Deliverable D.3.B

Methodology to determine a Safety Management Efficiency Index - Deliverable D.3.B

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Abstract. This report is a deliverable in the ARAMIS project. It described the background of the safety management concept and the methodology to assess the quality of safety management. A detailed audit manual and the Safety Culture Questionnaire are attached as annexes to this report. Preliminary responses from the test cases suggest that the methodology works, but especially the audit process needs improvement to make it less sensitive to the individual auditors attitude and experience. Principles for the quantification process to transfer the results from the management assessments to the risk level of a hazardous site are derived, but numeric values for weighting functions await the response from the expert elicitation process.

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Preface

The ARAMIS project (Accidental Risk Assessment Methodology for IndustrieS) is funded by the European Commission under Contract No EVG1.CT-2001-00036.

Work package 3 in the ARAMIS project addresses the development of a methodology to evaluate the efficiency and effectiveness of safety management to prevent and mitigate major accidents. This reports present deliverable D.3.B with a description of this methodology.

The report includes a description of the concept of safety management (chapter 2), and descriptions of tools to assess the safety management quality using audits (chapter 3) and a safety culture questionnaire (chapter 4). The safety management concept focuses on the management of safety barriers, and chapter 5 presents a classification of safety barriers from the point of view of safety management. The method of correct the reliability of safety barriers depending on the safety management quality is described in chapter 6. Finally some experiences from case studies and conclusions are provided (chapters 7 to 9).

1. Introduction

Work package 3 in the ARAMIS project addresses the development of a methodology to evaluate the efficiency and effectiveness of safety management to prevent and mitigate major accidents. The safety management applied in a Major Accident Prevention Policy leads to define actions related to technical, human and organisational factors. The operational goal of safety management is to strengthen the barriers and lines of defence (being technical or behavioural). The barriers' effectiveness depends on the organisational and management framework (maintenance, adequacy of procedures, education, safety attitudes of personnel, etc) against accidents. Safety management contains a large number of responsibilities, tasks and functions.

Safety management affects the probability of occurrence of the scenarios. Therefore the objective of this work package is:

- To assess the effectiveness of various forms and aspects of safety management in preventing accidents.
- To develop reliable indicators which are good measures of the effectiveness of a plant's safety management.

This task is built on the use of several research methodologies:

- Analysis and comparison of specific safety management systems (e.g. application of standards)
- Development and use of theoretical modelling of management tasks, with SADT techniques or function oriented modelling. This will be built on the work carried out in earlier EU projects that established different ways of linking technical risk analyses with organisational influences.
- Expert judgement, in particular to prioritise the management factors for assessment purposes.
- Identification and development of safety performance indicators using audit techniques, questionnaire techniques and analysis of incident reports.
- Analysis of safety barrier typology and the relation between safety management aspects and the effectiveness of the different types of barriers.

This report deals with the following items:

- A description of the concept of safety management (the model of safety management) on which the assessment methodology is based (chapter 2). This concept recognises the contribution of structural elements and cultural elements.
- A description how the structural elements can be evaluated (chapter 3)
- A description how the cultural elements can be evaluated (chapter 4).

(The tools developed for evaluation of the structural and cultural elements are described in detail in the attached annexes)

- A description of the different barrier types that we distinguish in relation to safety management is included in chapter 5.
- The weight factors that determine the importance of the different structural and cultural factors for barrier efficiency are described in chapter 6
- A discussion of the experiences with this method in applying it to a number of test cases (5 "Seveso" industries in Europe).

2. Model description of Safety Management

Safety management is defined as the set of management activities that ensures that hazards are effectively identified, understood and minimised to a level that is reasonably achievable.

This definition is the basis for recognising the activities in an organisation that are part of safety management. In the ARAMIS project, the activity of minimising risks[1] is considered to be performed mainly by means of the concept of implementing and maintaining safety barriers or lines of defence. So safety management includes:

– Hazard and risk analysis, in order to identify and understand hazards and risks; and
– Selection, implementation and maintenance of safety barriers, as the means of minimising the risks.

This leads to a picture of safety management as shown in Figure 1. Risk and hazard analysis is performed to identify hazards. The tools developed in the ARAMIS work package 1 on generic fault and event trees (bowties) assist the risk analysis process in a Seveso-II establishment. Part of the outcome of the risk analysis activity is the identification of existing safety barriers, and (if applicable) identification of the need to implement further safety barriers or lines of defence. The concept of safety barriers is to be considered broadly, so it includes any means that prevents or mitigates a critical event (see for a more extensive discussion of safety barriers chapter 5).

When all necessary safety barriers are identified and selected, the next task of safety management is to ensure the effectiveness of the safety barriers during their lifetime, i.e. the life cycle of the barriers needs to be managed.

The whole process of risk analysis, barrier selection and barrier life-cycle management will be repeated on a regular basis (the Seveso-II directive requires an update every five years) or as often as needed due to modifications to the plant or due to other triggering events (e.g. incidents).

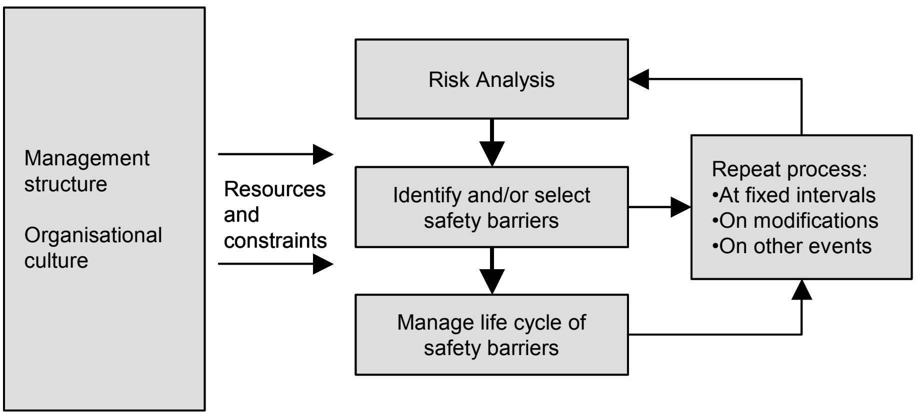

Figure 1. General process of safety management in relation to Major Accident Hazards.

In order to fulfil these tasks, the organisation has to provide resources, while it also will put some constraints on how the activities will be performed. This will first require a management structure, which can be considered identical to the safety management system (SMS) if you like. The structure includes the

[1] Although the definition only addresses hazards, for those hazards that cannot be eliminated, the corresponding risks should be minimised.

principles (policies), plans, formal organisation, responsibilities, etc. It will depend on the quality of this structure, how well the safety management tasks are performed. But we consider that not only the (formal) structure plays a role, but also the culture, i.e. the sum of the individual and collective attitudes, perceptions and practices.

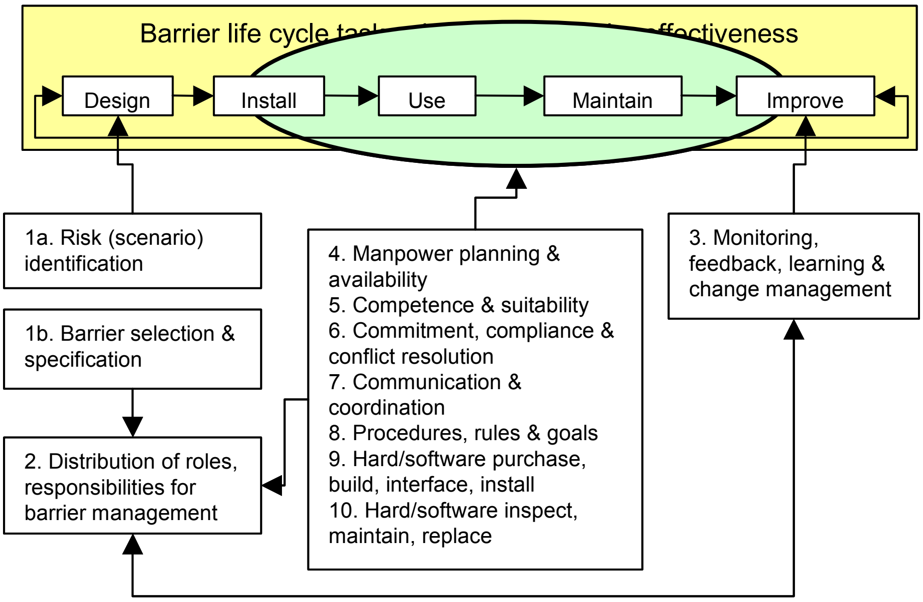

Figure 2. Structural elements of the safety management organisation in relation to the task of managing the life cycle of safety barriers.

This leads to a model where the structural elements of the safety organisation are considered as the essential conditions (sources) for providing resources and constraints to the primary business activities concerning maintenance and operation of the safety barriers, see Figure 2. In this model 10 structural elements are distinguished:

1. Risk identification and selection and specification of safety barriers
2. Distribution of roles and responsibilities for safety barriers management
3. Monitoring, feedback, learning and management of change
4. Manpower planning & availability
5. Competence & suitability
6. Commitment, compliance & conflict resolution
7. Communication & coordination
8. Procedures, rules & goals
9. Hard/software purchase, build, interface, install
10. Hard/software inspect, maintain, replace

(These elements are described in more detail in chapter 3)

When we in the ARAMIS procedure assess the safety of an existing facility with installed safety measures, the direct effect of safety management will be on the lifecycle phases “use” and “maintain”, and only to a limited extent on “install” and “improve”. As a consequence, when assessing the direct effect of safety management on existing safety barriers as they are identified during the risk analysis process (using the MIMAH/MIRAS methodology), the impact on safety levels will in first approximation depend on the structural factors 4 to 10 in the above list.

In conjunction with the structural elements of the organisation's safety management we recognise that there is a set of safety-culture elements that affect how well the safety management functions are performed. We recognise the following set of eight cultural factors:

- **Learning and willingness to report**. This is a broad factor that comprises employees' willingness / reluctance to report accidents and incidents, their perception of feedback from reporting and dissemination of lessons learned. It overlaps with trust in leadership with regard to "just culture". Associated with this factor are single items that may reveal why reporting is not satisfactory: reasons for not reporting.

- **Safety prioritisation, rules and compliance**. This broad factor comprises several factors and single indicators including use of and familiarity with rules and instructions; the prioritisation of safety versus productivity and ease of work; the extent to which and the circumstances under which safety procedures may be violated

- **Leadership involvement and commitment**. This dimension concerns both the avowed involvement and commitment of management and supervisors and team leaders as well as employee perception of their commitment and involvement

- **Risk and human performance limitation perception**. This battery, the items of which may vary according to the type of work domain, concerns management and employee awareness of hazards, risks and human error potentials (fatigue, automation etc.) relevant to their work.

- **Felt responsibility.** This factor concerns employee perception of who is responsible for safety at work including felt ownership of responsibility

- **Trust and fairness.** This factor involves management's trust in employees and, crucially, employees' trust in top management's and their immediate leader's and employee perception of fairness in the workplace

- **Work team atmosphere and support.** This is a broad factor that comprises employees' perception teamwork and the 'spirit' in their respective teams; the extent to which the team gives its members support and help; and the extent to which respondents are willing to speak up and warn each other of dangers.

- **Motivation, influence and involvement.** This broad factor comprises four batteries concerned with perceptions of (i) work as meaningful; (ii) own influence on work planning and execution; (iii) motivation and involvement; and (iv) feeling informed and finding work predictable

The modelling concept now considers that the cultural factors change the reliability of the individual safety barriers in an overall manner, parallel to the influences of the structural factors 4 to 10. The barrier quality is determined by the management/culture factors through its lifecycle phases, but we do not attempt to model this process explicitly. Rather, we assume that we can develop a matrix of weights of influence factors, that link barrier quality directly to the management/culture.

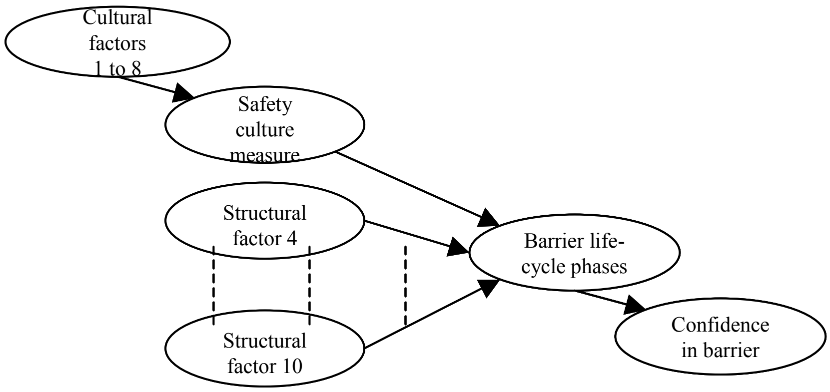

Figure 3. Safety management modelling concept and influences of the different elements.

This shortcut is shown in Figure 4. It requires a set of influence factors to be determined, the set **B** of 8 values per barrier type to determine the influence of the management efficiency on the barrier.

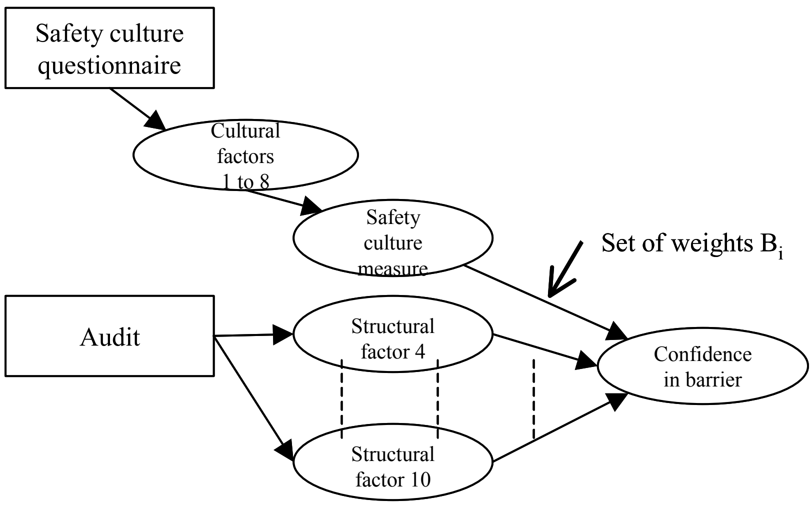

Figure 4. Simplified safety management model. The assessment of the structural factors and the cultural factors are combined into management indices M_i . The effect of the management indices on the barrier efficiency makes use of a set of weight factors B_i, see para 0.

3. Assessment of the structural elements

The structural elements of safety management are divided into a number of "boxes" that represent certain systematic actions necessary to be able to perform and deliver the required management function in question. For the 10 delivery systems, these boxes are described in detail in the Audit Manual, which is Annex 1 to this report, see also Figure 5.

. The number of boxes in each of the nine protocols is as follows:

1. Risk analysis and barrier selection 8
2. Learning & change management 10
3. Design, install, etc. hardware 9

4.	Inspect, maintain etc. hardware	7
5.	Procedures & rules	9
6.	Competence & suitability	10
7.	Commitment & motivation	6
8.	Communication & coordination	4

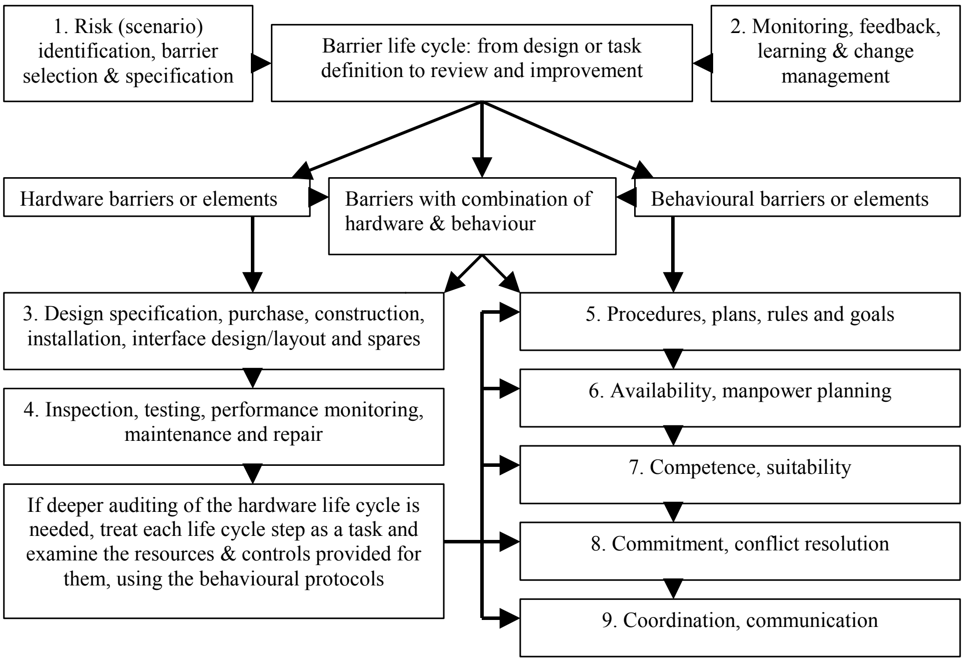

Figure 5 The audit structure

The audit process leads to a rating on a 4-point or 5-point scale for the individual boxes within the delivery systems. For the rating of the delivery system as a whole, the ratings of the individual boxes have to be combined in some way. This is done in the following way: For a number of delivery systems, one or two "dominant" boxes were identified using expert elicitation. For these delivery systems, the rating is expressed as:

$$R_{deliverysystem} = Min\left(R_{do\min antbox}, Average(Allboxes)\right)$$

For those boxes where no dominant boxes identified, the rating is the average of the rating of all boxes (with equal weight).
The expert elicitation led to the following result:

1. One group of delivery systems where all boxes are assumed to contribute equally to the failure of the delivery system:
   a. Manpower planning
   b. Communication
   c. Purchase/install
2. One group of delivery systems where a few boxes are assumed to contribute dominantly to the failure of the delivery system:
   a. Procedures (box 5: communicate, train, execute rules; and box 8: evaluate rule effectiveness)
   b. Competence (box 2: define suitability & competence needed for behaviour)
   c. Commitment (box 3: assess & modify behavioural antecedents & consequences)
   d. Inspect & maintain (box 1: define maintenance concepts & plans; box 6: execute maintenance & repair)

The further analysis and use of these rating is described in Chapter 6.

4. Assessment of the cultural elements

The cultural elements are assessed by performing a questionnaire investigation among the staff of the site to be reviewed. The staff includes all the staff who are involved in the hazardous installation(s) in some professional way, with a focus on the shop-floor labour force (operators, maintenance personnel, production workers, etc.). The questionnaire (SCQPI, Safety Culture Questionnaire for Process Industry) is enclosed as Annex 2 to this report[2].

The safety culture questionnaire

The ARAMIS questionnaire has its origin in a questionnaire on safety culture (or safety climate) factors and work environment aspects developed in 2002-03 by three partners (Herning Hospital, Dept. of Occupational Medicine, the [Danish] Inst. of Occup. Health and Risø National Laboratory) in an independent, nationally funded project on safety culture and occupational accidents. The Danish questionnaire, targeted at production and construction industry, has been based on results and experiences of the partners with safety factors survey development, and on other international sources, especially Nordic and UK ones. sources as well as on other international published sources about questionnaire development and validation in the domain of industrial health and safety and climate culture.

The Danish questionnaire has been adapted to the ARAMIS framework and especially process industry (Seveso type establishments). The adaptation to the process industry has entailed the introduction of additional individual items (i.e., risk perception and changes in definitions of safety events (types of accidents and incidents). The resulting questionnaire, the Safety Climate Questionnaire for Process Industry (SCQPI) contains 102 individual items (besides demographic/factual questions) – see Appendix B. The questionnaire items are arranged in 11 groups of closed questions asking respondents to answer on a five-point Likert-scale plus an optional group of three open questions asking respondents to write their own suggestions about safety, job satisfaction and efficiency. An additional set of three open questions is not included in this list.

1. <u>Reporting of accidents (12 items)</u>
2. *If and when incidents and accidents (all types) do not become reported, this is because ...* (10 items – proposed reasons for not reporting)
3. <u>Safety instructions and attitudes (14 items)</u>
4. *If and when incidents and accidents happen (all types) this is generally because ……* (10 items – proposed causes of incidents/accidents)
5. <u>Prioritisation of safety at work (7 items)</u>
6. <u>Employee involvement in decisions about safety (6 items)</u>
7. *Who do you think should be taking responsibility for safety?* (6 items)

[2] While most definitions of safety *culture* refer to partially implicit or tacit basic beliefs and values shared by members of an organisation, the notion of *climate* is often used to refer to attitudes and perceptions specific to time and location. We describe the questionnaire adapted to the ARAMIS project, which does not pretend to measure core beliefs and values, as a safety *climate* tool. Often, however, the term safety culture is used synonymously with safety climate. We shall often refer, using an inclusive slash, to safety climate / culture, but for brevity only one of the terms will mostly be used – such as in "safety culture factor" or "safety culture index".

8. *Who do you think is, in fact, taking responsibility for safety?* (same 6 items)
9. Commitment by management and leaders to safety (12 items)
10. Trust and fairness (8 items)
11. Work and social relations (13 items)

The items in the four groups listed in italics have been designed to serve as part of batteries to elicit responses that may serve to particular characterise strengths and weaknesses in safety climate (73 items in total). In contrast, the items (29 items in total) in the remaining seven groups (underlined) have been designed to serve (as elements in safety factor batteries) as indicators of the strength of safety climate or safety culture.

The sampling of five ARAMIS sites

The questionnaire was translated from English to Dutch, Slovenian, Czech, and French and the Danish re-translation was slightly modified. Samples were subsequently collected, in the period Feb.-Sept. 2004, from the five ARAMIS test sites for which the above described audit was conducted.

Test site nationality	Number of respondents	% of total
Dutch	47	18
French	25	10
Danish	100	39
Slovenian	35	14
Czech	48	19
Total	255	100

The calculation of the global safety culture index

It was decided among WP3 partners that, notwithstanding the distinction into individual safety climate / culture factors, it would be appropriate to construct a single, global measure of safety climate / culture. A chief reason for this decision was that it was considered impossible to obtain empirical data that would be able to reveal how different safety culture factors impact differentially on safety management and safety performance. In addition, it was considered reasonable by itself to derive and apply a single global safety culture / climate quotient, not least because there is evidence that a relatively high score on a given factor will more likely than not correspond to a relatively high score on any other factor. Finally, it was considered that a relatively simple algorithm for calculating the safety culture factor to be used in the application of the above described safety management model would be highly unlikely to yield a different output than a complex algorithm calculating distinct safety culture factor indices and integrating these.

In the following, we shall therefore deal with the questionnaire items in total, describing how a combined, global index is computed. The steps are as follows:

First, we have asked experts to judge, for each item, whether agreement with the given statement may be taken to reflect a relatively positive or negative safety culture or whether there is no connection. Asking four experts (who have not been involved in the adaptation of the questionnaire to this project) to independently rate each of the 72 items. For instance, respondents are asked to agree or disagree with the statement: ”In our workplace employees are willing to report all work accidents”. Experts were asked if relatively high proportion of

”agreement” and a low proportion of ”disagreement” is a positive indication of a ”good” safety culture, or of “bad” one, or perhaps has no bearing one way or the other.. Consensus among the four experts and the developers was obtained in 69 cases (96%). Only these 69 items have been retained for analysis.

Second, we have changed the sign of responses to “negative” items, so that all items have the same direction of “positive” (or “negative”) expression of safety culture. For instance, the sign has been changed of “I will sometimes violate safety instructions because I feel that my colleagues put”, or “I have not witnessed any improvements made because of reporting of incidents and accidents”.

Third, we have calculated the arithmetic mean of the responses of each of the five samples. We have considered transforming the response data to a parametric scale (so that equal distance between the values of the scale may be assumed). However, since it would be unlikely to make any measurable difference when compare responses from 69 items whether we compute the arithmetic means directly on the aggregated data or on the aggregation of data transformed to proper parametric scales, we have followed the route of simplicity, calculating the means directly (but on sign-corrected data, as described in the previous paragraph)

The results of calculating the means of the (corrected) five samples yields results that lie rather close to each other (on the scale from 1 to 5, where 1 is the highest, and 5 the lowest possible, the five sites scored, respectively, 2,5; 2,5; 2.7; 2.7 and 2.8. The mean score of the entire sample is 2,7 for the 69 items. .

5. Safety barrier types in relation to safety management

We have defined the barrier function as the starting point of our analysis. The function is further specified by the place that the barrier has in the bowtie. The reason that we place emphasis on the function is that we want to compare how different companies or sites choose to implement those generic functions with specific principles and forms of barrier. The implication is that the different forms have different intrinsic levels of performance of the functions (cf. the SIL values), but also that different forms of barrier require a different type of management system to keep them functioning to that maximum level.

The form that the barrier takes will have a major effect on its effectiveness and the management system needed to keep it functioning optimally. We recognise the following forms:

A. Hardware/software

   a. Passive hardware (no moving parts or actuation mechanisms; e.g. vessel wall thickness, a bund round a tank, a blank flange inserted into a line before maintenance, a safety helmet or shoes, a warning sign, painted lines on the floor) once they are designed into the plant or put in place

   b. Active hardware (often with some software components, but operating without human intervention, e.g. relief valves, automatic shutdown systems, automatic sprinkler systems)

B. Behaviour/procedure

Behaviour consists of acting in specific/ defined ways whilst interacting with the dangerous part of the plant, or with hardware elements of the barrier, e.g. evacuation in case of fire, safe working methods when handling chemicals, responding to an instrument reading by shutting down the plant, staying away from defined areas, refraining from touching or modifying parts of the plant

When we are dealing with behavioural aspects of barriers it is very relevant to distinguish the three levels of behaviour summarised in the Skill-Rule-Knowledge (SRK) hierarchy, since the problems of establishing and maintaining each level differ significantly. For example:

1. Skill-based behaviour involves highly learned responses to known situations, which are carried out almost automatically in response to triggers. They require no support from written procedures.
2. Rule-based behaviour requires training to differentiate the situations leading to different choices of behaviour, may be more open to influence by expectations and to choices not to bother with certain routines which appear unnecessary. Support from written rules may be essential if the routines are seldom carried out.
3. Knowledge-based behaviour requires a different type and level of training, allowing and encouraging more creative and self-critical behaviour, may require more support from others in communication to achieve success, and is more sensitive to disruption by time pressure.

Many barriers consist of both hardware and behaviour elements, which must interact to fulfil the total barrier safety function. In order to be clear about the range of choice which there is in choosing the form of barrier elements and the total barrier, it is valuable to specify further what a barrier function consists of. We identify the requirement to specify the barrier, followed by three things that must be performed to fulfil the total function:

Definition or specification of the barrier.

For hardware barriers this consists of the design specification, including the type and level of hazard against which it is proof and the specification of setting, if appropriate. For barriers relying on behaviour it is a specification of the behaviour that should be carried out and the circumstances under which that must take place; this is often defined in a rule or procedure. In summary, ways of specifying the barrier are:

a. Design specification

b. Written rule/procedure

c. Individually defined, informal procedure, devised at the time or learnt over time

d. Group-defined, informal procedure, devised at the time or learnt over time

The last three can be defined at a skill, rule or meta-rule level and the last two also at the knowledge level. Hollnagel (Hollnagel, E., 99)) identifies these rules or procedures as ‘immaterial barriers’, but we prefer to see them as elements in a total barrier function, since, on their own they achieve nothing.

Essential sub-functions (performed by barrier elements) in order to carry out a full barrier function are:

1. **Detection mechanism that the barrier should function.** Permanent passive barriers do not have this element, or rather, their development and installation beforehand is an indication that the need for the barrier has been detected and they are constantly ready to perform their function. Some passive barriers, such as safety helmets, safety barriers round holes dug in the ground, do have to be put in place at the start of work. All active barriers (hardware or behavioural) require this element. The ways of fulfilling this sub-function can be:

   a. Human perception of the need for action

   b. Presence of passive warning signs or protective or mitigating barrier elements, giving indication that the safe behaviour (e.g. steering of the car, donning of the protective equipment) should be activated.

   c. Indications on or from active instrumentation (e.g. radar pictures, pressure or temperature instruments, smoke detectors). Often the detector is directly linked to an actuator (see 2)

   Hollnagel () classifies b and c as ‘symbolic barriers’, but we prefer to see them as elements in a total barrier function, since, on their own they achieve nothing.

2. **Activation mechanism that triggers the response of the barrier.** Again passive barriers do not need this element, but all active barriers do. Sometimes this is incorporated in the detector, but may be separate. Activators can be:

   a. Human diagnosis and decision making (rule or knowledge based) and in some cases action (e.g. donning protective equipment)

   b. Warning given by one person to another

   c. Warning signal from detector, e.g. smoke alarm

   d. Hardware actuator linked to a hardware detector (e.g. automatic shutdown actuator, sprinkler actuator)

   e. Action of human on hardware actuator (e.g. manual shutdown button, control panel button)

   f. Interlock (mechanical, electrical or software)

3. **Response mechanism to perform the barrier function**. Passive barriers perform their function simply through their design and placing. All other barriers have an active hardware, software or behavioural action. In summary this sub-function can be performed by:

   a. Passive hardware (e.g. wall, bund, pipe wall, safety distance, helmet or ear defender)

   b. Active hardware (e.g. pressure relief valve, interlock guard, sprinkler, nitrogen inerter)

   c. Active behaviour, often combined with hardware (e.g. running away, steering or braking car, using fire extinguisher)

   Hollnagel’s categories of ‘material’ and ‘functional’ barriers are respectively b and a under this heading.

The issue of refraining from certain behaviour, e.g. leaving hardware barriers alone, staying away from danger zones, was identified in an earlier document as a barrier type, but we prefer to treat it somewhat separately, as part of the life cycle of the barrier, under the heading of use. Their inadvertent or inappropriate use or interference with a barrier element can be considered as a form of misuse.

This division into elements can form the basis of a matrix for classifying different forms of barrier for fulfilling a given safety function. Different forms for each of the three sub-functions or elements can be mixed and matched in a range of different combinations to achieve the complete barrier function (see Table 1). A more complete classification of barrier types, taking account of all of these aspects, is contained in Table 2.

Table 1. Example of the implementation of different barriers to fulfil the same safety function.

Function	Specify	1. Detect	2. Activate	3. Perform
Fight fire	Procedure	Personal observation	Personal decision	Individual or fire brigade fights fire
	Design	Smoke detector	Sprinkler activator	Sprinkler operation
		Heat detector	Automatic alert of fire brigade	
			Fire alarm	

Table 2. Classification of safety barriers.

	Barrier	Examples	Detect	Diagnose/ Activate	Act
1	*Permanent – passive – MORT control*	Pipe/hose wall, anti-corrosion paint, tank support, floating tank lid, viewing port in vessel	none	none	hardware
2	*Permanent – passive – MORT barrier*	Bund, dyke, drainage sump, railing, fence, blast wall, lightning conductor, bursting disc[3]	none	none	hardware
3	*Temporary – passive* Put in place (and removed) by person	Barriers round repair work, blind flange over open pipe, helmet/gloves/safety shoes/goggles, inhibitor in mixture	none	none (human must put them in place)	hardware
4	*Permanent – active*	Active corrosion protection, heating/cooling system, ventilation, explosion venting, inerting system	none	None (may need activation by operator for certain process phases)	hardware

[3] The AIChE-CCPS document on Layer Of Protection Analysis (CCPS, 01)considers a bursting disc to be an active component.

5	*Activated – hardware on demand – MORT barrier or control*	Pressure relief valve, interlock with "hard" logic, sprinkler installation, p/t/level control	hardware	hardware	hardware
6	*Activated – automated*	Programmable automated device, control system or shutdown system	hardware	software	hardware
7	*Activated – manual* Human action triggered by active hardware detection(s)	Manual shutdown or adjustment in response to instrument reading or alarm, evacuation donning breathing apparatus or calling fire brigade on alarm, action triggered by remote camera, drain valve, close/open (correct) valve	hardware	Human (S/R/K)	human/ remote control
8	*Activated – warned* Human action based on passive warning	Donning ppe in danger area, refraining from smoking, keeping within white lines, opening labelled pipe, keeping out of prohibited areas	hardware	Human (R)	human
9	*Activated – assisted* Software presents diagnosis to the operator	Using an expert system	hardware	software – human (R/K)	human/ remote control
10	*Activated – procedural* Observation of local conditions not using instruments	(Correctly) follow start up/shutdown/batch process procedure, adjust setting of hardware, warn others to act or evacuate, (un)couple tanker from storage, empty & purge line before opening, drive tanker, lay down water curtain	human	Human (S/R)	human/ remote control
11	*activated – emergency* Ad-hoc observation of deviation + improvisation of response	Response to unexpected emergency, improvised jury-rig during maintenance, fight fire	human	Human (K)	human/ remote control

6. Influence factors to relate safety management efficiency to barrier reliability

Combining the assessment of structural and cultural elements into a set of management indices M

The audit leads to a rating of the structural elements, indicating how well these elements are suited to deliver the intended resources and functions, assuming a perfect safety culture, and relative to an optimal score. For each of the distinguished elements, this results in a rate S_i in the range from 0 to 100%. From the total set of safety management elements, seven elements S_1 *to* S_7 are assumed to have a direct impact on the confidence (see Chapter 2 and 3).
Similarly, the questionnaire investigation leads to a rating of the eight cultural elements The results of the questionnaire will lead to a single measure for safety culture from 0 to 100%, also relative to a perfect score., which we call S_0 (See Chapter 4).

Rating of management influences on effectiveness of barriers

The ultimate aim of the assessment of the management structure and safety culture is to be able to make statements about the way in which the management system of the company will affect the effectiveness of the barriers which it has in place to control risk (in particular loss of containment).

A first assessment should include an a priori evaluation of the quality of the choices the company has made for fulfilling each of the safety functions identified in the chosen scenarios, in other words, whether the company has used state-of-the-art techniques in controlling the company-specific hazards. This would mean that the probability of barrier failure is As Low As Reasonably Achievable (ALARA principle) using available technology and non-excessive costs.

For the second step, the optimal SIL (Safety Integrity Level) in the case of hardware barriers or an equivalent generic performance level in the case of behavioural barriers should be allocated to the actually implemented barriers. This figure will anchor the safety management assessment. The assessment of the structural and cultural elements will lead to a rating of the extent to which the management system elements fail to meet the requirements. This means that for safety culture and any of the 7 distinguished delivery systems, a rating of the performance compared to optimal performance will be given, leading to the set of values (management indexes) S_i. The simplest model for the actual SIL for a safety barrier (or safety barrier component[4]) of type *k* is the following:

$$SIL_{actual,k} = \left(1 - \sum_{i=0}^{7} (1 - S_i) \cdot B_{i,k}\right) \cdot SIL_{optimal,k}$$

Here S_i represents the final rating for the delivery corresponding to structural element *i* including audit and safety culture assessments, $B_{i,k}$ represents an array of weight factors linking the importance of the delivery system *i* to the barrier type *k* in question, with $B_{i,k} \geq 0$ for all *k* and *i* (If sum over Bi larger than 1, then the result has to be maximized to 0).

With this result, and remembering that the SIL is defined as $SIL = -^{10}\log(PFD)$, the expected frequency of all relevant accident scenarios can be reviewed using the actual probabilities of failures on demand of the barriers that are identified in the bowtie. These expected frequencies include the assessment of the safety management system.

[4] The probability of failure on demand of a barrier is approximately (rare event approximation) the sum of the probabilities of failure on demand of the serial barrier components.

7. Results from case studies

Results from the audit process

The audit was trialled in four case studies in four countries (Netherlands, France, Denmark, Slovenia). The documentation discussed in 3.2 above was provided to each team, which was drawn from the participating institutes. Each team consisted of two to four auditors, at least one of whom had auditing experience. The trial audits were held in the first 6 months of 2004. The technical models for the sites chosen (a chlorine and phosgene plant, a refinery, a hydrocarbon storage facility, and a methanol, formaldehyde and resin plant) were developed by other ARAMIS partners and provided to the auditors. Un-fortunately the barrier information was not always available long enough in advance to ensure the necessary time for detailed planning.

The audits were conducted over periods ranging from 3 to 5 days. The results were fed back to the companies using the overviews of the different de-livery system protocols in the form of boxes and arrows, showing the set of management tasks and their relationships. Different colours were used to indicate how good the performance was on each box according to the auditors. This feedback session also gave the companies the opportunity to give their opinion of the audit tool and process.

The experience from the trial projects is summarized in section 4 below, together with the lessons to be learned for improving the audit structure and support material.

The general feedback from the audits was that both the auditors and the audited companies found the ARAMIS audit to be successful. It revealed shortcomings which other audits the companies had experienced did not. This was felt to be because its focus was clear and directed to the specific scenarios and barriers in ways not seen before. It was felt to be much more penetrating than general system audits

There were many minor problems with the protocol and guidance, which are characteristic of the early phases of developing an audit tool. These included inconsistencies in the documentation, difficulty in finding the way around in the protocols and some overlap of questions and attention points. There were also some gaps uncovered, which re-quire slight additions to, and rearrangements of the protocols.

More serious shortcomings were in the planning of the audits. The time necessary to make the technical models and arrive at a clear list of barriers to be used as the focus of the audits was seriously under-estimated, resulting in one audit being postponed and others going ahead with only partial lists. A lead-time of at least a month between getting the list of barriers and conducting the audit seems necessary.

It was also felt that it would be preferable to split the audit into two parts with some time (a few days) between each. The first should be devoted to under-standing the general operation of the safety management system and how it maps to the ARAMIS model and confirming who exactly is the owner of which barriers and what their roles should be. This is a largely top-down exercise, starting with senior managers and exploring the various line and staff functions represented in the delivery systems. In the second part the audit should home in on the actual operations of specific barriers, chosen to be representative of the different types being used, in order to verify whether the systems are actually working and whether the barrier owners are performing, as the company requires.

There were also some problems with timing of interviews. More room in the schedule was needed for the two auditors to discuss their interim findings and adapt the planning of later interviews, so as not to leave important gaps.

The technical modelling reveals far too many specific barriers for the audit to look at the management of all of them. The Dutch case had a list of 343 specific barriers. Even allowing for duplicates between scenarios there were still about 100 barriers which could have been chosen as the focus of questions, whilst it is only feasible to consider about 30 in a reasonable time. This makes it imperative to validate further the barrier typology proposed in the project and to use this as a way of choosing a representative sample of barriers for the audit. Whilst the typology did function reasonably, some auditors had difficulties interpreting it and further work is needed to see how consistently it can be used as a classification tool. It may be that a further refinement is needed to distinguish different elements of hardware and behaviour which make up the different barrier types.

The audit support tool was valuable, but needs far more development to become fully operational. It was felt by the companies being audited that they would have been helped by having in advance more information and overviews of the audit tool. The overviews of the different protocols used in the feedback sessions were felt to be very valuable as general guides to the audit structure, which could have been circulated in the preparation phase.

There was some difference of opinion between auditors over the need for detailed questions to fill out the general points of attention. Experienced auditors and those familiar with the structure of the ARAMIS model did not need them and found trying to use them distracting. Less well-informed and experienced auditors asked for far more specific questions and much more guidance on what they should expect to find in good, average and poor companies. This last problem of the calibration of the audit re-mains a thorny issue. There is far too little information available about what ‘an average chemical company’ does under each of the steps of each of the protocols. Filling this gap would require a major data collection exercise, which would also need to be repeated at intervals to keep up with changing practice. It was clear that the audit as it now stands is a tool requiring considerable knowledge from the audit team, both of the process being audited and of the skills of auditing.

8. Experiences/adjustements from case studies

To be included in deliverable D.3.C

9. Conclusions

The audit

The general conclusion of the ARAMIS audit project is that the tool has great potential. The idea of focusing the assessment of management influences on specific scenarios and barriers got general support from the companies as a helpful addition to their assessment tools. However, there is still considerable work to do in crystallizing this tool out and making it auditor-friendly. In parallel with this project a proposal has been developed to fill in these gaps and to provide a much more solid scientific basis for the models and typologies being developed (Betten, J. M., 04). There is much work still to be done to arrive at a practicable tool which will incorporate all of the development work done in the series of EU and national projects stretching from Manager (Technica, 88), through PRIMA (Hurst, N. W. and others, 96) and I-Risk (Oh, J. I. H. and others, 1998) to ARAMIS.

The SCQPI

To be included in deliverable D.3.C

The quantification

The quantification of the safety management influence depends on results from the expert elicitation process and will be reported in deliverable D.3.C.

Overall benefit

The experience from the case studies and the feed back from the review panel makes clear that the benefit of the methodology lies to a high degree in the qualitative feed back from the audit process and the safety culture investigation to the company on specific weak points and possible improvements in management. The quantification process still contains many uncertainties, though the process is transparent and cab provide help to prioritising safety management issues in relation to certain safety barriers in site-specific conditions

10. References

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