# Software interoperability in consequence assessment: results of a feasibility study

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The Competent Authorities responsible for the implementation of the Seveso Directive in their countries have, amongst others, the task of reviewing the safety reports of Seveso-type installations. This activity involves the examination of the hazard identification as well as the results of the frequency and consequence assessment of the identified accident scenarios. This verification activity might be very cumbersome and time consuming if the models and software tools used by the Authority are different from those used by the Operator. This is due to the lack of interoperability among the large number of software tools available for risk analysis, all considered acceptable by the scientific community. Considering that a relevant percentage of input data requested by the different tools is common, the software interoperability would strongly and effectively reduce the burden of work of authorities. Furthermore, the software interoperability in risk analysis would be very valuable also to operators and to models and software developers. The purpose of this paper is to describe the results of a feasibility study, recently completed by the authors, aimed at identifying the main problems associated with the definition of a common data exchange format for a fundamental phase of the risk analysis procedure: the assessment of accident consequences.

## 1. Introduction

Software interoperability is an important aspect that has recently been approached and resolved in many fields such as e.g. geographic information systems, satellite images, communications, building construction processes, by providing indisputable advantages to all involved stakeholders.

Interoperability means letting different software on different operating systems do what they do best, while agreeing on a common way to exchange data with one another. In the field of risk analysis the problem of software interoperability has not yet been considered in spite of the advantages that it would actually give. It is very important to emphasise that any effort aiming at achieving the software interoperability should not be confused with an attempt to harmonise and standardise the different methodologies and approaches which are used in the different countries and by the different risk analysis experts. As it is well known, there is not a unique and consolidated way to conduct such type of analysis. By contrast, there are several approaches, which are all potentially valuable. These approaches can be categorised in terms of different aspects as for instance: (*i*) the general philosophy adopted, (*ii*) the typology (i.e. probabilistic, deterministic), (*iii*) the level of calculation accuracy (quantitative, semi-qualitative, and qualitative) and so forth. In addition different approaches and methodologies are also applied for each single step of the risk assessment process. This implies that different software tools are available implementing the same model or models of different complexity. Furthermore databases, developed on different platforms, are used concerning e.g. accidents' frequency data, components' reliability data, and chemical substances.

However, independently of the applied approach a lot of data are common since the phenomena under scrutiny are always the same. For instance, the following information is typical of any methodology addressing the risks of chemical installations: (*i*) the relevant properties of the hazardous substances, (*ii*) critical aspects of the involved process and/or components, (*iii*) vulnerability of the surrounding environment, to mention only a few.

In order to establish a strategy to study interoperability problems in risk analysis and to assess the difficulties associated with this course of action, it is necessary to clearly identify for which models the software interoperability is most valuable. A not exhaustive list of some of the models and data applied in the chemical-petrochemical field for risk analysis is provided in Table 1.

*Table 1. Main methodologies currently in use for risk analysis purposes*

| RA phase | Models | Data |
|---|---|---|
| Hazard identification | HAZOP<br>FMEA | Process variables deviations, causes, consequences, protection systems.<br>Component failure modes, causes, consequences, alarms, etc. |
| Frequency analysis | FT, RBD, ET, | Structure function, mission time,<br>Components' reliability data,<br>Human error probabilities, CCF, etc. |
| Consequence assessment (CA) | Models from outflow to different types of fires, explosions, and dispersion of toxic/flammable substances. | Source term, substance data, meteorological data, models' parameters, etc. |
| Risk quantification | Risk analysis by combining frequency and consequences for each accident scenario. | Area site maps; Meteorological data, Population density and distribution, accidents' frequencies and consequences, Probit data, etc. |
| Emergency planning and response | Several models: accident consequences, evacuation, road traffic, spatial resource distribution, etc. | As for CA and risk quantification plus data on road traffic; evacuation, resources, etc. |

HAZOP: Hazard & Operability; FMEA: Failure Modes & Effects Analysis; FT: Fault-Tree; ET: Event-Tree; RBD: Reliability Block Diagram; CCF: Common Cause Failures; CA: Consequence Assessment.

A point to note is that the different phases of risk analysis are characterised by completely different objectives. As a consequence it is evident that separate sets of Common Data Exchange Formats (CDEF) have to be defined for achieving the interoperability in the different phases of the process. This is a long and challenging work that would offer many advantages to all organisations involved in risk analysis and risk management of Seveso-type installations. Indeed, the existence of such a data format would be particularly advantageous for the competent authorities in their verification activity of safety reports. CDEFs would allow to easily importing both input data and results of risk analysis as submitted by the operator. As the authorities make often use of alternative models and tools for the same calculations, in order to conduct a comparison these models have to be run with the same set of input data as used by the operator. Without proper CDEFs the verification activities would be much more complex, time consuming and expensive.

The existence of CDEFs would also be beneficial for the *operators* responsible for the preparation of safety reports. Safety reports have indeed to be reviewed on a periodical basis to account for possible modifications within the plant. The use of CDEFs would allow reusing the previous set of data even if the models in use during the reviewing phase are different. This is a rather typical situation when the operator relies on external consultants for the preparation of their safety report. These consultants may change over the time and the models employed may vary accordingly. Finally, suitable CDEFs would also be of great benefit also to model and software developers for facilitating the comparison of results obtained using other models and tools (test and benchmarking). Generally speaking, the existence of CDEFs would allow substituting one model with a better one with no effort.

Having ascertained the advantages of software interoperability in risk analysis the question that comes to mind is: which are the past and current initiatives on this issue? The first attempt to face the interoperability problem started in 2007 in the context of the worldwide OPEN-PSA initiative (http://www.openpsa.org/). The objective was to study the interoperability among software packages used in the nuclear field for probabilistic safety assessment, but open to other industrial fields. Fault trees and Event trees, which are the two main models in PSA, are in fact applied also for the risk analysis of chemical and petrochemical installations.

In the framework of this international driven initiative, some general requirements for a sound definition of a common data exchange format were defined. More specifically a common format should be:

- *Clear*, to avoid misinterpretations leading to different implementations;
- *Complete,* to cover data in all models;
- *Extensible*, to leave the possibility to introduce new constructs, even if these are not recognised by all tools; however, any addition should be public to allow other software developers to implement them.

Recently, the common exchange format was successfully implemented in XML (Extensible Mark-up Language) and tested on two of the major software packages used in Europe and in the USA: RiskSpectrum and CAFTA. The common exchange format for fault tree was also implemented in ASTRA, the JRC proprietary tool for fault tree analysis. Interoperability tests between ASTRA and RiskSpectrum were successfully carried out. Looking at Table 1, the format defined by the OPEN-PSA covers the accident frequency analysis based on fault trees.

## 2. Feasibility study on the interoperability of accident consequence assessment software

The need of defining a data exchange format also for accident consequence assessment was very clear, not only because it is important for risk analysis but also because of the large number of models and software tools available on the market, whose interoperability would be beneficial to end users. Thus, the feasibility study conducted at the Joint Research Centre (JRC) of the European Commission, aimed at defining a suitable CDEF by considering some of the most popular commercial and freeware software, together with some in-house tools. Obviously the study does not pretend to give a complete specification of the CDEF, but rather to start testing the interoperability between some existing tools, in order to identify the problems to be faced to achieve such an objective, and to evaluate the degree of complexity of this activity. More specifically, a CDEF prototype was created with the main objective of allowing the ease exchange of both input data and results of consequence assessment (CA) calculations.

The feasibility study had three main objectives:

1. to identify critical aspects in the definition of a proper CDEF for accident CA models;
2. to develop a prototype of a CDEF structure and to use it for testing a data exchange between different software for CA (i.e. fires, explosions and toxic release);
3. to apply the prototype to actual problems. In particular two examples were identified, i.e.: (*i*) the comparison of the results of different CA models for the same accident type, and (*ii*) the data exchange between a risk analysis tool (ARIPAR) and commercially available accident CA packages (PHAST, EFFECTS, ALOHA).

## 3. Main results of the feasibility study

In this section the main achievements of the study are briefly described (see Binda et al., 2009 for details).

### 3.1 The CDEF structure

The following aspects have to be taken into account when defining a CDEF for accident consequence assessment:

1. *type of accident (*i.e. fire, explosion, or toxic release);
2. specific *accident outcome* (e.g. for fire: pool fire, jet fire,…);
3. considered *type of model* (e.g. 1D, 2D);
4. all model's *input data and parameters;*
5. type of *representation of results* (e.g. 1D, 2D grid, iso-effect curves).

Points 1-3 are necessary for documentation purposes and to cross-check the compatibility of the information exchanged. Point 4 is the most complex because it requires a detailed knowledge of all models relevant for the accident type under scrutiny. Point 5 is essential to compare the models' outcomes. To note that when comparing two different models (*A, B*) for the same accident scenario, it can result that some of the input data used by model *A* could be different from those of model *B*. Thus, when the defined CDEF is used to export data from model *A* to *B*, it could be required to complement the data with supplementary information. In other cases, together with the input data, the comparison of two models requires the inclusion of the output data in the CDEF. This is the typical case of the comparison between the results of a single model and a multi-model (a set of models run without the user intervention), for which some of the intermediate results can be necessary as input data for the single model. Thus, in general, both input and output data have to be part of the common format.

Within the CDEF prototype defined in the present study, the data to be exchanged were organised in a tree-like structure containing three main sections: 1) general information, 2) input section, 3) output section. The input section is clearly the most complex and contains all data necessary to run a model e.g. data to calculate the outflow (source term), the different fire and explosion models; models to determine the air and/or water dispersion of dangerous substances. However, due to the extensibility requirement, this structure should be kept open, in order to give the possibility to include additional data in a later stage, when necessary. The problem of the measuring units used by different software was also considered and solved. By following the example of the OPEN-PSA initiative, the CDEF prototype was developed in XML.

### 3.2 Interpolation needs and methods

It is very important to stress that an XML file applied to interoperability applications should not exceed a certain dimension in order to make the data upload practicable. The main problem arises when dealing with data spread on a dense 2D grid. A possible way to overcome this problem is to export only part of these data (i.e. sampled points or effect contours) and to reconstruct the overall data set via interpolation methods. Interpolation is also necessary to compare the outcome of two different models. In such a case, the comparison requires the representation of data on a common 2D grid, where the direct comparison is actually done. Several interpolation methods are available in the literature. For the purposes of the present study, the output data of a typical CA model were interpolated using seven different methods. Among the methods considered the linear method provided acceptable results in all cases even though they were too conservative when the number of points was too limited or wrongly distributed. The test was conducted on Gaussian release dispersion, for which exact formulas were available. The Constrained cubic spline (CCS) method (Kruger C.J.C., 2002,) was the best amongst those submitted to test and it gave good results when the number of contours was greater than 5-6. This method was also tested on a more complex accident scenario (i.e. instantaneous heavy gas dispersion) whose consequence effects were calculated by using PHAST. Also in this case the test was successful.

### 3.3 Examples of CDEF use: comparison of different CA models

A first example of the use of a CDEF, was the comparison of the outcome of different CA models applied to the same accident scenario. For this purpose, dedicated software was developed, named *Comparison Effects Models* (CEM). An example is given in figure 1 showing one of the possible uses of CEM (Binda et al. 2009).

The input data and results of a 1D model are exported (XML file 1); the input section of this file is read by the second model; extra data may be manually inputted (if any). The input data and result of the run of this model is exported (XML file 2). The output sections of both models are interpolated on an automatically generated common grid and represented for comparison purposes.

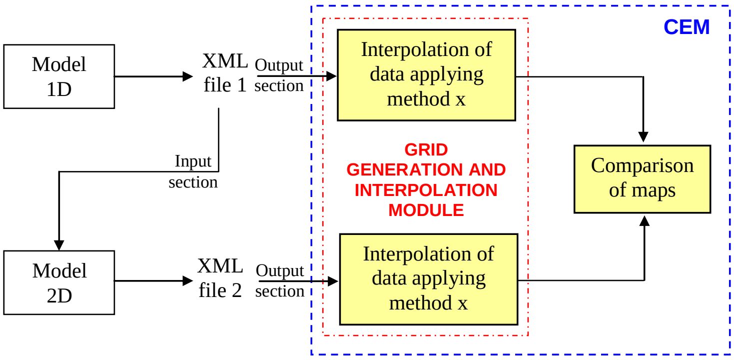

*Figure 1: Result of the difference between the 1D model and the 2D model.*

### 3.4 Interoperability between CA and risk assessment tools

As a second example the use of the CDEF prototype concerns the interface between the risk assessment tool ARIPAR (Spadoni et al. 2003) and different software packages for accident consequence assessment: PHAST, EFFECTS, ALOHA; in addition in house developed tools were used: GAUSS and STARS. For this experiment, due to the unavailability of the source code of the commercial software, ad-hoc modules were developed to generate the XML files from the output files. As shown in Figure 2 the overall procedure consisted in generating XML files from the above consequence models, interpolating the effect contours and generating the consequence data grids to be uploaded into ARIPAR. The risks of the different scenarios were calculated and suitably aggregated, and the overall result for individual risk is depicted in the risk map image of Figure 2.

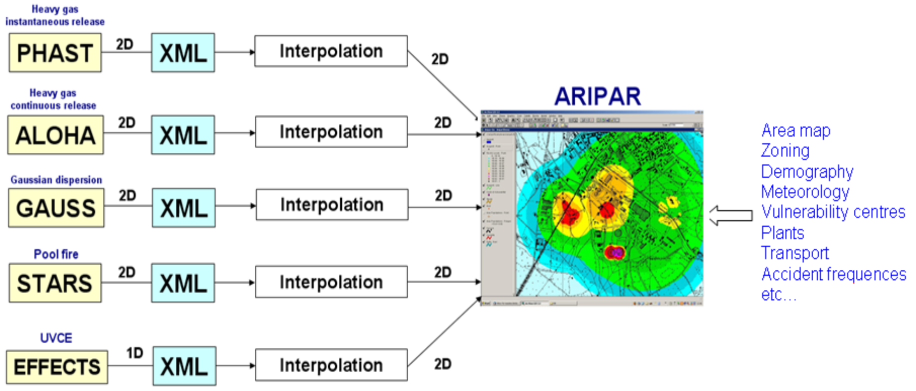

*Figure 2: Schematic diagram for the experiment aiming to interface ARIPAR with accident consequence tools*

## 4. Conclusions

In the present study it was developed a first prototype of a Common Data Exchange Format (CDEF) for accident consequence assessment software. The CDEF prototype was tested on a number of commercially available software for demonstrating their full interoperability. In addition, this preliminary study has allowed addressing the problems on the use of common data format as for instance: the model's parameters to consider, the different measuring units, the use of "extra data", multi-model software vs. single model software. This work, together with the common exchange format for Fault trees and Event trees developed by the OPEN-PSA initiative, and the on-going work of the authors for the definition of a CDEF for the hazard identification phase, shows the feasibility of achieving the full software interoperability in risk analysis.

Clearly, this can be obtained only with the agreement and the involvement of all relevant stakeholders (i.e. European Committee for Standardization, EU safety authorities, industry representatives, software and model developers, etc.).

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