Testing of the ARAMIS methodology in Slovenia – process and results

D. Kontić, B. Kontić & M. Gerbec
Jozef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

Abstract

In the framework of the ARAMIS project the Jozef Stefan Institute has been acting as one of the partners which tested the ARAMIS methodology. The testing has been designed so as to check how each step of the methodology works "in real life". The latter means that an industry has been selected as a subject of demonstration. In Slovenia this was Nafta Petrochem, a chemical factory producing methanol, formaldehyde, and synthetic resins.

The ultimate goal of the testing was to come up with specific results regarding S, M and V, where S stands for severity index, M for management index or rather an expression of the integration of safety culture and management activities of the establishment, and V stands for vulnerability of environmental components potentially exposed in the case of an accident. Final results were expected to be in the form of severity and vulnerability maps of the impact area around the site.

In the paper we describe a process and results of the testing. In terms of results we first show outcomes of selecting critical equipment, which we arrived at while the VADEMECUM, an initial step of the MIMAH approach, was still under development, and how these contributed to modifying VADEMECUM's "time criterion" for continuous processes. Similarly, we demonstrate changes in the vulnerability mapping results after changing default weighting factors in the vulnerability code. The importance of the latter change is that now an ARAMIS Methodology user can apply preferences about vulnerability and protecting environmental components as they are perceived locally instead of using those built and locked in the code, which was the case in the previous version of the code. At the end we present summarised results of the overall testing.
1 Introduction

In the framework of the ARAMIS project the Jozef Stefan Institute, Ljubljana, Slovenia has been acting as one of the partners which tested the ARAMIS methodology. The testing has been designated to Slovenian Nafta Petrochem factory, producing basic chemicals originating from methane as raw material. Main products include:

- methanol - 165,000 t/year (approximately 450 tons per day),
- formaldehyde (produced in two plants) - 120,000 t/year (as 37% water solution),
- synthetic resins/glues (urea/phenol formaldehyde) - 136,000 t/year.

The testing has been conducted according to initial plans and subsequent agreements among partners on the ARAMIS project. The primary aim was to come up with specific results regarding S, M and V, where S stands for severity index (of a certain accident), M for management index – an expression for level of confidence (i.e. trust) in safety culture of the establishment, and V stands for vulnerability of environmental components potentially exposed in the case of an accident.

2 Overview of the testing

2.1 General

The testing has been performed in two stages. The first stage took place in the period March – May 2004 while the ARAMIS methodology was still under development and was aimed at providing final moderations to the methodology. The second stage has been performed in January – February 2005 and has consisted of checking revised VADEMECUM approach, finalisation of the safety culture audit results, severity mapping, and revised vulnerability mapping. Preparatory works for the overall testing consisted of preliminary visits to the site, initial discussions with the managers of the Nafta Petrochem about the purpose and benefits of the testing, and activities aimed at getting familiar with the ARAMIS methodology tools (VADEMECUM, MIMAH, auditing – ARAMIS audit manual, methodology for the calculation of the risk severity index, vulnerability mapping tool, etc).

2.2 Testing of VADEMECUM - Selection of dangerous equipment

Selection of dangerous equipment as the first step of the ARAMIS methodology has been carried out by applying the approach named VADEMECUM [1]. The selection has been done in two stages. In the first stage the methodology was still under development while in the second stage a revised VADEMECUM approach has been applied [2]. Specific process information have been extracted from a Preliminary Safety Report for Nafta Petrochem [3].

Based on PFD and PID diagrams for the methanol, formalin and synthetic resins production, 51 pieces of equipment have been selected to be a subject of
classification by the VADEMECUM. These included storage tanks, production components and pieces of infrastructure (continuous and batch reactors, heat exchangers, rectification columns, condensers, pipelines, etc.). The methodology requires that properties of involved substances are considered together with process conditions (volume, temperature, pressure) as the basis for calculation of $M/M_b$. This quotient, expressed as $M/M_b > 1$, means that quantity of a hazardous substance present in a certain piece of equipment exceeds related threshold and is a criterion for further consideration in risk assessment.

Following this approach out of 51 pieces of equipment 19 have been identified as dangerous. The majority are storage tanks (eleven), others are various distillation/absorption columns for methanol or formaldehyde, and a process reactor for methanol synthesis. This outcome has been compared with the results of the HAZOP study [3] performed a year ago for the same installation. The comparison revealed that the VADEMECUM approach omitted to identify the following dangerous/critical components: a reformer at methanol plant and a catalytic oxidation reactor at formaldehyde synthesis. Additionally, in association with the production of synthetic resins, the VADEMECUM overlooked a couple of batch reactors. Except for the latter, the reason for these omissions was low retention time considered for continuous process equipment – 1 minute (suggested as one of the criteria by the VADEMECUM). Therefore we suggested a change of this criterion as to consider longer retention time. Existing version of the VADEMECUM approach now recommends 10 minutes as a criterion together with the application of common sense, possibility of runaway reactions and creation of flammable/explosive mixtures.

After applying the changed criterion 28 pieces have been selected for further consideration instead of 19. Matching with the results of the HAZOP study was now much better.

For testing MIMAH and MIRAS - further steps of the ARAMIS methodology – the equipment with the largest quotient $M/M_b$ was selected. This was the largest methanol storage tank labelled as M4, $V = 10,000$ m$^3$. Its $M/M_b$ is 283.

2.3 Testing of MIMAH and MIRAS - identification of major accident hazards and development of reference accident scenarios

Application of MIMAH [4] for M4 - atmospheric storage of methanol resulted in the following critical events:

- **CE5** Start of a fire (LPI)
- **CE7** Breach of the shell in liquid phase
- **CE8** Leak from liquid pipe
- **CE10** Catastrophic rupture
- **CE11** Vessel collapse
- **CE12** Collapse of the roof

Related dangerous phenomena are:

- pool fire,
- VCE (vapour cloud explosion),
- Flash-fire,
Based on identified critical events and after considering a potential for their development towards major accidents with specific dangerous phenomena the set of reference accident scenarios have been identified/developed. These were then classified based on risk matrix for the purpose of prioritising which to consider first in specific detail in the forthcoming risk calculation. In the case of M4 the attention was paid to tank overfill – major spills. The following consequence classes (in terms of risk matrix) were considered associated with previously selected dangerous phenomena:

- DP1 - Pool Fire: Consequence class C2.
- DP4 - Vapour Cloud Explosion: Consequence class C3 or C4.
- DP6 - Toxic Cloud: Consequence class C3 or C4.

Calculation of the probabilities has been done following the bow tie approach. The primary, secondary and tertiary critical events were identified and dangerous phenomena assessed using the fault tree and event tree approach [5]. The calculated frequency of storage tank overfill was $7 \times 10^{-6}$ year$^{-1}$, while the frequencies of related dangerous phenomena were:

- DP1 - Pool fire: $7 \times 10^{-9}$ year$^{-1}$ (probability of ignition at tank farm 0.001),
- DP4 - Vapour cloud explosion: $7 \times 10^{-9}$ year$^{-1}$ (probability of ignition at tank farm 0.001),
- DP6 - Toxic cloud: $7 \times 10^{-6}$ year$^{-1}$.

Since toxic cloud formation and pool fire/VCE are mutually exclusive the risk matrix has been applied for toxic cloud phenomena only. This is presented in Figure 1, which suggests that this scenario deserves further attention (thorough evaluation of risks, i.e. calculation of severity indexes with final severity and vulnerability mapping).

![Figure 1: Allocation of toxic cloud in risk matrix. Position of the scenario is represented by a black circle, co-ordinates are emphasised by arrows.](image-url)
2.4 Calculation of risk severity index (S) and severity mapping

Risk severity index was determined according to the methodology described in the deliverable D2B [6]. Overflow of the methanol at 27 L/s (21.6 kg/s) with duration of 600 seconds was considered (the duration of 5 minutes has been adopted taking into account existing monitoring, alarming and emergency praxis related to overfilling of storage tanks: 4 minutes are needed to identify and diagnose the event/incident, and 1 minute is needed to effectively react). The following wind rose data were used (table 2).

The default reference values for selected dangerous phenomena (thermal radiation, overpressure, concentration of toxic and time averaging for toxic release) are in Table 2.

The distances for individual severity classes for the three dangerous phenomena and the 1.5/F meteorological situation are compiled in Table 3.

Results of risk severity mapping are presented in Figures 2-5.
Figure 2: Severity mapping results for DP1-Pool fire.

Figure 3: Severity mapping results for DP4-VCE.

Figure 4: Severity mapping results for DP6-Toxic cloud.
2.5 Vulnerability index (V) and mapping

Environmental vulnerability assessment was conducted in accordance with the ARAMIS Spatial vulnerability index calculation methodology, as described in [7,8]. We used the vulnerability mapping code, as developed by UROM, version 2004. This version differs from the previous one (December 2003), primarily in that it enables application of the preference weighting factor distribution about vulnerability and protecting environmental components as locally perceived (instead of having the weighting factors encrypted/built in and locked in the code; this feature becomes significant in the process of validation of the risk vulnerability model in terms of whether it reflects, and to which extent, local conditions and state. The modification of the code has been suggested by the Jozef Stefan Institute after first step of testing the methodology).

Figures 6 to 8 show results of the vulnerability mapping. Attention should be particularly paid to the difference between Figure 7 which shows global environmental/spatial vulnerability when preference weighting factors are locked and non-changeable by an ARAMIS user, and Figure 8 where weighting factors are "free", i.e. defined as locally perceived. In our specific (testing) case enhanced concern for environmental targets is demonstrated as could be seen if Figure 8 is compared to Figure 6b.

Figure 6: (a) human vulnerability (left), (b) environmental vulnerability (middle), (c) material vulnerability (right).
2.6 Management index (M)

In the framework of evaluating M index first a survey based on a questionnaire
developed by the Risø National Laboratory has been performed. Then, an audit
focused on the performance of safety barriers for M4 has been done. The barriers
have been classified based on the Methodology to determine a Safety
Management Efficiency Index [9] and additional guidelines provided by TU
Delft and Risø National Laboratory taking into account agreement which has
been reached related to unclear definitions of barrier types [10]. The intermediate
results of the rating of the barriers' performance are given in [5], while the
overall results produced by TU Delft and Risø National Laboratory are given in
Table 4 below.
Table 4: Summary of selected results associated with the evaluation of M index.

<table>
<thead>
<tr>
<th>ARAMIS delivery system</th>
<th>Rating (%)</th>
<th>Design Barrier Level of Confidence or SIL</th>
<th>Operational Barrier Level of Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manpower planning &amp; availability</td>
<td>67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competence &amp; suitability</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commitment, compliance &amp; conflict resolution</td>
<td>60</td>
<td>2</td>
<td>1.76</td>
</tr>
<tr>
<td>Communication &amp; coordination</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedures, rules &amp; goals</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard/software purchase, build, interface, install</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard/software inspect, maintain, replace</td>
<td>80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3 Conclusions

The main components of the ARAMIS risk assessment methodology have been tested successfully in Slovenian test case. The methodology is trustworthy and straightforward. Its components can be used as standing-alone or in combination with other methods (e.g., MIMAH can be used in combination with HAZOP), depending on the installation under investigation and experience of a risk assessor.

Since there is a desire expressed by different risk assessment providers/users to deal with risks in an aggregated form, especially when associated with land-use planning and licensing, it remains to be checked how severity and vulnerability indexes/mapping can be integrated into a final common value of risk.

References


[2] ARAMIS Deliverable D1C - APPENDIX 1C Methodology for the selection of equipment to be studied, July 2004.


[10] E-mail communication among Andrew Hale, Nijs Jan Duijm and Branko Kontic in the period May – September 2004