

# **"Application of ARAMIS an integrated Accidental Risk Assessment Methodology for IndustrieS developed in the framework of SEVESO II directive to the Canadian context"**

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## ABSTRACT

This paper presents ARAMIS an integrated Accident Risk Methodology for IndustrieS developed in the framework of SEVESO II directive and how some elements could be applied to the Canadian context.

ARAMIS objective is to build up a new integrated risk assessment method that will be used as a supportive tool to speed up the harmonized implementation of SEVESO II Directive. The proposed method results in an integrated risk index composed itself of three independent indexes. Index S presents a structured method for the development of accident scenarios and assesses their consequence severity. Index M evaluates Safety Management effectiveness and accounts thus for the scenario probability. Index M estimates the environment vulnerability.

The paper will demonstrate that the methodology developed for Index S and Index M could be used for the development of credible alternate scenarios used in Risk Management Programme applied in Canada

Keywords: ARAMIS, ASSURANCE, IRISK, ACCIDENT SCENARIOS

During the last twenty years, risk analysis methods have continuously evolved and their results are now a deciding factor for risk management of industrial establishments generating risks. There is interest to increase the knowledge of risk results from major accidents that have occurred and that influence governmental and private policies world wide: Flixborough (1974), Seveso (1976), Bhopal (1984), Mexico City (1984), Pasedena (1989), Toulouse (2001). (Khan & all, 1999).



**Figure 1 Toulouse explosion, 21 September 2001**

In the OECD (Organisation for Economic Cooperation and Development) countries the concerns about safety are usually a matter of technical considerations, i.e. competencies of experts, risk analysis tools used to serve as a base for the decisions to issue permits to operate, land use planning and emergency plans.

Incertitude in risk evaluation remains still high and does not always make decision taking easy. Moreover, various approaches and methods are used by specialists at the national and also at the European levels, this being illustrated by the defenders of probabilistic and deterministic approaches.

Faced with low results from the first Seveso Directive and difficulties in implementing Seveso II and harmonisation of practices in member states, the European Commission has supported for the last ten years, research to reduce technological and natural major risks.

The European Commission has sponsored three projects: ASSURANCE and IRISK under the 4<sup>th</sup> research framework and ARAMIS under the 5<sup>th</sup> framework. ARAMIS started in January 2002 and uses the results and conclusions from ASSURANCE and IRISK as a starting point. ASSURANCE and IRISK will be described which will lead to ARAMIS.

## ASSURANCE

ASSURANCE follows after ten years, another European project BEMHA (Benchmark Exercise on Major Hazards Analysis). Following the example of this first project, the objective of ASSURANCE was to do a comparative analysis of the risk analysis methods and approaches to ensure safety in Europe. Therefore, between 1998 and 2002, nine European organisations specialising in risk analysis have evaluated the risks of an existing chemical site. Using the lessons from the first benchmark, the project was separated in discrete steps, in order to better center the work of the experts, and allow comparison of the intermediate results that enter in the final evaluation of risks. See Figure 1.

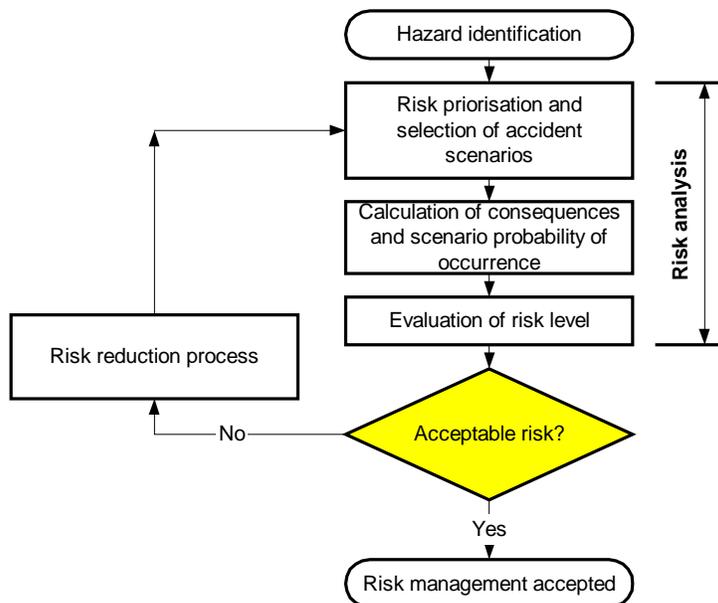


Figure 2 Risk analysis used in ASSURANCE

The ASSURANCE project was divided into three main phases. The first two phases cover the qualitative risk analysis (hazard identification, risk prioritisation and selection of accident scenarios, then quantitative risk analysis (consequences and probabilities calculation, evaluation of remaining risks). The third phase consisted in a sensitivity analysis: After Phase 2, the partners convened to retain six cases that would permit to test the sensitivity of the parameters that were identified and their influence on the final results (release volume calculation, release duration, dispersion models, etc.).

## **Reference site**

The reference site is a plant with 3,000 workers handling anhydrous ammonia for the production of fertilisers. The analysis covered in particular, a pipeline terminal linking two sites located 70 km apart, a tank farm with 10 pressurised tanks and a 15,000 ton cryogenic tank.

Participants to the study visited the site. The questions left unanswered were subject to arbitrary hypothesis.

## **Quantitative risk analysis**

First finding: each partner used his own method of analysis but relatively similar in its sequence to the other partners. For six partners on seven, hazard identification used an inductive method (HAZOP or What-If?). When undesirable situations were identified, each organisation prioritised them using a matrix based on severity and frequency. The purpose of the prioritisation was always to identify the scenarios to analyse their priority, and to choose those to be modeled as representatives of the site.

Regarding the choice of scenarios, there were differences in the level of details between partners that can be explained by the criteria chosen rather than the analysis method or the prioritisation. Whatever the criteria, all partners took into account for the quantification the scenarios susceptible to be an envelop for the plant without considering the probability of occurrence. Therefore, the partners had no difficulties agreeing on the eleven scenarios that were retained in the following steps.

## **Quantitative risk analysis**

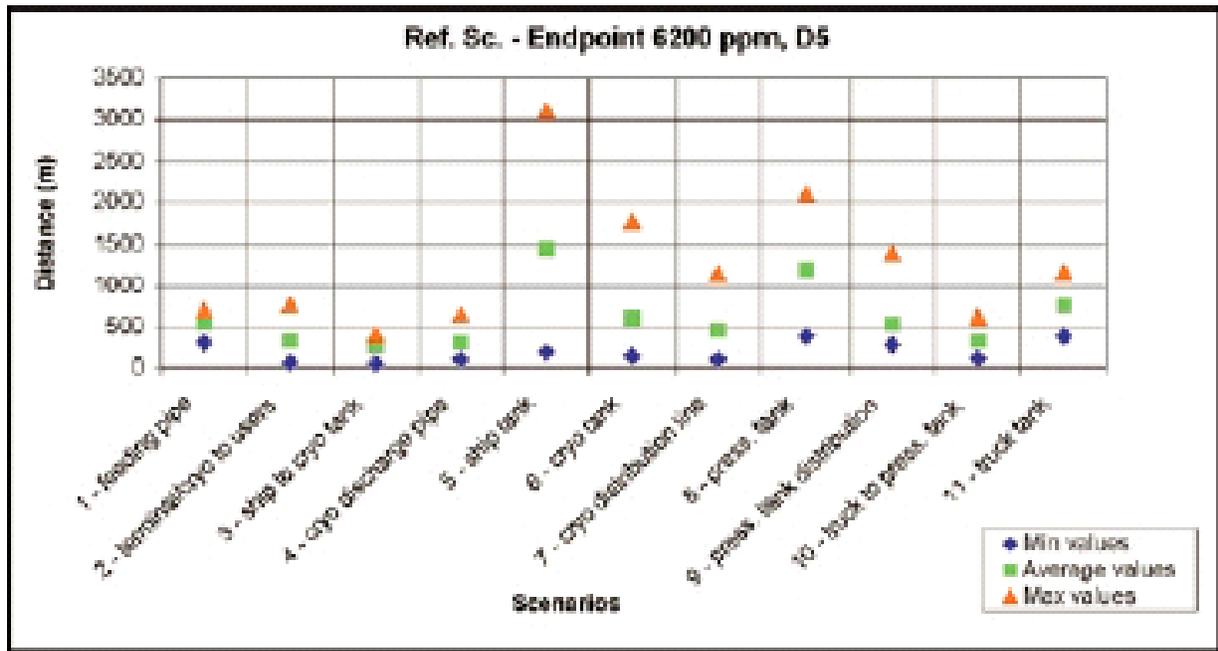
In order to achieve a better analysis of the results the consortium agreed after the qualitative phase to choose the scenarios to quantify. The eleven retained scenarios are presented in Table 1.

1. Full bore leak on an 8 inch pipeline feeding ammonia to the site
2. Full bore leak on a 4 inch line linking the cryogenic and pressurised tanks
3. Rupture or uncoupling of a ship liquid phase unloading arm
4. Full bore leak on the 10 inch line linking the cryogenic tank to the ship terminal
5. Catastrophic rupture of a ship compartment
6. Catastrophic rupture of the cryogenic tank
7. Full bore leak on the 20 inch outlet line on the cryogenic tank
8. Catastrophic rupture of one ammonia pressurised tank
9. Full bore leak of a 4 inch ammonia distribution line to consumer units
10. Rupture or uncoupling of truck unloading arm on the liquid phase
11. Catastrophic rupture of a tank truck

**Table 1** Eleven reference scenarios

Scenario	Partner 1	Partner 2	Partner 3	Partner 4	Partner 5	Partner 6	Partner 7	Variability
1	9.0 x 10 <sup>-7</sup>	1.0 x 10 <sup>-6</sup>	1.4 x 10 <sup>-5</sup>	9.0 x 10 <sup>-7</sup>	1.0 x 10 <sup>-6</sup>	-	1.8 x 10 <sup>-7</sup>	1.8 x 10 <sup>-7</sup> - 1.4 x 10 <sup>-5</sup>
2	1.0 x 10 <sup>-5</sup>	3.0 x 10 <sup>-6</sup>	1.4 x 10 <sup>-5</sup>	9.0 x 10 <sup>-7</sup>	7.3 x 10 <sup>-7</sup>	-	4.6 x 10 <sup>-6</sup>	7.3x 10 <sup>-7</sup> - 1.4 x 10 <sup>-5</sup>
3	4.8 x 10 <sup>-4</sup>	4.8 x 10 <sup>-6</sup>	8.0 x 10 <sup>-3</sup>	5.0 x 10 <sup>-3</sup>	5.4 x 10 <sup>-5</sup>	-	1.3 x 10 <sup>-5</sup>	4.8 x 10 <sup>-7</sup> - 8.0 x 10 <sup>-3</sup>
4	1.0 x 10 <sup>-6</sup>	-	4.0 x 10 <sup>-6</sup>	9.0 x 10 <sup>-7</sup>	8.0 x 10 <sup>-7</sup>	-	1.8 x 10 <sup>-6</sup>	8.0 x 10 <sup>-7</sup> - 4.6 x 10 <sup>-6</sup>
5	2.8 x 10 <sup>-7</sup>	6.4 x 10 <sup>-10</sup>	5.7 x 10 <sup>-5</sup>	-	2.3 x 10 <sup>-6</sup>	-	4.9 x 10 <sup>-6</sup>	6.4 x 10 <sup>-10</sup> -5.7 x 10 <sup>-5</sup>
6	5.0 x 10 <sup>-7</sup>	1.0 x 10 <sup>-8</sup>	4.0 x 10 <sup>-8</sup>	-	5.0 x 10 <sup>-8</sup>	-	5.0 x 10 <sup>-7</sup>	1.0 x 10 <sup>-8</sup> - 5.0 x 10 <sup>-7</sup>
7	6.0 x 10 <sup>-6</sup>	1.0 x 10 <sup>-6</sup>	5.0 x 10 <sup>-6</sup>	9.0 x 10 <sup>-7</sup>	4.0 x 10 <sup>-7</sup>	-	4.0 x 10 <sup>-7</sup>	4.0 x 10 <sup>-7</sup> - 6.0 x 10 <sup>-6</sup>
8	1.0 x 10 <sup>-6</sup>	5.0 x 10 <sup>-7</sup>	1.0 x 10 <sup>-6</sup>	4.5 x 10 <sup>-7</sup>	1.3 x 10 <sup>-5</sup>	-	4.0 x 10 <sup>-7</sup>	4.5 x 10 <sup>-7</sup> - 1.3x 10 <sup>-3</sup>
9	3.0 x 10 <sup>-6</sup>	3.4 x 10 <sup>-7</sup>	1.5 x 10 <sup>-5</sup>	9.0 x 10 <sup>-7</sup>	2.2 x 10 <sup>-6</sup>	-	8.0 x 10 <sup>-7</sup>	13.4x 10 <sup>-7</sup> - 1.5 x 10 <sup>-5</sup>
10	2.4 x 10 <sup>-6</sup>	1.5 x 10 <sup>-7</sup>	2.1 x 10 <sup>-3</sup>	2.7 x 10 <sup>-6</sup>	6.0 x 10 <sup>-6</sup>	-	5.0 x 10 <sup>-7</sup>	1.5 x 10 <sup>-7</sup> - 2.1 x 10 <sup>-3</sup>
11	5.5 x 10 <sup>-9</sup>	1.5 x 10 <sup>-9</sup>	1.2 x 10 <sup>-7</sup>	1.2 x 10 <sup>-7</sup>	4.7 x 10 <sup>-6</sup>	-	1.4 x 10 <sup>-8</sup>	1.5 x 10 <sup>-9</sup> - 4.7 x 10 <sup>-6</sup>

**Table 1 Comparison of frequencies of occurrence per year, as calculated by each partner for 11 scenarios of accident. For each scenario, the lighter shade cell represents the most optimistic calculated frequency and the darker one the most pessimistic one.**



**Figure 3 Comparison of distances of modeled effects. Each point represents a distance for a 6,200 ppm reference concentration. Maximum, average and lowest values calculated are presented for 11 reference scenarios. The atmospheric conditions are D5 : neutral atmospheric stability, wind speed 5 m/s (from ASSURANCE report)**

Table 1 presents the estimation of probability; it shows variations up to four orders of magnitude for the frequencies estimated for a scenario.

Figure 3 shows uncertainty related to the modeling to calculate distances for a specified level of consequences, for a deterministic approach to safety.



**Figure 4 : Variability of results in the estimation of individual risks as expressed by maxima and minima calculated by the partners for a  $1.0 \times 10^{-5}$  isorisk curve. (From ASSURANCE Report)**

Figure 4, deals with the inherent uncertainty related to the estimation of isorisk contours in a probabilistic approach.

Figure 5, presents the variability in the societal risk results.

When the two approaches are compared, we see that the notion of historic results, has a smoothing effect on the large uncertainty related to the sole evaluation of the consequence distances. In this case, the “weight” of the overall risk of the scenarios with long consequence distances / low probability has a levelling effect from shorter consequence distances / higher probability. Yet, uncertainty is still very large in the evaluation of individual and societal risks.

After analysis, the uncertainty could be understood for the evaluation of the probabilities or the consequences. The disparity in the results could be explained by the five following points:

- The identification and choice of the scenarios to model is fundamental. They result from the qualitative analysis of risks (hazard identification) and are completely dependant of expert judgment;
- The lack of precision or ambiguity in the definition of a scenario was a major source of disparity, specifically for the tank failures. If the failure resulted from an internal overpressure or an earthquake, the experts might model the first rupture of the inner tank, or the inner and the outer tanks or the roof of the tank. The choice of the initiating causes did strongly influence the calculation of its probability. In light of the importance of these scenarios for

land use planning, this point shows the difficulty and also the need to be precise in the definition of a scenario.

- The models used were always a simplification of the accidental phenomena being studied. For the evaluation of the consequences, the level of uncertainty depends as much on an adequate knowledge of the physical phenomena and the level of sophistication of the software used to model it. For the calculation of probabilities, the type of modeling used (generic data, fault tree, etc.) did influence the results.
- The choice of hypothesis constituted a major and recurrent source of variability. No matter which type of model was used, modeling always required the judgment of an expert. His/her experience and knowledge of the phenomena were important to define the most realistic hypothesis for the scenarios: leak duration, aerosol formation, length of the line, number of operations per year, correction coefficient applied in the calculation of probabilities.
- The level of prudence or conservatism manifested by each expert, finally directed each analyst to formulate hypothesis more or less on the higher side, as a function of his/her experience and his knowledge of the phenomena.

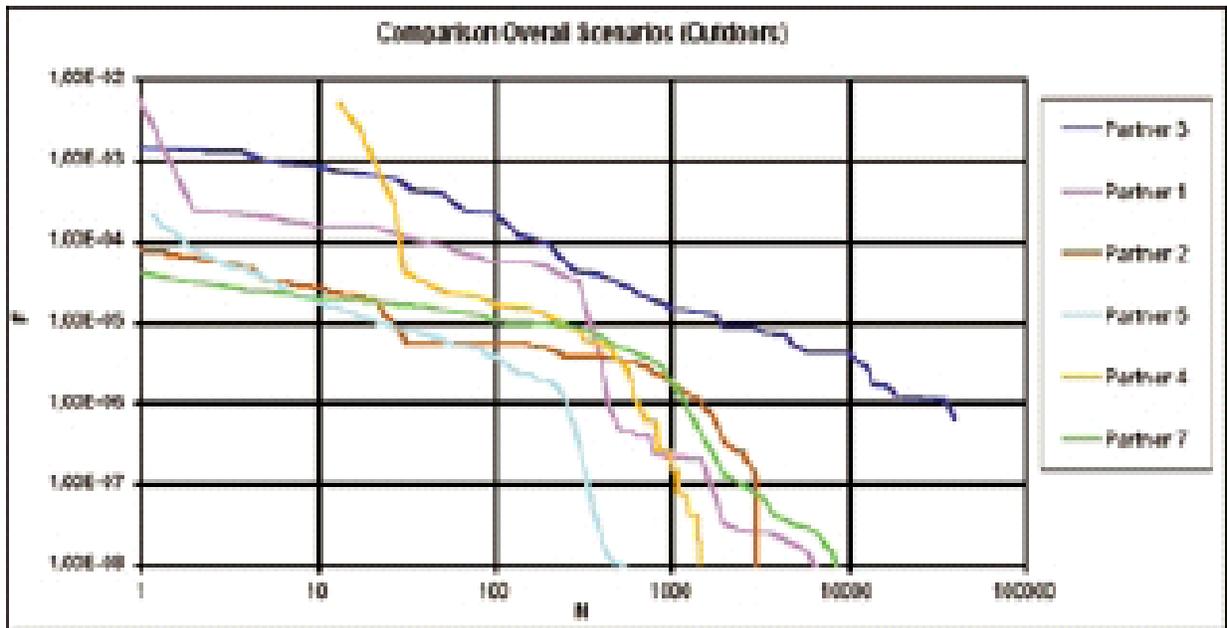


Figure 5 Variability of societal risks

## Conclusion ASSURANCE

Ten years after BEHMA, and with ten years of knowledge and risk analysis technique development, ASSURANCE still shows a large variability of the calculated results. This variability can be explained and seems unavoidable in a global risk analysis process. It is finally a combination of the sophistication of the models used and the experience, and the knowledge of the phenomena, the person that does the analysis has. It is not easy to separate one from the other.

In fact, his / her judgment and expertise, allows the expert to define the most realistic and well adapted scenarios for the models he/she uses. The work of estimation and evaluation always remains a simplification of a complex reality. Concerning the evaluation of individual and

societal risks – notions appropriate to the probabilistic approach – uncertainty still remains very high. It seems difficult to only base on this approach, a coherent and transparent policy of risk management. Moreover, recent examples have demonstrated the difficulty to sum up acceptable risk to a unique number such as “ $1 \times 10^{-6}$ /year“. It is necessary to define common hypothesis, formalized so that the decisions based on risk evaluations become coherent and similar. This is why the probabilistic and deterministic approach must not be opposed because they are complementary. Historically, the deterministic approach was used to verify the safe design of a facility; the probabilistic approach permits to evaluate the level of residual risk. Today, many European countries are choosing an alternate approach, a hybrid of the probabilistic and deterministic approaches based on the appropriateness and performance of safety barriers.

## **I-RISK**

The IRISK (Integrated Risk) project, similar to the ASSURANCE project lasted 3 years, from 1997 to 2000, with partners with diverse expertises originating from various countries, from research institutions, industries or consultants in risk management. The most important partners were the Safety Science Group from the University of Technology in Delph, The Netherlands, Demokritos in Greece and SAVE, a consultant based in The Netherlands. (IRISK)

The objective of this program was to produce a method for an integrated evaluation of the risks of major industrial accidents involving hazardous substances. The qualitative aspects of the program are presented here.

Integration of the risk evaluation disciplines is a recurring theme in the evaluation of major technological risks (Rasmussen, 1996, 2001). Interdisciplinarity should permit a better understanding of phenomena that are perceived to be complex. The ASSURANCE project had as objective to compare methods and practices, the objective of IRISK was to assemble competencies developed in various fields to integrate them, towards a global methodology.

The IRISK project offers an interesting practical illustration of these ideas and interdisciplinary aspirations.

The principle of this evaluation consists in doing a probabilistic evaluation of the site major accident risks by introducing human errors and then by balancing these evaluations by taking into account the quality of management of the site.

The principle used is that probability of an accident is influenced by the organisation of safety. After all, the probability calculations are done using operating reliability data that introduce parameters such as mean time between two maintenances, probability to make a human error, probability to recover from a human error, the mean time between two tests, etc. All these parameters vary as a function of the way the organisation that operates the site, is structured (maintenance planning has an impact on the mean time between two maintenances, training, cooperation modes etc. of the persons responsible for the operation, will cause variability of the probability to make a human error and to recover from it, etc.).

Therefore, the novelty of IRISK is to try to develop a risk evaluation that modifies the calculated probability in the probabilistic approach, as a function of the quality of management of prevention of major risk of a site. The objective consists in integrating three “levels”: technical, human and organisational.

This idea is not new and IRISK follows at the European level, two successive programmes that had the same objective. They are MANAGER (1983) and PRIMA (1993) conducted by British – Dutch consortiums, countries that use probabilistic approaches that have recognized very early the weight of management in the genesis of major accidents (notably after the study of major chemical accidents such as Flixborough, Piper Alpha or Bhopal). However up until now, the organizational models were not giving entire satisfaction to their designers, and the interfaces between the technical and organizational models were not articulated enough.

Therefore, the bulk of the work in IRISK consisted in developing an organisational model that could link with the technical approach.

The difficulties are important. They have the characteristics of the « objects » that are studied:

- On one side the risks related to the site, represented under an accidental sequences, with a mechanical vision of the phenomena with a specific cause resulting in a specific consequence. It is therefore possible to represent sequences modeled by a fault tree. An important number of initiating events could be represented at the base of the fault tree. These events could be failure of equipments or human errors.
- On the other hand, there is also the « organisational » risk, these are not facilities for which one tries only to identify the chain of causes – consequences, the possible links are infinite, but more than that the reality of the enterprise and of its organisation is dynamic, evolving, and the men and women that make it can not be described in a mechanical manner as the elements of the site. Neither the organisation nor the men that make it, are defined by laws, but rather act towards purposes, finalities. It is with this approach that the work of modeling management of safety starts. The objective of a system to manage safety is to control risks of major industrial accidents. It is this function that must be maintained to guaranty the management of risks of major industrial accident. The basic representation of this function originates from cybernetics. See Figure 6 from (Helighen, F., 2001).

The system defines objectives, these objectives are listed as action to execute, these actions result in variables allocated to the system environment. Environment disturbances modify these variables. These disturbances are examined by the system, and this information is represented and treated in order to find out which actions must be undertaken to maintain the objectives of the system. These steps result in a control loop<sup>1</sup> (« feedback loop »). It is interesting to keep this representation because this is these functions that must be maintained to guaranty the management of risks. It can be concluded that there is no management of risks without this control loop. The objective of a risk assessment will consist from then on to determine the state of this control loop, by evaluating the quality of these steps.

In IRISK, this loop was specifically defined in relation with the management of major risk. The proposed model is the result of the knowledge of the members of the working group, that tried to model a management system, in such a way that the model could be used in any organisation (See Figure 7). This representation consists in functions represented by boxes. These boxes ensure the function of the complete system, and the connections between them, represent direct or indirect informational links. (Inputs and outputs).

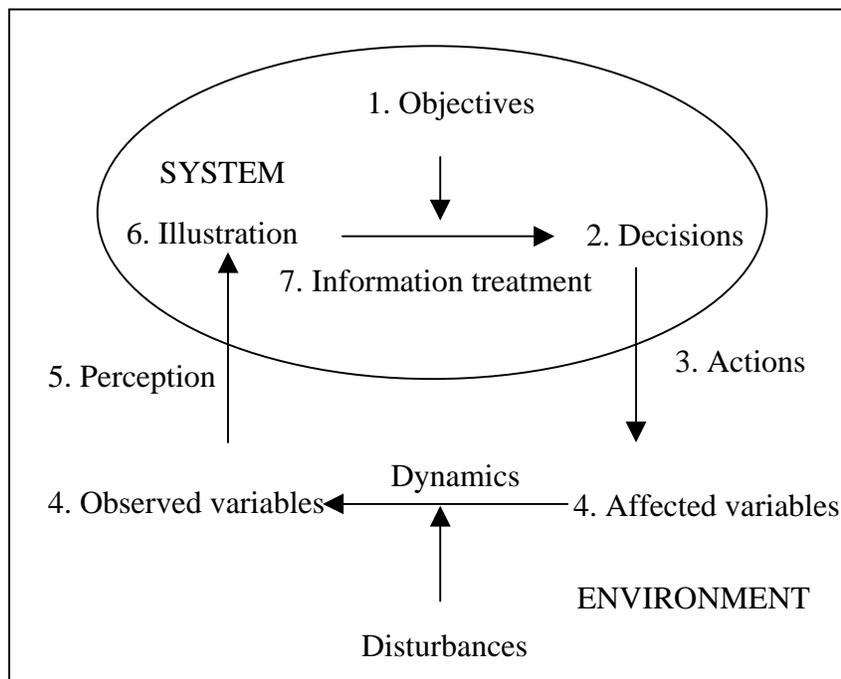
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<sup>1</sup> This representation is translated as Plan, Do, Control, Act (PDCA) in management.

The purpose of this model is to be able to mentally represent the working of the system and to organise the questions and the gathering of information (series of questions by box and links), as done using audits or other methodologies to gather perception (questionnaires, observations, interviews, etc.), in order to construct the state of the system (quality of the control loop) regarding the management of risks.

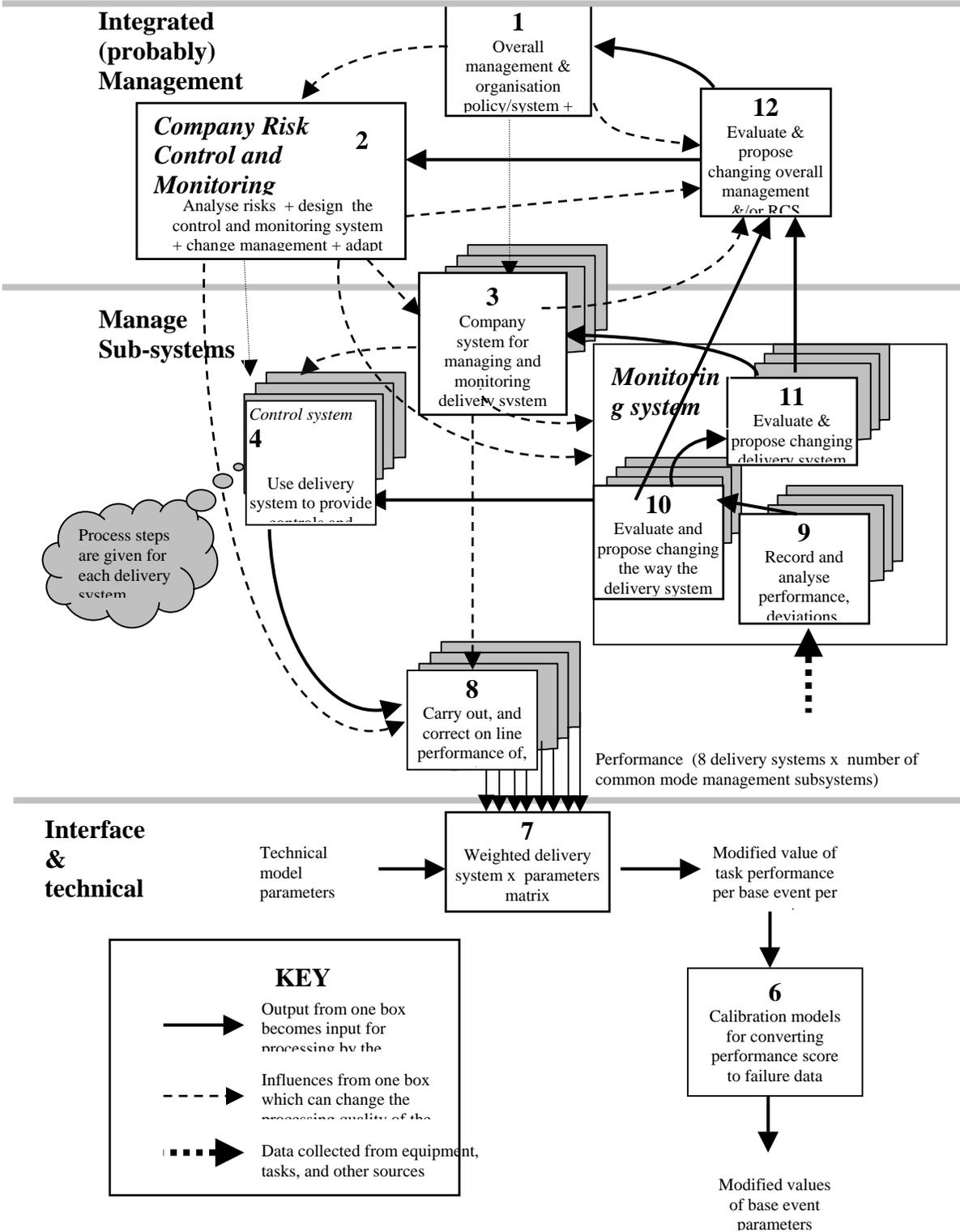
Tests were done to gradually improve the representation of existing operations. This development work is being completed in ARAMIS which will be described later. The objective is to precise how to model and evaluate the effectiveness of a risk management system.

IRISK has shown the complexity of the phenomena to be studied between technical analysis and systemic organisation modeling (See Figure 8), and work must continue to develop high quality evaluation tools.

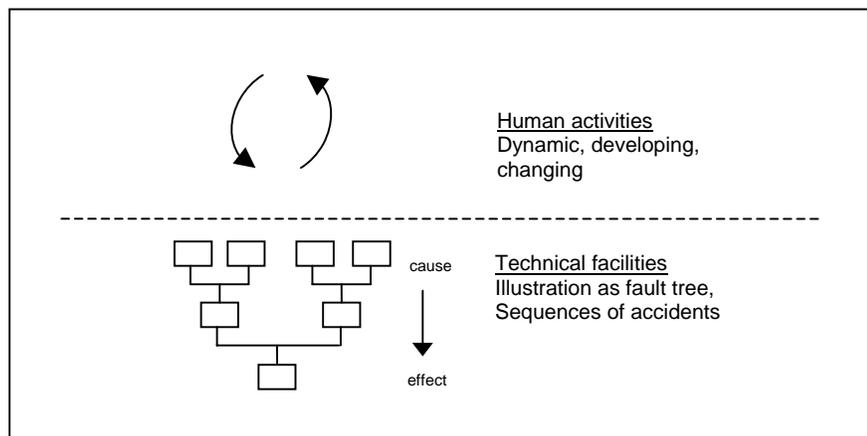


**Figure 6 Representation of a control loop**

**System Climate within which the site**



**Figure 7 IRISK Model (From IRISK Report)**



**Figure 8 Interface between two types of modeling**

**ARAMIS (Accidental Risk assessment Methodology for Industries in the framework of Seveso II directive)**

ARAMIS is a new European project initiated in January 2002. The project is planned for a three year period and is constructed on the conclusions of previous European projects, namely ASSURANCE and IRISK described previously.

ARAMIS objective is to develop a new risk assessment methodology for major accidents that integrates the strength of the various approaches existing at the European level, i.e. deterministic and probabilistic cultures. This research project aims for improving the analysis and risk management process of major accidents. It is based on the management principle that “all what is not measured cannot be managed” (Bellamy, 1999). ARAMIS must also be used as a tool to promote safety in the chemical industry and with the competent authorities, to contribute to harmonisation of the European practices in matters of risk assessment and promote the implementation of Seveso II directive in member states.

The proposed method in ARAMIS should allow to characterize an integrated risk index composed itself of three distinct and independent indexes. **Index S** is to assess the consequence severity of first defined reference scenarios. **Index M** is to evaluate prevention management effectiveness, which allows thus to account for the reference scenarios probability in a semi-quantitative manner. **Index V** is to estimate the environment vulnerability by evaluating the sensitivity of potential targets located in the vicinity of a SEVESO plant.

The project has been set up (Figure 9) to reflect the logical construction of the risk index and has been divided accordingly into work packages:

- 1 First goal is then to develop a method to identify “reference” accident scenarios. These scenarios are consensual “realistic” scenarios to be used in SEVESO II safety report and taking account of some prevention and mitigation measures of the site according to their effectiveness.
- 2 Second task is to build up the integrated risk index made up of the three distinct indexes, i.e.:
  - consequence severity evaluation - S
  - prevention management effectiveness - M
  - Environment vulnerability estimation - V

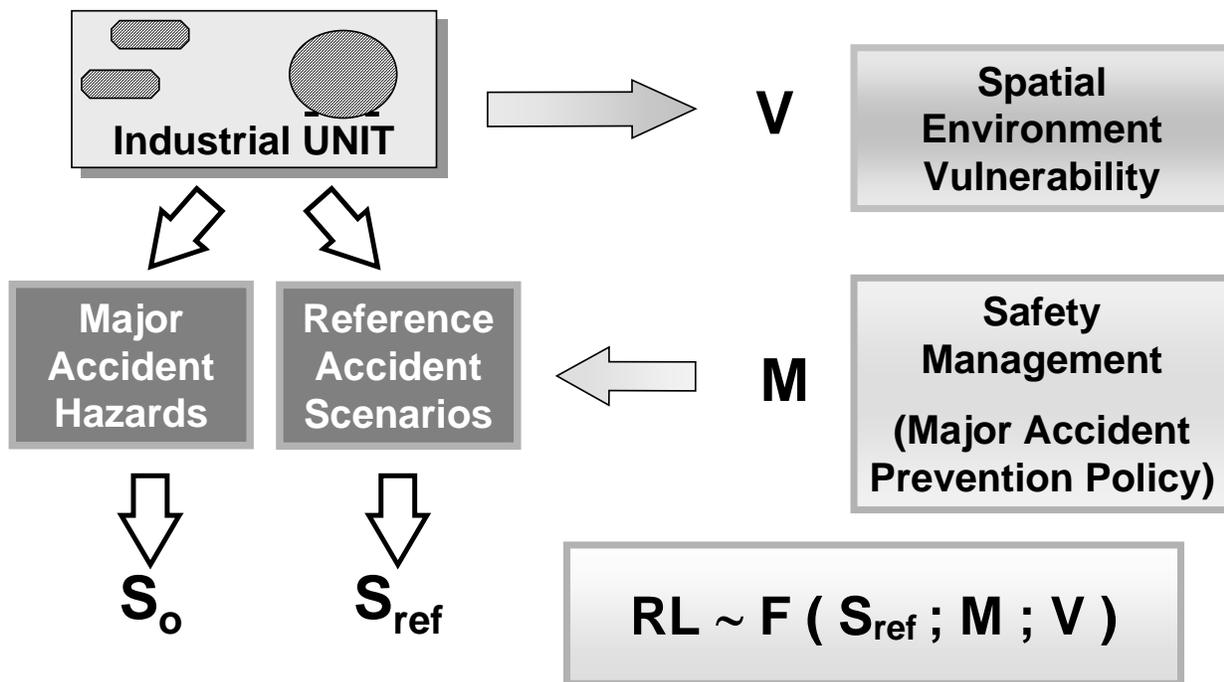


Figure 9 ARAMIS methodology representation

### Identification major accident scenarios

Identification of the possible accident scenarios is a key-point in risk assessment (Amendola & al., 2002). However, especially in a deterministic approach, worst case scenarios are considered, often without taking into account existing safety devices and implemented safety policy. This approach can lead to an overestimation of the risk level and does not promote the implementation of safety systems.

The aim is first to identify major accidents without considering safety systems. A second step is then to study in depth safety device effectiveness and safety management efficiency, which will allow assessing -qualitative- probabilities, in order to identify finally Reference Accident Scenarios taking into account some of the implemented safety systems.

The first objective is to define a Methodology for the Identification of Major Accident Hazards (MIMAH). On the basis of considered equipment and properties of handled chemicals, the methodology must be able to predict which major accidents are likely to occur. Properties of substances are found out thanks to Directive 67/548/EEC (substance classification and labelling) and their own conditions of use (pressure, temperature, flow, etc.).

The MIMAH methodology considers thirteen types of dangerous phenomena and four types of major events. Table 2 shows the links between dangerous phenomena and major events; as it can be observed, only the dangerous phenomena DP4 (VCE) and DP12 (dust explosions) have more than one major event associated.

Dangerous Phenomena		Major Events			
		ME1 Thermal radiation	ME2 Overpressure	ME3 Missiles	ME4 Toxic effects
Pool fire	DP1	X			
Tank fire	DP2	X			
Jet fire	DP3	X			
VCE	DP4	X	X	X	
Flash fire	DP5	X			
Toxic cloud	DP6				X
Fire	DP7	X			
Missiles ejection	DP8			X	
Overpressure generation	DP9		X		
Fireball	DP10	X			
Environmental damage	DP11				X
Dust explosion	DP12		X	X	
Boilover and resulting pool fire	DP13	X			

**Table 2 Links between dangerous phenomena and major events.**

The Severity Index (*S*) presented in this paper is based on a set of Dangerous Phenomena (*DP*) and its corresponding Major Events (*ME*), identified through the application of the MIMAH methodology (Methodology for the Identification of Major Accident Hazards) developed in the frame of the ARAMIS Project (Delvosalle et al. 2003).

Firstly, it was necessary to select a general approach. The bow-tie method was chosen (Bellamy & Van der Schaff, 1999) because it is a highly structured tool and it is considered as a very good way to establish links with other parts of the project and especially Management Efficiency (Figure 10). It assimilates an accident scenario to a succession of events.

Secondly, a special effort was made to develop a common typology of equipment and hazardous substances. Thirdly, event trees and fault trees centered on critical events have been built, and above all a methodology able to build generic trees was created. Critical events are defined as “Loss of Containment” or “Loss of Physical Integrity” event.

The bow-tie is centered on "CE" (critical event).

The **Critical Event** (CE) is generally defined as a Loss of Containment (LOC). This definition is quite accurate for fluids, as they are usually able to behave dangerously in their release state. For solids and more especially for mass solid storage, we would rather talk about Loss of Physical Integrity (LPI), considering a change of physical state of the substances. The other elements constituting the bow-tie are explained here after.

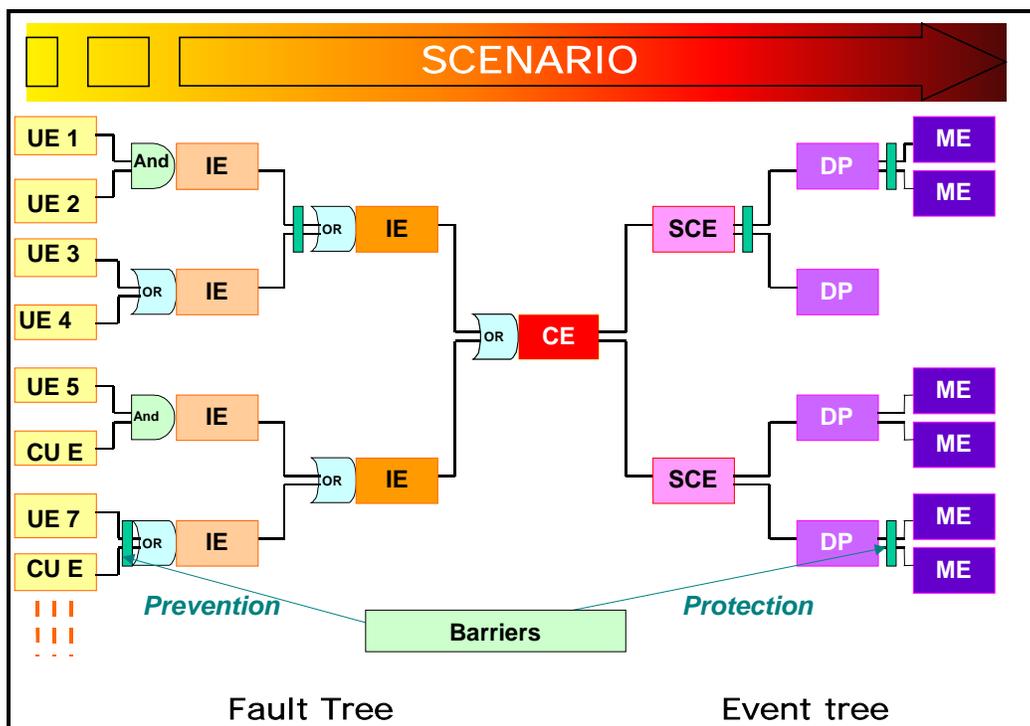


Figure 10 Bow tie approach (From Delvosalle et al, 2002)

### ***Fault tree***

The left part of the bow tie, named **fault tree**, identifies the possible causes of a critical event. The basic events in a fault tree are:

- **Undesirable Events** (UE), which are supposed to occur exceptionally in the usual conditions of operation
- **Current Events** (Cu E), which occur more or less frequently in normal conditions of exploitation and which are, in a certain way, foreseeable

The combination of Undesirable and Current Events may lead, taking into account the possible prevention barriers, to an Initiating Event (IE). An **Initiating Event** is defined as the step that precedes the occurrence of the Critical Event (CE).

### ***Event tree***

The right part of the bow tie, named **event tree**, identifies the possible consequences of a critical event.

The Critical Event (CE), such as a pipe failure, leads to **Secondary Critical Events** (SCE) (for example a pool formation, a jet, a cloud, ...) which leads to **Dangerous Phenomena** (DP) such as fire, explosion, dispersion of a toxic cloud, ...

**Major Events** (ME) are defined as the exposition of targets (human beings, structure, environment,...) to a significant effect from the identified Dangerous Phenomena.

### **Index S : Severity of the consequences**

The objective of this task is to define a severity index S characterizing the possible consequences of accident scenarios. In this respect, only the physical characteristics of the phenomena involved in accidents are studied in order to evaluate the severity of both major scenarios and reference scenarios identified.

The Severity Index is independent of the other two indexes, i.e. M and V. It is thus constructed in such a way that every dangerous phenomenon has a corresponding specific sub-index. The contribution of each dangerous phenomenon to the global index S is strongly related to the probability of occurrence of the phenomenon associated to each critical event (e.g. probability of ignition) and identified in event trees (Figure 10).

Each specific sub-index associated to the various physical phenomena takes into account in its construction the following parameters:

- the effect area concerned with the phenomenon, e.g. a circle in case of an explosion, a plume surface for gas dispersion ;
- the kinetic of the phenomenon: rapid for an explosion, much slower for a fire ;
- The potential of generating domino effect: fragment projection, delayed phenomena triggered off.

The severity index S is therefore a function of parameters only associated with physical phenomena. All the identified scenarios should then be evaluated and ranked in this way according to the calculation of  $S_o$  for Major Accident Hazards and  $S_{ref}$  for Reference Accident Scenarios.

### **Index M : Prevention management effectiveness**

The methodology is based on the identification of initiating events and direct causes of the accident scenarios (bow-tie approach). Safety barriers are then related to generic fault and event trees representing all possible accident scenarios leading to critical events (Figure 10). The safety organization includes both the adequacy and completeness of technical and managerial

barriers (lines of defence) that are implemented to prevent these accidents and the management system that ensures that these barriers are maintained and adjusted properly.

The methodology recognizes a number of dimensions of safety management (delivery systems), derived from previous work on safety management modeling, notably the IRISK. These are made explicit in specific functions that need to be executed to maintain a safety barrier. Examples of these delivery systems are: ensuring good competence and commitment of employees, manpower availability, communication, procedures, plans, hardware and human-machine interfaces.

Currently, the focus is on developing instruments to measure the set of dimensions, using a combination of audit, questionnaire, interview and observation techniques. The combination of measurements ensures that not only the implementation of functions, but also its conditions and outcome (e.g. good safety commitment of the employees) are taken into account.

The measurement techniques address in particular the specific safety functions in a given establishment. However measurement will also be carried out in a generic way onsite, assuming then the quality of the dimensions represents a common mode for the quality of safety barriers maintenance. The efficiency of the barriers can then be adjusted according to the measurement scores to select the final set of Reference Accident Scenarios.

The assessment of technical barriers effectiveness follows the principles described in the norms IEC61508 and IEC61511 (Functional safety: safety instrumented systems for the process sector). Among these principles, effectiveness is analyzed through the definition of "Safety Integrity Levels" linked to device characteristics (design, reliability, maintainability, testability...) and also through criteria upon the activities in charge to maintain them.

## **Index V: Environment Vulnerability**

An accident is only "catastrophic" if there are vulnerable targets that could be affected. The notion of risk makes sense only when it refers to targets that could be affected by this risk. This demonstrates the need to characterize the environment of establishments that could generate risks and to estimate its vulnerability. The problem is to define what are the most vulnerable zones. In other words to balance the vulnerability of the targets one against the other by integrating quantitative factors.

To achieve this, it is first required to characterise the environment against a typology of targets (population, natural environment, and property) and potential effects, and to evaluate the impact that could generate these effects on the targets.

After this work is done, it is required to prioritise the various impacts as a function of the consequences and the targets. The SAATY method is used to perform this task. This multicriteria prioritisation method, used also expert judgment, allows to establish priorities between the consequences of the various phenomena on the various targets using a matrix approach by comparing one after the other and two by two, the trios: phenomena – target – consequences.

## **Conclusion**

The original feature of ARAMIS is the integration of the three indexes, S, M, and S to characterize the level of risk in a site. It is a hybrid between the deterministic and probabilistic approaches used in risk management.

The bow tie approach and the typology of scenarios that are generated could be particularly useful for the development of credible worst case and alternate cases scenarios required in the Environmental Emergency Regulation under section 200 of the Canadian Environmental Protection Act.

The concept of a Management index is appropriate and could support the Site Self-Assessment Tool developed by the Major Industrial Accident Council of Canada (MIACC) under the Partnership Toward Safer Communities.

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