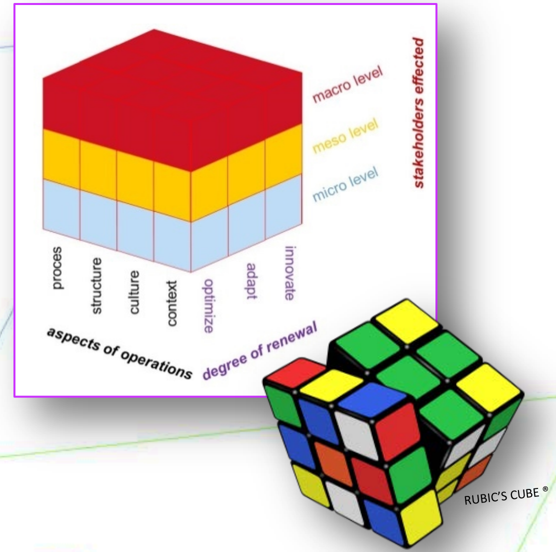
Case study analysis on dynamic learning from accidents

The ESReDA Cube, a method and metaphor for exploring a learning space for safety



ESReDA
European Safety, Reliability & Data Association

Case study analysis on dynamic learning from accidents,

The ESReDA Cube, a method and metaphor for exploring a learning space for safety

ESReDA Project Group Dynamic Learning as the Follow-up from Accident Investigations

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1 Summary

This publication, **Case study analysis on dynamic learning from accidents,** The ESReDA Cube, a method and metaphor for exploring a learning space for safety, aims to:

Report on 5 cases analysed on dynamic learning from accidents and gives an overview of cases of accidents in the context of high risk organizations with an eye on identifying learning barriers and opportunities.
Give an overview of how the ESReDA Cube, resulting from the analysis, may be utilized to identify possibilities to learn from accidents and assist in considering possible recommendations and changes needed to prevent future accidents.

The cases have been selected by the members of the ESReDA Project Group Dynamic Learning as the Follow-up from Accident Investigations (PG DLAI), based on their own expertise and preferences and in such a manner that they have become comparable across domains and sectors.

The aim is to analyse what and how lessons are learned and what barriers to learning can be identified. This will be done by analysing a diversity of accidents and accident reports. Case studies were chosen from several domains such as industry, aviation and rail transport. The case study analysis applies a line of inductive reasoning: starting from single event descriptions the study reveals commonalities and similarities on a generic level on how to learn from events. The common rationale in this inductive reasoning is in the use of the investigation process that is applied during an investigation, distinguishing the fact-finding/data collection phase, the analytic phase and the lessons learned/recommendation phase.

The approach as presented in this ESReDA document made it necessary to introduce two new notions in learning from accidents in order to make sustainable changes:

- A distinction is made between the event and the system in which the event occurs. To prevent a similar accident in the future it remains crucial to reduce the consequences and to make the activity acceptable safe. Such interventions aim at improving the safety performance of a system. In addition, the socio-economical context, operating conditions and environment in which the accident occurs also may contain potential for changing the properties of the system. The distinction is similar to the medical concept of curing the symptom or the syndrome. Both are valid but have different intervention strategies and require different learning mechanisms.
- The scope and nature of learning distinguishes three levels of change:
  - Optimizing existing processes and procedures consumes relative little time and resources and focuses on the operator level in standing organisations.
  - Adaptation requires more time and resources in changing system properties, operating conditions and requires consensus on feasibility and acceptability of the solutions that are recommended.
  - Finally, innovation may take a long time, requires intervention in the design phase and focuses on technological and organizational innovations or institutional changes in systems configuration and architecture. Support by R&D resources become inevitable.

The ESReDA approach is based on four principles:

1. Case based: learning from reality, disclosing dynamics and interrelations in a specific context;
2. Evidence based: providing proof of the actual and safety critical behaviour;
3. Knowledge based: generating knowledge to provide transparency, oversight and understanding;

4. Design based intervention: changing performance, properties and principles requires applying engineering design notions in adapting artefacts, processes, procedures and organisations.

Three main themes will be discussed:

1. Origin of the accident and the accidental event as such;
2. An analysis of lessons learned in a systemic context;
3. Conclusions and comments by the ESReDA Project Group members on how information on learning can be derived.

The case studies are based on accident investigation information readily available to the members of the ESReDA Project Group. The case studies (analyses) give an overview of relevant findings but do not have the intention to be complete. The case study analysis is case based and evidence based, relying on the information that has been available. Usually the primary sources have been official accident investigation reports and other public sources.

The concept of dynamic learning from accidents is derived from insights and notions in scientific literature, accident modelling and learning theories. This framework for learning from accidents has a focus on the collection and interpretation of facts and findings in order to allocate the information to its role in the system in which the event occurred. To understand WHY the event occurred is a different question. Answering such questions should be dealt with by applying specific methods, models and scientific theories that can establish causal relations and dynamic interrelations between components and decision points, such as FRAM, cognitive decision making models or physical simulation and computational modelling. Providing guidelines for such scientific proof is beyond the scope of this document.

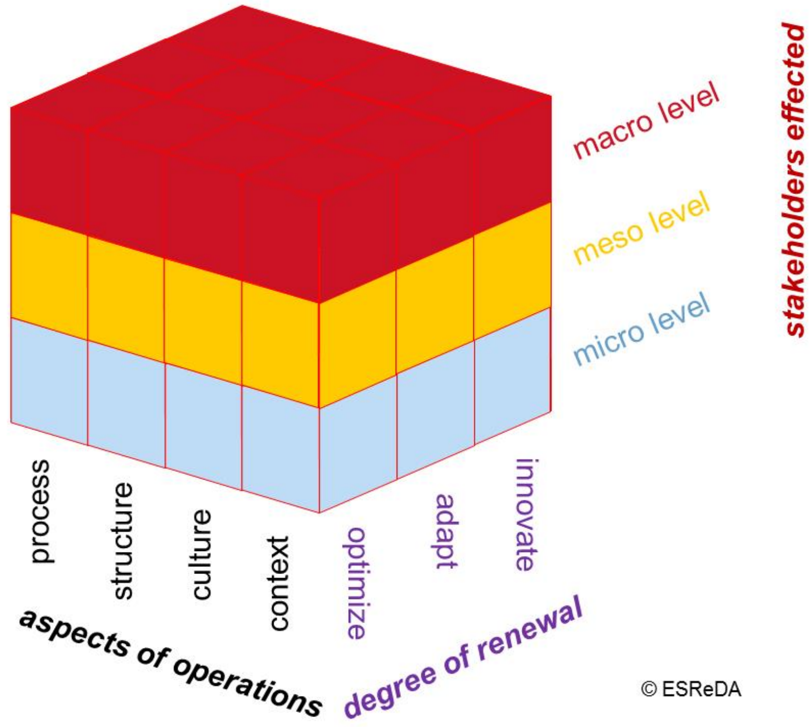
To form a structure for the analysis a three dimensional analysis grid was developed:

D1. **Aspects of operations**: the organizational context where the accident took place;

D2. **Depth of learning:** the kind of changes being implied in the recommendations given or (in theory) being considerable at the stage of drafting recommendations during and after investigation of events;

D3. **Stakeholders effected**: the societal level at which the recommended change (learning) by investigators should be projected (where are the root causes to be found) and be managed (when recommendation are accepted).

These dimensions can be combined in a three dimensional solution space, the ESReDA Cube, see next figure.



The examples of case study analysis which are presented in this document may also be used as examples in the framework for training which is also a result of the work of this ESReDA Project Group Dynamic Learning from Accident Investigation.

By applying the analysis grid, the case studies revealed not only a way of analysing the diversity and completeness of recommendations of accident investigation but also of the design of a program or set of accident investigations aimed at specific dimensions identified. This has become the ESReDA Cube © as a representation of those dimensions in a solution or learning space. This model allows researchers or investigators to get an overview of possible solutions in terms on what may be learned, who may have learned and what renewal is aimed at. It can be applied to ex ante and ex post accident investigation project evaluations, e.g.:

1. When scoping and defining an investigation project, e.g. what is project ambition, what actors/stakeholders and system levels to take into account, what learning/change is aimed at;
2. When evaluating possible preventive solutions when designing recommendations, e.g. are they complete and diverse enough to implement necessary technological progress;
3. When keeping track what solutions have been implemented (when and by whom) or
4. When identifying the learning barriers that bring the change wanted and assumed improvement to a standstill; or even when and where unlearning has taken place already, e.g. implemented measures are withdrawn or deteriorated.

2 Table of content

3 Introduction

3.1 Project Group Dynamic Learning as the Follow-up from Accident Investigations

The ESReDA Project Group Dynamic Learning as the Follow-up from Accident Investigations (PG DLAI) stands in a tradition of consecutive projects exploring several aspects of accident investigation and of a series of seminars transferring knowledge and opening new perspectives of domains to be explored and studied.

The main objective of the Project Group has been to work out recommendations on how to capture, document, disseminate and implement insights, recommendations and experiences obtained in investigations of high-risk events (accident and near-misses, and safety as well as security) to relevant stakeholders via:

1. Proposing adaptation of investigation methods to specific features of each sector and aimed at facilitating more impact;
2. Identifying barriers within companies, public authorities and other involved stakeholders that may hamper implementation of recommended preventive measures;
3. Providing methods for dynamic learning from accidents;
4. Highlighting good practices on how to develop recommendations from Accident Investigation findings and understanding relevant preconditions for future learning (resilience, learning culture);
5. Giving advices and suggestions regarding Operational Feedback Systems for relevant decision makers.

The latest 45th ESReDA seminar (2013) at EDP in Porto (Portugal) on "Dynamic Learning from incidents and accidents, Bridging the gap between safety recommendations and learning" provided the Project Group with valuable feedback on their work on dynamic learning. This seminar built on the 24th ESReDA Seminar (2003) held at the JRC-Institute for Energy in Petten (the Netherlands); on 'Safety investigation of accidents'; the 33rd ESReDA Seminar (2007) on 'Future challenges of accident investigations' at the JRC-Institute for the Protection and Security of the Citizen in Ispra (Italy); and on the 36th ESReDA seminar (2009) on 'Lessons learned from Accident Investigations' at EDP in Coimbra (Portugal).

The ESReDA project group DLFAI produced 5 deliverables published in 2015 on www.esreda.org:

- *"Case study on dynamic learning from accidents"* ESReDA report,
- *"Barriers to learning from incidents and accidents"* ESReDA report,
- this ESReDA report *"Guidelines for preparing a training toolkit on event investigation and dynamic learning",*
- an ESReDA website webpage *"Guidance for learning"*, and
- an essay by Professor Stoop *"Challenges to the investigation of occurrences. Concepts and confusion, metaphors, models and methods"*.

It has prepared in former projects three deliverables which have been printed and published by ESReDA:

1. Accident Investigation Practices - Results from a European Study (2003 - report);
2. Shaping Public Safety Investigations of Accidents in Europe (2005 - ESReDA Safety series);
3. Guidelines for safety investigation of accidents (2008) available for free download on the ESReDA website.

Members of the Project Group are:

- Mr. Nicolas Dechy, Engineer In Organisational And Human Factors IRSN, France
- Mr. Yves Dien, Expert Researcher, Electricité De France, EDF R&D, France
- Mrs. Linda Drupsteen, Researcher , TNO Urban Environment and Safety, The Netherlands
- Mr. António Felício, Engineer In Generation Management (retired) EDP, Portugal

- Mr. Carlos Cunha, Engineer in Optimization and Flexibility (Power Generation) EDP, Portugal
- Mr. Sverre Røed-Larsen, Project Manager, SRL HSE Consulting, Norway
- Mr. Eric Marsden, Department Recherche, Foncsi, France
- Mrs. Tuuli Tulonen, Senior Researcher, Tukes, FINLAND
- Mr. John Stoop, Managing Director Kindunos Safety Consultancy Ltd, The Netherlands
- Mr. Miodrag Stručić, European Commission, Joint Research Centre, Institute For Energy And Transport The Netherlands
- Mrs. Ana Lisa Vetere Arellano, Scientific Officer, European Commission, Joint Research Centre, Institute For The Protection And Security Of The Citizen Security Technology Assessment Unit, Italy
- Mr. Johan K. J. van der Vorm, Editor of this ESReDA-publication and Senior Technical Consultant, TNO Urban Environment and Safety, The Netherlands.
- Mr. Ludwig Benner as corresponding and Honorary Member of the ESReDA Project Group

Contact:

- Tuuli Tulonen (Tukes), Chairman PG DLAI
- Johan van der Vorm (TNO), Editor of this ESReDA-publication.

ESReDA, The European Safety, Reliability and Data Association, is a non profit European association that provides a forum for the exchange of information, data and current research in Safety and Reliability. The safety and reliability of processes and products are topics which are the focus of increasing European wide interest. Safety and reliability engineering is viewed as being an important component in the design of a system. However the discipline and its tools and methods are still evolving and expertise and knowledge are dispersed throughout Europe. There is a need to pool the resources and knowledge within Europe and ESReDA provides the means to achieve this.

Contact:

- ESReDA General Secretary, Mohammad Raza, ALSTOM Power,
  7, Brown Boveri Strasse, 5401, Baden, Switzerland
  Phone: +41562059743
  Mobile: +41795925653
- http://www.esreda.org/

3.2 Working method

The analyses of cases was one objective of the Project Group, with the aim to analyse interesting cases which were publicly available or could be presented from participating companies. The analysis concentrates on the identification of learning, potential learning, and potential barriers to dynamic learning.

During the project the task group has analysed five case studies over three technical domains:

- Industry (2)
- Railroad (1)
- Aviation (2)

The cases were set up in a structured format and the overall structure of the template was as follows.

First, the case was described by:

1. Description of the event (sequence and system involved);
2. Type of event;
3. Magnitude of damage to system involved;
4. Investigations known.

Second, the analyses themselves were done within a three-dimensional space:

1. Aspects of operations
2. Stakeholders
3. Depth of learning.

In practice, all the above dimensions were analysed against each other. This method of analysis is presented more descriptively by the ESReDA Cube © which was developed during this project and which is described in more detail in this document.

Each case study was completed with conclusions and observations made by the Project group.

3.3 ESReDA Cube ©

During the development of the framework for the case studies it was concluded that the three dimensions for a learning space and its aspects could be presented in a cube metaphor. The cube was baptised the **ESReDA Cube** © by the Project Group DLAI (Figure 13).

Working with the cube during the case studies it appeared to be possible to use it in several ways. It functions not only in ex post but also ex ante analysis in several phases of the learning process starting with the definition of the investigation targets and methods.

1. **Analysing the aftermath of accident investigation and related research**
   By plotting the solutions retrospectively, the envisaged learning solutions, recommendations, practice resulting from the accident in the findings and documents concerning an accident every solution can be attributed to certain cell of the cube.
2. **Defining and scoping an accident investigation project**
   What should be the scope, the depth of learning sought, stakeholders to effect, impact needed on the aspects of the operation taken into consideration?
3. **Defining and systemising recommendations**
   Who needs to be addressed by the recommendation, e.g. Is it an actor in the company, in the industry and/or in society? Another point of view is the kind of renewal to be considered necessary to prevent comparable accidents. E.g. to prevent a specific root cause, technological or organizational innovation may be necessary and triggered by a recommendation aiming at this impact needed.
   By looking at several points in the cube the diversity and completeness of recommendations necessary for change and learning process can be checked.
4. **Following the implementation of learning solutions**
   By filling the cube with new learning solutions and also deleting solutions an analysis is possible of the sustainability of the solutions being implemented. Unwanted regression to pre accident status of technology and management practices can be systematically highlighted in this way.

3.4 Copyrights

4 Conceptual framework

In order to set up a harmonized way to analyse accident cases the ESReDA Project group needed a framework to encompass learning dynamics and experience from a diversity of cases and domains.

As a working definition we define learning: as proposed by Carroll (1998) and discussed by Drupsteen and Wibeau[i] is: ''Organisational learning takes place through activities performed by individuals, groups, and organisations as they gather and digest information, imagine and plan new actions, and implement change''.

In our analysis we begin exploring the events by decomposing the accident into a series of questions that should provide transparency over the sequence of events. By having a first scan over the case several questions came to our mind:

- What do we know of the accident (event and system aspects involved)?
- What needs to be learned?
- Who should learn?
- How do we need to learn, gain impact by looking at what changes followed after an accident?
- Is soft/organizational "technology" and/or hard technology redesign implemented?
- Knowledge/implementation/learning management developed after the accident?
- What aspects which influence the learning process, need to be considered?
- What learning dynamics can be reconstructed from the evaluation of the aftermath of an accident in terms of who realized follow-up in practice and what resources were available?

Relevant dimensions of studying the learning dynamics which can be thought of are:

- Kind of production or service process that was effected by the accident;
- Surrounding of the organization (indirectly related to the accident e.g. a contracted supplier or a client);
- Actors that have been involved in starting and sustaining learning;
- Aspects and elements of the organization that are (to be) changed;
- System levels involved (organization, industry and society);
- Time line, milestones and speed of adaptation;
- The kind of organizational and technological changes that have been developed and effective.

Given those questions the ESReDA Project Group started to look for a model or framework to start analysis and to cover several domains of activity and of a diverse complexity. Having a focus on impact of learning (change in practice) three dimensions were identified. Those were used as a frame of reference and gradually appeared to be a very usable design or metaphor of a space for learning, the so called solution space, which we later baptized as the ESReDA Cube ©.

4.1 Three dimensions of the ESReDA Cube ©

Learning can be defined as the positive outcome of the negative experience of having an accident. Learning from accidents provides insight into who and which entity was directly or indirectly involved in the occurrence of the accident and also who has/can have influence on the prevention of this or similar future accidents.

During the analysis of the cases the Project Group identified three dimensions that would frame the areas where learning experiences of the accident are to be found, and who should have learned (the solution or learning space):

1. **Aspects of operations**: the organizational context where the accident took place;
2. **Stakeholders effected**: who are the sponsors or owners for implementing recommendations and pushing forward lessons learned (the necessary changes aimed at several societal levels). In other words who needs to manage the necessary changes?;
3. **Depth of learning:** to change potential having the knowledge from the investigating.

These dimensions represent:

D1. Domains of learning "W*hat needs to be learned?*"
The cube is inspired by TNO Safety@Corebusiness[ii] and Kindunos method©[iii], which are taken as a basis. It takes a specific primary process (business, production) as a starting point and puts this primary process in a context. It distinguishes three aspect of developing safety: structure, culture and learning.

D2. Scope of learning: "W*ho should learn?*" and on what system level the learning takes place

D3. Management of change "*How do we need to learn?*" gain impact and what change strategy is needed.

These dimensions are interrelated as continuous processes of development and adaptations of organizations.

The ESReDA Project Group acknowledges that stakeholders may appear as abstract representations of juridical entities, organizations or groups. In practice learning needs people who memorize history and solutions. People are able to create new designs, effective organizations and safe actions. It also needs people who are able to adapt according to new experiences and sense making to the occurrence of the accident.

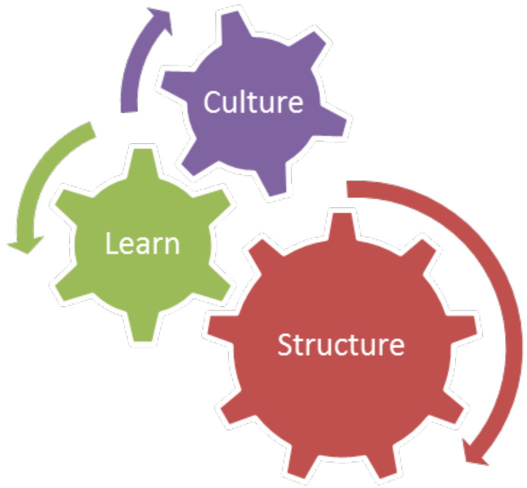


Figure 1: Structure, culture and learning are interrelated dynamics of business operations. (Source: J.K.J. van der Vorm, TNO)

A learning organization facilitates people not only to learn by structuring processes, setting up intelligent repositories, and knowledge management but also education and training systems to convey knowledge and capabilities. The appointment of a learning agent being a structural function in the organization (staff, task group or dedicated safety expert) which helps to drive and monitor a dynamic learning cycle also helps to organize organizational learning.

Processes, culture and learning are assumed to be primarily beneficial to the organizations mission and core business. On the other side these are also facilitating learning as such. They are together engaged in renewal: optimizing, adapting or innovation. Learning is only effective when change has impact and learning results in action if not only learning to learn.

Learning has also external impact and may be hindered by external constraints. Moreover it needs to have external impact in order to create momentum for change. Learning may need facilities to enable to create solutions requiring new technology or management methods. E.g. technical research and development leading to a new design solution as a result from a change process.

4.2 What needs to be learned?

Safety as core business with the company operations in focus is taken as a starting point in the Cube-model. This perspective creates the first dimension of analysis as illustrated in the Figure 2.

Dealing with operations, we will elaborate on the more detailed discrimination of 4 aspects as identified by Stoop (1990) which have to be described during the investigation separately: process, structure, culture and context.

These four aspects are:

Process (what is the work involved: what goes on in the primary processes). Operation is about what activities to deal with. How can the work be done safer and who is involved in organizing and executing these processes.
Structure (what is the business system architecture and functionality). Structure is about (re)design of hardware, technology and (re)design of organization and processes.
Culture (what are the values and norms, behaviour etc.). Culture is about several cultural aspects: organizational culture, learning culture and behavioural change.
Context (what is the direct operations environment). Context is about business/change management organized (learning agent), political, social changes needed, supporting organization (e.g. safety board) and knowledge development needed.

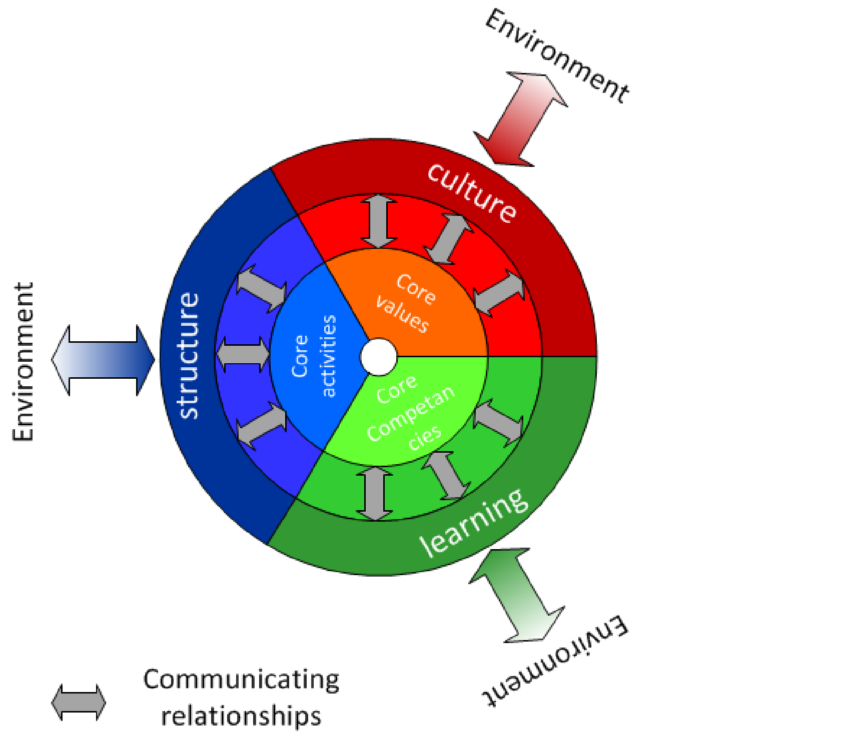


Figure 2: Safety performance is a function of structure, culture and learning capabilities and inseparable from core business and external factors (Source: TNO)

This is the first basic dimension of learning: plan-do-check-act at company level resulting only in optimization of existing practices. Some routine learning examples dealing with optimizing the structure (e.g. safety management system) resulting from this basic approach are given in Figure 3.

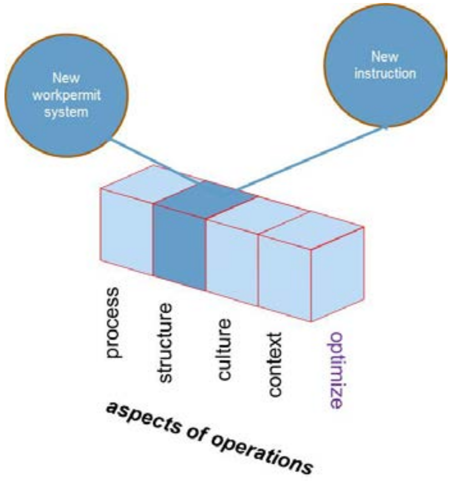


Figure 3: ESReDA Cube © D1, the first level of learning in operations is to optimize its structure, culture or direct relations with stakeholders (external context).

Any learning needs to lead to change into improved practices. People or a group as a learning or change agent need to come into action and act in accordance with knowledge acquired and actions decided upon. It needs to be monitored whether real impact is gained by follow up of recommendations and intended results. Drupsteen, Groeneweg and Zwetsloot[iv],[v] developed a model of learning from incidents, describing the steps from an incident to continuous improvement, see Figure 4. However each step may encounter learning barriers hampering the learning process or even stalling it.

In the end the change wanted may not be realized which leaves stakeholders with a residual risk not wanted or even with unwanted developments by overstressing for instance solutions by another detailed procedures, also called "negative learning", Tinmannsvik [vi] .

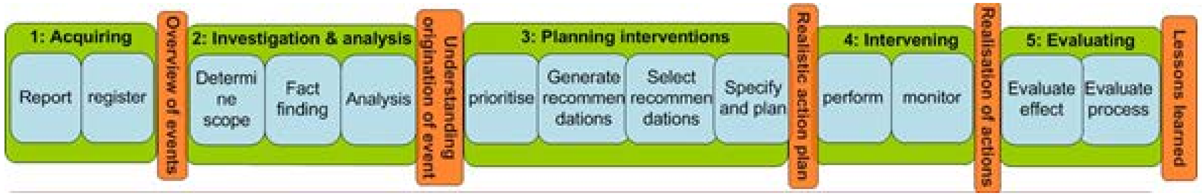


Figure 4: Barriers to learning. (Source: Drupsteen, TNO).

In order to achieve ongoing enhancement of the safety performance of a system, transparency is required about both the course of the event and the behaviour of the system.

Change will normally be the result of ongoing concern and ambition of an organization to adapt as a result of coping with challenges in their business environment, see Figure 1, be it opportunities or threats. Investigation of accidents is a way to cope with unwanted events like disturbances, incidents and accidents. Reflection on successful unexpected actions may deliver a learning or even innovation opportunity. Both are way to reflect on past and present business operations[vii]. Changes, be it formal or informal, always takes place and are an inherent characteristic of an organization, see Figure 6.
In order to enable change, a reliable and credible recomposing of the event should take place. The event should be adequately modelled to such an extent that the response to change can be predicted reliably and consistently. Whether intervention in the sequence of the event or the properties of the system - or both - is desirable or feasible, depends on the goals of the investigation and available resources to do an intervention. Such decisions are made by change agents in the system or actors who even change the dynamics of the system thoroughly (game changers) .

Figure 5: Organizational learning aims at robust and sustained impact. (Source: Johan van der Vorm, TNO)

During an investigation several *stop rules* need to be applied during the on-scene phase to limit the efforts and resources in collecting facts, factors, findings and variables. Also, the accident scene should be released without unnecessary delay in order for the company to be able to remove the victims, wreckage parts and debris, and also to restart its processes. Independently from the on-scene investigation - and frequently simultaneously -, post-scene information will be collected. On-scene and post-scene information is collected to serve in the re-enactment of the event, resulting in a credible and commonly acceptable description of the sequence of events: the accident scenario. To provide a basis for analysing the accident scenario, the context in which the event occurred has to described; the system and its operating environment. The information collected during the fact finding phase is transformed into ''building blocks'' that constitute the scenario and provide the input material for further analysis, Benner[viii]. Such building blocks enable an analysis of systemic behaviour and require specific tools and techniques, such as the FRAM method, Hollnagel[ix]. Each building block is pointing towards future solutions for preventive measures which can be plotted in the frame work of the ESReDA Cube-solution space.

Figure 6: Y-model; system as imagined by the designer, investigator and change agent (Source: Johan van der Vorm, TNO).

The ESReDA Cube method makes a clear distinction between describing the event and describing the system as its operating environment. In formal terms: we distinguish variables that can be changed by any of the parties involved (internal variables) and variables that are beyond control of any of the parties involved (external variables). In order to avoid an ever expanding search for variables, factors or actors stop rules for collecting information have to be recognized in a specific case study.

How much is learned depends on the scope of the investigation of an event on the one side and solutions sought or imagined on the other side. Recommendations can anticipate on the change needed and on how change can be managed, see Figure 7.

First stop rule of a case study:
Specifics of the event are collected, starting with the mission and primary production processes during which the event occurred (a departure of an aircraft, a production cycle or working shift) until the recovery of a system enables a return to normal operations. Generic aspects are dealing with the system in which the event occurred: its structure, culture and context, expressed as the ‘’operating envelope’’. Such systemic descriptions are potentially also available from previous analysis or can be collected and constructed later.

Second stop rule of a case study:
Learning and change are dependent on the extent to which control over the management of the change process is possible. It is important to know which change agents are involved, what their resources and opportunities are, which levels of systems are addressed, the nature and scope of change, etc. Unacceptable risks that should be addressed on a short notice cannot be postponed until innovations are implemented. The timeliness of change should be taken into account.

4.3 Who should learn?

Learning is considered as a multi-actor phenomenon depending on stakeholders on several levels of the organization and throughout the various phases of the life cycle that is under analysis. Learning takes places in interrelated systems: designers, manufacturers, organizations, authorities, insurance companies etc. References are: Hovden et.al.[x], Cedergren et al.[xi].

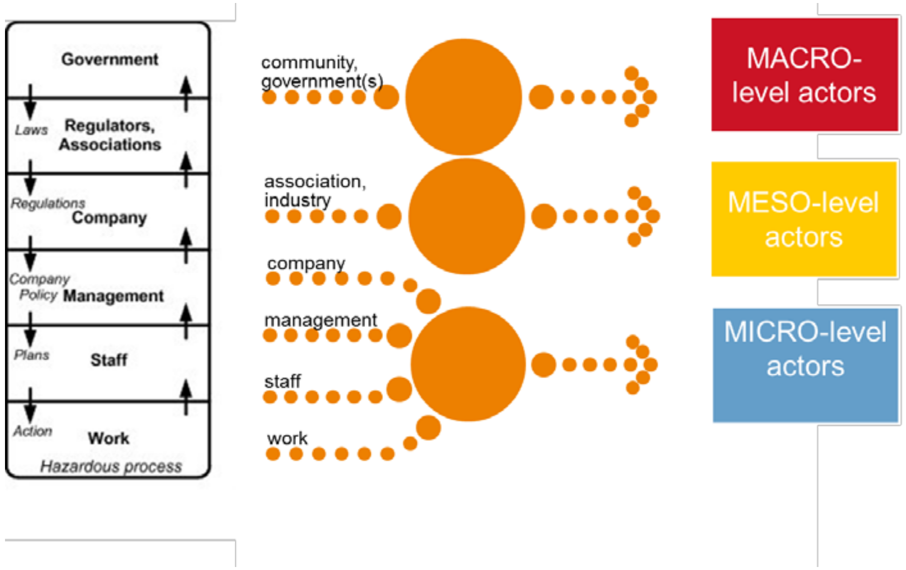


Figure 7: Learning according to Accimap (Source snippet Accimap: Svedung), summarized into the ESReDA Cube ©.

Systems can be categorized at several interacting levels (c.f. Rasmussen’s Accimap and Stoop’s DCP diagram) [xii], [xiii] and by an overview of stakeholders: government, branch, corporate holding, plant, process, man/machine interface.

For the purpose of the ESReDA analysis these levels are summarized:

1. Macro level: industry network, transport system, government (e.g. regulator) and society (e.g. safety board);
2. Meso level: corporate holding, branch of industry;
3. Micro level: individuals, team, organization.

These three levels build the second dimension of the ESReDA Cube, see Figure 8.

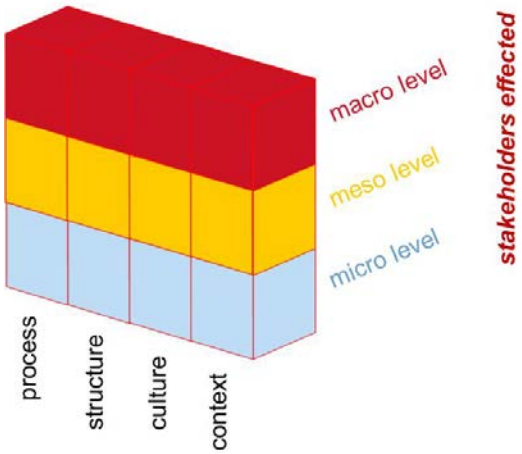


Figure 8: ESReDA Cube © D2, Several stakeholder levels may affect the conditions and the environment where the event occurred, and have a role in the learning process.

4.4 How to learn?

This aspect refers to the relevant changes[xiv] to be sought after to prevent accidents. Learning aims at improving or enhancing one's activities and development. Improvement of safety as an aspect of business processes is well known in the form of the management cycle (plan, do, check, act) or as part of the cycle that is presented in recent models[1] for management systems: policy making, planning, implementation, control and correct, review. The essence of both is continuous improvement, see Figure 9.

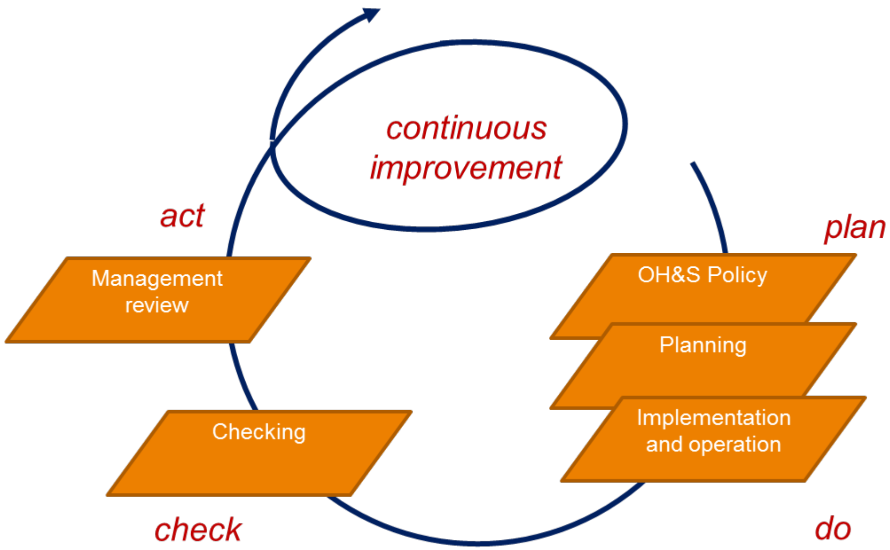


Figure 9: Basic learning loop of a management system (Source: e.g. ISO 18001).

The character of the improvement and the impact learning has on the organization or even business and industry is implicit however. In terms of

[1] *ISO standards on occupational safety and health, environment and quality control (ISO 18001, 14001 and 9001)*

change and even innovation, learning requires another and more detailed perspective.

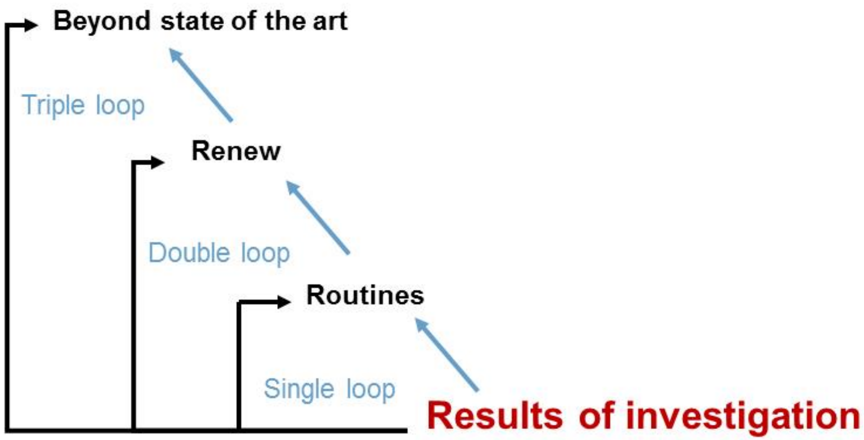


Figure 10: Levels of learning can lead to change of principles leading to innovation (Source: Johan van der Vorm, TNO)

Changes sought by learning, see Figure 10, eventually depend on the level or depth of learning aimed at envisaged:

1. Triple loop learning (learn to learn, introducing new principles, breakthrough of knowledge). This can be technological or organizational e.g. knowledge and science development.
   New principles lead to new developments and innovative practices.
2. Double loop learning (change of insight, norms and values).
   New insights lead to renewal and adaption of present practices.
3. Single loop learning (change of rules).
   Change of rules lead to new behaviour and practices but only optimizing them.

Taking the concept in Figure 11 summarizing learning theories as a basis, the ESReDA Cube framed it as Innovation, Adaptation and Optimization. These layers or depths of learning may be related with business or scientific initiatives resulting from knowledge emerging during accident investigations, see Figure 11.

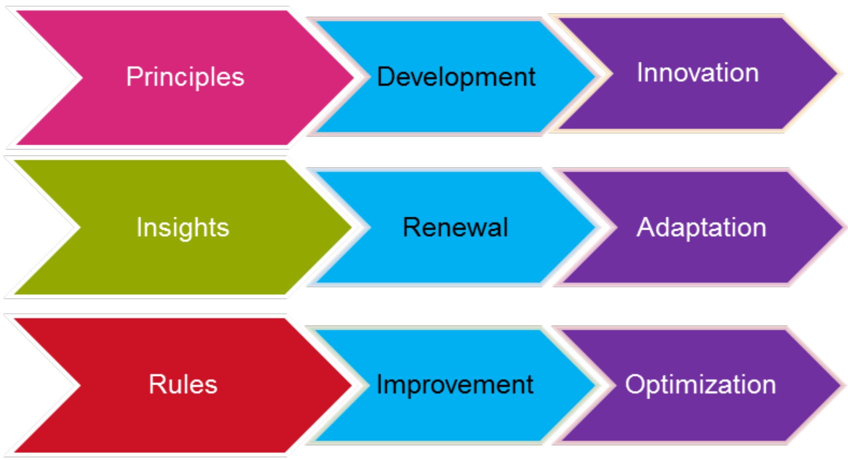


Figure 11: Impact from dynamic learning depends on depth of learning (Source: Johan van der Vorm).

This way of analysing opens up perspectives on systems changes needed rather than restricting the learning to identifying causal factors and solutions only at the micro level and at the sharp end.

The learning depth or degree of renewal modelled as the third dimension of the Cube see Figure 12. This figure shows also some examples at micro (and at adapt) and meso (and at innovate) level.

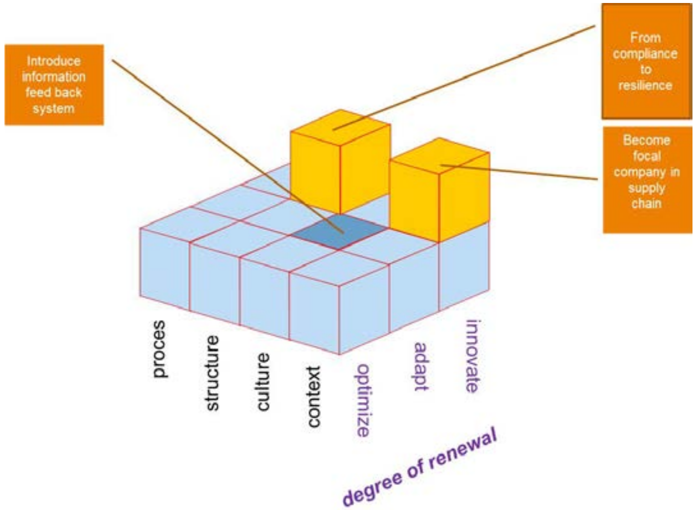


Figure 12: ESReDA Cube ©, D3 learning may result in several degrees of renewal.

5 Learning vector and solution space: the ESReDA Cube

5.1 Learning vector

Finally the combination of the three dimensions makes the ESReDA Cube © a frame and analysis grid, see Figure 13. It describes a three dimensional space in which the learning impact of envisaged preventive measures being anticipated during an investigation can be identified by a position in the Cube. It also enables to plot known measures resulting from investigations as being done in our case studies.

An empty space (or cell) in the Cube indicates the potential for learning as well as learning opportunities overlooked, e.g. when comparing results across similar events within a particular sector or across sectors. All learning opportunities being made explicit analysing results of several accident investigations can be categorized in this framework. Each solution may be indicated by coordinates in the cube, being more or less end points of a vector, learning may be aimed at. In this way a three dimensional analysis grid, see also chapter 8,Example of how to use the ESReDA Cube in an analysis, can be used.

5.2 Solution space

The cube encompasses all potential solutions being and representing a solution space.

In fact it can be used in a sequence of individual cubes each representing descriptive, explanatory or change variables:

1. During the conduct of an investigation, several types of variables must be identified and assessed separately.

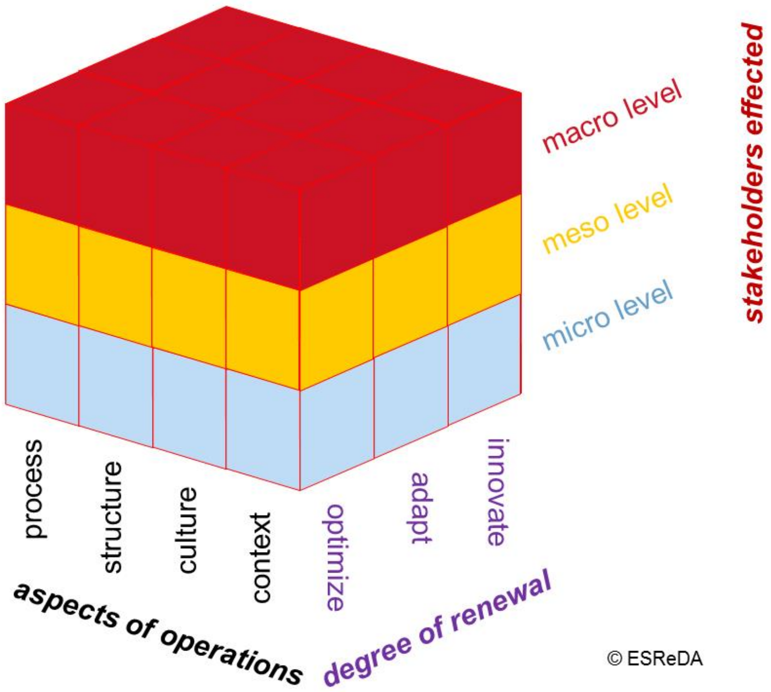


Figure 13: ESReDA Cube ©, solution space for designing recommendations from accident investigations.

2. During the fact-finding phase, descriptive variables combine into a narrative, the event scenario, depicting what happened and how the occurrence developed, along a timeline in the sequence of events.
3. During the analysis, explanatory variables are identified, providing transparency on why the event developed.

4. During the recommendations phase, change variables are indicated: where, by whom and how (sustainable) adaptation can be achieved. These variables are not identical, they may differ considerably due to their nature.

These change variables encompass the 3 dimensions as being represented in the cube-metaphor: the ESReDA Cube, see Figure 13.

Are all three dimensions important in the learning space? Do we need such a broadening of the investigations to a systemic and dynamic perspective? The answer is twofold and refers to differences between investigation theory and practices. An example is given, from the aviation sector:

In the early decades of aviation, stretching into the 50's and 60's, mid-air collisions and aircraft disintegration were a frequent phenomenon, in particular in bad weather situations. Such accident reconstructions provided descriptive variables and lead to the identification of this 'type' of accident. Such accidents could be explained by causal factors such as the loss of visual contact, lightning strikes, spatial disorientation, severe turbulence, and excessive loads due to flight dynamics control forces. All these variables could not be controlled by optimization of the flight path or adaptation of the operating conditions.

Since it is not possible to change the weather at cruise altitude, the only available change variables were to avoid the hazard of flying in such bad weather conditions by diverting to another route or cancellation of the flight. This however, was not always feasible for economical or logistic reasons. Eliminating the hazard was possible by change variables of an innovative nature: to fly above the weather. However, such a conceptual change required the application of more powerful jet engines and pressurized cabins to fly and to survive at higher altitudes. This lead to the introduction of a whole new generation of large commercial jets, such as the De Havilland Comet, Boeing 707 and DC8.

Such change variables were not only based on safety considerations: increasing reliability, efficiency, speed and capacity were major change drivers as well from a technological and economic perspective. Safety arguments coincided in the trade-off with other design arguments.

However, these aircraft designs have seen their own learning curves by the introduction of new hazards and systemic knowledge deficiencies regarding structural aircraft design and engine technology, such as metal fatigue, explosive decompression and engine reliability as demonstrated by a series of major accidents.

In discussing the evolution of accident investigation theory, a gradual expansion of the investigation scope has been observed from an event oriented, operational, technical and human factors level to a socio-organizational level and eventually to the legislation, regulation and governance level. Some consider the technical focus as static, Newtonian and obsolete, to be *replaced* by more modern perspective, dominated by dynamic modelling, sociological notions and systemic perspectives. In such an approach, technology is assumed more or less to be a constant. Such a replacement is an interesting academic discourse because the fundamental transition in focus from an event driven intervention towards a systemic intervention provides ample opportunities to enhance a sustainable intervention in systems performance and properties. Consequently, we need to model the system and explore all of its dimensions. However, such systems modelling is an *addition* to existing event description, not replacing the investigation of events.

A reality check on modelling and assumptions is required and learning from the unexpected and unanticipated remains indispensable.

In accident investigation practices, prevention of accidents remains of a primary interest because of the *consequences* of interrelated and new technologies, expressed in terms of preserving life and property, damage control, business continuity and maintaining public confidence. The potential to inflict damage and devastation has been tremendously enlarged due to increases in scale, dimensions, speeds and capacity. The kinetic energy that can be released during a major event may create massive destruction.

Prevention of accidents also remains important because in practice, non-linear interrelations between closely coupled systems and system dynamics exist beyond design expectations and assumptions. A lack of understanding of inherent properties –build in by design, current operational practices, gradual system shift and adaptations- may manifest itself by ‘emergent’ properties during operations.

Learning from accidents facilitates enhanced understanding of how complex and dynamic systems operate and explains why events occur in practice. Learning is about identifying systemic and knowledge deficiencies. The origins of such deficiencies are embedded in each of the physical, mental and virtual realities that exist in practice and the operating context in which such systems exist. Accident investigations bear the element of serendipity: finding out by accident the unforeseen and unanticipated.

In such investigations, there is no predefined preference for any factor, actor, aspect or performance indicator. Forensic principles apply because the determination of causes of failure and establishing the interrelations and dynamics within a system require familiarity with a broad range of disciplines and the ability to pursue several lines of investigation and implicitly assumed learning opportunities simultaneously.

Positioning their findings in the cube gives structure and cohesion to the learning potential or the solution space investigators or affected stakeholders encounter. The next chapter highlights how the ESReDA Cube may assist this process.

5.3 Application of the ESReDA Cube © to the ValuJet case

To illustrate how learning solutions and learning barriers can be plotted in the solution space of the ESReDA Cube the ValuJet case study has been used as a source, see Annex A, Case study 3.

An example of a workshop using the ESReDa Cube is being reported in chapter 8.

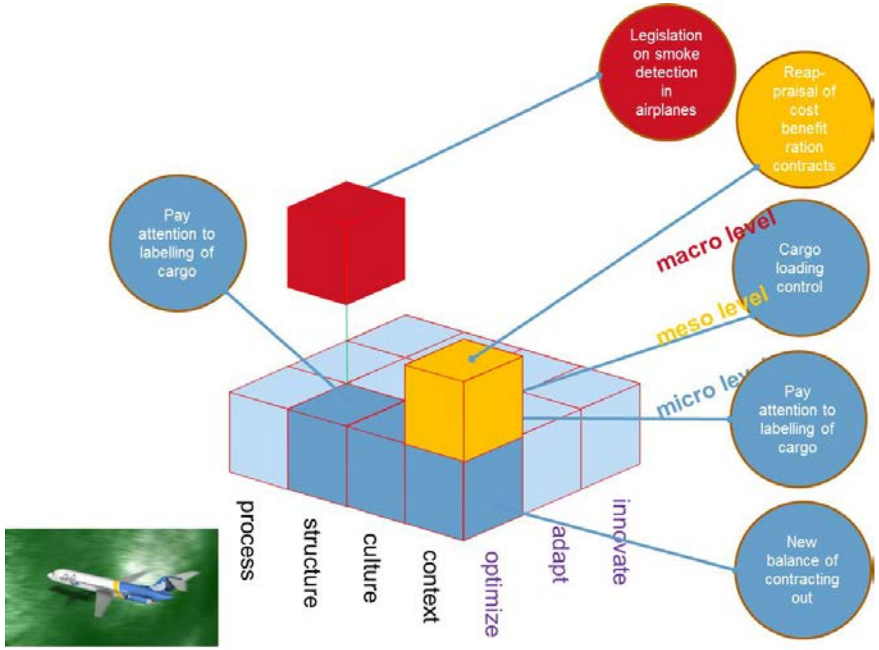
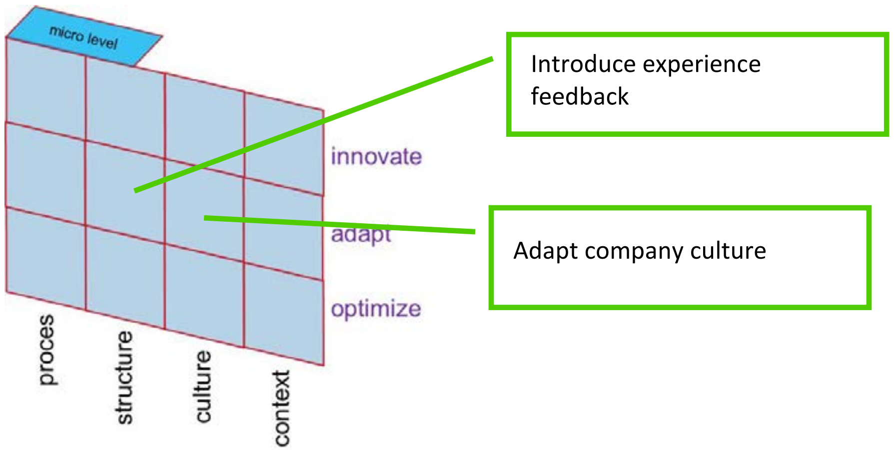


Figure 14: Example of application of the ESReDA Cube © “learnings” from ValuJet case study, see Annex A.3 plotted in the solution space . (Source photo ValuJet: http://nl.wikipedia.org/wiki/ValuJet-vlucht_592).

One way to use the cube is plotting an analysis by slicing cross-sections of the cube. In the following example on learning solutions the cub is split according to system levels. This way illustrates what kind of actors/stakeholders are involved: at company, branch/industry or societal level.



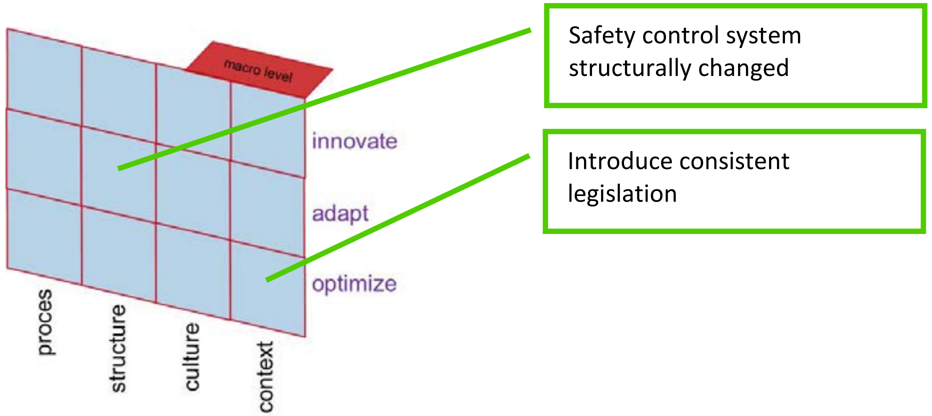
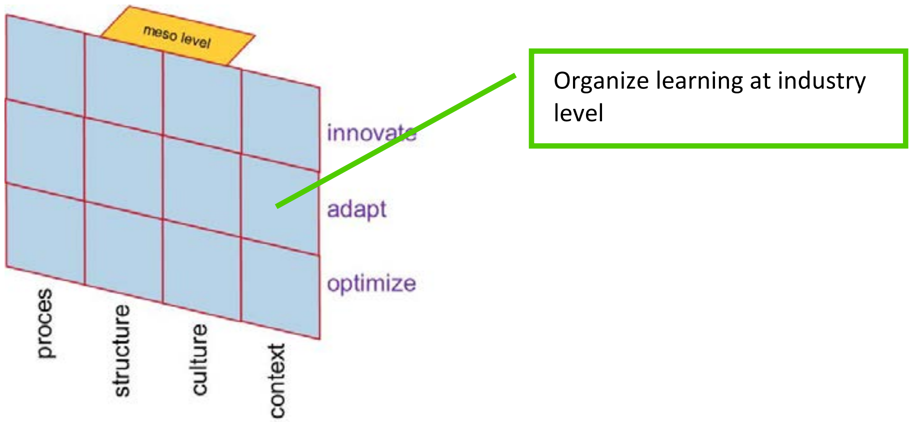
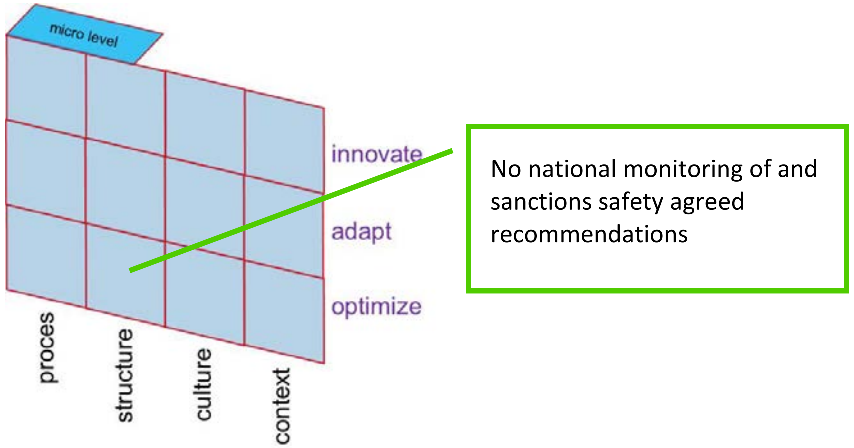


Figure 15: Example of tool to plot recommendation sought or summarizing preventive measures being implemented in the ESReDA Cube.



In the same way as learning solutions can be analysed or summarized, learning barriers can be plotted in the learning space as well.



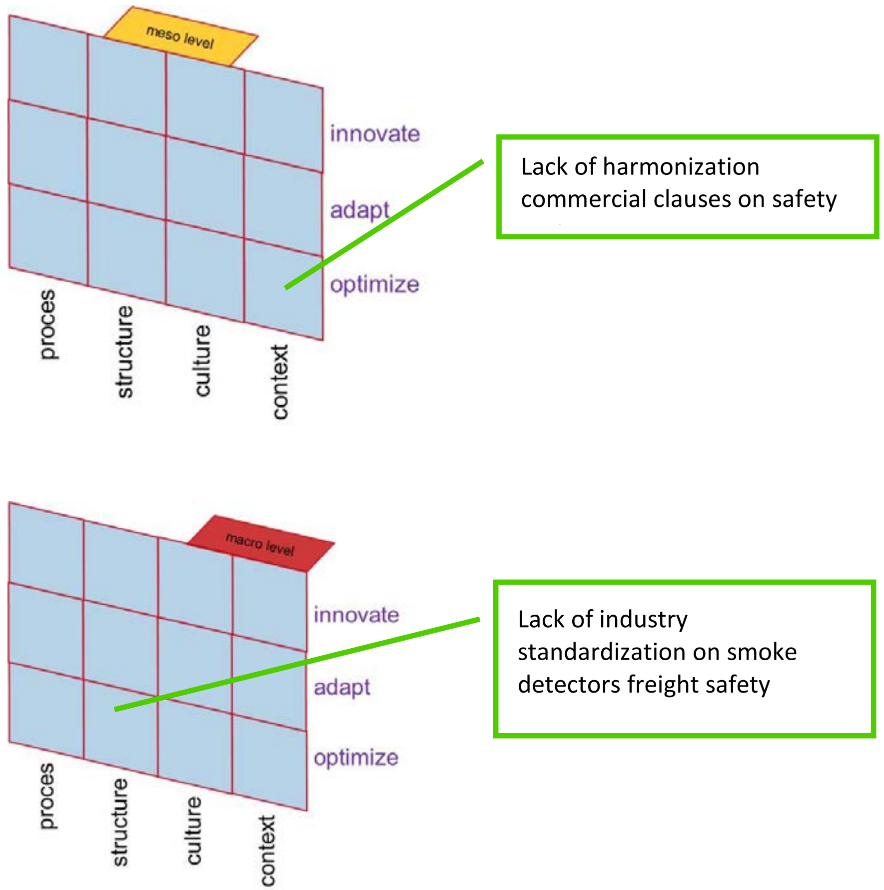


Figure 16: Example of a tool to plot learning barriers in the ESReDA Cube

6 How to work with the ESReDA Cube?

6.1 Focus on dynamic learning

Dynamic learning implies that learning already starts with a well-aimed investigation of events and goes on with managing the change process, monitors it and evaluates the impact.

The scope, expertise, methods, resources and power balance between actors affected by the investigation will determine the discourse of the investigation. The MH370 crash in the Indian Ocean is a more than tragic example in this respect. Without factual information no learning can take place because assumptions and speculations are no basis for change.

The ‘depth of learning’ dimension of the Cube depends on the scope and nature of learning. It is the combination of factors like definition and commissioning of the investigation process, making the step from data collection, to information processing, to knowledge about how the system works and how change can be achieved. It deals with prediction and expectations on future behaviour. Have we been able to identify the control and governance mechanisms? Can we predict side effects, residual risks and emergent behaviour? What barriers need to anticipated? Have we identified change levers, change agents and triggers for change? Such oversight should enable us to identify the potential for change by learning potential on the one side and addressing the barriers for learning on the other side. Both providing leads for recommendations and organizing the orchestrating of follow up by a learning agent having power and resources to implement findings. Those leads can be inventoried and checked by considering systematically the three dimensions of the ESReDA Cube:

1. **Aspects of operations**: the organizational context where the accident took place;
2. **Stakeholders effected**: who are the sponsors or owners for implementing recommendations and pushing forward lessons learned (the necessary changes aimed at several societal levels). In other words who needs to manage the necessary changes?;
3. **Depth of learning**: to change potential having the knowledge from the investigating.

In terms of the ESReDA Cube as a solution space: where to aim at in the Cube, what learning dynamics and what time horizon do you want to take into consideration?

6.2 Learning potential

Learning potential to be considered is:

- Learning organization and supporting structure (learning agent)
- Learning theory: Kolb[xv] (experience, reflect, think and apply), Argyrus[xvi] (single and double loop learning; triple loop/deutero learning)
- Anticipating and controlling learning barriers
- Management of (organizational) change
- Communications involved.

By making a difference between learning from accidents and learning from system behaviour, interventions also should discriminate such a difference. Intervention in events and intervention in systems have their own time scale: in general accidents have a short term intervention and systems have a long term intervention. Systems interventions also may have indirect ‘’emergent’’ effects when we move from the lower operator levels to higher levels, from a single actor commitment to a multi-actor perspective. Because accidents are stochastic by nature, it may require some time to see the effects of higher level interventions. Because they do not show immediately in similar circumstances, it does not mean that they do not occur! A delayed or remote manifestation even may induce complacency. Sharing information and knowledge and memorizing solutions is indispensable for common learning.

In terms of the Cube: which blocks are initially dealt with and which blocks can be effected by the intervention? Understanding the interrelations between the blocks can clarify where emergent effects may occur.

6.3 Time horizon and magnitude of impact

Accident investigation may have several aims while the follow up of findings and recommendation depends on the change and learning dynamics. Are barriers prevailing or is energetic, courageous and consistent change management successful in driving and monitoring implementation?

Complex and dynamic systems are non-linear by nature. So are the events. Interventions may have side-effects, residual effects and emergent responses. Identifying such dynamics is required to manage the effects. Measuring the outcomes by safety integrity levels, quantifying performance indicators and relations between effects is necessary to assess the eventual outcome of an intervention. Together they form the solution space.

The monitoring of those dynamics can be supported by the ESReDA Cube by plotting the implementation and effects but also the deterioration of the realized change in time by consecutive cubes:

Planned implementation of accident reduction measures;
The aftermath of the change process being managed;
Fall-back due to unlearning: e.g. drift into failure due to risk homeostasis: lessons lost, memory forgotten, system degradation.

In terms of the Cube: how many blocks are effected, where are they in the Cube and are they controllable and manageable by any of the actors and stakeholders involved in solving the safety deficiency? Does such problem solving help collaboration and communication?

6.4 Optimizing change management

Each cell of the cube may help to design effective change management. It may help to identify who, what and on what societal level progress in implementation of solutions need to be traced, monitored and influenced or controlled.

Some aspect to be considered are:

Shift from single cause isolated factors (linear thinking) to interrelated multi-causation and interrelated solutions (complex system thinking)
Systems aspects act synchronously: domains of influence
Change strategy: mixture of levels and domains
Barriers anticipated: power, authority and other influences (e.g. production pressure) are stimulating or hampering factors for solutions
Who governs, monitors effects and has power to influence implementation
What indicators needs to be used to measure progress?
Are solutions chosen effective and sustainable?
And finally: are similar accidents really prevented?

Working with the ESReDA Cube in this way enables dynamic learning. Not only looking back and forward at several moments before, during and after investigation of events but also during change management as part of the learning organization or society.

The ESReDA Cube used in this way and using the three dimensions enabled the PG DLAI to analyse a diversity of case across several industrial domains. A format to structure this analyse the case will be presented in the next chapter.

7 Case study format

The case study format follows the ESReDA Cube framework and is aimed at supporting structuring and documenting the case study.

The themes of the case study chosen are:

1. Description of the accident
2. Dimension of lessons learned and solutions developed
3. System levels involved
4. Depth of learning
5. Impact
6. Evaluation of accident and follow-up
7. References to resources used.

7.1 Description of the accident

Description of the event (sequence and system involved):

1. What has happened (short description, pictures etc.)?
2. How did it happen?
3. Why did it happen?
4. Who/what was involved?
5. When: date, historical events?
6. Where: place , context of event and system (general, environment, topography, weather)?
7. Sector involved.

Type of event:

1. Process aspects: what business process was involved, what activity was going on?
2. Structural aspects: what kind of structure was involved?
3. Cultural aspects: was any culture aspect of importance?
4. Contextual aspects: are specific items or influence of interest?

Magnitude of damage to system involved:

1. What kind of property damage?
2. Victims
3. Scale (magnitude) of damage
4. Down time of the business process and connected logistics chain, infrastructure involved.

Investigations known:

1. Summarise investigations known (at least most influential)
2. Sources of information: reports, literature, key articles, specific training, safety campaign etc.
3. Communication of recommendation: how have the results been communicated.

7.2 Dimensions of lessons learned: operations

Solutions developed:

1. Process (what goes on in the primary process):
   How can the work be done safer?
2. Structure (system architecture and functionality): lessons on aspect structure; what structural improvements are sought e.g. Organisational, procedures?
   (Re)design hardware, technology and (re)design organization and processes.
3. Culture: what behaviour or even cultural changes are sought or have been developed as a result of the accident?
   Organizational culture, learning culture, behavioural change.
4. Context (operation environment).
   Business/change management organized (learning agent), political and

social changes needed, supporting organization (e.g. safety board), development of knowledge

7.3 Dimensions of lessons learned: system levels involved.

System level with on each level groups of stakeholders: government, branch, corporate holding, plant, process, man/machine interface. As a system definition a socio technical system is proposed while levels are a simplified reference to the Accimap model of Rasmussen and the DCP diagram of Stoop.

System levels refer to the three system levels identified in case studies:

1. Micro: individuals, teams, company and corporate holding level
2. Meso: industry and industry branch level
3. Macro: government and society level, industry network, transport system, government: regulations, society: safety board.

7.4 Dimensions of lessons learned: depth of learning

Depth of learning refers to type(s) of learning identified:

1. Optimize: restore and repair (cf. First loop/order learning; change of rules)
2. Adapt: improve solutions (cf. Second loop/order learning; change of insight, norms and values)
3. Innovate: renew solutions (cf. Deutero/third order learning; learn to learn), technological (new principles, breakthrough) knowledge development.

7.5 Impact

1. Changes identified: What changes in safety climate are observed?
2. Change/learning agent:
   a. Who/what takes care of follow up?
   b. Who/what keeps memory/knowledge alive?
   c. Who/what monitors effectiveness?
3. Timeline of change
4. Changes in the investigation process
   Did the accident and following investigations lead to any changes in the way investigations are structured (investigation board) and done?

7.6 Evaluation of accident investigation and of its follow up

1. Discussion by the group that conducts the investigation. Since a multidisciplinary conduct of an investigation is submitted to principles of group dynamics, collaborative decision making is inevitable. The group eliminates speculation, achieving consensus on the sequence of the event, acceptance of uncertainties, deficiencies in knowledge and in deficiencies in providing proof, achieving a satisfactory level of explanation, credible and feasible levers for change.
2. Are changes sustained? A desirable follow-up should encompass decisions and actions that create acceptable residual risks and foreseeable instead of emergent side-effects.

7.7 References to resources knowledge used

1. Communication of findings, recommendations
2. Other transfer of knowledge by parties involved, professional organizations, other domains or scientific disciplines.

8 Example of how to use the ESReDA Cube in an analysis

In this chapter one of the ESReDA Project Group members tells about the own experience in using the ESReDA Cube.

The ESReDA Cube was tested in spring 2014 by a small group of safety experts, of whom only one (myself) was a member of the ESReDA Project Group on Dynamic Learning. In a group of four people we re-analysed a five-year-old accident by using the Cube. Two members of the group had carried out the original accident investigation five years earlier.

The analysis begun with a short introduction of the Cube to the other group members. As all participants were already familiar with the accident scenario, the group moved directly to the analysis. After a short discussion we concluded that we will dissect the Cube into three three-by-four planes from the point-of view of micro-meso-macro. It would also have been possible to slice the cube into three or four planes from the other directions (dimensions) but this direction was seen most easy to grasp, from the point-of-view of this accident and what we already knew about the factors that had contributed to the accident.

All three empty planes were reflected on the meeting room wall simultaneously, and we started to fill in the planes with the information we had on the causes of the accident. We started by discussing the micro-level accident causes, and filling out the micro-level plane during the discussions, but we also put information on the meso- and macro-level planes when the discussions concluded that the item under discussion was a higher-level problem. During the discussions it was discovered that some of the cells in the plane would be filled with factors that did not in fact fail but instead worked well to reduce the consequences of the accident. An example of a positive accident factor was a lightweight wall which filled its purpose by directing most of the pressure of the explosion to the direction where it would do least damage.

When compared to several other accident investigation methods, the ESReDA Cube was especially useful in finding opportunities to learn: What could be learned from this particular accident? Both the direct causes of the accident and the factors that contributed as mitigating factors were looked at.

The results indicate that if the Cube is utilized in a real-time accident investigation process, it would be most useful in the final stages (e.g. last third) of the investigation. The Cube helped identify factors that should be taken into account in the prevention of (similar) accidents. It also identified mitigating factors: the factors that prevented the expansion of the accident and/or minimized losses to the environment, property and/or human health. These mitigating factors should also be included in accident analyses - as good practices for others to learn from.

9 Conclusions and observations

Exploring and expanding the learning space introduces opportunities to learn within complex and dynamic systems of a socio-technical nature. Such an expansion fulfils the need to deal with new type of systems and consequently, does not replace other types of learning or make these types obsolete. As indicated by Amalberti and Hollnagel et al., a new class of events has emerged, dealing with properties and interrelations in dynamic and complex systems, which already operate beyond the 10^{-7} safety performance level with respect to their accident frequency (Amalberti 2002, Hollnagel et.al. 2008). Such systems may require a distinct approach with respect to their event analysis.

Based on the experiences and discussions in the ESReDA Project Group, such systems also require a new approach in *structuring solutions*, in providing the links between problem and solution. It does not suffice to understand where and why interventions in a sequence of events or system's functioning are required. Such interventions must also be designed into the sequence of events or into the system or both. In the Project Group discussions, the need for a relation between investigating, understanding, learning and engineering solutions became self-evident. Adding such an engineering design perspective is critical. It expands the scope of interventions from technological redesign to designing procedures, organisations, decision making processes and governance arrangements. Such an expansion requires collaboration between technical and social disciplines, between investigators, analysts, scientists, managers, operators and practitioners. Such collaboration may cover a range from a short term intervention in the sequence of events or mitigating consequences, up to a major redesign of systems and its supporting technology. Interventions may be aiming at preventing future damage and injuries, changing performance during operations and dynamic behaviour, or changing system's properties by innovation and redesign. Since complex events are non-linear, a simultaneous elaboration of all solution spaces is also likely.

Earlier phases of the investigation process are already highly elaborated with respect to forensic engineering, accident investigation, scientific analysis and data management. The phase of learning and drafting recommendations is not so well developed yet. The approach as developed by the ESReDA Project Group tries to bridge the gap between learning and change. We have tried to develop a roadmap through the landscape of getting to safer systems. We developed a tool and a communication metaphor –the Cube- to get the message from the investigation findings across to those who are able to deal with change.

Several conclusions can be drawn while introducing the ESReDA approach and ESReDA Cube.

The ESReDA approach provides structure to the findings of an investigation along three generic dimensions; aspects of operation, stakeholders affected and levels of renewal. The ESReDA Cube provides an overview over the various aspects, actors, factors and findings that are disclosed during an investigation by placing them along the three dimensions. A further processing of such information has to take place to enable further analysis and enhance the safety performance of the system. The 'building blocks' of Ludwig Benner (2013) indicate how such a further processing could be achieved.

The ESReDA approach clarifies the role of an investigator in charge, or chairman of a safety board as the manager of the investigation process. The approach provided transparency during the transition between the various phases of the investigation process with respect to the description, explanation and change perspectives. By structuring the beginning of the process, the final phases of reporting and recommendations can be based on consistent and harmonized inputs, taking into account the non-linearity of cause-effect relations and systemic dynamics. Such structuring also enables comparisons across domains.

The ESReDA approach demonstrates that comparisons and harmonization across industrial domains are feasible. The 5 case studies in this document provide the proof of concept. Frequently, major events are considered unique by their nature of low-probability/high-consequence occurrences. Unique events are assumed to have very limited learning potential and are considered beyond comparison across lines of domains. Structuring and harmonizing the investigations of serious events in their systemic context makes such events accessible for further investigation as a specific class of case-based and evidence-based phenomena.

The ESReDA Cube provides a new metaphor for communication across actors and stakeholders in complex and dynamic systems. The Cube (like the numerous combinations of the Rubik cube) has provided inspiration for manipulating a huge amount of information. Introducing the Cube as a new metaphor represents the hidden rationale of complex multidimensional decision making algorithms in a multidimensional learning space. The non-linearity between findings, learning and solutions introduces awareness that multiple problem solving strategies are possible. The ESReDA Cube represents a metaphor for communication and negotiations to achieve a consensus on acceptable solutions.

Specific observations can be made for a future expansion of the work of the ESReDA Project Group initiatives. Such initiatives should facilitate a linkage between safety on one hand and systems engineering design and operations on the other:

Trade-offs are common in multidimensional decision making environments. Such trade-offs occur in the engineering design environment as much as in the operational trade-off between effectiveness and thoroughness, but each have their own rationales, principles and paradigms. How to implement learning in both engineering design and operations faces new challenges by the fact that safety in complex dynamic systems is defined as a system state and strategic value. In such systems safety is not a mono-dimensional operational performance indicator that can be quantified and managed by dashboard technology. Complex optimization algorithms are required to assess the variety of values and operational trade-offs. In systems engineering design, -in particular the conceptual design phase-, parameterised primitives, derivate and surrogate modelling approaches are required to compare different design options and trade-offs between design configurations. Such optimizations rely on Knowledge Based Engineering design and Concurrent Engineering design principles. The challenge in incorporating safety in value engineering approaches and system optimization processes is to synchronize the learning vector and the systems safety vector by transforming the event problem state/space vector into the system solution state/space vector. However, such a vectorial connotation is in its first phases of development and requires considerable further theoretical, mathematical and methodological development. The ESReDA approach intends to give a practical application of these theoretical notions by transforming such a vectorial approach into the three ‘Cartesian’ dimensions of ‘aspects of operations’, ‘stakeholders affected’ and ’degree of renewal’.

In a multi-actor decision making environment, deliberations and negotiations define the eventual outcomes of the optimization process. In addition to the substantive trade-offs, a communication and decision making process is required to implement learning into systems safety enhancement and system change strategies. To this purpose, the ESReDA approach provides a basis for integration of safety strategies in multi-agent modelling, multi-actor decision making, serious gaming and dynamic simulation. The social dimension of system dynamics and decision making processes can benefit from developments in social sciences, such as resilience engineering, group decision making simulation and game theories. Organizing the design process along lines of concurrent and collaborative engineering principles, the use of prototyping can be combined with engineering design engines mobilizing libraries of primitives and solution principles.

In applying new principles of safety enhancement for intractable and dynamic systems as depicted in the ESReDA approach, we can reinforce and adapt the two main firewalls against disaster; certification of the engineering design results and investigation of current operational practices.

The ESReDA Cube serves as a decision support tool by providing each and all an overview over options for learning and change across actors, stakeholders and industrial domains. The Cube creates a basis for achieving consensus on the course of the event, a starting point for intervention and a discussion platform for deliberations on an acceptable and feasible change strategy.

The introduction of the ESReDA approach discloses an almost unnoticed shift in investigation practices from metaphors, through models towards methods. The investigation process itself and the learning that emerges from the investigations becomes a focus for attention dealing with decision making, optimization strategies and communication issues.

How to deal with such learning is the subject of complementary documents produced by the Project Group. We therefore refer to the documents on:

1. Barriers for Learning,
2. Training Toolkit and
3. Concepts and confusion, metaphors, models and methods.

The project will publish these documents on its website and plans to open them on a special ESReDA site-page Guidelines for Learning.

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Annex A. Accident cases studied

Overview cases

Members of the ESReDA Project Group have selected five cases. The cases analysed represent the following domains:

1. Industry:
    a. Pressure shock at stainless steel manufacturing melt shop in Tornio, Finland
    b. Toulouse Disaster, France
2. Aviation:
    a. Crash of the ValuJet Flight 592, DC-9-32, USA
    b. ElAl air crash Schiphol, The Netherlands
3. Rail transport:
    a. Astaa train collision, Norway.

A.1 Explosive fire at a melt shop in Tornio, Finland

Analysis

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
Event description (system involved)		
Accident description	Short description	Explosive fire killed three at a stainless steel manufacturing melt shop in Tornio, Finland, on September 19th, 2003.
	What happened (description, pictures etc.) What agents (the damaging energy source e.g. nuclear hazard)	It was the first annual maintenance stoppage of the melt shop line. During the stoppage back pressure valves were installed in the oxygen lines. After the installation two men went into the valve room in order to re-open the main shut valves of the raw oxygen line and the pure oxygen line. The latter valve was jammed. The valve was turned with pliers when an explosive fire ignited.
	How did it happen, what were the circumstances	First the two men opened the valve of the pure oxygen line. Then they started to open the valve of the raw oxygen line, but the valve was probably stuck as the bolt pin holding the hand wheel in the valve stem had broken. The men asked for pipe tongs to turn the stem, and the tongs were delivered to the men. The men managed to turn the stem somewhat when an explosive fire ignited. The fire kept burning because of oxygen leakage from the damaged piping. For an unknown reason a third person had entered the room just before the ignition occurred, and all three men were killed instantaneously.
	Why did it happen? Direct causes	Three possible causes of ignition were identified, dealing with friction and particle impact: (1) The bearings of the valve could have been damaged and thus ignited as they were of a material which ignites more easily than steel. (2) The valve may have been opened without prior equalization of pressure in which case small particles in the fast oxygen flow may have become hot and ignited the valve. And (3) a foreign object may have gotten stuck in the valve and caused friction, heat, and ignition.
	Why did it happen? Root causes	Factors that may have contributed to the accident include possible omission of pressure equalization prior to the opening of the valve, valve material, lack of safety culture in relation to risk-taking, and inadequate or undefined working instructions especially in relation to gases and unplanned situations.
	Other root causes	

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
	When did it happen? Timeline of main events	At the end of the first annual stoppage of the new melt shop line, on Friday, September 19th, 2003, just before lunch time. Production was due to restart the following Monday.
	Historical events	There have been several similar smaller incidents in Finland both before and after this accident. Oxygen valve fires have also been studied internationally and a summation of the investigations and their results is presented in e.g. the article based on this accident which was written by Risto Lautkaski: "Investigation of a large industrial oxygen valve fire" and published in the Journal of Loss Prevention in the Process Industries in 2008.
	Place Context of event and system (general environment, topography, weather)	The accident occurred in northern Finland, in the town of Tornio which is situated by the Swedish border at the far end of the Baltic Sea. The factory is located about 10 km south from the centre of the small city of Tornio. The factory area is about 4,2km^2. The melt shops 1 and 2 were altogether about 63 000 m^2 and the height of the building itself ranged between 1-5 floor levels. The accident occurred in the valve room, on the third floor of the melt shop. The accident occurred inside the building and the prevailing weather conditions were irrelevant to the occurrences. Nevertheless the weather was clear and the temperature was +7°C.
	Sector involved	Industrial accident, metal industry
Type of event	Content aspects: primary activity, operational aspect involved General or macro description of plant or system involved	Stainless steel manufacturing melt shop, new melt shop line, maintenance activities during first annual stoppage, opening of oxygen line valve. Stainless steel manufacturing plant located in northern Finland. The consolidated corporation is exchange-listed and employed in 2004 about 19 000 persons in 40 different countries. The affiliated company where the accident occurred employed 9000 persons of which about 2200 were in Tornio. The plant area consists of the melt shop, hot- and cold-roll buildings, a laboratory and plant service. Another company, which produces ferrochromium used in the manufacturing of stainless steel, is located within the same plant area. The opening of the second melt shop line increased the number of personnel in the melt shop from 229 to 351. About half of the personnel from the old line transferred to work at the new line, and the tasks of all but 20 people changed at least somewhat.
	Local or micro description of process/system involved in accident	Maintenance activities in the valve room of the melt shop building. The maintenance activities (opening of the valves) were performed by a plant foreman and the foreman of the contractor in charge of the valve installation during the stoppage. Both were experienced and knew the hazards of oxygen and the new melt shop line.
	Structural aspects: e.g. relevant organisational structures, infrastructure,	Melt shop building in the stainless steel manufacturing plant area. The new melt shop line had been built by the same contractor who was in charge of the installation of the back pressure valves during the stoppage.

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
	buildings etc.	
	Cultural aspects: personal safety culture company safety culture	A risk-taking culture was recognized within the plant.
	Contextual aspects e.g. industrial safety culture	
	Area and stakes vulnerability to the system	The hazards of oxygen were not adequately acknowledged. The risk of oxygen valve fire had not been identified. Previous oxygen-related risk and safety analyses concentrated on the oxygen gas station, although a safety analysis of the melt shop oxygen pipeline changes had been made.
Magnitude of damage to system involved	Scale and kind of property damage	Property damages were restricted to the melt shop. Several pipelines and cables in or near the valve room were damaged by the heat as well as the room itself and the space under the valve room.
	Victims	Three fatalities: plant foreman, contractor foreman, welder. Minor injuries to several workers related mainly to smoke inhalation.
	Magnitude of damage financial Environmental	Property damage (repair 2M€, production losses 9M€) None
	Down time	Approximately 1 month
	After the event, aftermath actions to restore, repair, de-pollution, compensate	
	Speed/pace of recovery completely back into business	
Investigations known	By safety board/special commission involved	Accident Investigation Board Finland (Onnettomuustutkintakeskus), Federation of Accident Insurance Institutions (TVL)
	Public authorities	Safety Technology Authority (Tukes), current name Safety and Chemicals Agency (Tukes)

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
	By companies involved	
Dimension		
Content	Elements of the primary process to be improved	Remote control valves, protective walls by the valves, clear and easily noticeable markings on valves and oxygen lines, valves adequate to be used with pure oxygen, pressurization of pipelines with nitrogen before insertion of oxygen. During accidents and incidents: prevent oxygen from entering main pipeline, quick emptying of pressurized oxygen from the pipeline to a safe place
Structure	Organizational structure	The company should identify potentially hazardous aberrations and have precise guidelines on how to act in such situations. All aberrations should be reported. The authorities should demand this. People who work with or maintain oxygen systems should be properly trained in its use and hazards Assessment of hazards involved in the use and storage of oxygen should be improved The responsibilities, know-how and commitment to safety in relation to oxygen and other hazardous chemicals should be improved
	Technological structure	Valves which are involved with hazardous tasks should be a part of the company's preventive maintenance plan
Culture	Change of culture	After the accident the company executed a full safety status analysis with the help of outside-expertise. Based on the results of the analysis a five-year aim was set: to reduce accident frequency from 29 to 4 accidents per one million working hours. After the accident the company also started to pay more attention to the reporting and analysis of near miss situations, with the aim of change of safety attitudes and culture.
	Change of behaviour	After the accident, near miss and fault situations were reported more frequently. The management has begun safety walks on the shop-floor level and the observations are logged.
Context	Supporting conditions	The ministry should oversee that the EU legislation concerning pressurized equipment demands manufacturers to provide guidelines on adequacy of valves on different gases. The guidelines should take into account prevailing conditions and what the valve is used for. The authorities should supervise that companies identify hazardous tasks and have precise instructions on how these tasks are implemented

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
	Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system	The authorities should monitor that companies who build or modify oxygen lines have a cleansing and checking plan.
System level involved		
Micro	Solutions at company level, subcontractors at company level Timeline of implementation of solution months/years	Remote control valves, protective walls by the valves, clear and easily noticeable markings on valves and oxygen lines, valves adequate to be used with pure oxygen, pressurization of pipelines with nitrogen before insertion of oxygen. Training, instructions,…
Meso	Actions of safety authorities, what actions? Timeline of implementation of solution months/years	E.g. the preventive maintenance plan of safety-critical parts is looked at during safety inspections.
Macro	EU-level development, directive or standard being changed or research program being started or... Timeline of implementation of solution months/years	One of the recommendations of the accident investigations boards was that the ministry should oversee that the EU legislation concerning pressurized equipment demands manufacturers to provide guidelines on adequacy of valves on different gases. The guidelines should take into account prevailing conditions and what the valve is used for.

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
Depth of learning		
Optimize **Adapt** **Innovate**		Procedures
Impact		
Changes identified	What really changed	Safety status assessment made by outside experts, improvement of reporting and analysis of near misses, changes in attitudes and safety culture, safety walks, precise written working procedures were made, instructions were simplified and unified, planning meeting before rare tasks, changes in oxygen pipelines (incl. remote-control valves, protective walls, pressurization with nitrogen, no raw oxygen, less pressure,…), activities and responsibilities after stoppage are gone through, markings on pipelines improved, instructions next to valves, valve rooms are locked and outside the rooms are oxygen signal lights which indicate the oxygen level, the authority has changed its mode of supervision.
Change/learning agent	Who/what takes care for follow up Who/what keeps memory/knowledge alive Who/what keeps monitors effectiveness	
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	
Change of investigation process		More focus on accident precursors

Item	Explanation	Explosive fire at a melt shop in Tornio, Finland
Evaluation of accident and follow up		
	Specific experiences/observations/discussion by ESREDA group	
	Are changes sustained	Structural changes, such as protective walls and remote control, are fixed. Otherwise it is uncertain how widely the memory of the incident and the lessons learned are sustained within the large factory area or within the industry.
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission	Accident Investigation Board of Finland: http://turvallisuustutkinta.fi/en/index/tutkintaselostukset/muutonnettomuudet/tutkintaselostuksetvuosittain/muutonnettomuudet2003/b52003yrajahdysmainentulipaloterastehtaallatorniossa19.9.2003.html
	Report inspectorate/third party	Safety Technology Authority (Tukes): http://www.tukes.fi/Tiedostot/varoasiat/raportit/tornio_avesta_happilinjapalo190903.pdf
	Company reports	
Other transfer of knowledge by parties involved, professional Organizations, Scientists etc.	Articles in journals, magazines, internet	Lautkaski, R. 2008. Investigation of a large industrial oxygen valve fire. In: Journal of Loss Prevention in the Process Industries 21, pp. 466-471.
	Courses, training	Internal company training
	Relevant links	

Conclusion

Most conclusions have been inserted into the table above. More conclusions in Chapter 8, concerning the use of the ESReDA Cube (different case study) in the identification of negative and positive accident-related factors.

Comments

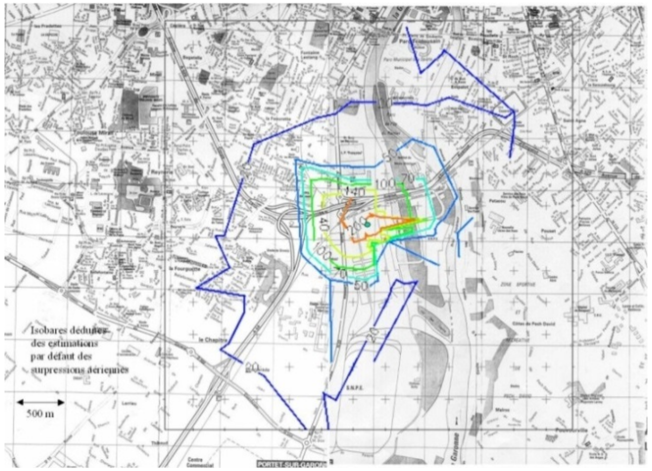
No Comments

A.2 Toulouse Disaster, France

Analysis

Item	Explanation	Toulouse Disaster
Description event (system involved)		
Description accident	Short description	A terrible explosion of off-specification ammonium nitrate occurred on 21st September 2001, in Toulouse in France, in AZF, a chemical and fertilizer plant belonging to Grande Paroisse Company, now Total group (former Total Fina Elf at the time of the accident).
	What has happened (description, pictures etc.)	Main scenario and hazardous phenomena. The explosion produced a seismic wave that was estimated at 3.4 on the Richter scale, but no analysis had been initiated by the INERIS into this aspect for its investigation. *The AZF crater produced by the explosion.*  Source: INERIS, MEDDE

Item	Explanation	Toulouse Disaster
		The explosion produced a crater of about 65 m x 54 m in diameter and 7 m in depth. From the blast analysis carried out by INERIS, it has been deduced that the TNT equivalent required to produce the damage observed would have to have been between 20 and 40 tons. It should be kept in mind that this assessment corresponds to the arithmetic mean of the weight values calculated from the overpressures estimated respectively on the low side and on the topside. Furthermore, it should be noticed that: 54% of the estimates are below 20 tons, whereas 24% of the estimates exceed 40 tons. Statistical data showed the disparity in the estimates obtained for the TNT equivalent. The disparity can be explained essentially by the difficulties in interpreting the damage observed within a very short time.



Overpressures estimates (low range).

Source: INERIS, MEDDE

The Total Fina Elf investigation commission listed several estimates of TNT equivalent by the following different companies:

Item	Explanation	Toulouse Disaster
		SNPE Environment estimated 165 tons with a range of 140-200t which were mostly based on window damage observed Laboratoire de Géophysique estimated 10 to 100 tons using several methodologies with a maximum of 200t. Technip estimated 15-25 tons by analysing the effects on the building structures TNO first estimated 30-40 tons but concluded with a range of 15-40t by analysing the effects on the building structures INERIS estimated 20-40t by using windows, building structure, roofs, walls etc. The Tota lFina Elf internal investigation commission stated the most relevant estimate to be 15 to 40 tons of TNT equivalent because methodologies used by Technip and TNO seemed more accurate and it confirmed the orders of magnitude found by INERIS. A few months later, the Justice mentioned an estimate of 70 to 126 tons for the TNT equivalent mass (the methodology is unknown to us).
	How has it happened, what were circumstances	The building 221 was adjacent to the sack-filling building, 123, 124 and 125, where combustible products were stored. This group of buildings was not fitted with a fire detection system. Work to bring the infrastructure of the building up to the required level had been undertaken over the last few years. Building 221 and 222 did not have any nitrogen oxide detectors and in a note dated 6th June 2001 about the retention of water for firefighting sent by Grande Paroisse to the DRIRE (pursuant to the authorisation order dated 18th October 2000) it was listed under the heading “improvement”: “The presence of NOx detectors would help to reduce the time taken to raise the alarm and consequently the time taken to put any fires out and the amounts of water used to do so.” Such devices were present on other larger storage facilities on the site. This situation was consistent with the fact that whilst the risk from fire was contemplated on this type of storage facility, the risk of explosion was considered by the operator to be negligible. The running of building 221 and 222 was supervised by Grande Paroisse’s dispatch department and sub-contracted to outside firms. Handling operations in this building were carried out by personnel from a sub-contracting company called TMG who also carried out the handling of nitrates in sacks and on pallets. The warehouse 221 had no gas supply, no steam pipes and only natural light.
	Why did it happen? Direct causes	Several years after the accident, the controversy about the direct causes is still there. The origins of the accident haven’t found yet an agreement among investigators (company, justice). The trial is being held and the conclusions are not known yet.

Item	Explanation	Toulouse Disaster
		The controversial key element is to find the ignition source of the off-specification AN stored. Investigations showed the origin was neither a fire nor a first explosion followed by the mass explosion. Investigations of the Justice have therefore focused on reviewing the role of contamination in AN decomposition, and in particular on the chemical incompatibility. Indeed, some chlorinated compounds for swimming pools were manufactured on the southern part of the site. Those materials were supposedly not to have ever been mixed. The Justice's main assumption focuses on a reaction between AN and DCCNa (SDIC, sodium dichloroisocyanurate) or AN and ATCC (trichloroisocyanurate acid) that is strongly incompatible and releases trichloramine NCl_3, that is very sensitive and has explosives properties. This material could have been brought in by error some minutes before the explosion. The other scenarios were numerous and where mentioned in the press by the Justice or from other sources: among them: A huge underground electric arc between a transformer on SNPE's site (owned by the French State) and EDF's electric line. An unidentified gas leak coming that would have contaminated the storage of off-spec AN, Other assumptions such as terrorism act, malicious intent or meteorite fall have been investigated as well, but have not appeared relevant so far.
	Why did it happen?	Comment on investigation and trial: disclaimer on root causes
	Root causes	Several investigations launched by several stakeholders, a public investigation, a national debate and a parliamentary enquiry were launched (see list of references below) that enabled the risk management system and several stakeholders to identify numerous probable risk factors and generic lessons to be learnt. Final Root causes are still under investigation in connection with the outcome of the trial. But, among root causes, some deficiencies are already identified. Some of the main ones are listed here. However as the direct causes of the disaster are not yet established, these root causes should be taken with caution. *Technical, technological* AN Fertiliser grade and moreover technical AN grade are not inherently safe towards the explosion risk. For economic reasons, those fertilizers have kept an efficient dose of fertilizing capacity, meaning a sufficient ratio of Nitrogen. This implies that they kept a latent risk of explosion if they are mixed with some chemicals and

Item	Explanation	Toulouse Disaster
		combustibles such as fuel. Despite a good knowledge and experience of some of the pure AN properties, there are still a lot of unknown properties, in particular for fertilizer grades, with the interactions and sensitivity towards impurities, pollutants, and combustibles. The certification test of AN has probably decreased the explosion risk perception. Despite recognizing that the off spec AN had greater sensitivity, research was not undertaken. *Management* Another probable root cause was the subcontracting of some activities with a loss of risk knowledge and control. It was the beginning of the implementation of Safety Management System (the Seveso II regulation transposition was made 1 year before) that was not developed enough, formalised or implemented. *Governance, Communication* Several root causes were acknowledged such as the lack of use of governance tools (communication and participation of other stakeholders than industry, State and experts; acceptability criteria unclear). It was pointed that the lack of governance inside the hazardous sites, with the lack of process safety overview by internal workers of the Health and Safety Committee were not mandated on process safety (major hazard) issues, and mostly focusing on health and safety at workplace. It was noticed that there was a lack of control and lack of inspections from the inspectors of the control authorities (means that there were a number of inspectors but a lack of expertise). *Policies, Regulation, Standards* A root cause was the lack of Seveso II regulatory overview on off-specification AN. Only AN that complies with quality and safety norms were considered by the regulation. Some AN technical grade, used for explosives and some others were sold as fertilizer grade, with at the time, a low probability risk of explosion. The position of the industry for risk assessment in safety studies was to evaluate the fire risk scenario. Lessons from historical explosions involving AN materials were considered in the design of the materials specification, preventive measures and regulations. The Seveso Directives also had some more general limits in the risk assessment, risk management and risk control issues. The risk zero faith was down and the belief in the control given with Seveso II Directives implementation was lost after Enschede, Toulouse and now Buncefield. A Seveso III Directive is under preparation. Another root cause was the LUP process, which was inadequate and had no retroactive force. It led to a high

Item	Explanation	Toulouse Disaster
		exposure of several stakes (houses, schools, companies, stores, infrastructures) in the safety perimeters around the plants. The LUP was edited too late after the suburbs of Toulouse had surrounded the plants.
	Other root causes	*Pre assessment* At first the explosion scenario of the storage of off-specification AN was not considered in the safety studies nor in the LUP safety perimeters. Indeed, at that time, the position of the industry for risk assessment in safety studies was to evaluate the fire risk scenario (in an industry safety guidelines). Due to the consideration of lessons learnt from previous explosions, the risk of explosion was thought to be low. However, the Seveso II regulation and other regulations did not consider the particular risk of 'off-specification' of AN. Today, these materials, with badly defined properties, but higher risks than fertiliser AN that comply with norms, are considered to have a risk level similar to technical grades of AN. Secondly, at a more general level, the outcome of the risk assessment process through the Administrative and parliamentary inquiry showed that a deterministic approach and more detailed probabilities needed to be included into the risk management process. It insisted on the need of assessing scenarios with a consideration of a possible failure of the safety devices (the deterministic approach in France). In other words, "real safety studies" should reveal the hazard potential. This is also in line with practices in other countries and industries such as nuclear or transportation. *Risk appraisal* Concepts of defence in depth, safety barriers, likelihood, scenario, methodologies of risk assessment (HAZOP, fault trees) and safety management systems are widely used today. For the probabilities, it was explicitly mentioned to learn from Dutch and English practices and to seek harmonisation throughout EU. Another important lesson is that "the explosion could have had larger human consequences if a storage container of toxic gases had been damaged or if a chlorine or ammonia wagon was closer to the location of the explosion". "The effects would have been larger because the explosion had damaged windows in a large perimeter" and people would not have been able to protect themselves. A domino effect did not occur but could have and was not considered for 'realistic' 'worst case' safety perimeters. In addition, the worst-case scenarios were not taken into account in the safety studies or LUP. In the end, the accident showed the incompatibility between the hazardous activities and the vicinity of the urban area.

Item	Explanation	Toulouse Disaster
		Tolerability and acceptability judgement
		In 2001, for different ammonium nitrate manufacturing sites, different ranges of safety distances regarding lethal or irreversible effects existed that varied with one order of magnitude. They were mostly based on ammonia release scenarios. This experience of the Toulouse disaster was used by the Administrative and Parliamentary inquiry to ask for a methodology review of the safety studies in France. There is a need for a better quality and harmonisation of safety studies of any site. E.g., It was recommended to the Environment Ministry to define the rules on the scenarios to assess (storage, wagon, trucks, piping system), the external interference (natural hazards like earthquakes, centennial flooding, domino effects, dam rupture, airplane crashes and malicious intent) and to define criteria for effects on people.
		It was also found also that the inspectors had to do trade-offs (between scenarios, LUP and acceptability), which they were not supposed to do.
		Risk management
		The subcontracting of some activities, in particular activities linked to process safety and major hazard, were lacking overview. This transfer of activities to external contractors was found to generate a loss of risk knowledge and control.
		It was the beginning of the implementation of Safety Management System (the Seveso II regulation transposition was made 1 year before) that was not developed, formalised or implemented.
		In addition, it was noticed that there was a lack of governance on these hazardous sites and a lack of process safety overview by internal workers of the Health and Safety Committee, which was not mandated on process safety (major hazard) issues. This could have improved debates about risk management activities.
	When	The explosion occurred on Friday at 10:17 am, 21st of September 2001.
	Timeline of main events	It was 10 days after the 9/11 disaster
		One of the key issues was the nature of the product which was put on top of the AN storage hours before the explosion at 10h17 am.
		The day before the explosion, 15 to 20 t of ammonium nitrate containing an additive that had been manufactured and was at the qualification stage were brought into this building.
		On the morning of the explosion, products resulting from the packing of ammonium nitrate and from the

Item	Explanation	Toulouse Disaster
		manufacturing workshops were brought into this room. The last product having been brought in less than half an hour before the explosion was a skip coming from another storage area. A Grande Paroisse employee had left the sack-filling building 5 minutes before and had not noticed anything out of the ordinary. Investigations about the nature of the products stored were then conducted within the Judicial inquiry. No one was in the storage warehouse at the time of the explosion.
	Historical events	There were several accidents and disasters involving ammonium nitrate in the last century. Their sensitivity to fuel became well known. Their sensitivity to other materials was also recognized. Detonation test were put in place to secure the safety of materials in normal operations.
	Who/what was involved	In connection to the possible most credible scenario, the key actors in connection to the direct causes are some subcontractors that were in charge of the AN waste and other chemical materials waste. Indeed, there was a bin of waste of chlorinated materials manufactured on site possible poured on the storage of AN waste, which were off-specification (no conformity to quality standards, tests and start-ups of the unit,…).
	Place	The plant was settled on the border of the river Garonne, one of the fifth biggest rivers in France.
	Context of event and system (general environment, topography, weather)	On the side of the river the ground was flat and made of silt. The underground alluvia water was a few meters under the plant (which can be seen in Figure 3, taken a few days after the explosion). On the other side there was a hill of 50 to 100 meters high, which effected the overpressure propagation. At 10:17, 21st of September 2001, the atmospheric conditions were stable.
	Sector involved	The plant was a chemical industry plant, in charge of manufacturing AN for explosives and fertilizer purposes but also manufacturing other chemical compounds.
Type of event	Content aspects	The manufactured chemicals in the plant were mainly ammonium nitrate, ammonium nitrate-based fertilisers and other chemicals including chlorinated compounds.
	General or macro description of plant or system involved	The explosion took place in a warehouse, located between process parts, storage and packaging areas for AN (ammonium nitrate). It was used as a temporary storage of ‘off-specification’ AN (‘downgraded’ AN). The Grande Paroisse company’s factory is situated on a 70 ha site to the south of Toulouse about 3 km from the centre of the city, on the left bank of the Garonne (see next figure).

Item	Explanation	Toulouse Disaster
		It employed 470 people. The factory produced fertilisers and a variety of chemical products. From natural gas, the factory produced: • ammonia (1150 tons/day) • nitric acid (820 t/d) • urea (1,200 t/d) • ammonium nitrate The production of ammonium nitrate consisted of: • 850 t/d of granules for fertilisers, • 400 t/d of granules for industrial use (mainly for the manufacture of explosive “foul” nitrate used in quarries and civil engineering) • nitrogenous solutions (1,000 t/d). The factory also produced various other chemicals: melamine (70 t/d for the manufacture of resins), formalin, chlorinated derivatives, adhesives, resins and hardeners. The factory stored considerable amounts of hazardous substances, the maximum permitted values being: ammonia: a tank containing 5,000 t, a 1,000 t sphere in cryogenic form and 315 t stored under pressure. chlorine: 2 x 56 t tankers ammonium nitrate: 15,000 t in bulk, 15,000 t in sacks and 1,200 t of hot solution. On the 21st of September, on the Southern area of the site there were also 4 tankers of chlorine and 20 tankers of ammonia.

Item	Explanation	Toulouse Disaster
		 *The AZF plant with the city of Toulouse in the backstage* Source: INERIS, MEDDE
	Local or micro description of process/system involved in accident	*Ammonium Nitrate manufacturing* The synthesis of ammonium nitrate (NH_4NO_3) needs to be performed from two raw materials - ammonia (NH_3) and nitric acid (HNO_3) - through an exothermic reaction. The hot AN aqueous solution obtained after this first step is concentrated before being cooled in a pilling tower. By easy modifications of this synthesising and cooling process, several kinds of AN-based products can be obtained, each of them having their own use: the two most well-known are as fertiliser (called “fertiliser grade” if satisfying to EC criteria) and as a component in explosive preparations (called “technical grade”). Moreover, AN-based product is also used for the production of some special chemicals, e.g. N_2O. AN is a crystalline white hygroscopic solid and acts as an oxidising agent. It has a high solubility in water and its molecular weight is 80 g/mol. Its melting point is 169,6°C and its boiling point is 210°C. *Hazards of Ammonium Nitrate* Pure AN is stable under normal handling and storage conditions. However, as the detonation properties of AN were so poorly misunderstood before the 1950s, explosions of stored solid AN-bases products occurred. Since then there have been a reduced number of explosion accidents as changes were made to the production process.

Item	Explanation	Toulouse Disaster
		The major explosion in Toulouse was a severe reminder of the inherent hazards associated with the handling and storage of AN. The importance of an appropriate explosion risk assessment methodology for use in Land-Use Planning for the production of AN is again highlighted. *The off-specification Ammonium Nitrate storage* The materials stored in the temporary storage of 'off-specifications' AN ('downgraded' AN), were aimed to be recycled in AN-based binary / ternary fertiliser process. These materials that do not fulfil the requirements (under-sized, downgraded, start-ups and shut-downs, return from customers, production tests as new additives) from different process units of the site (fertiliser and technical grade), did not have clear defined properties. Dirty products may come from the cleaning of these units. The investigations of INERIS led to a final estimate of 390 to 450 tons of 'off-specification' AN stored the day before the explosion and were able to retrace the entries before the morning of 2st September 2001.
	Structural aspects	*History of the chemical plants* In the 17th century, there was an explosives (black powder) factory on the île de Tounis that was then obliged to relocate after a series of accidental explosions (1781, 1816, 1840). In order for the factory to carry on benefiting from the energy provided by the river, and at the same time moving it away from the growing city, it was relocated towards the South. Between 1914 and 1918, the national explosives factory underwent an exceptional period of growth, spreading along the left bank of the Garonne and swallowing up land as far as the Southern limit of the Commune of Toulouse. In 1924, the ONIA (Office National de l'industrie de l'azote/National Nitrogen Industry Board) was created, as a result the production of nitrogenous fertilisers was separated from the explosives department. The ONIA then became APC then CDF Chime-AZF, SCGP and since 1991 Grande Paroisse which now forms part of ATOCHEM and therefore part of the TOTAL FINA ELF Group. SNPE was created by a law that was passed on 8th of March 1971, which transformed part of the Explosives Department and a branch of the Ministry of Defence, into a national company. The manufacture of gunpowder on the Toulouse site was halted in 1973 and since that time SNPE's activities on the site have been directed toward

Item	Explanation	Toulouse Disaster
		chemicals. Tolochimie was set up in 1961, formed part of the Rhône Poulenc Group and, since 1996, has been incorporated within the SNPE Group.
	Cultural aspects	Limited data was collected and analysed in that purpose. The chemical plant has however a long history and was managed in the last decade by a petrochemical group (ELF and then TOTALFINAELF which became later Total).
	Contextual aspects	The plant belonged to a multinational of the petrochemical industry (TOTAL FINA ELF). It was on a market of fertilizer with low added value and margins. The plant was located within the suburbs of a major city of France (Toulouse, that had 750 000 inhabitants).The event occurred 10 days after the 9/11th which influenced the very first minutes of the emergency response.
	Area and stakes vulnerability to the system	History of the Land Use Planning (LUP) at Toulouse near the plants The chemical plant settlement and urban development's around them had a long history. Finally, the plant settled at the beginning of the 20th century 3 km south from the centre of Toulouse city but was overwhelmed by the development of urban area in the fifties and sixties when the priority was to build flats and schools to follow the economic development of that period. From 1914 to 2000, the Toulouse city population multiplied by factor of five and ten in the Toulouse urban area (750 000 inhabitants in the urban area in 2000). In the seventieth century an explosive factory was built close to Toulouse and in 1840, it had a non-aedificandi zone. Three accidental explosions later and due to the urban pressure, the factory was removed twice out of the inner city and the latest move occurred at the beginning of the 20th century. In 1928, another aedificandi zone was proposed but could not cope with the urban development. In 1947, another LUP was approved but not applied because of the development requirements. The urgency was to build flats, universities and roads, see Figure 2. In 1976 a law for the authorisation or declaration of installations on industry was passed. Due to this law and following the Seveso shock, the risk from the factory to the Environment and public health was raised in the EU. In 1983, safety studies were started and LUP was applied for and approved in 1989. The urban development was controlled (no new risk with no new exposure of new buildings or activities, but no retroactive force) but the situation was understood to be risky. After the Seveso II Directive in 1996, the local plan finally took a clear position advocating for a long-term change.

Item	Explanation	Toulouse Disaster
		 *The location of the AZF plant, the crater, the motorway and the city of Toulouse* Source: INERIS, MEDDE
Investigations known		As a reminder, five authorities carried out 5 separate inquiries with different perspectives: • The Inspection Générale de l'Environnement (IGE) issued a public report (in which, some technical investigations were led by INERIS) on 24th October 2001 ordered by the French Ministry of Environment, Yves Cochet, • The Labour Inspection (Labour Ministry) made an investigation (march 2002), • The TotalFinaElf Group also carried out an investigation and reported in march 2002, • The Police and Justice gave a preliminary press report on June 2002, • The CHSCT (health, safety and working conditions committee) of the employees of the site subcontracted an investigation to Cidecos-conseil (June 2002) • Also parallel actions were launched by the authorities: • A Parliament Commission (Loos, Le Déaut et al) that led a large number of visits and interviews at a national level issued a public report in February 2002, • The Environment Ministry organised a national debate on industrial safety after Toulouse, led by Philippe Essig who issued a public report (February 2002),

Item	Explanation	Toulouse Disaster
		• The Institut National de Veille Sanitaire (InVS) was mandated to conduct an epidemiological survey and to monitor the health effects of the disaster (acute, and long term).
Magnitude of damage to system involved	Damage	Due to the vicinity of the plant within a 750 000 inhabitants city in 2001, the effects to people and the damages were very large and evolved from a major accident to a disaster: • The damages were very large, for instance 27 000 houses were damaged. • The total cost of damages estimated by insurers was between 1500 million euros to 2500 million euros. • Several companies were shut down for days.
	Victims	Due to the vicinity of the plant within a 750 000 inhabitants city in 2001, the effects to people and the damages were very large and evolved from a major accident to a disaster: • The explosion caused 30 fatalities, 21 in the plant and 9 outside (note that according to some newspapers the figures were higher) • Estimates from the InVS and the local committee for the sanitary watch indicated 3 years after the explosion, that 10 000 people were wounded (body) and roughly 14 000 people have asked for medical treatment for post traumatic acute stress in the months after the explosion. Officially, 6 months after the disaster, 2242 injured were recorded.
	Magnitude of damage	The extent of damage was very large
	Down time	The plant was finally shut down by the CEO of TOTALFINAELF petrochemical group and the decision of the Prime Minister of the time, Lionel Jospin.
	Event management, chronology, emergency rescue measures, crisis management	In the following days of the 21st of September, 1570 firemen and militaries, 950 policemen were involved in the emergency response and housing monitoring. Twelve hours after the explosion, there were 300 vehicles and 900 firemen. The problem was that they arrived without any plan or discussion by phone, as the classical phone lines were partly destroyed and the mobile phone network was saturated. In those kinds of situations, the experience of forest fires should help to organise the arrival of little groups of vehicles. The state emergency plan was however efficient.

Item	Explanation	Toulouse Disaster
		The internal and external emergency plans were not prepared for this scenario and its severity. Indeed, the explosion scenario was not considered. Scenarios of toxic releases of phosgene, chlorine and ammonia have been used to design the emergency plan for the 3 main plants of the chemical platform. The INESC (Institut National d'Etudes de la Sécurité Civile) stated that the documents were not of much use. The previous training helped the firemen and others to have good judgement. However, the first firemen were not protected with adequate PPE for any toxic clouds and were not equipped with any devices to detect these toxic gases. To get information to the public was a problem as the warning buzzer was not working and the radios were out. Also the instructions given to stay inside their houses due to the toxic cloud made no sense with broken windows. The communication network should be designed to have a separate network for crisis management.
	After the event, aftermath actions to restore, repair, de-pollution, compensate	According to the Fédération Française des Sociétés d'Assurance, 75 000 damages (7 000 were from business activities) were notified to insurers, 10 % of whom were companies that counts for 90 % of the compensation payments. Approximately 30 000 dwellings and 5 000 vehicles were damaged. According to the insurers for TotalFinaElf company, the company Equad, six months after the event, had treated 70% of the 20 000 notifications made by other insurers. There was still 60 000 cases to analyse. One year after, the insurers had compensated 50 000 cases with 25 000 without any expertise (if damages were under 1500 euros). 4 000 cases of injured people have been registered after the first year. Some class actions are running at the time for better compensation of injuries. Notice that in this case, TotalFinaElf accepted (and was able) to compensate damages before the trial.
	Speed/pace of recovery completely back into business	The plant was shut down and dismantled. The site was depolluted and converted in other activities (research). The neighbouring plant SNPE, using hazardous chemicals like phosgene was shut down too by the Prime Minister (Jospin). It took several months for some neighbouring plants (Isochem) to repair, restart and obtain the agreement of authorities.

Item	Explanation	Toulouse Disaster
Sources of information	investigation report	Several stakeholders prepared several reports. As a reminder, five authorities carried out 5 separate inquiries with different perspectives: • The Inspection Générale de l'Environnement (IGE) issued a public report (in which, some technical investigations were led by INERIS) on 24th October 2001 ordered by the French Ministry of Environment, Yves Cochet, • The Labour Inspection (Labour Ministry) made an investigation (march 2002), • The TotalFinaElf Group also carried out an investigation and reported in march 2002, • The Police and Justice gave a preliminary press report on June 2002, • The CHSCT (health, safety and working conditions committee) of the employees of the site subcontracted an investigation to Cidecos-conseil (June 2002) Also parallel actions were launched by the authorities: • A Parliament Commission (Loos, Le Déaut et al) that led a large number of visits and interviews at a national level issued a public report in February 2002, • The Environment Ministry organised a national debate on industrial safety after Toulouse, led by Philippe Essig who issued a public report (February 2002), • The Institut National de Veille Sanitaire (InVS) was mandated to conduct an epidemiological survey and to monitor the health effects of the disaster (acute, and long term)
	Publication	See last chapter for detailed references
Communication of recommendation	Confidential reports	Not known.
	Public reports	See last chapter for detailed references
	Courses, training	Not known.
Dimension		
Content	Items to be improved	A major lesson was the lack of Seveso II regulatory overview on off-specification AN. The regulation was updated with new categories on off-specification AN.

Item	Explanation	Toulouse Disaster
		The Seveso Directives also had some limitations. The risk zero faith was down and the belief in the control given with Seveso II Directives implementation was lost after Enschede, Toulouse and now Buncefield. A Seveso III Directive has been published. The LUP procedures have been initiated too late and had little or no retroactive force. As a consequence, typical high-risk situations of the 20th century of industries and urban areas could not be reduced. LUP procedures were constrained by this situation. The chosen scenarios and safety perimeters for LUP and emergency perimeters were too small compared to the hazardous potential or worst cases. They reflected the pressure of the urban area. Indeed, one of the main conclusions is that controlling major accident hazards by reducing the risk on-site is not sufficient enough to promote a sustainable development for both industry and urban areas without Land Use Planning in the next decades. This conclusion was shared by the European Parliament, which has asked for regulation and policy changes within EU member states. Other main lessons were drawn upon governance tools (communication and participation of stakeholders other than industry, State and experts and acceptability criteria unclear), safety overview by internal workers of the Health and Safety Committee and external inspectors from the control authorities. Another lesson was the subcontracting of some activities resulted in a loss of risk knowledge and control.
Structure	Organisational structure	The plant was shut down. It is not known if TOTAL changed its safety structures. The inspection of the control authority was granted a hiring plan to move from 700 Inspectors to 1400.
Culture	Change of culture	This is hard to tell as there are no studies on the subject. The plant was closed.
	Change of behaviour	This is hard to tell as there are no studies on the subject. The plant was closed
Context	Supporting conditions	Regulations were changed on AN in Europe. Regulation on major hazard risks (Seveso II Directive) was complemented by a new law requiring several measures for upper tier Seveso II plants (LUP around sites, governance principles with public information, internal workers through health and Safety Committee overview, insurance and compensation) Inspections by control authorities were strengthened.

Item	Explanation	Toulouse Disaster
	Development of knowledge	AN properties knowledge was updated and regulation was changed. LUP regulation became more stringent.
System level involved		
Micro		Storage of off-specification AN is revised according to the new classification of materials.
Meso		Employee involved in overview or risk report Better Control of sub-contractors.
Macro		LUP regulation changed Governance around plants
Depth of learning		
Optimize		The main recommendations were to: • update French and Seveso II regulation, about off-specification AN • update Seveso II Directive (Seveso III), • change risk assessment procedures, to keep deterministic approach insights but integrate probabilities, • harmonise risk assessment and safety study procedures and control, between sites, hazardous goods, fixed plants and between chemical and pyrotechnic plants • review LUP procedures, • review public information and consultation procedures for LUP, • integrate employees in decision-making processes and review processes of safety management, • control subcontracting and interim work with regard to hazardous activities, • improve compensation of victims, • increase the control authorities means : number of inspectors, expertise • increase budget for third-party expertise such as INERIS, IRSN.
Adapt		

Item	Explanation	Toulouse Disaster
Innovate		
Impact		
Changes identified		The findings, the lessons and the proposal for new prevention measures, were used by the French Authorities to implement a new law issued the 30th of July 2003. The Decrees and methodological tools came later after 2005. Some lessons were implemented also at the European Union level within Seveso II Directive (in particular off-specification AN were not covered by regulations such as fertiliser and technical grade that stick to some standards and norms). The updating of the Seveso II Directive was adopted in view of classifying two new categories: "off-spec." materials (unclassified AN), taking into account one of the lessons of Toulouse's explosion and AN based composite fertiliser because of other accidents in EU with self-sustaining decomposition. The new French law 2003-699, focuses on several key points to prevent major accidents on Seveso II sites (high threshold): • Improving regulation by information and governance principles: law measures to enable involvement in the decision making process of public, employees and subcontractors, • Defining new land use planning rules that deal in particular with potential hazardous situations: in addition to restrictions for future construction, it introduces retroactivity principle and defines 3 safety perimeters around sites (area where buildings would be expropriated, areas where owners will be given to force the city to buy real estate, areas where city as priority to buy when owners want to sell). • Improving financial compensation for victims after major accidents • Harmonise regulation requirements in the transport of hazardous goods and areas such as ports and marshalling yards. • The aim of these measures was therefore not to change Seveso II Directive transposed in France, but rather to strengthen it on complementary dimensions of prevention layers or defence in depth principles.
Change/learning agent	Who/what takes care for follow up	Mainly the control authority
	Who/what keeps memory/knowledge alive	The regulator keeps memory into regulation but no actor specifically is in charge.
	Who/what keeps monitors	Mainly the control authority and internally the companies.

Item	Explanation	Toulouse Disaster
	effectiveness	
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	Regulation enforcement and full implementation of LUP procedures around Seveso upper tier sites took several years. The Law was published in 2003, its Decree in 2005, the LUP procedure were started and most LUP were fulfilled 10 years after the disaster.
Change of investigation process		No change if we consider the regulation for investigation.
Evaluation of accident and follow up		
	Specific experiences/observations by ESReDA group Are changes sustained	
References		
Communication of findings, recommendations	Report safety board/special commission Report company	Several stakeholders prepared several reports. As a reminder, five authorities carried out 5 separate inquiries with different perspectives: • The Inspection Générale de l'Environnement (IGE) issued a public report (in which, some technical investigations were led by INERIS) on 24th October 2001 ordered by the French Ministry of Environment, Yves Cochet, • The Labour Inspection (Labour Ministry) made an investigation (march 2002), • The TotalFinaElf Group also carried out an investigation and reported in march 2002, • The Police and Justice gave a preliminary press report on June 2002, • The CHSCT (health, safety and working conditions committee) of the employees of the site subcontracted an investigation to Cidecos-conseil (June 2002)

Item	Explanation	Toulouse Disaster
		Also parallel actions were launched by the authorities: • A Parliament Commission (Loos, Le Déaut et al) that led a large number of visits and interviews at a national level issued a public report in February 2002, • The Environment Ministry organised a national debate on industrial safety after Toulouse, led by Philippe Essig who issued a public report (February 2002), • The Institut National de Veille Sanitaire (InVS) was mandated to conduct an epidemiological survey and to monitor the health effects of the disaster (acute, and long term)
	Report inspectorate/third party	Inspection Generale De L'environnement : François Barthelemy (Ingénieur Général des Mines), Henri Hornus (Ingénieur en chef des ponts et chaussées), Jacques Roussot (Contrôleur général des armées en second), membre de l'IGE, et Jean-Paul Hufschmitt (Ingénieur en chef de l'armement, Inspection des Poudres), Jean-François Raffoux (Directeur scientifique de l'INERIS). Usine de la société Grande Paroisse à Toulouse, Accident du 21 septembre 2001, rapport de l'Inspection Générale de l'Environnement conjoint avec l'inspection des poudres et avec le concours de l'INERIS, 24 Octobre 2001, affaire n°IGE/01/034 , IGE Main Report to download on http://www.ecologie.gouv.fr: Loos F., Le Déaut J-Y., et al, 2002, Rapport N°3559 fait au nom de la commission d'enquête sur la sûreté des installations industrielles et des centres de recherche et sur la protection des personnes et de l'environnement en cas d'accident industriel majeur, enregistré le 29 janvier 2002 à l'Assemblée Nationale, Constitution du 4 Octobre 1958, onzième législature Total internal investigation report : Macé de Lépinay A., Peudpièce J-B., Fournet H., Motte J-C. , Py J-L. Domenech J., Lanelongue F., 2002. "Commission d'enquête interne sur l'explosion survenue le 21 septembre 2001 à l'Usine Grande Paroisse de Toulouse, point de situation de travaux en cours à la date du 18 mars 2002" *named in this paper the TotalFinaElf internal investigation report* Essig P., 2002, "Débat National sur les Risques Industriels, Octobre-Décembre 2001, Report to the Prime Minister, January 2002 Several report by the InVs (French National Institute on Health Monitoring), http://www.invs.sante.fr. Report of FFSA : Un an après la catastrophe de Toulouse, l'expérience et les propositions de la FFSA

Item	Explanation	Toulouse Disaster
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Article	Merad M., Dechy N. (2011), Risk governance for sustainable territories: the French case and some challenges. Jounal of Institut de Seguretat Pública de Catalunya (ISPC), http://www20.gencat.cat/ Hoyle B., Dechy N. (2008), The Toulouse and Texas City disasters: comparing their consequences, investigations, and lessons learned ; Proceedings of the American Chemical Safety conference/Aiche 2008 Dechy N., Salvi O., Rodrigues N., Merad M. (2006), The Toulouse disaster and the changes in managing risks related to hazardous plants in France, Proceedings of the VGR 2006 5th Conference on risk assessment and management in the civil and industrial settlements, 17th-19th October 2006, Pisa, Italy. J.M. Ham, J.J. Meulenbrugge, N.H.A. Versloot, N. Dechy, J-C. Lecoze, O. Salvi, (2006), A Comparison between the Implementations of Risk Regulations in The Netherlands and France under the Framework of the EC SEVESO II Directive, Proceedings of the 21st annual CCPS international conference, 23-26th April 2006, Orlando, FL, USA N. Dechy, S. Descourrières, O. Salvi, (2005), - The 21st september 2001 disaster in Toulouse : an historical overview of the Land Use Planning – Proceedings of the 28th ESReDA Seminar on the Geographical Component of Safety Management: Combining Risk, Planning and Stakeholder Perspectives - Karlstad University, Sweden - 14-15 June 2005 Salvi O., Dechy N., (2005) - Toulouse disaster prompts changes in French risk management - Environment and Poverty Times - January 2005 - 03 - a periodic publication by UNEP/GRID-Arendal (United Nations Environment Program) - Special Edition for the World Conference on Disaster Reduction - January 18-22, 2005, Kobe, Japan Dechy N., Bourdeaux T., Ayrault N., Kordek M.-A., Le Coze J.-C., (2004), First lessons of the Toulouse ammonium nitrate disaster, 21st september 2001, AZF Plant, France, Journal of Hazardous Materials 111 - July 2004 (special issue on JRC-ESReDA seminar on Safety accident investigation, Petten, the Netherlands, 12-13 May 2003) Dechy N. , Mouilleau, Y. 2004, « Damages of the Toulouse disaster, 21st september (2001) », Proceedings of the 11th International Symposium Loss Prevention 2004, Praha, 31 May - 3 June 2004. - *Re-Published in the Loss Prevention Bulletin n°179 of October 2004 (Icheme).* Mouilleau Y., Dechy N., (2002). « Initial analysis of the damage observed in Toulouse after the accident that occured on 21st of september on the AZF site of the Grande Paroisse company », International ESMG Symposium, Nürnberg, Germany 8-10 October 2002, on Process safety and industrial explosion protection

Conclusion

Safety lessons

- Risk analysis procedure and scenario selection for land use planning is a risky activity when trying to balance worst case approach, integrate the positive effects of safety barriers and the structural limits such as given by the history of LUP nearby : it is the reason why it should become more transparent and debated with workers, third party expert, control authorities, neighbours within a governance framework
- Worst case scenario approach should not be overwhelming to other scenarios and phenomenon which are more likely and need preventive measure
- Probabilistic approach are complementary to deterministic approach and where introduced for communication reasons but can lead to perverse effects of not enhancing the safety barriers
- Historical vulnerability leads to unacceptable risk : there is a need for retroactive power
- Ammonium nitrate properties showed knowledge deficiencies : safety margins are negotiated with business margins
- Regulation gaps did exist at the EU level (Seveso II, AN regulation coverage) and French level (on AN) : reducing risk on site is not sufficient to reduce risks ; it requires to reduce vulnerability around the plant
- Control gaps did exist with the lack of oversight by inspectors

Promoters for learning

- Several stakeholders launched their investigation which creates a diversity of information sources, learning purposes which can enrich the lessons, their multidimensional aspects, stimulate the debate to the controversy, but also make harder to get the global view
- In parallel to investigations, some other learning the lessons and engineering change tools were useful with a parliament commission, a national debate.
- The consequence of an accident may require a long term monitoring to be fully determined (e.g. impact on health, environment,…)
- Research work was available to complete the lessons and for the engineering of changes

Barriers for learning

- Retroactive power to reduce LUP vulnerability: who is empowered to take hard decision to close a unit/plant or expropriate neighbours? More than 10 years after the implementation of these principles, little changes were implemented but not big changes ; Sharing the burden of the cost of risk reduction measures between stakeholders is a complex and long lasting mechanism
- Human and organisational factors analysis was not performed and likely lessons were missed

Comments

- It is possible to learn some lessons and implement some changes (regulatory, and others) without knowing the direct causes of the accident 10 years after!
- The EU level of regulation may limit the lessons learning (minimum agreed regulation level in EU, complement but not revise the EU regulation in one country)

A.3 Crash of the ValuJet Flight 592, DC-9-32, USA

Analysis

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
Description event (system involved)		
Description accident	Short description	Crash of ValuJet DC-9-32, flight 592, into the Everglades near Miami, Florida (May 11, 1996).  Source picture: http://nl.wikipedia.org/wiki/ValuJet-vlucht_592.
	What has happened (description, pictures etc.) What agents (the damaging energy source e.g. Nuclear hazard)	On May 11, 1996, at 2PM (Eastern Time), a Douglas DC-9-32 crashed into the Florida Everglades about 10 minutes after take-off from Miami International Airport. The airplane was being operated by ValuJet Airlines, Inc., as flight 592 and its plan destination was the Atlanta International Airport, Georgia. There was no survivor: one hundred and ten persons (5 crews and 105 passengers) were killed. The direct probable cause of the accident was a fire in the airplane's class D cargo compartment. At that time class D cargo compartments were not equipped with fire detectors[2]. The fire was initiated by the actuation of

[2] *In Class D design fire suppression is supposed to be accomplished by sealing off the hold from outside air. Any fire in such an airtight compartment will in theory quickly exhaust all available oxygen and then burn itself out. As the fire suppression is accomplished without any intervention by the crew, such holds are not equipped with smoke detectors.*

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
		one or more oxygen generators being improperly carried as cargo. The fire was certainly accelerated and strengthened by 3 plane tyres located right next to the boxes containing oxygen generators. The fire was so intense that within minutes it burned through passengers' cabin and cockpit.
	How has it happened, what were circumstances	
	Why did it happen? Direct causes	Initial causes of the event can be traced back end of January 1996 and early February 1996 when ValuJet purchased three McDonnell Douglas (2 MD- 82s and 1 MD-83). All three airplanes were ferried from the locations where they had last been operated to the Miami maintenance and overhaul facility of the SabreTech Corporation for various modifications and maintenance functions. One of the maintenance tasks requested by ValuJet was the inspection of the oxygen generators on all three airplanes to determine if they had exceeded the allowable service life of 12 years from the date of manufacture. In March 1996, SabreTech technicians removed, from two airplanes, the canisters which were either approaching or had passed their expiration dates[3]. At that point, the canisters were to have been disabled and disposed of. One step of the removal procedure states: "*Warning* […] *when removing unit,* ***install safety cap***[4] *over* primer." The safety caps that were required to be installed on the chemical oxygen generators were considered "peculiar" expendables because they were not routinely carried in SabreTech's inventory. (The removal of chemical oxygen generators was an infrequently performed task because of the generators' 12- year life limit.) It appears from the service agreement that ValuJet was responsible for supplying peculiar expendables to SabreTech. However, ValuJet did not ensure that the required safety caps were obtained and installed. On the other hand, SabreTech never specifically requested that ValuJet supplies it with safety caps. Safety caps were not installed over the removed canisters. Instead, some mechanics tried either to empty the oxygen generators or cut the lanyards from the generators in order to prevent any accidental discharge. After the removal, there is no indication on the canisters about their dangerousness. Furthermore, green tags, labelled "Repairable", were attached on some of them. It has to be noted that according to the contract between ValuJet and SabreTech, SabreTech agreed "to credit ValuJet the amount of $2,500 per calendar day as liquidated damages for each day the aircraft is delayed beyond the redelivery date"[5]. As the ValuJet deadline approached,

[3] *This was the first time ever that the SabreTech Miami facility had performed this task.*
[4] *Emphasis added.*
[5] *Yet, two planes were delayed (1 day et 13 days).*

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
		personnel worked in shifts, day and night, and sometimes through the weekend as well. SabreTech also hired contract mechanics from other companies on an as-needed basis[6]. The mechanics signed off on the work cards[7]. The SabreTech inspector who signed off the “Final Inspection” block of the non-routine work card for N802VV, in being aware that the generators needed safety caps. He further stated that he brought this to the attention of the lead mechanic on the floor at the time, and was told that both the SabreTech supervisor and the ValuJet technical representative were aware of the problem and that it would be taken care of “in stores.” The removed canisters were put in cardboard boxes and stored in the ValuJet section of SabreTech’s shipping and receiving hold area, once again with no specific indication about dangerousness of materials. A few days before the accident a SabreTech manager told the shipping clerk to clean up the area and get all the boxes off the floor in preparation for an upcoming inspection by a future potential customer. The shipping clerk prepared to send the oxygen generators home to ValuJet headquarters, in Atlanta. After sealing the boxes he applied address labels and ValuJet company-material stickers (COMAT[8]), and wrote "aircraft parts." As part of the load he included two large main tires and a smaller nose tire. The next day he asked a co-worker to make out a shipping ticket, and to write "oxygen canisters—empty" on it[9]. The cargo stood for another day or two, until May 11, when the SabreTech driver had time to deliver the boxes across the airport to Flight 592. There the ValuJet ramp agent accepted the material, though federal regulations forbade him to, even if the generators were empty, since canisters that have been discharged contain a toxic residue, and ValuJet was not licensed to carry any such officially designated hazardous materials. He discussed the cargo's weight with the flight 592 co-pilot, who also should have known better. Together they decided to place the load in the forward hold, where ValuJet workers laid one of the big main tires flat, placed the nose tire at the centre of it, and stacked the boxes (containing oxygen generators) on top of it around the outer edge, in a loose ring. They leaned the other main tire against a bulkhead. It was an unstable arrangement. No one knows exactly what happened then, but it seems likely that the first oxygen generator ignited during the loading or during taxiing or on take-off, as the airplane climbed skyward.

[6] It turned out that three fourths of the people on the project were temporary outsiders.
[7] Meaning “work completed”.
[8] Company-owned material.
[9] He wrote "Oxy Canisters" and then put "Empty" between quotation marks, as if he did not believe it.

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	Why did it happen? Root causes	All these initial causes leading to the disaster are embedded in pathogenic organizational factors: the root causes: **Inadequate safety culture and inappropriate daily safety practices**: lack of work preparation (e.g. absence of safety caps); no risk analysis prior to implementation of work; signature of work cards showing a "notarial vision" of the safety (tick the box mentality); lack of training regarding removal of oxygen generators; unawareness about labels/tags; ineffective communication; poor handling (by ValuJet) of the whole outsourcing process (cascading contracts); …, **Weaknesses of the Operational Feedback System**: between 1986 and 1996, seven cases of oxygen generators untimely actuation while they were in a plane cargo compartment. No one led to significant improvement of securing (actuation of) oxygen generators, **Production syndrome**: context competition and deregulation in the aviation sector; quick and massive growth of ValuJet (created in 1993 with a 4 million US $ capital, it reached 21 million US $ of profit in 1994, value of share increase of 800% in one year, fleet increase of about 20 planes per year10); cascading outsourcing leading to a lack of global vision of the whole process by ValuJet; top management of ValuJet and of SabreTech mainly focused on production performance11 (versus safety performance), **Sloppy Safety Authorities**: till 1995 number of FAA audits was disproportionate[12] in relation with numbers of violations recorded for ValuJet. End of 995, a specific audit recommended to "re-certificate" ValuJet (meaning that it be grounded and started all over again). The audit report was "buried" at the FAA headquarter till the accident. Furthermore, we have to note that other events dealing with smoke/fire in cargo compartment with no such dramatic outcome already occurred. Thus, on February 3, 1988, an American Airlines flight experienced an in-flight fire (passengers and crew members safely evacuated the plane). The NTSB[13] found that an oxidizer and a sodium -based mixture had been shipped and loaded into cargo compartment of the airplane and determined that the chemicals were improperly packaged and were not identified as hazardous materials. After FAA reacted negatively to the recommendations that NTSB made about smoke detectors and fire extinguisher in Class D cargo compartment, after its events investigations[14].

[10] Average age of planes: 26 years (to be compared to 8 years for other American companies).
[11] ValuJet flights were cheap and full, and its stock was strong on Wall Street!
[12] I.e. too little.
[13] National Transportation Safety Board.
[14] After the accident, in 1997, the FAA issued required the installation of smoke detection and fire suppression systems in all class D cargo compartments. The airline industry would have 3 years from the time the rule becomes final to meet the new standards.

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	Other root causes	
	When did happen? Timeline of main events	
	Historical events	The disaster is rooted in "History" and mainly involves three parties: SabreTech[15], for improperly packaging and storing hazardous materials, ValuJet, for not supervising SabreTech, and The FAA[16], for not mandating smoke detection and fire suppression systems in cargo holds.
	Place Context of event and system (general environment, topography, weather)	
	Sector involved	Aerospace transport accident
Type of event	Content aspects: primary activity, operational aspect involved	Transport of oxygen generator, hazardous material.
	general or macro description of plant or system involved	No detection system in cargo space
	Local or micro description of process/system involved in accident	

[15] SabreTech was a maintenance facility with which ValuJet had an ongoing contractual relationship for line maintenance and heavy aircraft maintenance.
[16] Federal Aviation Administration: amongst its major roles, FAA is in charge of regulating U.S. commercial space transportation and regulating air navigation facilities' geometry and flight inspection standards.

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	Structural aspects: e.g. Relevant organisational structures, infrastructure, buildings etc.	Outsourcing chain of contractors
	Cultural aspects: personal safety culture company safety culture	Culture of operation companies: Production oriented versus safety oriented Culture of Safety/Control Authority: Notarial vision of safety versus vision of effective safety
	Contextual aspects e.g. Industrial safety culture	At ValuJet, so much work was farmed out to temporary employees and independent contractors that ValuJet was sometimes called a “virtual airline”. Overview contracting program Interpretation of requirements Company overgrowth (in a –too– short duration)
	Area and stakes vulnerability to the system	
Magnitude of damage to system involved	Scale and kind of property damage	One plane (McDonnell Douglas DC-9-32) destroyed
	Victims	110 deadly victims
	Magnitude of damage financial environmental	(small) environmental pollution in the Florida everglades;
	Down time	ValuJet fleet grounded for about 3 months (FAA decision). ValuJet was allowed to resume flying with a standardized fleet of 15 planes (to be compared to 52 planes before the accident)[17];

[17] *Fall of ValuJet share value (90%).*

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	After the event, aftermath actions to restore, repair, de-pollution, compensate Speed/pace of recovery completely back into business	In 1997, ValuJet merged with AirTran Airways. Although ValuJet was the nominal survivor, the ValuJet name was so tarnished by this time that it was scrapped in favour of the AirTran name; 3 SabreTech employees were fired; 2 Facilities of SabreTech (Miami and Orlando) shut down; SabreTech was criminally prosecuted for its role in an American airline crash. As a result of few trials it was sentenced to penalties more than 1 million US $. The Head of FAA Safety Department was fired; The Head of the FAA resigned.
Investigations known	By safety board/special commission involved Public authorities By companies involved	NTSB
Dimension		
Content	Elements of the primary process to be improved	Fire Installation of smoke detectors and fire extinguishers; in cargo space airplane Accident precursors to be taken seriously Training regarding packaging, labelling and transportation of hazardous materials;
Structure	Organizational structure	Relationships and communication between an ordering party and its contractor's); Monitoring and control of outsourced work;

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	Technological structure	Improvement of Operational Feedback systems and processes.
Culture	Change of culture Change of behaviour	Promote Safety Culture (to counterbalance production culture); Promote effective safety culture (opposed to notarial safety). Reappraising of Cost/Benefit analyses[18].
Context	Supporting conditions Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system	
System level involved		
Micro	Solutions at company level, subcontractors at company level Timeline of implementation of solution months/years	Maintenance procedures. Maintenance training. Fleet immobilization right after the accident Shut down of maintenance facilities
Meso	Actions of safety authorities, what actions?	FAA NPRM regarding implementation of smoke detection and fire suppression systems

[18] *The refusal of the FAA to take into account the NTSB recommendations about smoke detectors was based on a cost/benefit analysis.*

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	Timeline of implementation of solution months/years	Decision made by American airlines; ban on oxygen generators transportation, installation of smoke detectors in cargo compartment.
Macro	EU-level development, directive or standard being changed or research program being started or... Timeline of implementation of solution months/years	New Federal regulation regarding transportation of oxygen generators and smoke detection within cargo compartment.
Depth of learning		
Optimize **Adapt** **Innovate**		New regulations
Impact		
Changes identified	What really changed	proposed rulemaking effective now? corporate image: new branding Collapse of one “agent” at fault (ValuJet) more homogeneous fleet
Change/learning agent	Who/what takes care for follow up	Company, FAA American airlines

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
	Who/what keeps memory/knowledge alive Who/what keeps monitors effectiveness	NTSB
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	
Change of investigation process		What was not changed: Quest/race for profits: production pressures are still alive and well in the aviation sector Tick the box mentality: the FAA is still focused on compliance to references
Evaluation of accident and follow up		
	Specific experiences/observations/discussion by ESREDA group Are changes sustained	
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission Report inspectorate/third party Company reports	NTSB (1997), In-Flight fire and impact with terrain – ValuJet Airlines Flight 592 – DC-9-32 – N904VJ – Everglades, near Miami, Florida – May 11,1996, Report PB97-910406 NTSB/AAR-97/06 DCA96MA054

Item	Explanation	Crash of the ValuJet Flight 592, DC-9-32
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Articles in journals, magazines, internet	Langewiesche, W. (1998), *Inside the sky: a meditation on flight*, Pantheon Books. Perin C. (2005), Shouldering risks. The culture of control in the nuclear power industry, Princeton University Press[19] Strauch, B. (2002), Investigating Human Error: Incidents, Accidents, and Complex Systems, Ashgate.
	Courses, training	
	Relevant links	

Conclusion

Incidents may lead to long processes with discussions amongst several authorities concerning the feasibility of identified safety solutions like smoke detectors in cargo spaces of airplanes.

Several paradigms about mission, accountabilities and remit of authorities concerned lead to diffuse power to drive changes necessary in the industry.

Comments

Possible learning barriers identified:

- Paradigm that safety relies on proper compliance to procedures leads to small array of solutions
- Production pressure leading to structural use of short cuts in decision making not being identified in term of drift into failure
- A narrow scope on separation of responsibilities hampers learning and cooperation in exchange of knowledge in production/service chain
- Paradigm in industry that cost benefit analysis is determining choice of preventive measures shifts attention to profitable solutions only
- Using old occurrences of accidents as basis for risk management may lead to neglecting potential high consequence accidents.

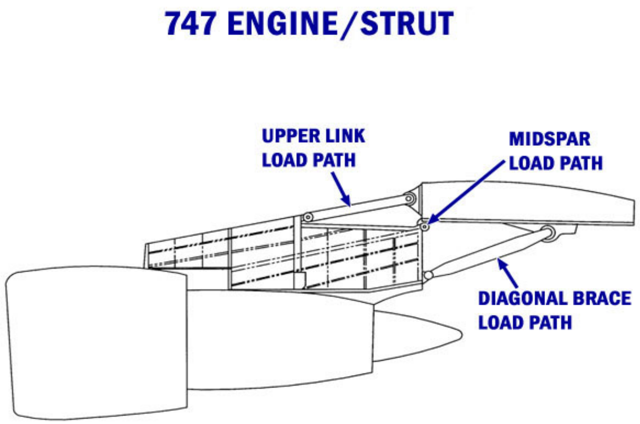
[19] *Flight 592 semantic related issue is tackled in this book.*

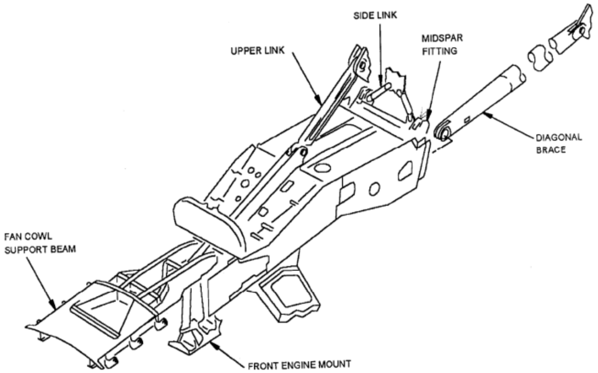
A.4 ElAl air crash Schiphol 1993 The Netherlands

Analysis

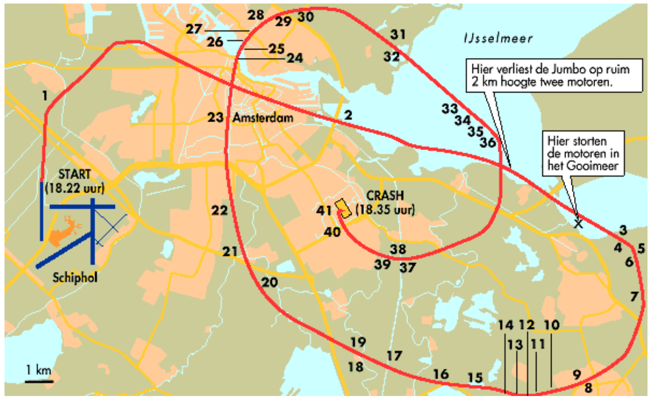
Item	Explanation	ElAl air crash Schiphol 1992
Description event		
Description accident	Short description	On 4 October 1992, at 18.22hrs ElAl flight LY 1862 departed from Amsterdam to Tel Aviv. During initial climb, the aircraft encountered an engine failure. The aircraft immediately declared an emergency and returned to Schiphol Airport. During reconfiguration for final approach, a split flap situation developed, after which the aircraft crashed in an apartment block in the Bijlmermeer near Amsterdam. In total 43 people died, of which 39 on the ground.
	What has happened (description, pictures etc.) What agents (the damaging energy source e.g. nuclear hazard)	At arrival at Schiphol airport, an aircraft spotter took photos of the plane. These photos were used later on during the investigation to verify whether or not the engines suffered already from misalignment during arrival.  Source: Studio LCP Assendelft During take-off, the aircraft encountered an engine surge in no3 engine, after which no 3 and no 4 engine separated from the right wing. The leading edge of the right wing was destroyed and several systems became inoperable, including flaps, slats and thrust on both engines 3 and 4. During turning

Item	Explanation	ElAl air crash Schiphol 1992
		back to Schiphol, the aircraft became uncontrollable and plunged into an apartment block. The apartment block was destroyed during impact, creating a huge fire due to the fuel on board. Rescue and emergency services entered the scene but were unable to recover anybody from the inferno.  Source: www.zero-meridian.nl  Source; www.zero-meridian.nl

Item	Explanation	ElAl air crash Schiphol 1992
	How has it happened what were causes	The immediate causes as established after the crash by the Dutch Aviation Council was the failure of a engine strut and fuse pin due to fatigue and corrosion.
	Why did it happen? Direct causes	The direct cause of the accident was identified as a mechanical failure of the engine pylon design.
	Why did it happen? Root causes	Several root causes were known at the time by the manufacturer, necessitating a revision of the ''safe separation'' principle of the engine from its mounting.
	Other root causes	The design of the 747 was an upgrade of the 707 design, extrapolating the concept of 'safe separation' into an unknown load spectrum. After an initial static load calculation based on FTA, after the event simulation on high capacity computers clarified an actual tenfold load as calculated previously.  Source: www.lessonslearned.faa.gov
	When did happen? Timeline of main events	The event took place at departure from Amsterdam Schiphol Airport, in the early evening of October 4th 1992. The actual aftermath of the event covered several years, formally closed by a Parliamentary Hearing in Feb. 1999.
	Historical events	Several previous events had occurred with engine separation before the event on the Boeing 707 (5 times) and 747 (4 times).

Item	Explanation	ElAl air crash Schiphol 1992
		After redesign and retrofitting of the pylons and fuse pins, no engine separation occurred.  Source: www.lessonslearned.faa.gov
	Place Context of event and system (general environment, topography, weather)	The event took place in a suburb of Amsterdam, early in the evening when everybody was at home.
	Sector involved	The event not only covered the aviation industry, but was embedded in a context of expansion of the airport and suburban developments regarding social tensions and racial sensitivities in a densely populated area. Eventually, the policy making domains of transport and infrastructure, environment, housing and land use and rescue and emergency were involved. On an international basis, ICAO, EU and EASA became involved because of the context of international rules and regulations.
Type of event	Content aspects: primary activity, operational aspect involved	The event was part of a regular ElAl flight from Amsterdam to Tel Aviv. The company however, had gained protected status due to the political sensitivities involved with flying to Israel.

Item	Explanation	ElAl air crash Schiphol 1992
	general or macro description of plant or system involved	During the event, Schiphol had been involved in a political and economic debate in parliament dealing with a major expansion of the airport into a European Mainport concept. The number of flights and airport capacity limits were discussed with respect to noise, pollution, land use and land based traffic congestion.
	Local or micro description of process/system involved in accident	The Schiphol airport community was involved in the assessment of the autonomy of foreign carriers in the European aviation network in the security and terrorism protection aspects.
	Structural aspects: e.g. relevant organisational structures, infrastructure, buildings etc.	The airport authorities were the leading agent/actor with respect to the daily operational practices at the airport. In addition, the Dutch Ministry, Inspectorate, local municipality and regional government were involved in regulations, legislation, inspection and supervision responsibilities.
	Cultural aspects: personal safety culture company safety culture	Cultural aspects in aviation were part of the accident causation due to a laissez faire attitude towards companies. During the process of investigation, a tendency to keep information shielded from public notice even created a new expression: ‘to keep information under your cap’.
	Contextual aspects e.g. Industrial safety culture	The surrounding cultural aspects were dominated by the prevailing attitude in the aviation industry to focus on internal safety: airborne aspects were dominant. Only after the event, external safety became a political and substantive issue in safety of aviation.
	Area and stakes vulnerability to the system	Safety was a disintegrated and fragmented issue: well taken care of by each individual stakeholder and organisations, but not managed at an airport level, nor as an integral safety issue.
Magnitude of damage to system involved	Scale and kind of property damage	The aircraft was a hull loss, the apartment block was demolished, while 43 people died at the scene. Long term health effects were suspected, but not proven despite longitudinal medical health surveys. Mental traumas are discernible until this day. The formal investigation complied with ICAO Annex 13 protocols, including a full 2 D reconstruction of the recovered parts of the aircraft in a hangar at Schiphol airport and a reconstruction of the flight path. The reconstruction was conducted based on ATC data and eye witnesses on the ground because the data recorders were never retrieved

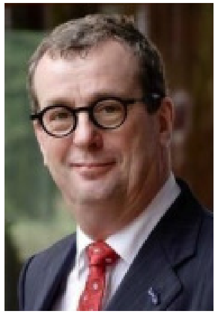
Item	Explanation	ElAl air crash Schiphol 1992
		 Foto: Rijkspolitie Dienst Luchtvaart Schiphol-Centrum Hangar 8, Schiphol-Oost Source: RP, Dienst Luchtvaart Schiphol Centrum  Source: www.quoticliberationfront.com

Item	Explanation	ElAl air crash Schiphol 1992
	Victims	In total 43 people were killed, while hardly serious injuries were sustained.
	Magnitude of damage financial environmental	The financial and environmental damage was never assessed in detail. Long term effect were suspected due to exposure to depleted uranium, but never proven.
	Down time	The suburb was reconfigured over a periods of several years. The damaged apartment blocks were removed and never rebuild.
	After the event, aftermath actions to restore, repair, de-pollution, compensate	The damage was compensated to some extent, but due to the lack of convincing and exclusive evidence of the relation between the impact and damaged claimed, the overall compensation was never exactly established. In the aviation industry, many measures have been taken on an technical, organisational and institutional level. An overview of all direct and indirect costs was never achieved.
	Speed/pace of recovery completely back into business	The speed varied across all parties involved. The aviation community restored flights on a very short notice with little downtime of its primary processes. Due to the magnitude of gradual changes in the aviation community, the system never recovered to the initial state. Many changes have altered the system over about 20 years.
Investigations known	By safety board/special commission involved	The investigation was conducted by the Dutch Aviation Council, conform the ICAO Annex 13 regulations being the official investigation agency.
	Public authorities	Many parties were involved under the supervision of the Dutch Aviation Council. Several Ministries conducted their own governmental and judicial investigations, focusing on the crash as such. In the direct aftermath of the crash, the Dutch Ministry of Transport and Infrastructure organised a safety audit by RAND Europe, to assess the safety of the airport. Although this audit was collateral to the crash and independent to the actual investigation, it would not have been ordered if the crash had not happened. In the aftermath of the event, in 2001 the Dutch Ministry of Transport and Infrastructure ordered the development of an external safety assessment tool for identification of acceptable risk limits with respect to land use and urban planning issues. This resulted in the CATS model (Causal Model for Air Transport Safety), eventually completed in 2009.

Item	Explanation	ElAl air crash Schiphol 1992
		In the aftermath of the event, Dutch Parliament organized a Parliamentary Hearing on the medical and social impact of the crash.  Source: Parlementaire Enquete Bijlmerramp Eindrapport, SDU This Parliamentary Hearing however did not lead to consensus on the causes and collateral health damage to the public In the aftermath of the crash due to exposure on depleted uranium from the wreckage, but almost lead to a political controversy between the coalition partners in the administration. Some individual members of parliament became a whistle blower in their own party during the final vote on the outcome . One of them was nicknamed ''Bijlmerboy'' in the press.

Item	Explanation	ElAl air crash Schiphol 1992
		 Source: Foto RD / Henk Visscher
		The EU commissioned a survey into the safety of foreign aircraft on European airports, the SAFA initiative. Eventually, this lead to additional regulations and a formal option for Blacklisting substandard performers.
	By companies involved	As a consequence of the event, Schiphol Airport conducted a separate safety survey into the integral safety of the airport.
	By journalists	Several books were published, revealing the ‘truth’ on the actual sequence of events, the omissions in the official report and allegations on a cover up.
Learning dimension: solution developed		
Content	Elements of the primary process to be improved	The design of the Boeing 747 pylon and the fuse pins were adapted to the finding of the investigation. The pylon version that caused the event was phased out over the years by introduction of a redesigned engine separation principle. The responsibility of the airport community was acknowledged by the introduction of an Integrated Safety Management System at the airport, covering the airport community as such. The primary processes in flight handling were changed with a supervisory role of the Dutch government

Item	Explanation	ElAl air crash Schiphol 1992
		on minimal performance standards, according to EU regulations in the SAFA program. The rescue and emergency aspects were taken into account by introduction of a ‘safety critical size’ (Maatramp) of events, to be elaborated by allocation of sufficient resources to rescue, emergency and recovery authorities and services.
Structure	Organizational structure	The Integrated Safety Management System was introduced at the airport.
	Technological structure	The pylon of the 747 was completely overhauled and adapted. The safety assessment methodology of the design process was adapted by taking into account dynamic and critical loads, simulation techniques provided a improved reliability of the stress calculations, while corrosion prevention was incorporated in the construction and maintenance procedures.
Culture	Change of culture	The change in culture took place at a company as well as governmental levels on an airport, national and international scale. A change with respect to beliefs and values in safety perception and acceptance was initiated. Due to a series of major events shortly after the ElAl crash in other domains, the general public and political atmosphere in risk and safety awareness was raised to a next level in the Netherlands. The Enschede fire work explosion, Dakota crash at Den Helder, several railway accidents and the New Year’s Eve disco fire in Volendam had major impact on the safety and risk culture in the Netherlands. ElAl can be considered a benchmark event in this development.
	Change of behaviour	The change of behaviour is not easily interpretable: after a period of increased risk awareness, environmental issues such as noise and pollution took over the political primate, while an institutional change in addressing safety by independent and expert groups was replaced by a multi-actor consensus achieving development. Safety faded away quite soon after the issues related to the eventual crash were settled.
Context	Supporting conditions	Various supportive measures were taken on a national level by several parties and stakeholders, by starting specific surveys on safety performance of carriers visiting Schiphol Airport, rescue and emergency initiatives and the CATS model for external safety assessment. Technological solutions were developed by the Boeing company in redesigning the aircraft structural integrity. Neither academic courses or research developments were initiated to enhance safety management in aviation nor an industry oriented safety academy was established to train practitioners at a post-

Item	Explanation	ElAl air crash Schiphol 1992
	Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system	doctoral level. The event was not incorporated in a regular knowledge development of academia or dedicated professional courses. Solutions were found at a level of practitioners communities of airport stakeholders, governance and policy making authorities and inspectorates.
System level involved		
Micro	Solutions at company level, subcontractors at company level Timeline of implementation of solution months/years	At the company level, Schiphol Airport has taken the initiative to establish the Integrated Safety Management System. The timeline involved in implementing solutions diverged across the actors and stakeholders. On a short notice, Boeing took direct corrective, short term specific measures to improve the design of the pylon.
Meso	Actions of safety authorities, what actions? Branche involvement	EU safety authorities introduced the Black Listing principle for poor performing parties. At several occasions, a withdrawal of the licence to operate has been effected. In particular Indonesian, Libyan and other African carries have to adapt to regain the licence to operate in European skies again. After some years, the debate on the safety of Schiphol lost momentum in the public and political arena. Regular issues such as noise, health, land use and acceptance of a permanent growth of the airport took over.  Source: www.Alderstafel.nl

Item	Explanation	ElAl air crash Schiphol 1992
		The Schiphol Safety Advisory Committee was dismantled and replaced by the Alders Table in 2006. This Table aimed at achieving consensus across social parties, balancing growth, environmental impact and sustainability of the aviation sector in the Netherlands. The Table not only focused on Schiphol, but also on regional airports as satellites for the mainport development.
	Timeline of implementation of solution months/years	Such processes take years to develop and by their complexity, cannot be linked to a single event any longer that has occurred in 1992.
Macro	EU-level development, directive or standard being changed or research program being started or...	Governmental measures at the EU level have been initiated and are deployed at this moment.
	Timeline of implementation of solution months/years	Such long term generic measures take years and require an incremental introduction to gain the support of every actor and stakeholder in the open network system.
Dimensions lessons learned: depth of learning		
Optimize		Due to the severity of the event, no short term repairing and local improvement activities were undertaken
Adapt		A complicated framework of production process, technological and organisational change as well as safety culture redesign and adaptation of organization took place.
Innovate		At the level of technological change, no major innovations took place. At the level of the airport community organizational and cultural changes took place. At the national level, innovation took place regarding external safety assessment, rescue and emergency organisations and land use planning policy making. At the level of the EU, initiatives were taken to incorporate new aspects in the safety assessment framework, such as safety of foreign aircraft, and the mandatory introduction of independent safety investigation boards .
Impact		
Changes identified	What really changed	At the airport level, safety has taken a solid position in the debate on critical social values. The ISMS has been established and operates on a regular basis. Capacity issues however, are taking over again in the

Item	Explanation	ElAl air crash Schiphol 1992
		discussion on priorities and cost-effectiveness. At the national level the increase in safety perception and awareness has fallen back after a short period of awareness. Several expert groups and advisory groups have been dismantled again, in favour of the conventional issues of noise, pollution, growth and sustainability. Throughout the aviation community in Europe, the cultural changes and awareness and assessment of poor performers has been increased.
Change/learning agent	Who/what takes care for follow up	Since the aviation community is an open community, the advocacy role for safety promotion is changing over time. The powers that advocate safety on a continuous basis are originating from the aviation community itself: it is a survival issue in terms of business continuity. The outside world responds to visible disturbances and incidents that make it to the newspapers. Public perception is an ad-hoc change agent.
	Who/what keeps memory/knowledge alive	It is hard to keep safety in the focus of the public and political attention: accident and near misses (such as recent loss of separations in Dutch airspace).
	Who/what keeps monitors effectiveness	Institutional arrangements in the aviation community itself are the best triggers for keeping up safety: Boeing Dreamliner battery issues, final reports on cases such as AF447, QF 32 and MH370. A public span of attention is short and unpredictable..
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	Milestones of the change process can be identified in a time perspective in a positive as well as negative manner. Positive incentives are crashes, incidents and perceived risky events. Negative incentives are public pressure on other eventful occurrences that may drain the willingness to invest in aviation safety.
Change of investigation process		The investigation has given reason to reflect on methods used and needed alternatives to be developed with respect to independence of the investigation, creating an international framework within the EU for a mandatory basis for aviation accident investigations by creating EU Directives.
Evaluation of accident and follow up		
	Conclusions and comment with respect to specific experiences/	A reflection on this case in terms of barriers to learning are identified as a relatively rapid decay of safety attention of the national governmental agencies. In contrast with the international governance, EU as

Item	Explanation	ElAl air crash Schiphol 1992
	observations/ discussion by ESReDA group	well as ICAO, a national government shift priorities on a relative short notice to production, capacity and market demands. Such a shift is guided by a policy making process approach, not a substantive assessment of long term developments in the aviation community itself.
	Are changes sustained	In hindsight it can be confirmed that implementing change has a lasting and sustained effect if it is recognized and supported by the sector itself. The need to make a leap forward in traffic volume and infrastructure capacity also requires a reflection on safety: there cannot be a linear relation between growth and the present safety performance. Public acceptance of any major crash is not to be expected. The travelling public demands a Zero Accident strategy, as phrased in the Flight Plan 2050 of the EU.
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission	There are relatively few public resources for further reading and extended reflection on the case, compared to the impact it has had on the Duct society and international aviation community.
	Report inspectorate/third party	Rand Europe report on Safety of Schiphol 1993. Dutch Aviation Safety Council, final report 1994. Parliamentary Inquiry on the aftermath1999. CATS model, Ministry of Transport and Infrastructure 2009. Ministry of Internal Affairs, Critical Size Event Guidelines, 2000.
	Company reports	An inventory has to be made to gain overview over the various topics.
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Articles in journals, magazines, internet	The amount of further study and evaluations of an academic nature have been limited, while discussion in the branch of rescue and emergency services has been restricted. Several academic papers by different authors have been written (key authors in the Dutch research community are Ale, Stoop and Roelen). At TUD a PhD has been based on the development of the CATS model. NLR in the Netherlands promotes a wider application of the CATS model in the aviation community.

Item	Explanation	ElAl air crash Schiphol 1992
	Courses, training	No courses or training have been developed from this on a regular basis. Several courses and learning labs have been given at an academic level on incidental basis at TU Delft and Lund University.
	Relevant links	Academic links provide information on accident or related publications and studies.

Conclusion

Some conclusions can be drawn from this survey with respect to dynamic learning:

- Safety has -event driven- broadened towards an integral safety notion incorporating aircraft safety, airport safety management, external safety and rescue and emergency services
- The focus of the Dutch TSB shifted from investigating before and during, towards after the event, broadening the scope towards a multi-actor involvement at all systems levels, including governance and control
- Providing transparency at the operational level of an airport community is difficult to maintain. Safety is submitted to a complex, operational assessment of balancing safety against other dominant aspects, such as noise abatement and limitations to growth, while safety awareness fades away some time after an accident. Gradually, safety may reduce from a strategic decision making criterion to an operational constraint
- Independence of a public safety assessor at the airport level is indispensable in order to facilitate a sustainable, proactive and integral assessment of operations, while it's functioning is assured by legal and organizational arrangements.

Comments

Possible learning barriers identified

Lack of awareness that experience and technology of the Boeing 707 was too limited to be transposed in the design and calculation of the Boeing 747 being a more complex design;
The manufacturer based risk acceptance on quantitative risk levels, leading to acceptance of the design, overruling the potential severity of the consequences;
The airport community was not cooperating on an integrated vision on safety, which however was possible given their individual knowledge and experience
The system of event reporting of companies on Schiphol were focussed on each of their core businesses: only one actor appeared to have registered the accident
No overall risk governance was available as a management structure to orchestrate individual responsibilities and accountabilities.
No common policy and shared indicators on access of poor performers to process and follow up on information of poor performers
No common memory of basic knowledge about physical failure mechanisms resulting in a opportunity for unlearning and ignorance when (re)designing new technology
Unlearning of experience and severity of disasters because safety is seen as an operational affairs instead of a strategically issue being considered in future design and long term planning of the airport and its environment.

Lessons learned

In general, based on this descriptive analysis of the development of safety around Schiphol airport, four lessons can be learned:

Each actor and stakeholder has its own potential for change due to differences in learning potential, position and resources, either by aircraft design, airport operational practices or institutional governance and control:

- During the design, systemic deficiencies can be eliminated by changes in the design philosophy and assumptions
- In practice, single, isolated safety aspects can be integrated into an integral safety notion, scaling up the intervention potential to the airport systems level
- At the control and governance level, procedure and regulations can be installed, taking care of international arrangements, modelling and investigating safety.

Organizational learning has a high potential, but the existence of safety enhancement organizations is not automatically guaranteed at an airport level once they are designed and implemented. Organizations are submitted to operational decision making mechanisms of a higher level due to which a substitution may take place of a prospective, substantive expert assessment by a stakeholder consensus decision making process. A selective focus on critical aspects during operations may cause a preferential treatment for growth limitations and noise abatement procedures

There is a prominent role for single event investigations in learning processes to provide factual information on the functioning of the aviation system in practice. Such a role fits in with resilient design of organizations. Retrospective learning loops from independent accident investigations may provide valuable factual information and transparency over operations. Establishing independent investigation agencies identify a fourth learning loop at the institutional level; a need for legal embedment of the safety aspect is identified in order to a sustainable incorporation of safety at a national as well as international safety policy decision making level.

Learning does not stop after publishing a report on the actual accident. The dimension of time is crucial, not only in the –sometimes long- time that is required to implement recommendations from an investigation. By changing technology, system architecture or operational context and company culture, internal dynamics may take over, creating emergent outcomes or side effects that have not been foreseen earlier. A focus on the inherent properties and dynamics of the system is necessary in addition to a focus on the sequence of events. Otherwise, the non-linearity of systems and their long term dynamics cannot be managed.

Lessons forgotten

Unfortunately, this case study also indicates that lessons can be forgotten or downscaled in their importance and relevance.

The establishment of the Alders Table indicates a shift in interest from expert based assessment of the nature of safety towards actor based consensus on acceptability of risk. Separating a safety assessment process from the content may create a loss of expertise and understanding of the primary processes that ultimately may lead to a drift into oblivion of previous lessons learned.

Probabilistic assessment of risk cannot replace understanding of causal failure mechanisms because of the involvement of physical phenomena with catastrophic potential. A very rare event may have a negligible frequency, but its consequences may disrupt societal safety awareness to such an extent, that change becomes inevitable. Case studies may bear an element of serendipity: learning from the unanticipated by feedback from reality.

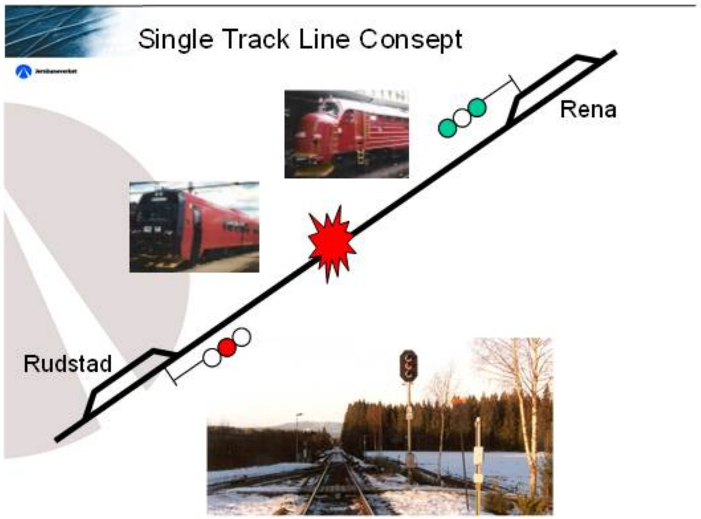
Complex and dynamic systems such as aviation are characterised as intractable, but also as non-plus ultra-safe. Such properties are designed into such a system by applying notions of robustness, redundancy and reliability. Such systems have evolved and matured over decades and have become very resistant to change. The aviation system is hard to change at a systems level, while change is incremental and very time consuming. While small adaptations are easily absorbed, major changes are hard to implement, requiring a worldwide adaptation. Sometimes, lessons learned have to be repeated before a new window of opportunity for change opens up.

A.5 Aasta train collision, 2000, Norway

Analysis

Item	Explanation	Aasta train collision
Description event (system involved)		
Description accident		
	Short description	4 January 2000 at 13.12 (1.12 p.m.) , two trains collided near Aasta, Norway.
	What has happened (description, pictures etc.) What agents (the damaging energy source e.g. Nuclear hazard)	The accident occurred when a northbound passenger train entered a single track where a southbound passenger train was approaching in the opposite direction. The speeds were 70 and 90 km/hour. The trains met at Aasta, causing a powerful collision followed by a fire. The trains had 75 and 11 passengers.  Source: NTB Cornelius Poppe/NTB scanpix
	How has it happened, what were circumstances	One train entered a single track while an other train was coming from opposite direction on the same track

Item	Explanation	Aasta train collision
		 Source: NTB Cornelius Poppe/NTB scanpix
	Why did it happen? Direct causes	According to the STEP analysis, which was one of the basic documents used by the JBV (Infrastructure Manager) Accident Investigating Commission (AIC) , the direct cause is supposed to be that one of the trains passed a signal indicating STOP when it passed the main exit signal at Rudstad train station.

Item	Explanation	Aasta train collision
		 Source: Ove Skovdahl, JBV, 2003
	Why did it happen? Root causes	As an underlying cause, the analysis points out that the main exit signal at Rudstad station was not equipped with an Automatic Train Control system (ATC). The train would consequently not be stopped or the driver not warned if he had overlooked or misinterpreted the light signal. All together, the STEP analysis identified 12 concrete safety factors that contributed to the scope of the accident. The factors were characterized as engineering factors, human factors and organisational factors. Some missing safety measures include the lack of an acoustic alarm-system that should have been installed in the remote traffic control centre in Hamar, absence of on-board radio communication systems, insufficient routines for reporting and unclear routines for the use of mobile phone numbers in trains and control centres and dysfunctional departure process from station. The section of the track between Røros and Hamar, where the collision took place, was not yet equipped with Automatic Train Protection (ATP) due to low priority in the budgets concerning the years before. In addition, this line was not equipped with electricity.

Item	Explanation	Aasta train collision
		During the investigation, a time log was reconstructed, showing all important movements from 07:15 until 13:14 on the track the day when the accident occurred. Although all accidents are unique, another train accident with important similarities took place in Norway 25 years earlier. The accident Investigation commission proposed in their report several important safety measures which could prevent or lower the risk for a similar accident in the future. However, some of the recommendations proposed in 1975 were still not implemented in the year 2000, when the Aasta accident took place. And some of the recommendations implemented after 1975 contributed to the accident in 2000 (single person train departure responsibility).
	Other root causes	
	When did happen? Timeline of main events	
	Historical events	
	Place Context of event and system (general environment, topography, weather)	Track between Rudstad and Rena in Norway
	Sector involved	Transport rail accident
Type of event		The event was a transportation accident within the railway sector in Norway. The section is single tracked and was neither electrified nor equipped with Automatic Train Control System (ATC). All traffic consists of diesel-powered trains. The stations on the relevant section were controlled by the train controller at the Hamar Control Centre.
	Content aspects: primary activity, operational aspect involved	Train driving
	general or macro description of plant or system involved	
	Local or micro description of	

Item	Explanation	Aasta train collision
	process/system involved in accident	
	Structural aspects: e.g. Relevant organisational structures, infrastructure, buildings etc.	infrastructure concept and lay out
	Cultural aspects: personal safety culture company safety culture	
	Contextual aspects e.g. Industrial safety culture	
	Area and stakes vulnerability to the system	
Magnitude of damage to system involved	Scale and kind of property damage	Local train system; two passenger train
	Victims	The train collision at Aasta in 2000 was the most serious rail accident in Norway since 1975 – a total of 16 and passengers and 3 rail employees died and several passengers were injured in the accident. None of the locomotive drivers survived. 67 persons survived the accident; several with major injuries.
	Magnitude of damage financial environmental	Major damage
	Down time	
	After the event, aftermath actions to restore, repair, de-pollution, compensate	
	Speed/pace of recovery completely back into business	
Investigations known	By safety board/special commission	The accident was investigated by a number of involved parties. The Government set up an Ad Hoc Accident Investigation Commission (the Groth Commission), which published the official report (NOU

Item	Explanation	Aasta train collision
	involved	2000:30). Furthermore, the accident commissions of both the operator company (The Norwegian State Railways - NSB) and the rail infrastructure managing company (The Norwegian National Rail Administration - JBV), made separate investigations and reports.
	Public authorities	The Norwegian Police Authority wrote a separate report. In addition, special factors related to the accident have been examined separately, e.g. the crisis communication between the authorities involved, and the role of the health services and personnel.
	By companies involved	
Dimension		
Content	Elements of the primary process to be improved	Several elements were identified and proposed improved by different measures by the Ad Hoc Accident Investigation Commission, like Diesel tanks – preventing large amounts of diesel fuel from being released in a collision or derailment involving a diesel engine Technical installations – securing relay station houses and other locations where technically sensitive equipment is located Storage of luggage on trains – preventing passengers from being injured from luggage being thrown around in accidents
Structure	Organizational structure	The Commission in their report, printed as NOU 2000:30, recommended: Overall safety management – proactive safety management should be applied to all railway operations Direct line between the Safety manager and the top management The following-up and implementation of safety measure should be the responsibility of the line management The use of risk analysis to assess the risk connected with railway operations Incident reports should be collected and systematized to reveal whether any faults recur and whether they are safety-critical Analysis of reported incidents should be made more available in organisations Clear rules and procedures for internal accident commissions should be formulated, giving especially priority to secure evidence Research should be done into the possibility of equipping all railway lines with reliable logging systems

Item	Explanation	Aasta train collision
		An appropriate train radio system The Commissions main conclusion was that the Røros line lacked adequate barriers against single human failure accidents.
	Technological structure	NSB and JBV should develop high quality, efficient internal control systems
Culture	Change of culture	The Commission also proposed: • All staff with responsibility for safety should meet new competence requirements and training plans • All staff should be better motivated to report and provide information about undesirable incidents The safety culture within the JBV was especially studied. The Commission highlighted the contrast between the traditional (“old”) railway culture based on a hierarchical system, the rail workers understanding of their role and functions and their general knowledge of the whole railway system on the one hand and the different conditions for newly employed personnel on the other. While the traditional system is working well in a static organisation, there are several weaknesses when performed in a system which is undergoing changes and developments, as the railways in the 1990-es. The decision-making system on the top management level was not sensitive to opinions expressed by employees further down in the hierarchy.
	Change of behaviour	
Context	Supporting conditions	The train accident at Aasta 4 January 2000 and the investigation done and the reports delivered by several accident investigation bodies have triggered research institutions and researcher to analyse, systematize and conclude about causes, conditions, organisational aspects etc. The accident has alone or in combination with other major accidents in Norway been the object for developing or testing accident theories and hypothesis, for scientific comparisons, and – not least – as a source for studies about learning, e.g. ACCILEARN (Accident investigation and learning effects within transport organizations and across societal sectors, financed by the Research Council of Norway, 2008 -2009). In a political context, the accident contributed to highlight the poor maintenance conditions on the Norwegian rail network and put pressure on the allocation of resources to the railways – the lack of necessary resources to both fill the gap caused by decades of scarce founding and necessary modernization of the communication systems, tracks, the signalling system, the control centres etc. In the latest years, the grants from the Parliament to the JBV have increased.

Item	Explanation	Aasta train collision
	Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system	
System level involved		Stakeholder perspective and change agent
Micro	Solutions at company level, subcontractors at company level Timeline of implementation of solution months/years	At the time of the accident in year 2000, the rail organizational system in Norway consisted of three major players: 1. The operator – the Norwegian State Railways (NSB), 2. The infrastructure manager – the National Rail Administration (JBV) and 3. The inspectorate - The Norwegian Railway Authority (SJT). While the NSB had a very long tradition as a general railway company, JBV and SJT in 1996 was split from the NSB and organized according to EU regulations as separate companies.
Meso	Actions of safety authorities, what actions? Timeline of implementation of solution months/years	The main actors at that time were the public authorities, represented by the Ministry of Transport and Communication and the Parliament (Stortinget), which decided the overall principles and resources, the Accident Investigation Board Norway (AIBN - SHT), which in 2000 was limited to investigate air accident (railway accidents was part of the mandate from 2002), and all the stakeholders, including the trade unions, the railway industry, the research and academic institutions, the mass media, and others. The Police, the Fire Brigade, the Health institutions, Emergency units etc. are also important players at this level. In the accident analysis performed by the major accident investigation bodies, only some minor attention were given to these actors, especially those (Police, Fire Brigades, Health units) who were directly involved in activities connected to the train accident.
Macro	EU-level development, directive or standard being changed or research program being started or...	Although Norway in 2000 was not and still is not a member of the European Union, Norway is via European Free Trade Association (EFTA) a part of the European Economic Area (EEA). As a consequence, Norway is obliged to implement in national laws most of the approved EU regulations, as directives. In 2000, both NSB and JBV were also members of the International Railway Union (UIC), which since 1922

Item	Explanation	Aasta train collision
		has played a strong role as a kind of standardizing body. Many of the rail safety requirements adopted in Norway over several decades were initiated and finalized by UIC. Other important bodies within UIC, are at that time the European Rail Research Institute (ERRI) and the Community of European Railways (CER). The role of system actors at this level and their connection to the directly involved players at the micro level or the meso level are almost absent in the analysis made by the investigation bodies in 2000. Fire services and emergency call centres The Norwegian National Railway Administration The Norwegian State Railway The State Railway Inspectorate The Ministry of Transport The National Transport Accident Investigation Board The trade unions and employees in the railway companies The mass media, incl. TV and radio, newspaper, magazines The Police The railway industry: companies and institutions The research and academic institutions, universities etc. International institutes, institutions and organisations The political system: Parliament
	Timeline of implementation of solution months/years	
Depth of learning		Changes identified
Optimize		Among the actors of rail companies that were involved in the Aasta accident, the JBV (the infrastructure company) both initiated and accomplished several investigation studies and was at the same time the company that received most complaints for safety deficiencies from other investigation bodies. A STEP

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<tr><th>Item</th><th>Explanation</th><th>Aasta train collision</th></tr>
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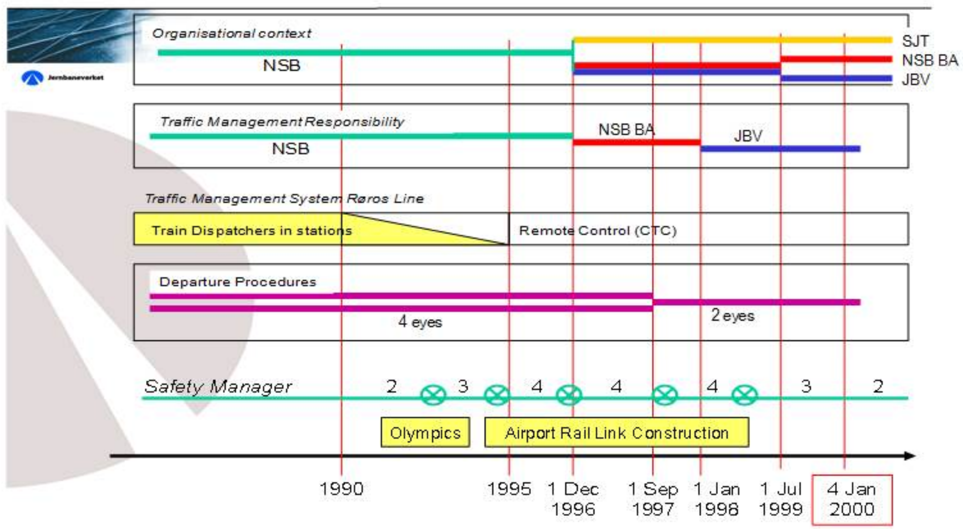
analysis by the JBV Accident Commission, revealed altogether 16 actors, 126 events and 12 safety factors in connection with the accident. The research report concludes with 23 recommendations of short and long-term measures and measures on different organizational levels. Among the recommendations forwarded are installation of GSM-R communication system, reviewing routines for information from traffic operating personnel to train control, better routines for recording, storing and revising telephone numbers and introducing improved routines for securing data logs in accidents.

An overview of the organization context concerning safety management between the main rail companies (NSB and JBV) and the Railway Authority during the decade 1990 – 2000, indicates both the traditional NSB role up till 1996/97 and the rather complex interplay between the enterprises in the short period 1997 - 2000:



Source: Ove Skovdahl, JBV, 2003

A critical organisational factor was the fatal decisions in 1992-93 to install remote train control (CTC) on the Røros Line without at the same time include an ATP system. The decision, which leads to a degraded
</td></tr>
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Item	Explanation	Aasta train collision
		safety level on this line from 1995 until the Aasta accident, can be explained by the organisational environment in early 1990es. The conclusions from the Groth Commission (NOU 2000:30) involved among others recommendations for upgrading old rolling stock so that it meets current requirements and that the existing regulations should be thoroughly reviewed in order to streamline and simplify them.
Adapt		The 3 investigation commissions presented several proposals to enhance the safety for rail passengers and on board personnel. The commissions recommended more specific that a complete reengineering of interlocking systems should be carried out before normal operation, that Automatic Train Control (ATC) should be installed on the Røros line (and other lines) and that procedures and rules for the use of mobile phones should be introduced until new radio communication systems were installed. The Groth Commission also proposed increased use of risk analysis as an important tool in a safety management system. In addition, several other measures were proposed (see a more detailed list under Dimension/Structure).
Innovate		The Commission recommended considering the establishment of a permanent commission of serious train accidents and also that a permanent commission should be an independent body with a clarified relationship to investigations exercised by the police authority. The mandate of the Accident Investigation Board Norway, established in 1989 as an investigation board for air accidents and incidents, was shortly after the Aasta accident amended. In 2002, the commission widened its mandate to cover rail accidents (later also sea and road traffic accidents). Such investigations are now regulated by the Norwegian Act of June 3rd 2005, No.34, relating to notification, reporting and investigation of railway accidents and railway incidents, and regulations stipulated pursuant to the Act. Railway accident investigation in Norway is further regulated in detail by the EUs safety directive for railway which was adopted and made official March 1st 2006 as Regulation 2006-03-31 nr 378. Regulation for official investigation of railway accidents and serious incidents etc. ("The Railway Investigation regulation"). And, as mentioned earlier, both the Norwegian Research Council and research institutions allocated more resources and priorities to research projects in the transport sector after the Aasta accident. Especially important is the RISIT research programme (Risk and Safety in Transport). RISIT was administered by the Norwegian Research Council and financed several safety transport research projects in Norway during the period 2002 – 2009. The importance of safety in transportation has increased in the official long term, cross sectorial transportation plans, especially the ten-years National Transportation

Item	Explanation	Aasta train collision
		plans, which were the Government's white papers to the Parliament. The increased focus on safety in transport during the period 2000 – 2010 by public authorities and politicians, mass media, the opinion, the academia and the actors in the transport field, was, to a considerable degree, due to the tragic and major transport accidents in rail, at sea (e.g the Sleipner high-speed craft accident in 1999 with 16 fatalities) and on the road the years before. Another factor that enhanced the interest and participation in research projects about safety in transport was the EU's framework research programmes. They had a heavy impact on the priorities of the Norwegian research institutions and on the interests from single researchers.
Impact		
Changes identified	What really changed	The Aasta accident and the subsequent investigations and reports with recommendations, initiated and set priorities to several changes in the whole railway sector, both on a system level, e.g. risk based safety management and barrier philosophy, via specific technical improvement in several sectors and on the employee level, as improved competence and training. Although several recommendations are mentioned before, the highlights in this connection implies measures as: • A lot of new technical measures implemented, such as reengineering of interlocking system, installation of ATC (ATP) on all CTC lines, installation of Train Radio System, installation of audible alarm for safety-critical faults in rail traffic control centres, and – in addition – procedures for use of mobile phones in the signalling and interlocking system • New management regime based on line responsibility and proactive approach, mandatory use of risk analysis in several connections (overall risk as well as planned organizational or technical changes, e.g. review of departure procedure) and implementation of improved incident reporting systems • Improved internal control systems in all its activities within NSB and JBV • Structured education and training, e.g. of train drivers • Higher priority on crisis management • Improved dialogue between JBV and NSB • RAMS-methodology according to EN50125 introduced • AIBN - SJT: increasing number of employees, more personnel with specific rail safety competence and reconsidering of the position as an agency in the Ministry of transport and communication • Permanent, independent multimodal Accident Investigation Board (AIBN), incl. rail accidents (from

Item	Explanation	Aasta train collision
		2002) • New research projects were proposed and later implemented (like RISIT) • A new, proposed act on investigation (in force in 2005)
Change/learning agent	Who/what takes care for follow up	The Groth Commission identified JBV as the main actor to change and learn. The Commission concluded that "in the view of the Commission, the Aasta accident occurred because of basic inadequacies in the Norwegian National Rail Administration with regard to safety consciousness and safety management". JBV worked out a comprehensive action plan based on several inputs from different sources with many identified tasks to be introduced, revised or improved. The consequences were over time a remarkable change in the safety management system, in internal rules and regulations, in training, in competence, in operations and – not least – in technical systems and equipment. Other actors which were in need of learning from the accident, were the Norwegian State Railways (NSB), the Norwegian Railway Authority (SJT), the Ministry of Transport and Communication and the Accident Investigation Board Norway (AIBN - SHT). However, there is no scientific study which has studied the degree of and in detail the actual changes in these organizations as a result of the Aasta accident and the investigations done. Nevertheless, the Ministry worked out regulations for investigations of rail accidents and expanded the mandate for the SHT to cover rail accidents in 2002. In 2005, an "Act on Notification, Reporting and Investigation of Railway Accidents and Railway Incidents" etc. (Railway Investigation Act) entered into force. The Parliament also supported the Ministry's proposal to strengthen the role of the SHT - both legally (new act) and increased work force. In 2007, the Ministry issued both "Regulations on the Obligation to Notify and Report Railway Accidents and Railway Incidents (Notification and Reporting Regulations), and "Regulations on Public Investigations of Railway Accidents and Serious Railway Incidents etc. (Railway Investigation Regulations)".
	Who/what keeps memory/knowledge alive	The research community in Norway has responded positively to several of the challenges which the Aasta accident represents. Major research studies have been undertaken, both as Norwegian or Nordic projects and as Aasta-studies or comparative studies with several major transport or offshore accidents as research objects. In some of these studies, questions related to the learning potential or "lessons learned" have been the basic topics. In a SINTEF study from 2004, reported as SINTEF report no STF38 A 04403, five different perspectives are discussed in operational and resilient organisations: the energy and barrier perspective; the normal accident perspective; the HRO perspective, the information processing perspective, and the conflicting objectives, adaption and drift perspective. The practical implementations include a question about "How can we learn from disasters and incidents?", using Aasta accident as one

<table>
<tr><th>Item</th><th>Explanation</th><th>Aasta train collision</th></tr>
<tr><td></td><td></td><td>of the basic examples. The researchers have the following comments regarding the relationship between minor and major accidents (Rosness et al, 2004).
<table>
<tr><th>Issue</th><th>What is the relationship between minor and major accidents?</th></tr>
<tr><td>Issue</td><td>What is the relationship between minor and major accidents?</td></tr>
<tr><td>Energy and barrier perspective:</td><td>Minor and major accidents have the same basic causes. However, major accidents tend to involve failure of more than one barrier.</td></tr>
<tr><td>Normal accident perspective</td><td>Minor accidents are often caused by a single failure. Major accidents are caused by multiple failures and are related to the structural properties of the system (complexity, coupling, and control).</td></tr>
<tr><td>HRO perspective</td><td>Not explicitly discussed. In a HRO, one would expect major accidents to involve failure of one or more recovery mechanisms.</td></tr>
<tr><td>Information processing perspective</td><td>Many smaller accidents can be indicators for disasters (large-scale accidents), but they do not necessarily have the same root causes - failures in information processing.</td></tr>
<tr><td>Conflicting objectives, adaptation and drift</td><td>Major accidents tend to arise through a pattern of distributed decision-making and conflicting objectives, more often than minor accidents do.</td></tr>
</table>
Other stakeholders, as the mass media, the train passengers, the fire services, the emergency call centres etc. have been the object of a few, very limited studies.</td></tr>
<tr><td></td><td>Who/what keeps monitors effectiveness</td><td>The role of the State Railway Authority (SJT) has also been strengthened after the Aasta accident. The “Regulations on Public Investigations of Railway Accidents and Serious Railway Incidents etc. (Railway Investigation Regulations)” (2006) authorize SJT as the supervisory authority.</td></tr>
<tr><td>Change timeline</td><td>Can phases be identified in their implementation process are implemented measures lost in time</td><td>It may be difficult to identify some major mile stones in the process and work by the different actors after the Aasta accident. JBV followed up the recommendations from the Groth Commission in a very systemic way. The Ministry authorized the SHT to investigate rail accident already in 2002 and followed up with legal improvement in 2005, 2006, and 2007.</td></tr>
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Item	Explanation	Aasta train collision
		The DIRECTIVE 2004/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on safety on the Community's railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification (Railway Safety Directive) were both important directives in the legal process, as Norway is a member of the EEA agreement.
Change of investigation process		As mentioned above, both new act and regulations were implemented on national level some years after the Aasta accident.
Evaluation of accident and follow up		
	Specific experiences/observations/discussion by ESREDA group	The accident was analysed and evaluated by four major parties. In addition, different aspects of events and activities connected to the accident were described and evaluated in some minor, sectorial reports, e.g. the crisis communication between the authorities involved and the role of the health services and personnel. All the general investigations concluded with several recommendations for necessary change in order to improve safety and prevent accidents. The most important investigation commissions and their conclusions are: The Ad Hoc Governmental Commission (ref.): The Groth Commission formulated main recommendations within the following fields: • Overall safety management • Signalling and interlocking system • Rail traffic control centres • Upgrading of old rolling stock In addition, the Commission also recommended improvements in Norwegian Railway Inspectorate concerning: • Regulations for railway operations • Norwegian Railway Inspectorate • Train operation • Securing technical installations • Diesel tanks

Item	Explanation	Aasta train collision
		• Storage of luggage on trains • Fire services and emergency call centres • Permanent accident commission The commission formulated several specific measures within these fields and addressed many involved players. In total, the Commission had 29 recommendations for the rail industry (see NOU 2000:30). The JBV's Accident Investigation Commission (ref.): The final conclusion in the main report identifies three major safety fields for recommendations – all based on the STEP analysis. The fields are: • Engineering factors • Human factors • Organizational factors Altogether, 12 concrete safety factors are identified as being relevant for the accident. Earlier identification of these could have prevented or reduced the scope of the accident earlier. The proposed measures cover both short-range and longer range measures. Some of them are related to technical improvements (like Centralized Traffic Control (CTC), Automatic Train Protection (ATP), Track to Train Radio Communication (GSM-R) on all lines, special alarms in remote control centres, permanent data logs). Others imply system improvements (like a uniform mode of operation on all rail lines in JBV, conducting of risk analysis and risk evaluations etc.). The NSB's Internal Accident Investigation Commission (ref.): • The final report from the commission concludes by excluding NSB for responsibility for the accident - with one exception: IF – and only if - one of the trains left the station against a red signal. The commission had no mandate to investigate other causes, which are mainly the responsibility of the National Rail Administration. The commission identifies, however, some measures with relevance to the accident and several new measures of general character that could be further explored. The Police Report (ref.):

Item	Explanation	Aasta train collision
		• In the summary, the police investigation states the fact that the National Rail Administration has an overall responsibility, since JBV has not developed necessary procedures concerning operation and maintenance of the signalling installations on the Røros line. JBV has furthermore constructed, built, controlled and approved these installations without the use of an independent third party to assess the processes used. The Police report underlines the lack of simulation and testing of the safety installations on the Røros line, and cannot exclude the possibility of failures. But, on the other hand, the Police could not find any evidence for the probability that the accident has been directly caused by technical failures. In addition, since the accident and the reports have inspired several researchers to analyse especially the learning potential of the accidents, there are several conclusions and recommendations based on independent scientific work, reports and books. Some of the important dimensions or topics for scientific data analyses and reflection, have been to identify WHAT relevant or involved actors have learnt from accidents like Aasta, which conditions that hamper learning from accidents and what conditions that enhance such learning. Several studies from SINTEF in Trondheim/Norway may serve – among others - as a useful example of such scientific accident research. In the contribution to the Working on Safety-conference in September 2010 at Røros/Norway, which was partly based on the Aasta accident, the main objective was defined as follows: “Develop knowledge about which characteristics/properties related to accident investigations and follow-up efforts that have the most significant impacts on multilevel learning from accidents.” And the key learning points were summarized as (Størseth and Tinmannsvik, 2010):

Peak pointers –key learning points & themes	Description
Awareness	Massive change, increased safety consciousness. Wake up call, safety applies for the entire organization.
Safety Management	Shift towards more risk based safety management, barrier thinking.
Communication	The importance of communication and adequate communication devices

Item	Explanation	Aasta train collision

	took centre stage.
Technology	A range of technical measures have been implemented, incl. measures to improve communication between different actors.
Leadership	New leadership regime; safety more clearly defined as a line management responsibility.
Training	More structured training (including simulator training), and an increased focus on emergency preparedness, communication.
Documentation culture	Shift from “verbal culture” towards “documentation culture”. Practices and principles for safety management adopted from the oil industry.
Procedures	Procedures and management systems have become overwhelming, too big, heavy, and rigid.

The two main conclusion were in short:

- Accident learning processes escapes a solid demarcation point.
- Learning takes place in the untidy interlock of various actor-context constellations.

Other research conclusions underline the following factors:

- Multilevel approach
- Different types of learning
- Learning in different phases of the accident and the follow-up
- The complex pattern and interaction between influencing factors
- The external frame-of-references

Item	Explanation	Aasta train collision
	Are changes sustained	

Item	Explanation	Aasta train collision
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission	NOU 2000:30, Åsta-ulykken, 4. Januar 2000. Hovedrapport fra undersøkelseskommisjonen. (The Groth Commission: main report. Norwegian text with a summary in English). Mustaq, S., Lindem, T. og Holter, K. (2000) Åstaulykken 4. januar 2000. Politirapport. Oslo. (The Police Report, Norwegian text only).
	Report inspectorate/third party	
	Company reports	JBV's Accident Investigation Commission (2000) Train Collision at Åsta on the Rørosline, 04.01.2000 – Systematic review with the aid of the STEP Method. Oslo: Norwegian National Rail Administration.
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Articles in journals, magazines, internet	Christoffersen, C-E. og Nonseid, J. (2003) *Evaluering av myndighetenes krisekommunikasjon i forbindelse med Åsta-ulykken*. Oslo: Statskonsult 2003:22 (Norwegian text only). Hovden, J., Størseth, F. and Tinmannsvik, R.K. (2011) *Multilevel learning from accidents – Case studies in transport*. Safety Science, vol. 49, pp. 98 – 115. Rosness, R., Guttormsen, G., Tinmannsvik, R. K. and Herrera, I. (2004) *Organizational Accidents and Resilient Organisations: Five Perspectives.* SINTEF-Report STF38 A 04403. Trondheim: SINTEF. Roed-Larsen, Sverre (2009) *The Aasta train tragedy in Norway 2000: Lessons from the different investigation reports*. Paper delivered to the ESReDA 36th Seminar, 2-3 June 2009, in Coimbra, Portugal. Runarson, J. (ed.) (2008) Learning from accidents – an anthology based on thoughts and ideas from young research fellows. Huskvarna: Swedish Rescue Services Agency NCO 2008:5. Størseth, F. and Tinmannsvik, R.K. (2010) The critical re-action – Learning from accidents. Working on Safety Conference, Røros, 2010. Thuen, F. og Palner, J. (2003) *Evaluering av den menneskelige oppfølging etter togulykken på Åsta.* Bergen: HEMIL-senteret, Universitetet i Bergen (Norwegian text only). Tinmannsvik, R.K. and Størseth, F. (2013) *Major accidents – what have we learned about learning?* Paper delivered to the ESReDA 45th Seminar, 23 – 24 October 2013, in Porto, Portugal.
	Courses, training	

Item	Explanation	Aasta train collision
	Relevant links	

Conclusions

The general safety level on the section involved (a.o. Rustad – Rena/the single track) has been improved since the accident in 2000 (GSM-R, ATC, improved signal system and safety routines etc.). The financing of these measures has predominantly taken place through reallocation of budgets (JBV); rather than by increased grants from the Parliament. Such reallocations have, of course, consequences for (the) long term and short term safety and action plans. The “lessons learned” from one single accident highlight the problem of taking into account a holistic risk approach and of learning effects at a system level.

The stakeholders in the Aasta case include several and varying actors. A closer cooperation between them and more extensive use of the cross-sectorial experiences could have improved the general level of learning, e.g. the interaction between organizational learning and the reconstruction of barriers in the total rail system.

A support organization of survivors and relatives was spontaneously established a short time after the Aasta accident, and the organization was soon in dialogue with the train operator (NSB) which went on for some years. Organizations of this kind have, however, not the necessary resources to continue the dialogue in a longer perspective.

A complete study of the Aasta accident in 2000, including both the learning possibilities in a wide perspective, the systematic listing of measures implemented by the different actors and an evaluation of the effects of these measures (both positive and negative), has not yet been made. However, some scientific studies have contributed to more knowledge and better insights in the learning problems connected with the safety management processes after the Aasta accident.

Comments

The Norwegian ad hoc government accident investigation commission (The Groth Commission) concluded with proposing several measures, especially addressed to The Norwegian National Rail Administration (JBV), which was singled out as the main responsible actor. Many stakeholders, like public authorities and the mass media, paid extremely high attention to the implementation of these specific proposals. However, the recommendations were connected to the investigation of one specific, single accident. The challenge facing the JBV was therefore to integrate these proposals in the total collection of risk analysis for the national railway system in Norway, to make comparative evaluations of risks, to prioritize, to allocate resources, and to implement necessary safety improvements on the national level.

Some actors, within the range of relevant actors called “second multileveled configuration” by some scientists, presented, years after the accident, critical remarks to the scope and speed of safety measures implemented. As one example, five years after the accident the main trade union (Norsk Jernbaneforbund) heavily criticized the Parliament and the politicians for not following up promises given shortly after the accident of increased economic recourses to JBV.

In hindsight, it seems obvious that the mass media (disaster journalism), as one of the certain central actors, did not use the potential learning lessons from how the accident was exposed in public - neither at the time of the accident nor in later follow-up articles.

Abbreviations

ABBR.	ENGLISH
ACCILEARN	Accident Investigation and Learning Effects within Transport Organization and across societal Sectors
AIBN	The Accident Investigation Board Norway
ATC	Automatic Train Control

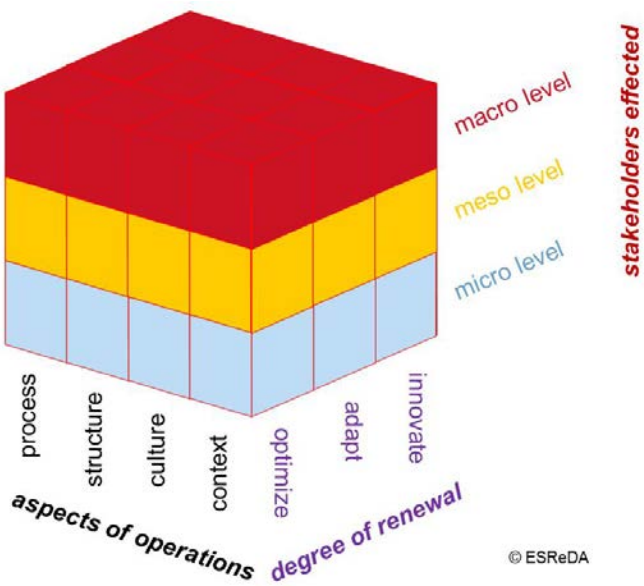
ABBR.	ENGLISH
ATP	Automatic Train Protection
CER	The Community of European Railways
CTC	Centralized Traffic Control
EEA	The European Economic Area
EFTA	The European Free Trade Association
ERRI	The European Rail Research Institute
EU	The European Union
GSM-R	Global System for Mobile Communications - Railways
JBV	The Norwegian National Rail Administration
NOU	Norwegian Official Report
NSB	The Norwegian State Railways
RAMS	Reliability, Availability, Maintainability and Safety
RISIT	Risk and Safety in Transport
SHT	The Accident Investigation Board Norway
SINTEF	Foundation for Scientific and Industrial Research in Norway – now SINTEF Group
SJT	The Norwegian Railway Authority
STEP	Sequentially Timed Events Plotting
UIC	International Union of Railways

Annex B. Case study framework and format

B.1 Frame for case study analysis

The case study format is aimed at supporting structuring and documenting case study. A description of each item will be given and reference to other wiki's to the concepts behind gives support on sharing knowledge and develop better understanding of learning from lesson's learned.

In the following figures solution spaces are represented as a structure for identifying the outcome of follow up of the accident investigation.



B.2 Themes of case study analysis

1. description accident
2. dimension lessons learned and solutions developed
3. system levels involved
4. depth of learning
5. impact
6. references to resources knowledge used

Description accident

1. what has happened short (description, pictures etc.)?
2. how has it happened?
3. why did it happen?
4. who/what was involved?
5. when: date, historical events?
6. where: place , context of event and system (general, environment, topography, weather)?
7. sector involved

Type of event

1. content aspects: what business process was involved, what activity was going on?
2. structural aspects: what structure was involved?
3. cultural aspects: was any culture aspect of importance?
4. contextual aspects: are specific items or influence of interest?

Magnitude of damage to system involved

1. kind of property damage
2. victims
3. scale (magnitude) of damage
4. down time business process and connected logics chain, infrastructure involved

Investigations known

1. summarise investigations known (all least most influential)
2. sources of information: reports, literature, key articles, specific training, safety campaign etc.
3. communication of recommendation: How results have been communicated?

Dimensions lessons learned: solutions developed

1. content (what goes on in primary process):
   How can the work be done safer?
2. structure (system architecture and functionality): lessons on aspect structure: what structural improvements are sought: organisational, procedures?
   (Re)design hardware, technology and (re)design organization and processes.
3. culture: what behaviour or even cultural changes are sought or have been developing as a result of the accident?
   Organizational culture, learning culture, behavioural change.
4. context (operation environment)
   Business/change management organized (learning agent) Political, social changes needed, supporting organization (e.g. safety board), development of knowledge

Dimensions lessons learned: system levels involved

System level) and overview stakeholders: government, branch, holding, plant, process, man/machine interface. As a system definition a socio technical system is proposed while levels are a simplified references to the Accimap model of Rasmussen and the DCP diagram of Stoop

System levels refer to recursive system levels identified in case studies:

1. micro: individuals, teams, company and holding level
2. meso: industry and industry branch level
3. macro: government and society level, Industry network, Transport system, Government: regulations, Society: safety board

Dimensions lessons learned: depth of learning

1. optimize: restore and repair (cf. first loop/order learning (change of rules)
2. adapt: improve solutions (cf. second loop/order learning (change of insight, norms and values)
3. innovate: renew solutions (cf. deutero/third order learning (learn to learn), technological (new principles, breakthrough) knowledge development.

Impact

1. changes identified: What changes in safety climate are observed?
2. change/learning agent
    a. who/what takes care for follow up?
    b. who/what keeps memory/knowledge alive?
    c. who/what keeps monitors effectiveness?
3. change timeline
4. change of investigation process
   Did the accident and following investigations lead to any changes in the way investigations are structured (investigation board), done?

Evaluation of accident and follow up

1. discussion by ESReDA group
2. are changes sustained?

References to resources knowledge used

1. communication of findings, recommendations
2. other transfer of knowledge by parties involved, professional organizations

B.3 Template case studies

Item	Explanation	
Description event (system involved)		
Description accident	Short description What has happened (description, pictures etc.) What agents (the damaging energy source e.g. nuclear hazard)? How has it happened what were causes? Why did it happen? Direct causes Why did it happen? Root causes Other root causes When did happen? Timeline of main events Historical events Place Context of event and system (general environment, topography, weather) Sector involved	
Type of event	Content aspects: primary activity, operational aspect involved general or macro description of plant or system involved Local or micro description of process/system involved in accident	What was the primary process of the company involved were the accident happened?

Item	Explanation	
	Structural aspects: e.g. Relevant organisational structures, infrastructure, buildings etc.	What organisational systems and assets were involved?
	Cultural aspects: personal safety culture, company safety culture	Which cultural aspects were part of the accident causation?
	Contextual aspects e.g. Industrial safety culture	What influences had the surrounding of the company on the accident e.g. industry culture, competition?
	Area and stakes vulnerability to the system	
Magnitude of damage to system involved	Scale and kind of property damage	What kind of damage or injury happened?
	Victims	
	Magnitude of damage: financial, environnemental etc.	
	Down time	
	After the event, aftermath actions to restore, repair, de-pollution, compensate	
	Speed/pace of recovery completely back into business	What impact had accident on downtime of primary process involved?
Investigations known	by safety board/special commission involved	What organizational or public bodies investigated the accident?
	public authorities	
	by companies involved	
Learning dimension: solution developed		
Content	Elements of the primary process to be improved	What are the changes in the primary process?
Structure	Organizational structure	What structural organizational change was implemented?
	Technological structure	What technological change was implemented?
Culture	Change of culture	Was company culture change with respect to beliefs and values with respect to safe production
	Change of behaviour	Were specific aspects of individual behaviour addressed (compliance, motivation,

Item	Explanation	
		awareness and mutual talk about conduct?
Context	Supporting conditions	Where supportive measures taken in the surrounding of the organization like starting specific research and development to look for technological solutions or developing of industry safety academy?
	Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system	
System level involved		
Micro	Solutions at company level, subcontractors at company level	What measures are taken at company level?
	Timeline of implementation of solution months/years	What was the timeline involved: real time direct corrective and/or preventive, short term generic measures?
Meso	Actions of safety authorities, what actions? Branch involvement	Shut down, withdrawal licence to operate. Order to change.
	Timeline of implementation of solution months/years	What was the timeline involved: real time direct corrective and/or preventive, short and long term generic measures
Macro	EU-level development, directive or standard being changed or research program being started or...	Governmental and industry measures promoting research , legislation, code of conduct
	Timeline of implementation of solution months/years	What was the timeline involved: preventive, short term and long term generic measures?
Dimensions lessons learned: depth of learning		
Optimize		Only repairing and local improvement
Adapt		Process and technological and change safety culture redesign and adaptation of organization, industry
Innovate		Develop new technology to prevent accident and renew organizational culture
Impact		
Changes identified	What really changed?	What improvement can be identified?

Item	Explanation	
Change/learning agent	Who/what takes care for follow up?	Who is responsible and the authority and resources to implement change recommended?
	Who/what keeps memory/knowledge alive?	
	Who/what keeps monitors effectiveness?	Who keep record of implementation and has authority to correct when planned change last to long or is forgotten?
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	Can milestones of the change process be identified in time perspective?
Change of investigation process		Has the investigation given reason to reflect on methods used and needing alternatives or development?
Evaluation of accident and follow up		
	Conclusions and comment with respect specific experiences/ observations/ discussion by ESReDA group	What are reflection on case in terms of barriers to learning identified, learning lessons overlooked etc.?
	Are changes sustained?	Can with hindsight be confirmed that implemented change last and are sustained?
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission	References to public resources for further reading and extended reflection on case.
	Report inspectorate/third party	
	Company reports	
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Articles in journals, magazines, internet	Has the accident investigation and follow up of accidents been subject of further study, evaluations, academic discussion or discussing in branch?
	Courses, training	
	Relevant links	What links provide information on accident or related publications and studies?

ESReDA Project Group Dynamic Learning as the Follow-up from Accident Investigations

http://www.esreda.org/ProjectGroups/DynamicLearningastheFollowupfromAccident/tabid/2095/Default.aspx

ESReDA
European Safety, Reliability & Data Association