Enhancing Safety:
The Challenge of Foresight

ESReDA Project Group *Foresight in Safety*

Chapter 7

Utilizing the ESReDA Cube
to detect early warning signs

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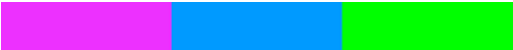
7 Utilizing the ESReDA Cube to detect early warning signs

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7.1 Executive summary

The ESReDA Cube model was developed by the ESReDA Project Group on Dynamic Learning and published in 2015. In this chapter we propose that the Cube model may be utilized to identify early warning signs of the system functioning, and solutions to improve the safety performance of the system in which the failures occur.

The purpose of this chapter is not to have foresight results, but to show how the Cube can be utilized to identify foresight potential. Applying the Cube makes it possible to explore links between otherwise isolated solutions, causal aspects and contributing factors. Here we are interested in the context, operating conditions and system states in which such factors, actors and aspects can serve as early warning signs. In doing so, we can use the Cube as a proactive, analytic tool to identify early signals of system safety performance during design regarding assumptions, simplifications and modelling, including or excluding specific safety aspects. Moreover, we can identify suppressed safety signals that get lost in daily operations, traded-off against economy, environment, lead time and production stress.

By such a coherent scan of all system dimensions, in practice the mapping will give us insight by e.g. helping to identify early warning signs and safety management system components that need to be followed in a systematic way in order to gain foresight and avoid future accidents and other undesirable events. Yet, it is not only the goal, it is the road towards it: The Cube model should not be looked at as merely a mapping of all the elements involved. In addition, the mapping of the elements generates a process that aims to provoke discussion of aspects (incl. insight, and foresight potential) that might otherwise be ignored or get lost in the shuffle. The 'rote faden' of our chapter is to structure the search for order in the complexity chaos, discriminating between safety interventions in either the event or the system, while accumulating understanding of the coherence and dynamics of what is going on.

7.2 Introduction

The ESReDA Cube is a model developed by the ESReDA Project Group on Dynamic Learning during 2010-2015 and published in 2015. Originally, the Cube model was developed to give structure to the various descriptions of what a 'system' could look like in accident investigations. Throughout the debates in the project group, several additional options for application became feasible regarding foresight and early warning signs. Modelling the system behind accidents could better identify successes and failures behind occurred accidents, identifying learning agents and change agents at various system levels. This resulted in a Cube 2.0 version.

The ESReDA Cube has been published on the ESReDA website where it is freely available (ESReDA 2015). As named, it is a cube, a three-dimensional model which can be used as a tool to demonstrate and communicate feasible, credible and plausible system changes and adaptations. The Cube is illustrated in Figures 1a and 1b, and in more detail in Figure 2. The three dimensions represent viewpoints to change potential and learning: 1) stakeholder affected: the organizational levels where learning occurs, 2) work organization: the constituent parts of operational environment where the learning is executed and 3) degree of renewal: an assessment of the impact such learning may have on the system's safety performance. The cross-sections of these viewpoints create 3x3x3 "building blocks" of learning and change, expressed as elements that can be utilized as a systematic way to create new understanding and solutions. The Cube is chosen to visualize issues of a complex nature, in analogy with the Rubik Cube. Careful manipulation of the 'building blocks' should demonstrate the ability to produce the primary system dimensions in a logical and formal manner in an apparently chaotic environment.

The Cube 2.0 version does not add another communication metaphor to existing ones, such as the Swiss Cheese, Domino Stones and Iceberg. The Cube aims at structuring the collected investigation information, interpretation of findings and

potential for change in terms of system dimensions, contributing variables, actors and actions. The Cube has two functions: first it helps the analyst to identify the position of learning agents, and second, it identifies change agents and change drivers in a complex modern socio-technical system. By combining the two functions, a relation is established between the problem definition (what went wrong) and solution diagnosis (what can be done about this). These activities may intervene in the event as well as the system. Since it is not likely that – due to a variety of non-linear relations between multiple contributing factors- the problem definition and solution diagnosis are to be found in the same cell of the Cube, interrelations between cells are identified. Consequently, the Cube may picture the complexity and dynamics of modern socio-technical systems. The actual accident scenario under scrutiny is considered the sequence of events, vectoring its path through the Cube by linking cells.
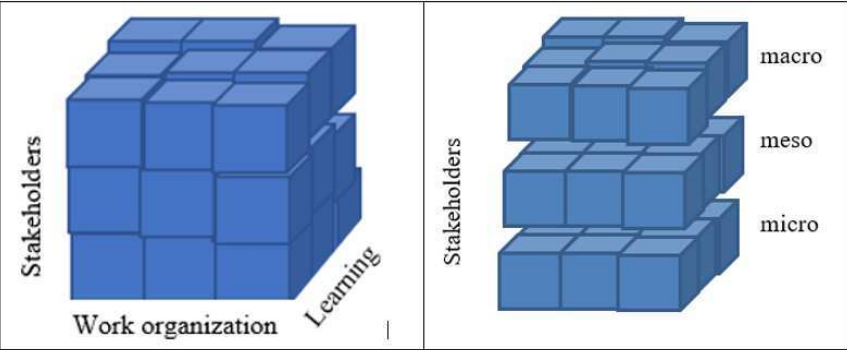
The Cube is supported by a Template (see ESReDA 2015) that serves as a user guideline for categorizing and ranking of contributing factors, actors and aspects into the Cube. While the Template provides an assessment of the results of the analysis phase of the investigations, the Cube provides a communication tool for further learning and needs for change.

Since the publication of the Cube it has been tested by both members of the ESReDA project group and external researchers. These analyses have led to knowledge that the Cube may be used in several ways that are beyond its original purpose, and to the further development of the Cube. Therefore, the Cube 2.0 presented in this chapter is the more matured second version of the Cube.

Figure 1a. The ESReDA Cube 2.0. A model with three dimensions and 27 individual cells that represent different possibilities to improve safety.

Figure 1b. The Cube may be sliced into planes. If sliced into horizontal planes, each plane represents a different organizational or societal level where safety may be improved. Slicing vertically (different aspects of work organization) or in-depth (levels of learning) is also possible, depending on the objectives of the analysis. We can discriminate between the questions: WHAT to change (aspects, factors), WHO is changing (actors, agents) and WHERE to change the system (components, configurations, concepts)
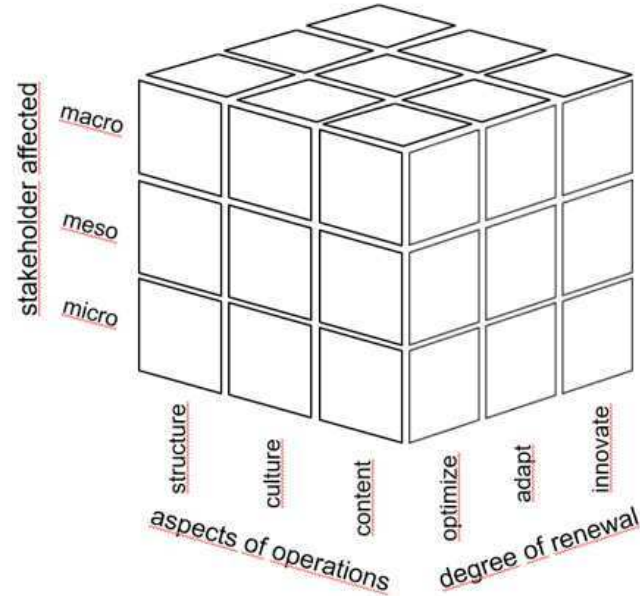

Figure 2. The "building blocks" of Cube 2.0.

The Cube 2.0 version differs from the original ESReDA Cube most notably by dealing with the former fourth operational aspect "context" separate of the Cube, for two reasons. First, the context adds case specific short-term operational conditions (such as deteriorating weather conditions, occupational stressors or aggravated system states) which may pull the event outside the intended and normal operating envelope. Second, it puts the event in a long-term historical development which may deviate from intended performance by design and foreseen operations. In short, the description of the event in the first phase is a specific representation of the occurrence. This occurrence may deviate from the designed and intended performance of the system under normal conditions in its intended operating envelope. The difference between 'as is' versus 'as ought to be' may provide transparency to what actually happened and requires further investigation into why this difference occurred.

Safety experts are hereby invited to test the Cube and the ESReDA project group is highly interested in feedback from various industrial domains, scientific disciplines and actors with different expertise and backgrounds.

7.3   Application of the Cube in the investigative process

Generally, the investigative procedures can be divided into three phases, each with a specific function. The aim of the first phase is accident reconstruction, the aim of the second phase is the analysis and interpretation of system deficiencies leading to the accident, while the third phase aims at adaptive intervention in the system itself. The investigation itself is an iterative process. In the investigation, and in exploring the usefulness of the Cube, we rely on the tools and techniques that are readily available from investigation practices across various sectors and domains.

Most prominent are:

- Timeline reconstruction of each potential contributing event
- Preservation of volatile data by digital information storage and analysis
- Interview techniques, covering actors, witnesses and bystanders
- Document analysis, such as maintenance and operational logs
- Historical surveys of past performance, accident reports and safety audits
- Inventory and repositories of already published recommendations.

A completely new domain to be explored is the use of Big Data analysis techniques to identify patterns and trends in data that has been collected for other reasons, but that can be useful to create a more complete picture of the system under scrutiny.

Timeline reconstruction is essential since we want to elaborate on the dynamics of complex systems. This is what is asked for in classical investigative questions: "What happened?" and "When?" However, it is even more useful for the investigation of accident when the above-mentioned techniques help reach the reconstruction of the accident scenario. In an ideal case, such a scenario describes the accident as a (possibly branched) sequence of events occurring under certain circumstances.

The second phase of the investigation is to determine the causal factors behind the accident. Here the Cube may be utilized to identify causes systematically and thus achieve a more complete overview of the 'big picture'.

In the third phase of the investigation process, the function of adaptation and change is dominant in phrasing: What can be done to prevent similar occurrences. The Cube serves as a repository of already existing solutions and provides a learning potential for change, varying from optimization and adaptation to innovation. The focus can be on the event, the system or both, depending on the scope and goals of the investigation.

From the system perspective, it is ideal to apply the Cube to the learnings and recommendations of each causal factor. Because it clarifies interrelations between factors, components, decisions and intentions, dynamic behaviour can be made more transparent. Consequently, multiple applications of the Cube are necessary. The number of applications is equal to the number of causal factors that make up the accident. Results of individual applications of the Cube can be surprisingly variable not only because the causal factors are different, but also because the application of the Cube reflects that causal factors i.e. deficiencies in the system's functioning may occur in the different processes implemented within the system.

7.4   Foresight potential of the ESReDA Cube

In order to have foresight potential, it is essential that foresight potential elements can be identified. Every event (accident, incident or near miss) is the end-product

of a breakdown of the design or operations of a system. Such breakdown can be traced back to certification, its safety management system (SMS) or governmental oversight. SMS elements could be of the following nature:

- human-related behavior and procedures
- organisational-related behavior and procedures
- system component (equipment) condition
- environment conditions, etc.

The challenge to obtain foresight is to be able to select key SMS elements that would be ideal candidates to be potential foresight elements that could be monitored and evaluated on a continuous basis.

Additionally, it is essential to stress the importance of multi-stakeholder involvement in the process to obtain foresight potential elements: operators, line managers and senior managers are key actors in the process. At the operational level, operators' knowledge is essential because they are the ones doing the work. They will better understand which behaviors and work routines failed and succeeded. They know their designated system and they would be able to identify where improvement could be made, and which could be candidate foresight potential elements. To complement this, the knowledge of the overall management perspective is very important because floor workers are limited in what they are able to see at the organisational level. They may detect the cause of the organisational stress that led to the event but will be limited in identifying the foresight potential elements at the organisational level. Thus, managers and operators need to be together on this fact-finding journey to be able to design a foresight program and a foresight seeking system ad hoc to the SMS of their organization. They should also be together in the design of the audits and corrective actions (e.g. new procedures) related to the foresight potential elements.

Examples of foresight potential elements that could be regularly monitored and audited by both operators and managers are:

- workflow systematism
- equipment abuse/misuse
- deviation in work procedures
- behavioral trends

- production pressures
- etc.

This chapter describes five application types of the ESReDA Cube. The objective was to verify whether some foresight notions could be obtained for each use case. Each application type is also accompanied by at least one example and discussion on the application's potential to identify early warning signs and foresight potential. Figure 3 below portrays, for each application type, when the ESReDA Cube analysis has been carried out.
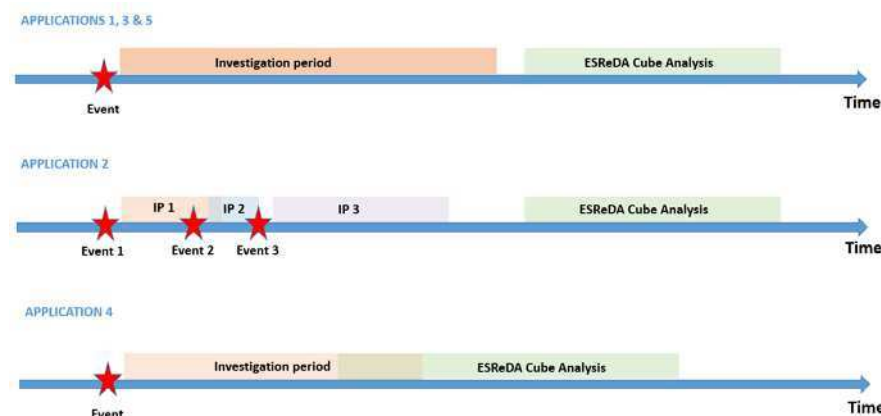

Figure 3. Temporal position of the ESReDA Cube analysis.

7.5   Application 1: Single case analysis

Single case analysis. The original purpose of the development of the ESReDA Cube was the need to construct a model that would help analyse all the pieces of a large-scale accident in a systematic way.

Example of single case analysis
One of the cases utilized in the original Cube analyses was an explosive fire that had occurred in Finland in 2003. Inserting the causes and recommendations onto the Cube identified e.g. the several culture-related changes that had been made in the company's safety management system after the accident, including better reporting of accidents and near misses, and sought-after changes in attitudes and safety culture.
Examples of analyses are available in the original ESReDA Cube publication (ESReDA 2015). Also, three large-scale aviation accidents were analysed by Martens (2015).

7.6   Application 2: Theme analysis

Theme analysis is a method to get more from less. Analysing several similar "smaller" cases with the Cube will result in more information than can be obtained from one case alone. Examples of use could be e.g. incidents occurred with LPG (liquified petroleum gas) cylinders, building fires with similar consequences or immediate causes, and other incidents which constitute a need to make an emergency call to the Fire and Rescue Services, but do not usually necessitate the creation of a larger investigation body. The reports of these incidents usually have the common factor that one case itself does not contain enough information to draw wider conclusions that will prevent similar accidents in the future. Nevertheless, combining the information of all known such incidents may result in new findings concerning most common problem areas and e.g. what should be improved on the organizational level. Basically, the outcome of the analyses is a "trend" or knowledge of what the cases have in common. This can be used as

foresight to what might happen if such knowledge deficiencies can be resolved and new solution domains are opened for further elaboration.

Example of theme analysis
Instead of grouping causes, Karanikas et al. (2018) used an adaptation of the ESReDA Cube to group recommendations. They grouped the recommendations of 82 aviation accident investigation reports and the results of their analysis indicated that most recommendations are located near a particular corner of the Cube, but that there are significant differences across investigation authorities. Also, the severity of the accident influences the location of recommendations in the Cube.
These results may be used to gain insight of how recommendations are constructed and to subsequently identify best practices for the formulation of effective regulations.

To identify the knowledge deficiencies and new solution, theme analyses could be made inside of an organization, or (probably most important) inside of a network (system). Also, the analysis could be made between different systems (aviation, railway, maritime).

7.7   Application 3: Analysis of investigation success

This type of analysis may be utilized both in-house and by outsiders. Learning from investigations has two purposes: first, to improve the skills of the investigators, which will mean better investigations in the future. Second, to analyse the completeness of the investigation and thus the investigation report. The ESReDA Cube will reveal if there are aspects missing from the report. Aspects which either were thought to be irrelevant by the investigators (in which case they still should have been addressed in the report to avoid elements that remain open and questions that remain unanswered to the reader) or they were actually missed by the investigators altogether, and should therefore be re-opened for scrutiny. A third possibility, which should be addressed in the final investigation report, are the boundaries of the investigation that are due to e.g. a predefined scope (e.g.
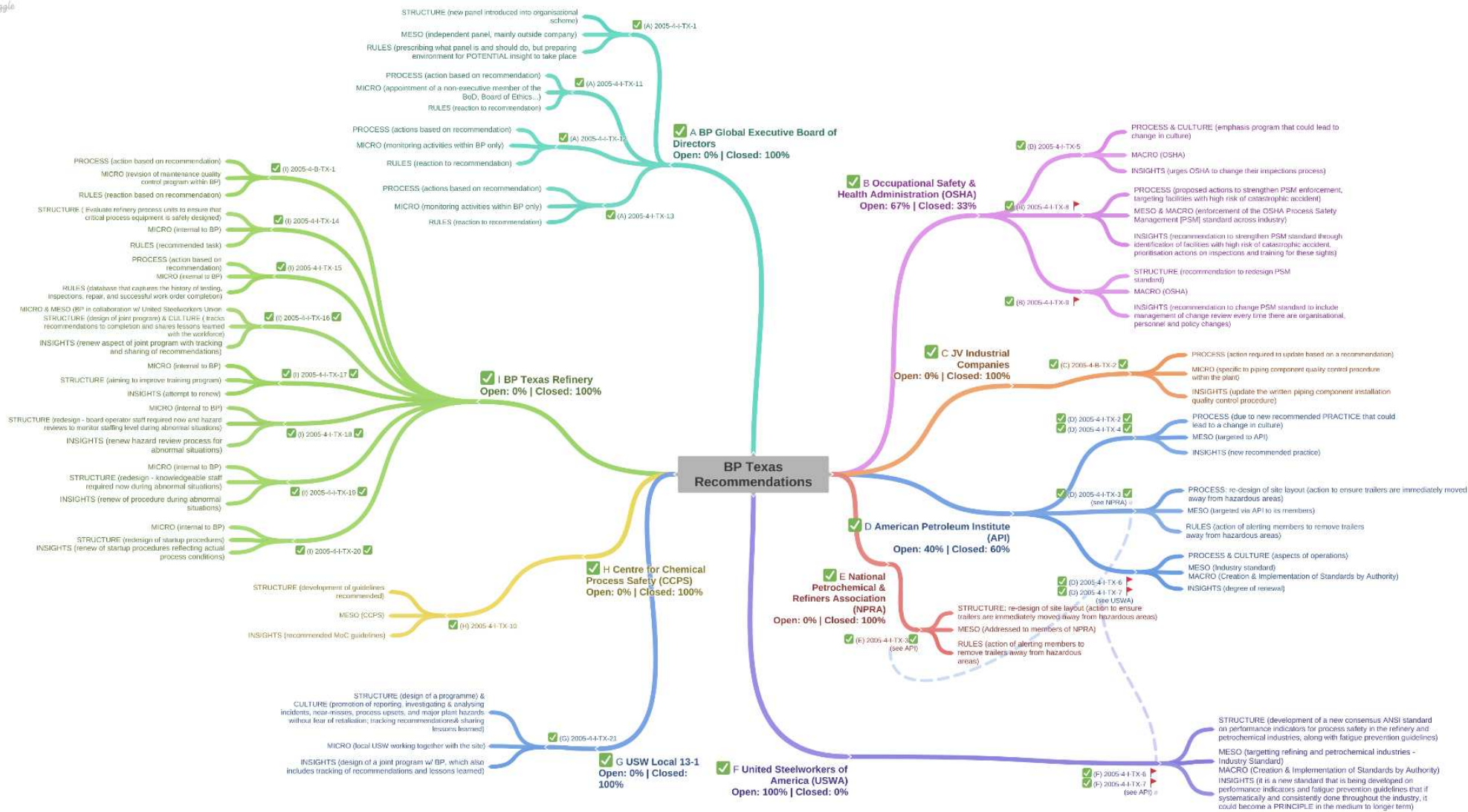
Figure 4. Mind map of recommendations according to groups requiring to implement them, along with ESReDA Cube textual classification (created using Coggle).

"we will not examine further than..", "we will not ask the managers" or "subcontractor's organizational culture issues were not examined") or stoprules during the investigation process, such as the limited time, funding or human resources of the investigative body.

Example of analysis of investigation success

The explosion at BP Texas in 2005 led to several accident investigations executed by different stakeholders. This resulted in the production of several investigation reports, most of them now available online (see e.g. list of references on the Wikipedia page of the accident). Although the incident's chain of events remains the same, in other aspects the investigation reports are significantly different and concentrate on different issues, whichever viewpoint deemed most important by the investigative group. Still, one of the key results of the investigations was that BP Texas had not monitored the process safety status of the site. Nowadays companies have the foresight (as a result of e.g. the investigation of this accident) to include several process safety indicators in their safety management system to gain insight of increase in accident risks via the monitoring of process aberrations.

The CSB accident investigation report concerning the BP Texas accident was analysed by Tulonen et al. in 2018. The analysis was continued further for this report. Before mapping the recommendations onto the Cube, an initial mapping using a mind map (see Figure 4), was carried out according to actors required to address the recommendations. The mindmap helped in the analysis of the recommendations and facilitated mapping onto the ESReDA Cube.

The mapping of the meso-scale recommendations led to some interesting results and related questions:

- There were no triple-loop learning recommendations.
- There were no culture-oriented recommendations.

With the ESReDA Cube each investigation report (like the individual reports concerning the BP Texas accident) may be analysed separately, to identify the priorities of each investigation group. The Cube will also identify the possible differences or contradictions in the results of the investigative groups, and aspects (empty cells in the Cube) that each group has possibly missed or omitted.

On the other hand, as investigations with differing objectives produce reports with differing focus, combining the results of all the investigations and inserting them into the cells of the ESReDA Cube will gather all the results into a systematic and easy-to-understand form that will help assess the incident as a whole. In addition, it will identify accident factors that need to be addressed without the risk of ignoring others.

Perhaps, when designing recommendations, safety boards should take care to also target recommendations that lead towards triple-loop learning and culture-building at all levels (meso in the example above, but also micro and macro). That should be an objective from the start. Interestingly enough, Karanikas et al. (2018) arrived at a similar conclusion: 80% of the recommendations in aviation were targeted toward single-loop learning, and 95% towards other than culture-oriented recommendations (see also summary of their results in Tulonen et al. 2019).

Concerning the example above, it would be interesting to do the exercise for different levels for this event, but also to do it for several other accidents. Would the outcome be similar? It would be interesting to see how many boards in the past have strived to make recommendations addressing triple-loop learning and culture-building in an explicit manner.

Additionally, what would be very interesting to check with this BP Texas accident is to verify if all recommendations have been implemented and consequently map the current follow-up situation onto the Cube. Such an exercise would trigger questions such as:

- What were the obstacles encountered at the meso level that made it difficult to implement a given recommendation?
- Which recommendations led to an improvement in the mapping classification onto the Cube?
- How can these results feed into improving safety-related aspects at the meso-level across the given industry?
- How can we design better recommendations that target a triple-learning loop learning level and a culture-building organisation level?

The use of the Cube serves as a consistency check and quality control on the investigation process management.

In this application, the aim was to validate whether the Cube can be used as a tool for foresight in safety based on knowledge gained from past accidents. When studying past accidents one is usually interested in knowing four main issues: causes, lessons learned, recommendations and follow-up (implementation, effectiveness).

The BP Texas accident causes, lessons learned, and recommendations have been identified as knowledge elements that were mapped onto the Cube cells. This process resulted in a systematic way of better understanding the accident from an operational perspective in terms of different stakeholder levels, operational aspects and degrees of learning potential. The Cube can assist to gain insight on foresight as the mapping process facilitates identification of questions that need answers, such as what do the empty cells mean. Why do some cells have many knowledge elements more than others? Which learning from these knowledge elements can be implemented for foresight in my organization? Answering questions such as these, with a visual tool such as the Cube, facilitates and structures multidisciplinary teams to discuss foresight issues in relation to a specific scope in a systematic manner, e.g. cell by cell.

7.8   Application 4: Investigation support

The ESReDA Cube cannot be classified as an accident investigation method, but as a tool.

Utilizing the Cube at the end of the investigation, or during different phases of the investigation process, can be very useful. After those involved in the accident have been interviewed and the collection of information seems to be at an end, the Cube will help identify which aspects of the accident have indeed been covered and which have not (Cube cells remain empty).

Thus utilization of the Cube will help formulate further questions that require answers in order to obtain a more comprehensive investigation and report.

Example of investigation support

This was tested at the end of an accident investigation concerning a chemical explosion that occurred in Finland in March 2018. (Tulonen et al. 2018). The identified causes of the accident were compared against the cells of the Cube, with the aim of provoking further discussion about potential accident causes.

At the end of the investigation the ESReDA Cube may be used to help construct the final chapter of the report, the recommendations on how to prevent similar accidents in the future.

7.9   Application 5: Recommendations check

Recommendations check helps to detect if there are differences between the results of the analysis, the recommendations and implementation.

Example of recommendations check

This was also tested at the end of an accident investigation concerning a chemical explosion that occurred in Finland in March 2018 (Tulonen et al. 2018). The cells of the Cube were compared to the draft investigation report to identify possible missed viewpoints.

This application was also illustrated in the previous examples in applications 2 and 4 concerning the analysis of the 82 aviation accidents and the analysis of the CSB recommendations concerning the explosion that occurred at BP Texas in 2005.

Ideally, cells in the Cube that should be occupied by root causes should be identical to points in the Cube that should be occupied according to recommendations resulting from the accident analysis and to the points in the Cube that are occupied by the measures which were implemented after the accident.

7.10 Conclusions

The Cube and its underlying template is an investigation tool available to analyse the lessons learned in order to explore solutions and recommendations. The structure of the Template and the Cube provide a checklist for completeness of analytical conclusions, facts, and findings. The results yield information about not only the direct causes of the accident(s), but also the underlying surroundings. This information may be used to formulate an overview and foresight on what should be done to prevent other accidents.

The Cube identifies an overview of shared lessons and solutions for specific types of events beyond a case by case basis of analysing of events. To provide an encompassing overview, single event investigations should be rich of information or combining information into a category of similar cases should be used. The Cube serves as a quality check for completeness of findings and conclusions of an investigation. Rather than counting the number of recommendations and solutions in a cell of the Cube, understanding of their relevance and potential for learning and change counts.

7.11 Discussion

Differences in investigation results may origin from vision, mission and legal mandates of an investigative author, resources, past performance and competences. Differences may also stem from the methods applied, procedures and limitations in qualifications and competences and proficiency in conducting investigations. In general, investigation authorities are highly qualified in the forensic first phases, sophisticated in the second phase of analysis of systemic deficiencies, but less experienced in effectively dealing with systemic safety deficiencies. The Cube 2.0 version might add to their intervention potential in enhancing safety at a systemic level.

Utilizing the ESReDA Cube is integrated into modern accident investigative procedures. The Cube is applied within the different phases of investigative procedure in direct relation to timeline development, creating scenarios (see chapter 5 on scenarios) and system perspective (see chapters 1 and 2).

Creating a timeline is a collaborative effort of all investigative parties and intends to lead to consensus on the sequence of events. Creating a timeline is based on the available data at the moment of the on-scene data collection. Since such data collection is never complete, missing information on critical steps and building blocks may create gaps in understanding the sequence of events and leaves opportunities for speculation, interpretation and continuation of the fact-finding process. A more encompassing data set can be created by combining similar events and re-opening of investigations in case of new evidence. Here the ESReDA Cube shows its strengths.

The company gains foresight from the results of the Cube analyses. The results give information about underlying problems and needs for learning and change. Through this information the company gains foresight to change its safety management system, e.g. to redefine what should be measured – what could be indicators of a rising accident risk.

The ESReDA Cube provokes discussion on learning beyond 'the obvious', beyond the general idea of preventing similar accidents by identifying and eliminating the direct causes of an occurred accident. The Cube invites parties to discuss potential for double- and triple-loop learning: to adapt and to innovate. These discussions will result in new ideas to increase safety, beyond the prevention of 'similar' accidents only by providing foresight to prevent any/all accidents by identifying underlying causal factors that are the root of the system safety as a whole, and needs to learn and change the system in more innovative ways.

Applying the Cube supports the transition from evidence based understanding of the event towards transition based intervention in the safety performance of the system. It visualizes the links between *insight*, -based on the investigative reconstruction-, towards *oversight* over the system operations and safety performance -by analytic interpretation-, leading to *foresight* over the consequences of adaptive interventions.

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