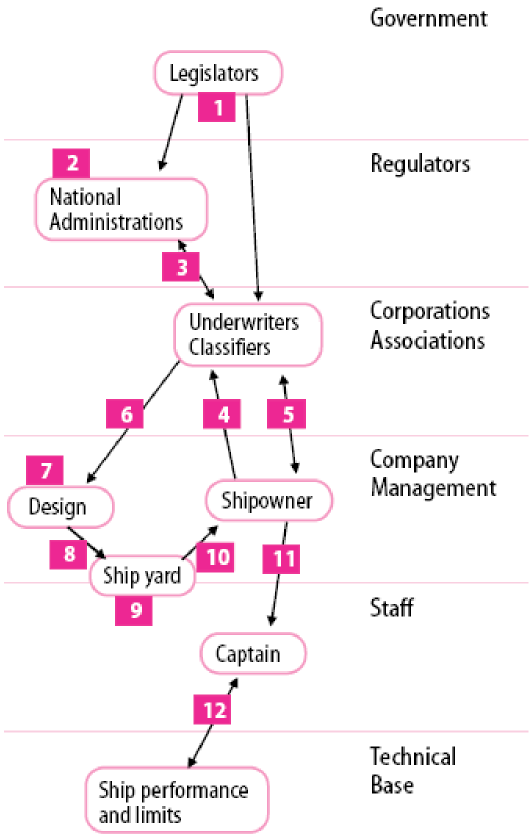


Figure 41 Conflictmap

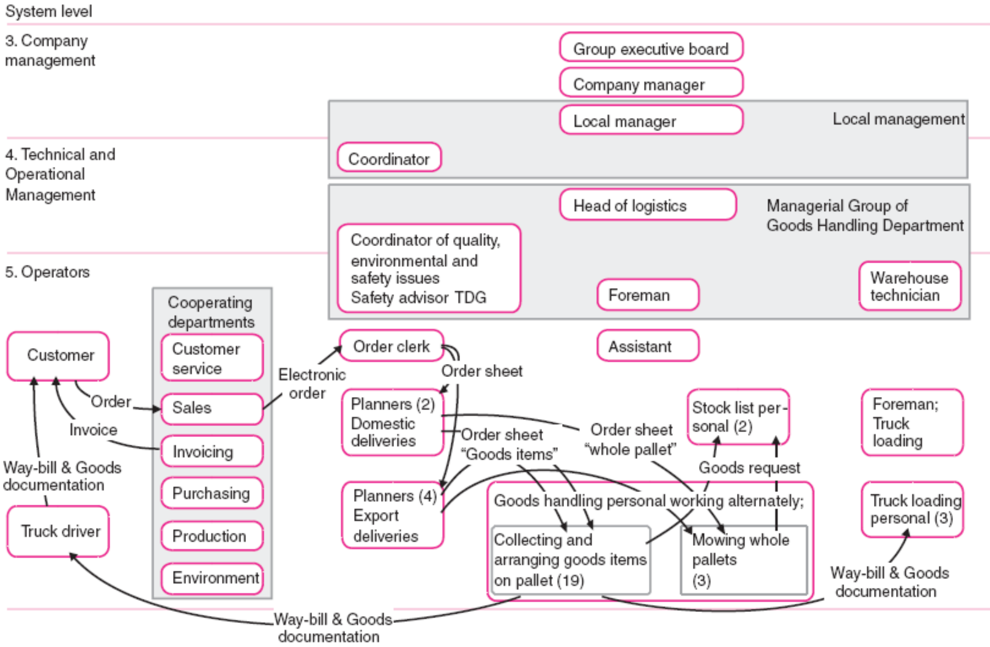
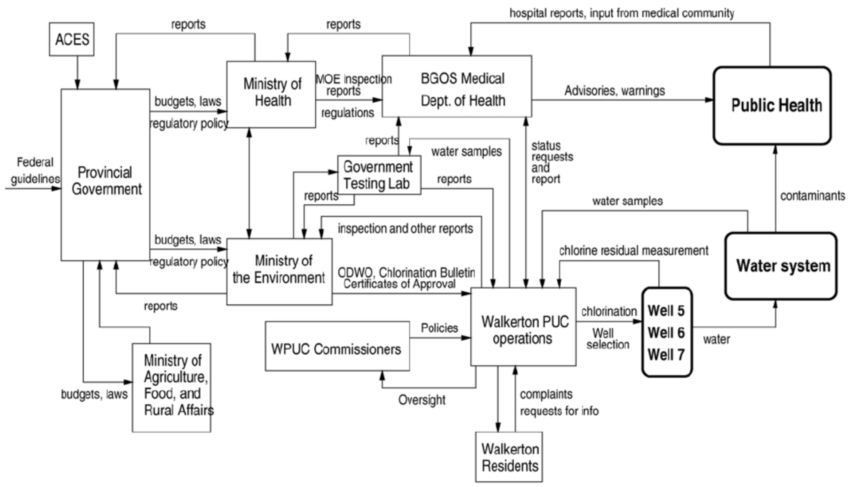


Figure 42 Infoflow map

Appendix XI Method: STAMP

Name	STAMP
Author(s)	Nancy Leveson
Year	2003
M/T	Method
Aim	Describing the accident process, defining questions to ask during investigations.
Keywords	Resilience Constrains Controls Processes (actual state versus original state)
Description	
Context	Accidents arise from interactions among system components, and usually not from single causal variables or factors.
Risk management	Accidents result from inadequate control or enforcement of safety related constraints on the development, design and operation of the system.
Challenges	
Accident investigation	A STAMP analysis can be divided in two stages: Identify constraints en controls: system hazards and system safety constraints control structure in place (as designed, see Figure 43; and actual state, see Figure 22 in Appendix XI) Classification and Analysis of Flawed Control, consisting of Classification of causal factors: inadequate constraints inadequate execution of constraints inadequate or missing feedback Reasons for flawed control and dysfunctional interactions
Additional background information	Between the hierarchical levels, of each control structure, effective communication channels are needed. A downward reference channel, providing information necessary to impose constraints, and a measuring level to provide feedback about how effectively the constraints were enforced. Leveson also emphasises the dynamic complexity of systems. Constraints and controls degrade over time, and one should considers reasons for the (directions) of change. In complex systems, two main forces on directions can be discriminated: positive (reinforcing) and negative (balancing). These directions can be reinforced or balanced directions by endogenous and exogenous influences (read: actors). When safety controls are degrading, balancing forces should overcome the negative influence. Accidents in complex systems frequently involve a migration of the system toward a state where a small deviation can lead to catastrophe. Degradation of safey margins occurs over time, without a specific decision.

Possible questions for investigation	What are the identified system hazards and system safety constraints What was the control structure designed originally What was the control structure as in place What were the – inadequate constraints – inadequate execution of constraints – inadequate or missing feedback – Reasons for flawed control and dysfunctional interactions
Main References	Leveson, N. Daouk, M, Dulac, N. Marais, K. Applying STAMP in Accident Analysis (2003).
Supporting graphs	



Safety Requirements and Constraints :

Federal Government
- Establish a nationwide public health system and ensure it is operating effectively.

Provincial Government
- Establish regulatory bodies and codes of responsibilities, authority, and accountability
- Provide adequate resources to regulatory bodies to carry out their responsibilities.
- Provide oversight and feedback loops to ensure that provincial regulatory bodies are doing their job adequately.
- Ensure adequate risk assessment is conducted and effective risk management plans are in place.

Ministry of the Environment
- Ensure that those in charge of water supplies are competent to carry out their responsibilities.
- Perform inspections and surveillance. Enforce compliance if problems found.
- Perform hazard analyses to identify vulnerabilities and monitor them.
- Perform continual risk evaluation for existing facilities and establish new controls if necessary.
- Establish criteria for determining whether a well is at risk.
- Establish feedback channels for adverse test results. Provide multiple paths.
- Enforce legislation, regulations and policies applying to construction and operation of municipal water systems.
- Establish certification and training requirements for water system operators.

ACES
- Provide stakeholder and public review and input on ministry standards

Ministry of Health
- Ensure adequate procedures exist for notification and risk abatement if water quality is compromised.

Government Water Testing Labs
- Provide timely reports on testing results to MOE, PUC, and and Medical Dept. of Health

WPUC Commissioners
- Oversee operations to ensure water quality is not compromised.

WPUC Operations Management
- Monitor operations to ensure that sample taking and reporting is accurate and adequate chlorination is being performed.

WPUC Operations
- Measure chlorine residuals.
- Apply adequate doses of cholorine to kill bacteria.

BGOS Medical Department of Health
- Provide oversight of drinking water quality.
- Follow up on adverse drinking water quality reports.
- Issue boil water advisories when necessary.

Figure 43 Example of a control structure

1. Inadequate Enforcement of Constraints (Control Actions)

- 1.1 Unidentified hazards
- 1.2 Inappropriate, ineffective, or missing control actions for identified hazards
  - 1.2.1 Design of control algorithm (process) does not enforce constraints
    - Flaw(s) in creation process
    - Process changes without appropriate change in control algorithm (asynchronous evolution)
    - Incorrect modification or adaptation
  - 1.2.2 Process models inconsistent, incomplete, or incorrect (lack of linkup)
    - Flaw(s) in creation process
    - Flaws(s) in updating process (asynchronous evolution)
    - Time lags and measurement inaccuracies not accounted for
  - 1.2.3 Inadequate coordination among controllers and decision makers (boundary and overlap areas)

2. Inadequate Execution of Control Action

- 2.1 Communication flaw
- 2.2 Inadequate actuator operation
- 2.3 Time lag

3. Inadequate or missing feedback

- 3.1 Not provided in system design
- 3.2 Communication flaw
- 3.3 Time lag
- 3.4 Inadequate sensor operation (incorrect or no information provided)

Figure 44 Classification of flaws

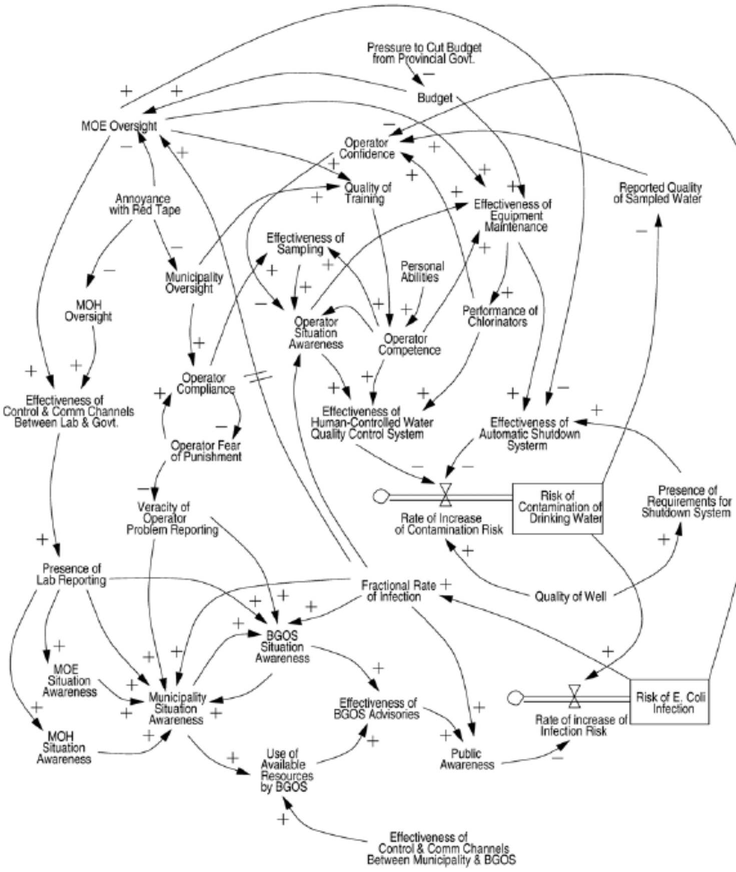


Figure 45 System dynamics model

Appendix XII Method: IPIC RAM

Name	IPIC RAM (as part of Tripod Extended Model)
Author(s)	Jop Groeneweg
Year	2006
M/T	Method
Aim	The main objective for the project was to develop an Extended Tripod Model in order to identify latent failures outside the boundaries of the organisation. The main aim of the IPIC-RAM Model is to generate valid research questions, and to dig 'deeper' into the extra-organisational causes of an accident and effectively identify the factors with a negative impact on the decision-making process in the influencing governmental and non-governmental and situational organisations.
Keywords	Interactions
Accident investigation	A a structured approach facilitating accident investigators to generate questions in a structured and methodological manner.
Additional background information	Failures such as lack of (regular) inspection by authorities, badly managed permit/licence systems, complex or ineffective laws, regulations and standardized procedures, diffusion of responsibility for certain domains, tasks, or objects between different parties, can have a direct and indirect effect on how processes are managed and organized within organisations and can ultimately lead to accidents and incidents in organisations. Governmental and non-governmental organisations which are responsible for (inter)national policy making must therefore carefully investigate the quality and monitor the effectiveness of their (inter)national policies and (inter)national standards and regulati-ons: policy, standards and regulations must be ade-quate guidelines representing the current scientific knowledge and best practice. Often, causes of accidents can be traced back to influencing organisations which are not necessarily involved in the accident itself. Influencing organisations are governmental and non-governmental organisations such as governmental institutes and trade/industry associations. These organisations usually interact with situational or-ganisations through laws and regulations, standard-ized procedures, policies and other processes and regulations and are therefore passively or indirectly involved in the occurrence of an accident, through their influence on organisation and management of business processes. They influence the management of business processes: how processes are managed and organised within the organisation. The new Tripod Extended model should incorporate a framework in which the complete system of organisations (situational as well as influencing organisations) involved in the accident can be identified in order to 'scan' these organisations effectively for possible factors which

may have contributed to the accident. Furthermore, the model does not only need to identify and describe certain failures, but al-so explain why certain latent failures in the organization exist: the fallible decision-making process which causes latent failures in the organisation (Reason, 1997).

The Tripod Extended model includes latent failures of higher level organisations. The changes com-pared to the original Tripod Beta model include:

- The latent failures of influencing organisations can be linked to a latent failure in the situational organisation, but can also be directly linked to a precondition in the situational organisation.
- The latent failure of influencing organisation can in itself also be caused by other latent failures of other higher level organisations.
- Organisational latent failures and failures in influencing organisations can be caused by or lead to more than one other latent failure. For example, one failure in an influencing organisation can cause more than one latent failure in the situational organisation and multiple failures in the organization can cause one single latent failure in an influencing organisation.
- The kind of latent failure in an influencing organization is not necessarily the same as the type of latent failure to which the latent failure is linked in the situational organisation.

Possible questions for investigation

I Inform in

Is the organisation aware of (known with) the failure(s) in the organisation?

P Process

Has the organisation processed the information and undertaken action, (e.g. development of standardized procedures, audit tools, guidelines, laws and regulations) to prevent it?

I Inform out

Has the organisation informed relevant departments and organisations about these actions?

C Comply

Has the organisation assured that relevant departments and organisations complied with these actions, for example by means of inspection, meetings, reward systems?

R Responsibility

Is the organisation formally responsible to

- be aware of certain failures, omissions, etc
- develop procedures, standards, etc
- inform organisations about actions (procedures, standards, etc)
- make sure organisations comply with developed rules, regulations etc?

Did the (f)actual responsibilities differ from the formal responsibilities?

A Authority

Did the organisation have the authority which was needed to be able to

- be aware of certain failures, omissions, etc
- develop procedures, standards, etc
- inform organisations about actions (procedures, standards, etc)
- make sure organisations comply with developed rules, regulations etc?

M Means

Did the organisation have the essential means to

- be aware of certain failures, omissions, etc
- develop procedures, standards, etc
- inform organisations about actions (procedures, standards, etc)
- make sure organisations comply with developed rules, regulations etc?

Means: organisation, communication structure, people, time, money, technical equipment, knowledge etc

Science

Proof

Preliminary results showed that expanding the scope of the investigation in a structured manner, about 40% more relevant factors could be identified. Implications of these findings are discussed.

Weaknesses

The Tripod Extended model does not take into account the organisations' power to compensate for structural weaknesses.
The Model focuses on the elimination of errors instead of incorporating an organisations resilience which compensates for structural weaknesses or latent failures

Main References

Groeneweg, J., Van Schaardenburgh-Verhoeve, K. N .R., Corver, S., Lancioni, G. E. & Knudsen, T. (2007) *Accident investigation beyond the boundaries of organisational control*. In: Aven T. and Vinnem J.E. (eds). Risk, Reliability and Societal Safety. Proceedings of the ESREL 2007 Conference, June 25 - 27 2007, Stavanger, 2007,Taylor and Francis, 929 – 936.

Groeneweg, J. Verhoeve, K.N.R. & Corver, S. (2006) *A model-based approach to facilitate the identification of (non-) governmental factors in accidents* . Leiden University: Report prepared for the Dutch Safety Board.

Groeneweg, J. Verhoeve, K.N.R. & Corver, S. (2006). *Tripod outside the organisation*. Leiden University: Report prepared for the Dutch Safety Board.

Supporting graphs

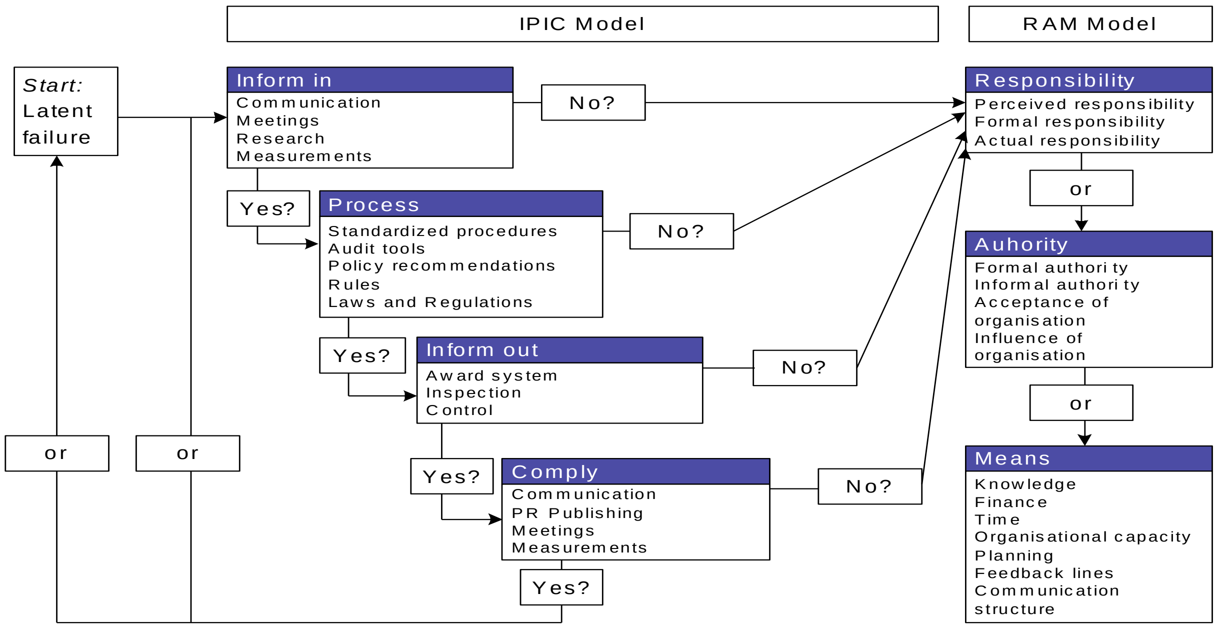


Figure 46 IPIC RAM cascade model

Appendix XIII Method: Backward & Forward mapping

Name	Backward & Forward mapping
Author(s)	Hans de Bruijn
Year	2007
M/T	approach
Possible questions for investigation	– Has both backward- and forward reasoning been applied? – Has the context in which errors took place been investigated? – Has both negative as positive consequences been investigated?

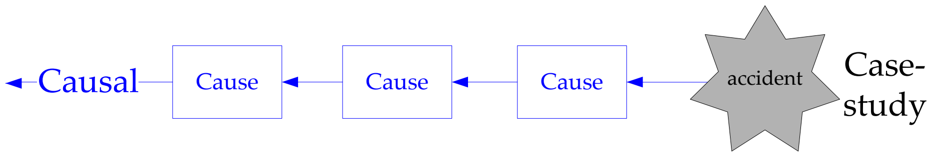


Figure 47 Accident as starting point: Case Study; linear from cause to cause: Causal reasoning, Backward mapping

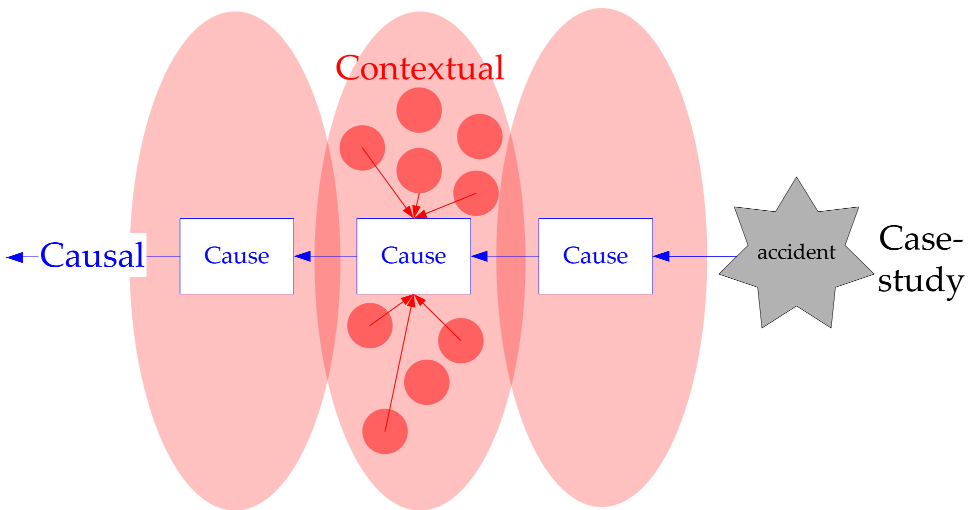


Figure 48 For each cause: identify context in which it occurred: contextual reasoning

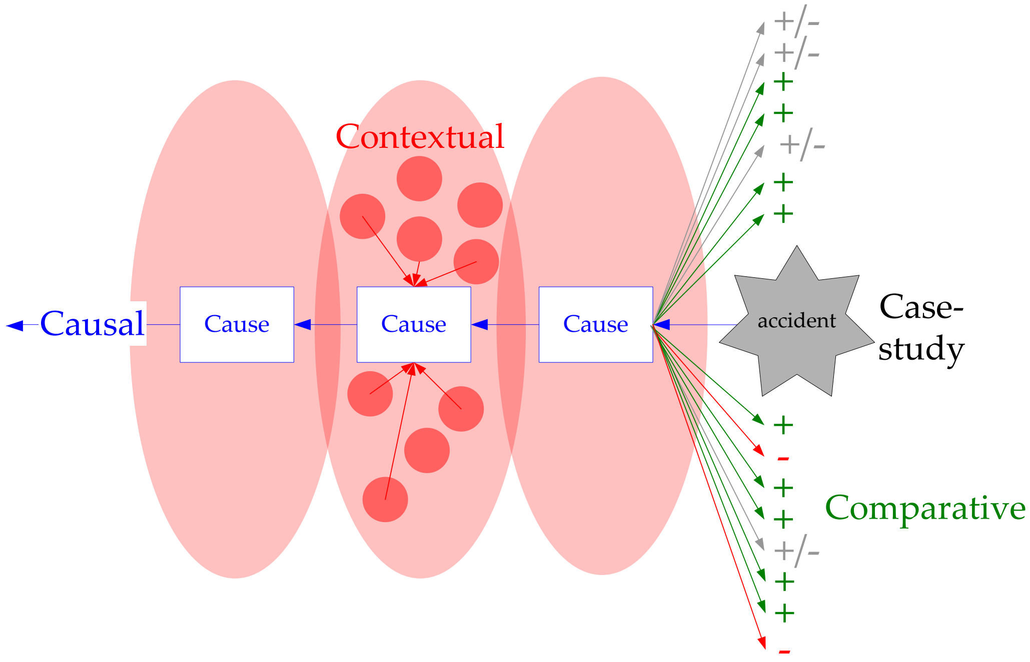


Figure 49 For each cause: identify other consequences: comparative reasoning, Forward Mapping