Development of barrier-oriented audit protocols and safety culture questionnaires: application to Dutch and Danish test sites

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Abstract

Within the ARAMIS project methods were developed to assess the quality of safety management with respect to implementing and maintaining effective safety barriers. This paper summarises the development of the framework of the safety management model and, based on this, the development of an audit protocol and a safety culture questionnaire for “Seveso” companies. Some results from audit and safety culture assessments at a few test sites are reported.

Keywords: safety management, safety audit, safety culture, safety barrier.

1 Introduction

The ARAMIS project (Accidental Risk Assessment Methodology for IndustrieS) aims to develop a fully integrated set of risk assessment methods to assess the probabilities and consequences of major hazard risks in “Seveso” companies. This paper describes the results of the activities related to safety management. The objective of the ARAMIS project in this field was to develop a methodology that provides an assessment of safety management quality at a major hazard site, and to include this assessment in the overall conclusion about the total risk level of the site. The main activities in the field of safety management assessment can be divided into:
− Development of a description or modelling concept for the safety management processes in major hazard plants;
− Development of an audit system, based on this modelling concept, that could be used to assess the quality of safety management;
− Development of a method to assess safety culture in major hazard plants, recognising safety culture as an important parameter in accident prevention; and
− Development of a method to turn the output from the audit- and safety culture assessment schemes into adjustments of the overall safety level of the major hazard plant.

2 Modelling concept

The ARAMIS project has exploited the concept of bowtie diagrams to describe the possible accident scenarios in a major hazard plant, and the concept of safety barriers as means to control hazards. The barriers consist of a combination of hardware, software and behavioural/procedural elements, which are assigned a SIL (Safety Integrity Level) value for the hardware or an equivalent nominal effectiveness or “Level of Confidence” value for behavioural barriers (which we will denote as “SIL” in this paper).

The management model considers two dimensions: the structural dimension, which consists of the (formal) intentions and processes; and a cultural dimension, comprised of the attitudes of the workforce towards safety and the organisational climate as a condition for safe operation. The cultural dimension provides a measure of the present (snap-shot) organisational conditions for safe operation, while the structural dimension provides a measure of the lasting and future condition of both the organisation and the technical installations.

The structural dimension is based on the concepts of safety barriers. Each barrier has a life cycle, and safety management processes have to provide (deliver) necessary conditions for maintaining the effectiveness of safety barriers, such as training, manpower allocation, and technical maintenance. This model used has been described in earlier papers (Duijm et al. [2, 3]), and is based on the management model devised for the I-Risk management audit (IRMA) (Oh et al. [6], Hale et al. [4,5]). The safety management task consists of a general activity to identify hazards, and to select, implement and evaluate and improve the necessary barriers to control those hazards, and then seven management processes to be performed, so as to deliver the following resources for the good functioning of the whole barrier life cycle (see Figure 1):

1. Manpower planning and availability of staff
2. Competence and suitability of staff
3. Commitment, compliance and conflict resolution
4. Communication and coordination
5. Procedures, rules and goals
6. Hard/software: purchase, build, interface, install
Activities 1 to 5 relate to barriers where people are involved in their use, whether they are pure behavioural barriers or mixed ones in which people operate hardware, while activities 6 and 7 deal with hardware barriers. Activities 1 to 5 are, however, also relevant for pure hardware barriers, when dealing, for example, with underlying maintenance. Each management process or delivery system includes the practice of review, monitoring, learning, and management of change in order to improve the delivery systems. A comparable step to improve or change the barrier system forms part of the general safety management system.

Figure 1: Diagram showing the relation between the life cycle of a safety barrier and safety management activities.

3 Assessment of safety management quality

The assessment of safety management is based on the assumption that the effectiveness and reliability of safety barriers, depends on the quality of the formal practices for the safety management activities, as described in the section above (the structural factors of safety management), as well as on the actual practices and attitudes of the work force with respect to safety-critical activities (the safety-cultural factors).

The suggested direct coupling of the rating of safety management and safety culture to the barrier’s SIL is a simplification of reality. The most important short cut is that the present methodology assumes that deficiencies in the process of safety management are directly linked to deficiencies of the safety barriers,
see Figure 2. In reality, deficiencies in the process of safety management will increase the likelihood of deficiencies in the output of safety management (follow-up on training, maintenance planning). This in turn will increase the likelihood of deficiencies in conditions for safe operation (competence, maintenance) and finally decrease the SIL. The ARAMIS methodology draws a direct relationship between the (measured) levels of safety management and safety culture and the SIL.

Figure 2: Relationships between safety management quality, safety culture and SIL of safety barriers.

4 Development of the ARAMIS Audit

In order to perform the assessment of the structural dimension of safety management, an audit protocol and manual was developed. The audit process consists of the following steps:

1. First a selection has to be made of the barriers that the audit will address. It is impossible to audit all barriers at a site, so a number of representative barriers are chosen, with the results obtained for these barriers applied to all barriers of the same type at the site (common mode approach).

2. Mapping a company’s Safety Management System on the ARAMIS audit structure and preparation of an audit questionnaire; this includes, for example, identifying what organisational entities or persons have to be reviewed and interviewed for what elements of safety management and for which barriers.

3. Conduct audit and make assessments of: processes of risk identification and the selection and implementation of safety barriers; the lifecycles of selected barriers and delivery systems; monitoring, feedback, change and learning capabilities.
4. Quantification of audit results.
5. Reporting.

Each of the seven delivery systems (see Figure 1) consists of a number of management tasks (e.g. the tasks to effectuate continual learning and improvement), and for each of these tasks, the protocol identifies critical items that the auditors have to check. The auditors evaluate each of the tasks, using the following scale:

- 5 - fully implemented, improvement not (really) needed
- 4 - largely implemented, minor improvements needed
- 3 - some aspects present, significant improvements needed
- 2 - under development, overall improvement needed
- 1 - absent, development must be started

Quantification of the audit results is obtained by integrating the scores for the separate tasks to a single score for each of the seven delivery systems. The procedure for this is based on input from an expert opinion review: in four out of the seven delivery systems, the experts agreed on some tasks that are dominant to the other tasks in these delivery systems: the score for the delivery system cannot be higher than the lowest of these dominant tasks. For the other three delivery systems averaging of the scores of the tasks is applied. Finally, the scores are transferred to a scale from 0 to 100%, a score of 5 (in the above mentioned scale) corresponding to 100%, and a score of 1 to 20% (so even if the auditors rank the system as being absent, we still expect some – ad hoc - management activity).

5 Development of the safety culture questionnaire

We developed a framework of safety cultural factors applicable to process industry including a survey tool (a questionnaire that will be referred to as SCQPI – Safety Climate Questionnaire for Process Industry), designed to measure safety cultural factors that have an effect on the functioning of the safety delivery systems and, hence, on the safety of the major hazard site. A discussion of the definition and notions of safety culture and safety climate is included in (Andersen et al. [1]).

The SCQPI has its origin in a Danish questionnaire, developed in 2002-03, concerning safety culture/climate factors and work environment aspects. This questionnaire was, in turn, based on results and experiences with, inter alia, safety factors survey development, from both Nordic and UK sources and other internationally published sources, concerning questionnaire development and validation in the domain of industrial health and safety and climate/culture.

The SCQPI contains almost 100 individual items eliciting attitudes and perceptions. These items ask respondents to indicate their answer on a five-point Likert-type scale, ranging from “strongly agree” to “strongly disagree”, or from “to a very large degree” to “to a very small degree”. In addition to items about attitudes and perceptions, the SCQPI contains demographic items and items asking respondents to report their experience of (industry specific) kinds of accidents. The SCQPI targets process industry, probing attitudes to, and
perceptions of, factors relating, primarily, to process risks (but also work accident risks). The individual respondent is asked, for different types of accidents, if s/he is willing to report any accident occurrence and, subsequently, if employees in “this workplace” are willing to report. The SCQPI also contains additional items (e.g., on risk awareness and blame in relation to reporting). The items of the SCQPI may be categorised in the following eight clusters of safety culture factors:

1. Learning and willingness to report.
2. Safety prioritisation, rules and compliance.
3. Leadership involvement and commitment.
4. Perceptions of risk
5. Perceived ownership of responsibility
6. Trust and fairness
7. Work team atmosphere and support
8. Motivation, influence and involvement.

Experience and analysis of the predecessor to the SCQPI (Andersen et al. [1]), indicate that about 70 questions are diagnostic for safety culture, that is, the responses to these questions show the inclination to “good” or “bad” safety attitudes and practices. It is, therefore, possible to derive from these responses a “Safety Culture Indicator” for a (group of employees at a) major hazard site. The responses are scaled by comparison to a reference set that is based on the responses from the five test sites investigated during the ARAMIS project. Throughout the analysis it is assumed that the five-point Likert scale may be transformed into a equidistant linear scale from 1 to 5 in order to perform the numerical analysis.

6 Results

Results from safety culture questionnaires like the SCQPI provide useful feedback to management about the safety attitudes of the staff in comparison with other sites. A useful representation is one as in Figure 3, where the responses on one statement are shown for the five different test sites (the sites are ordered from scoring “bad” to “good” on this statement).

The results from the test sites were combined and the averaged scores and standard deviations calculated. Here we will focus on a comparison of the results from the Danish and Dutch test site; compared to each other and to the total reference set.

The absolute value of standard deviation per questionnaire item is of the order of one scale unit, with relatively little variation: the highest standard deviation (STD) is 1.084 units (on a scale from 1 to 5) and the lowest STD is 0.617. Typical differences in response are shown in Table 1, where the deviations compared to the total set’s mean are listed. Positive values are on the “good” side. This table shows that on individual items the differences can be significant, and also the difference on the average score is statistically significant. Andersen et al. (Andersen et al. [1]) demonstrated that the scores on similar safety culture questionnaires correlate with actual safety performance, but in this case we have no material to investigate this aspect.
"In this plant safety is taken seriously and not just for the sake of appearances"

<table>
<thead>
<tr>
<th></th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>7</td>
<td>43</td>
<td>33</td>
<td>15</td>
<td>2</td>
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<td>Site 2</td>
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<td>Site 3</td>
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<td>Site 5</td>
<td>36</td>
<td>42</td>
<td>17</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Distribution of test site responses to one of the SCQPI statements.

Table 1: Safety culture comparison between the Danish and Dutch test site.

<table>
<thead>
<tr>
<th>Questionnaire Item</th>
<th>Site A (STD)</th>
<th>Site B (STD)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I will sometimes bend safety instructions to get the work done in a smoother and easier fashion”</td>
<td>-0.55</td>
<td>0.23</td>
<td>Largest variation in the data set</td>
</tr>
<tr>
<td>“I have received instructions and information about how to work safely in my present job and present work place”</td>
<td>-0.17</td>
<td>0.15</td>
<td>Least variation in the dataset</td>
</tr>
<tr>
<td>“In our workplace employees are willing to report all work accidents”</td>
<td>-0.68</td>
<td>0.27</td>
<td>Largest difference between the two sites</td>
</tr>
<tr>
<td>All items</td>
<td>-0.15</td>
<td>0.19</td>
<td></td>
</tr>
</tbody>
</table>

The general feedback from the test-case audits was that both the auditors and the audited companies found the ARAMIS audit to be successful. It revealed shortcomings that were not revealed by other audits at the companies. 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, because it focussed on a life cycle approach that linked the risk analysis to the organisation.

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 in the audit, whilst it is only feasible to audit about 30 in a reasonable time. This makes it imperative to coordinate the risk analysis and the audit planning.

Quantification of the audit results remains a difficult issue; especially as the audit teams are different, and both experience and subjective judgements play an
important role in audit ratings that are not based on exactly and complete predefined questions.

Figure 4: Safety management ratings for the Dutch and Danish test sites and average of all test sites.

Figure 4 shows the safety management assessment for the Dutch and Danish test sites, denoted Site A and B (as in Table 1). Both sites are rated better than the average of all test sites, but it should be noted that Site B scores better on safety culture (see also Table 1), while Site A scores better on the audit on at least three items, including commitment and communication. Of course it is not known whether this is an artefact, or whether this demonstrates the different subjective judgements of the audit team. This poses the question of whether there is a correlation between the safety culture rating and the audit rating. In general one may expect that a badly run site will show bad safety culture (many safety culture items are closely linked to general job conditions), but this correlation may disappear at the high end of the scale, where all sites are managed professionally. Based on the results of four test sites (we don’t have quantitative audit results for one of the sites), we calculated the correlation between safety culture rating and the rating on the individual seven audit items (see Table 2. It is somewhat surprising to note, that there are quite good indications of a positive correlation between the processes around “observable” deliveries of hardware and procedures, while there is no evidence for a correlation with the delivery of commitment which might be expected to be the primary structural corollary of a good safety culture.

Figure 5 shows the correlation between some of the audit item assessments and the safety culture assessment. A trend line is added for the relation between the average of all seven audit items scores and the safety culture assessment.
Table 2: Correlation between safety culture assessment and audit assessment.

<table>
<thead>
<tr>
<th>Audit item</th>
<th>Correlation coefficient (Pearson’s r)</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manpower planning &amp; availability</td>
<td>0.325</td>
<td>0.337</td>
</tr>
<tr>
<td>Competence &amp; suitability</td>
<td>0.417</td>
<td>0.292</td>
</tr>
<tr>
<td>Commitment, compliance &amp; conflict resolution</td>
<td>0.141</td>
<td>0.455</td>
</tr>
<tr>
<td>Communication &amp; coordination</td>
<td>0.491</td>
<td>0.255</td>
</tr>
<tr>
<td>Procedures, rules &amp; goals</td>
<td>0.759</td>
<td>0.120</td>
</tr>
<tr>
<td>Hard/software purchase, build, interface, install</td>
<td>0.663</td>
<td>0.169</td>
</tr>
<tr>
<td>Hard/software inspect, maintain, replace</td>
<td>0.732</td>
<td>0.134</td>
</tr>
<tr>
<td>Average of all audit items</td>
<td>0.603</td>
<td>0.198</td>
</tr>
</tbody>
</table>

Figure 5: Correlation between safety culture and safety audit items.

7 Discussion and conclusions

An audit protocol was developed based on the ARAMIS framework. This audit reviews a site’s management processes and activities with respect to maintaining different types of safety barriers. The output can be used to assess whether, as a consequence, one can trust that the barriers will function as intended when needed.

Similarly, a safety culture questionnaire (SCQPI) was developed. Both the audit and the SCQPI were used successfully in five European test sites, and some of the results are presented. Both the ARAMIS audit and the SCQPI provide valuable information to the site management.

It is observed that the SCQPI provides a good means of comparing, at least in a qualitative way, the safety culture performance of different sites. Biases can occur due to difficulties in translating concepts into different languages, and due
to national differences in the expression of perceptions and attitudes. On the other hand, the level of experience and subjective interpretations of the audit teams affect the results of the audit.

Nevertheless, our results suggest that the ARAMIS audit data and the SCQPI survey data are correlated. Due to the scarcity of data points, this conclusion is necessarily tentative. However it supports the idea that these tools are useful in revealing safety management problems.

Acknowledgement

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References


