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# **Risk Assessment: methods on purpose?**

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## **Abstract**

When considering three proven methods of risk assessment widely used within energy sector, PHA, FMEA and HAZOP, the question of the adequacy of the method to objectives is raised. After introducing the methodological framework for risk assessment, we take a look at an overview of the three methods. From a perspective shaped by systemic paradigm, we propose the concept of symptom, as thread running through of each method. After detailing the specific symptoms for each method, we put forward two hypotheses. First, a method is not neutral and symptoms are a sign of inclination and drive representations of the scenarios developed. Second, risk assessment workshops, seen as privileged locations for organizational learning, change the relationship between actors and hazardous situations. By locating each method within the triangulation of definition from the systemic paradigm, we invite risk assessment experts to make their tacit knowledge as explicit as possible in order to identify operational levers to control their activity.

## **1. Introduction**

The international standard ISO 31000 (International Organization for Standardization 2009) defines risk assessment as a comparison of a level of risk determined during the process of risk analysis to criteria for risk acceptability. Based on the results of the risk analysis, the purpose of risk assessment is to help decision makers to identify risks requiring treatment and to prioritize their implementation. Risk analysis is defined as the process used to understand the nature of risk and to determine the level of risk. [ISO Guide 73:2009, definition 3.6.1]. Energy sector has made consistent efforts to ensure efficiency of risk management, but when come the times to actually choose a method of risk analysis, it appears that around 40 different techniques are of common use within the industry (Glossop, Loannides, and Gould 2000a). If one dig further the investigation, more than 700 risk analysis methods are available (Everdij and Blom 2008). In order to determine which methods are representative of a world-class engineering practice in energy sector, we have reviewed several standards and guides of energy sectors. Those guides set framework of an industrial project and define which methods should be used for each step of an industrial project. We have considered a sample of guidelines from 23 Oil & Gas companies (15 NOC, 8 IOC), 6 mining and extractive industry, 6 Energy multinational companies, 12 guides from services provided by international consulting companies, 5 Engineering companies (EPC contractors) and recommended practices from professional bodies and institutions (OGP, API, World Bank...). As a result, Preliminary Hazard Analysis (PHA), Failure Mode and Effects Analysis (FMEA) and Hazard and operability study (HAZOP) are mentioned in almost all the literacy. It is recommended to start PHA as early as possible at pre-project stage and then update and develop the analysis all along the project. HAZOP is generally intended to be set two times during the Front End Engineering Design (FEED stage). First HAZOP takes place at first emission of Process and Instrumentation Diagram (P&Id) then a second one at the end of FEED.

A third HAZOP is expected during detailed engineering when details regarding process of vendor's package are available. Only few details are given about the purpose of FMEA (e.g. can be use for assessment of a High Integrity Protection System - HIPS). Others methods are mentioned but with less frequency ( SWOT analysis, What If, Fault tree, Bowtie...).

Two of these methods were created in the 1960's: the Preliminary Hazard Analysis (PHA) to analyze the risks when designing aviation and military systems and Failure Modes and Effects Analysis (FMEA) developed by aircraft manufacturers. Failure Modes, Effects and Criticality Analysis (FMECA) integrated "criticality" in the criteria of initial FMEA (Everdij and Blom 2008). The successes of the Apollo space missions have demonstrated the merits of this type of method (NASA 1966). The 1970s saw the emergence of HAZOP (HAZard analysis and OPerability), developed by Imperial Chemical Ind. for chemical processes (Lawley 1974)(Lawley 1976). Although developed for specific applications, these three methods among the most commonly used, have subsequently been generalized to broader fields of application (Kletz 1999). Several methods can be used for the same problem of risk analysis. The origin of this paper lays in the question whether several methods are applicable and how to determine whether one method is more appropriate than another. Regarding potential outcomes of the issues covered by risk assessments (Paté-Cornell 1993) (Lagadec 1982) (Flournoy 2011) (Shrivastava 1987) (Acton and Hibbs 2012), the question is definitely a serious one.

## **2. Three methods : a guide overview**

### ***2.1. Preliminary Risk Analysis (PHA)***

PHA is used to identify and assess risks associated with the use of a system, and preliminary to the use of more precise methods of analysis.(Villemeur 1992)(Glossop, Loannides, and Gould 2000b). The core concept of PHA is a "hazardous situation", resulting from the combination of a hazard and the activity that links system and hazard. "*A list of hazards and generic hazardous situations and risks is formulated by considering characteristics such as materials used or produced and their reactivity; equipment employed; operating environment; layout; interfaces among system components, etc.*" (International Organization for Standardization 2009). Situations are represented through a model in which sources of a hazard interact with targets (people, environment, assets, etc.) via the flux of the hazard. Hazard Identification as a first step, allows the definition of critical systems due to their vulnerability to internal and external hazards (Wells 1996) (Vincoli 2006) (Roland and Moriarty 2009). The intent of the PHA is either to influence the design for safety as early as possible in the development program (Ericson 2005)(Everdij and Blom 2008) or to select major significant scenarios to optimize the allocation of resources available to do a detailed risk analysis(e.g. that requires modeling studies such as consequence analysis) (Rausand 2005a) (International Organization for Standardization 2009). PHA is often seen as a simple method as it can be used without a comprehensive package of documentation at an early stage of the project (Popović and Vasić 2008)(Favaro and Monteau 1990)(Glossop, Loannides, and Gould 2000b).

### ***2.2. Failure Modes and Effects Analysis (FMEA)***

Originally, the FMEA was developed as a tool to assess the reliability of equipment and systems for the U.S. Army (Department of Defense 1980). It is used to assess the effects resulting from failure modes to implement any design changes if the consequences are unacceptable in terms of reliability, safety or operability (IMCA 2002). The probability of the failure of a component or subsystem is derived from a failure rate associated with each failure mode. Originally used in reliability, the scope extended to issues of safety systems (Smith 2001). A failure is defined as "the termination of the ability of an item to perform a required function " (International Organization for Standardization

1974). Failure mode is the phenomenon by which a failure is observed. The criticality of a failure mode is defined as the product of 3 items : (1) the expected number of failures, (2) an index for rate and reliability and (3) of an index on the severity of the effect (Mikulak, McDermott, and Beauregard 2011) (Reid 2005). The total criticality of the system is then the sum of the criticality of the individual components. Finally, the FMEA can provide insight into the reliability of the system that can serve as input data for other methods of risk analysis (e.g. causal tree) (Stamatis 2003). FMEA requires a decomposition of the system studied in subsystem that can go down to component level (NASA 1966). The FMEA is thus structured around the following questions: what can malfunction? How? At what frequency? What are the consequences of failure? What reliability can be attributed to the system? What are the potential impacts in terms of safety (Rausand 2005b) (Smith 2001) ? The relevance of the method both as a design tool and as an aid to decision, is largely dependent on the quality of the functional analysis (Gressel and Gideon 1991).

### ***2.3. Hazard and Operability (HAZOP)***

HAZOP aims at improving and securing processes within a system (Chemical Industries Association 1992) (Crawley, Preston, and Tyler 2008). Specific physical parameters play a distinctive role in the definition of the equilibrium states of a system. These are parameters that can be measured at the macroscopic level, directly or indirectly through instrumentation devices. Each system is designed to operate at precise conditions of temperature, pressure, flow and levels. These conditions related to the design intent are called "nominal conditions" (Lawley 1974) (Kletz 2001). HAZOP is based on the systematic review of the design and operating principles based on (1) the search of all causes that lead to deviation of the different operating parameters from design intent, (2) analysis of the consequences of these deviations, (3) a means of protection (Swann and Preston 1995) (Smith 2001)(Nolan 1994)(Wu et al. 2014). The HAZOP study is usually carried out on "Piping and Instrumentation Diagram (P&ID)". The description of a unit may require the development of dozens of P&ID. These diagrams synthesize all the elements of the chemical process. The facilities, valves and control elements are described using standard symbols (Knowlton 1976). In a pre-meeting, the facilitator of the review divides the unit to be studied into subsystems called "nodes" that will each be reviewed in turn. HAZOP uses guidewords (e.g. more, less, no, etc.) combined with process parameters (e.g., pressure, temperature, flow, level, etc.) to express deviations (e.g. less flow, more temperature) of the process (Knowlton 1987) (International Organization for Standardization 2001). Having determined the deviations, the expert team explores their feasible causes and their possible consequences. For every pair of cause-consequence, safety barriers intended to reduce the occurrence (prevention) and effects (mitigation) must be identified (Sklet 2006). To conclude the analysis, if the safeguards are estimated as insufficient, recommendations or improvements are put forward (Dunjó et al. 2010).

## **3. On the adequacy of a method to a situation**

### ***3.1. Looking for the specificity of each method***

Literature gives primarily the following differences in the methods as: (1) levels of detail of the analysis and associated project development phases (Glossop, Loannides, and Gould 2000b) (Popović and Vasić 2008), (2) inductive or deductive pathways (Hoepffner 1989) (Stephans 2012), (3) quantitative and qualitative aspects (Montague 1990) (Tixier et al. 2002) and (4) the assumed adequacy of one type of industry over another (Lees 1980) (Freeman 1985) (Knowlton 1986) (Nolan 1994). It is often pointed out that a method is not in itself better than another (Gressel and Gideon 1991). Guidances also mention the need to use several methods in a complementary way. The question of the adequacy of a method is frequently raised, but very little help is provided to check its appropriateness (International Organization for Standardization 2001) (Montague 1990) (Glossop,

Loannides, and Gould 2000b) (Rausand 2013). Experience shows that HAZOP is mainly used in process industries such as Oil & Gas (C. Bullock, Mitchell, and Skelton 1991) while FMEA is favored by automotive and aircraft industries (Dyadem Press 2003). PHA does not seem to be connected to any specific type of industry. Empirical evidence shows that a given method is used for a given situation (Knowlton 1979) (C. J. Bullock and Bradley 1995) (Reid 2005) , but no satisfactory theoretical framework is ever mentioned. Furthermore, the guidance available appears to concentrate on providing a description of the technique rather than setting any standards relating to the quality of its application.(Glossop, Loannides, and Gould 2000a)

### ***3.2. Expected results from risk analysis***

Selected methods (PHA, FMEA and HAZOP) have had a proven track record of success within industry for forty years and it can be seen that they are still cohabiting. The expected output of risk analysis is the construction of a reliable information base in order to inform decision makers regarding risk acceptability (Starr 1969) (Fischhoff et al. 1980) (Starr 1985) (IAEA 1998) (Rausand 2013). Operationally, this leads to the systematic identification of how feared events may occur. As with a lot of other risk analysis methods, results are formalized in cause–consequence scenarios, identified safeguards and recommendations for additional barriers (Gressel and Gideon 1991) (Glossop, Loannides, and Gould 2000b) (Tixier et al. 2002) (Everdij, Blom, and Kirwan 2006) (Popović and Vasić 2008). We argue that the fact that results from risk analysis from different methods are formalized in a way that looks similar (e.g. worksheet with cause-consequence scenarios and safeguards) tend to make one believe that methods are fungible (American Society of Mechanical Engineers 1999). If we go back to the roots, a method could be defined as an ordered list of operations supposed to provide ideal guidance in the process of scientific knowledge production. It means that they have a lot in common (e.g. some steps are identical, multi-disciplinary teams, causal framework, etc.). Thus, it can be said that although they look similar, they definitely do not tell the same story. Assuming that the world is objectively available and apprehensible and can be compared to an internal corresponding mirror of it involves epistemological issues (Dekker 2012). The following part of this paper aims at demonstrating that the epistemological background of each method defines a perspective of the system, which will drive expected results. Consequently, it will be a main parameter regarding adequacy of each method to objectives of risk management process. The epistemological background of each method is set regarding concept of definition as triangulation from the systemic paradigm (Boulding 1956)(Forrester 1995) (Le Moigne 1977) (Simon 1965) (Simon 1996).

### ***3.3. Underlying assumptions***

Historically, accidents are represented as a consequence of the failure of machines or people (N. Leveson 2004) (Hollnagel 2013). From this perspective, risk can be estimated as a linear combination of failures. The systemic approach goes beyond this viewpoint and a feared event is the outcome of an unexpected combination of actions. Traditional approaches of risk assessment are governed by the following two assumptions: first, events occur according to predefined sequences; secondly, the main source of risk is the failure of components (Hollnagel 2008). As a consequence, the methods presented in this paper are adapted to technical systems (i.e. they are decomposable as they are designed by humans and describable as component assembly into subsystems). All these risk analysis methods have in common the construction of a shared vision of risk scenario. We use the term of *workshop* or *risk analysis workshop* to mention the meetings during which expertise among participants is gathered in order to be formalized into a report.

### **3.4. Symptoms**

Exhaustiveness is probably the main challenge of using a method. That is to say that, at the end of the day, we want to be sure of not having missed any risk. As a result, each single method is based on its own specific thread. PHA, FMEA and HAZOP review respectively: structures, failure modes and deviations. Here, we propose to define the concept of "symptom" to find a common point between the three methods. The term is borrowed from Low Latin doctors *symptoma*, transcribing Greek συμπτωμα "happenstance, coincidence" and in particular "sign (of a disease)". The modern meaning of the term is no longer restricted to the medical field: "what reveals, manifests a state of things; sign, forerunner of a phenomenon, a process". There is an additional resonance: the "symptom" itself carries a meaning, because its structure distinguishes it from a natural piece of evidence. Therefore, each method reviews a series of potential symptoms as a starting point for the development of feared scenarios. Our first hypothesis is that the method is not neutral. In order to challenge this hypothesis, we have looked through several reports of risk analysis workshop we have conducted during the last decade. We have checked scenarios that can be compared (i.e. that are based on a similar sequence of events) and compared how risk reduction measures are expressed for each method that had supported the assessment (PHA, HAZOP and FMEA). We now propose two examples. The first one involves hydrocarbon atmospheric storage tank overfilling. Risk reduction measures from HAZOP are related to safety-instrumented system (SIS) (i.e. independent Level Switch High High or LSHH). FMEA outputs focus on reliability of level gauge at process control level and suggest a benchmark through different technologies of level measurement (e.g. radar, electromechanical, ultrasonic...). PHA mentioned retention bunds and dikes capacities and adequacy of liquid hydrocarbon detection. The second one is about overpressure protection of a vessel. HAZOP mentions again Safety Instrumented System (i.e. Pressure Switch High High – PSHH), checks vessel design pressure and assumption for Pressure Safety Valve (PSV) calculation. FMEA recommendations are about metallurgy class and reliability of PSV regarding available technology (spring loaded, balanced PSV, pilot operated...). Risk reduction measures from PHA are about layout considerations (spacing between equipment and units) and possibility of domino effects resulting from an explosion of the vessel. Regarding safety, all these recommendations make sense and each of them contribute as a layer of protection. But they are never mentioned altogether within report of a single specific method. By using a method of risk analysis, we extend the space in which we look at the system. But not a single method can allow to highlight the system we study as a whole, choosing a method is equivalent to highlight a specific area of the problem. The symptoms of each method are thus a sign of inclination and underlie the scenarios developed. We now propose to explore this point based on the relationship between methods and models.

## **4. Tangible and intangible results of risk analysis**

### **4.1. Dynamic of risk analysis**

It is observed that results of risk analysis fall into two general types: tangible and intangible (Fischhoff et al. 1978) (Pully 1993). The formal objective of a risk analysis review is to identify prevention and mitigation barriers to control risk, and so tangible results stand out (e.g. worksheets which feature scenarios, and recommendations for changes to process equipment or procedures). Nevertheless, a risk analysis workshop is definitely the place for the development of organizational learning. It allows better sharing of knowledge on hazard identification and an increased investment in risk management. So intangible results consist of: (1) knowledge gained by the team participants, and (2) better resource allocation. It also contribute to influence the safety climate as it seems to proceed via the individual's perception of the shared climate." (Tholén, Pousette, and Törner 2013). Whatever the method, risk analysis workshops are led by a professional risk-management facilitator to ensure appropriate implementation of the selected risk analysis method. From our perspective, animation of a risk

analysis review is a situation of dynamic environment management, which means that other human actors are the objects of its action. From a model that places the concept of activity at the core of the evolving relationship between subject and situations (Leplat 1997), we put forward a second hypothesis : beyond production or formalization of knowledge of risks, a risk analysis workshop transforms the relationship between stakeholders and hazardous situations. To question that hypothesis, we have performed an analysis of both feedback reports and semi-directive interviews that have been conducted after risk analysis workshops. Regarding scenarios of overfilling previously mentioned, it appears that facilitator used some lessons learned from the Buncefield accident (Buncefield Major Incident Investigation Board (Great Britain) and Office of Public Sector Information 2008). As a result, all interviewed participants admitted that they realized how far from a purely technical accident (i.e. failure of a level gauge) can be an accident. Those people who are not safety specialist said that risk assessment workshop contribute to have a better ownership of expectation from the safety management system of their company. By going through risk scenarios and sharing with other disciplines, they were definitely convinced that safety and integrity of operations couldn't rely only upon technical barriers. They also declare that they are more aware of how human and organizational aspects are key factors in building safety. The point we want to stress is that these evolutions of risk representations are not the formal purpose of risk assessment workshop but are a main contributor to the resilience (N. Leveson et al. 2006) of the organization by enhancing the quality of exchange and expanding the area of questioning risks.

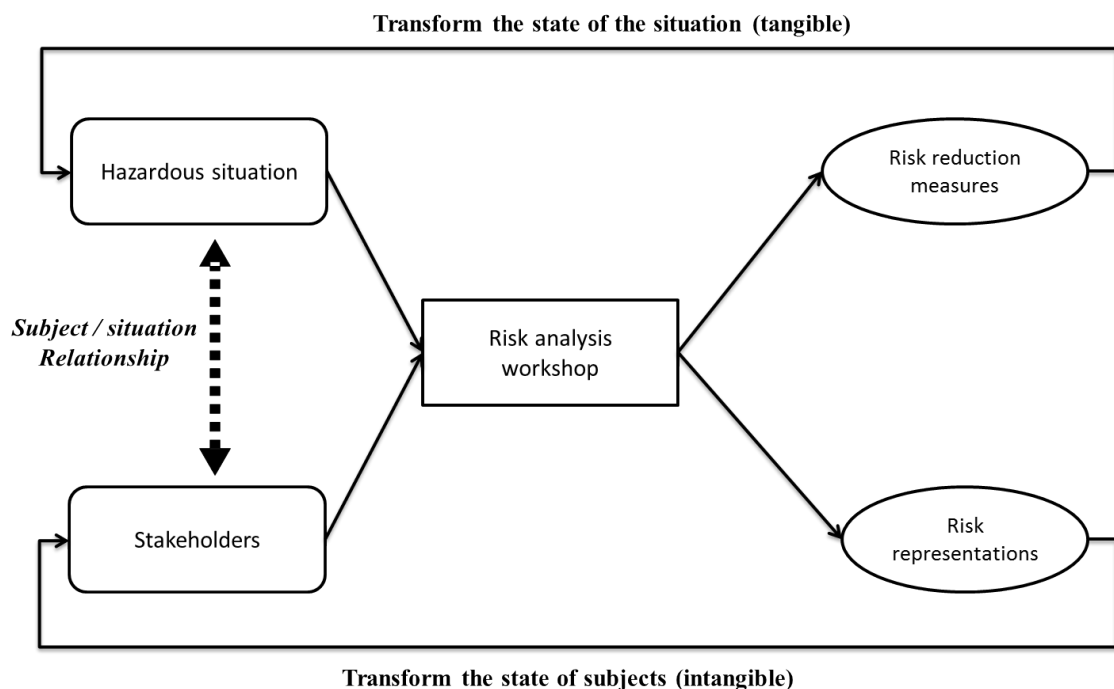


Fig. 1: Regulation of the activity of the system through the properties of the situation and characteristics of the subject. Adapted from Le Plat 1997

Risk management involves both the production of knowledge (concerning the feared situation, its causes and its consequences) and the will to act by implementing measures. Three types of activities structure risk management: anticipation, awareness and emergency preparedness. Anticipation involves process design, risk analysis, writing work procedures, implementation of safety dashboards, training ... During this phase, knowledge of the system is created and integrated into the system. So, the Risk Analysis workshop is a significant part of the process allowing the creation of learning mechanisms necessary for the development of a safety culture (Pidgeon 1991).

## 4.2. Facilitator

The task of the facilitator is mediated by methods and it targets in the co-construction of a shared representation of risk among stakeholders. We emphasize the usefulness of identifying the drivers enabling risk practitioners to reconsider their own practices (Denis-Remis 2006). This will help them to better control their activities. A key success factor is the wealth of the range of methods and tools which risk managers can use facing wealth of stakeholders representation (Breakwell 2001) (Fischhoff 1989). Although the effectiveness of a method relies on the quality of its conception, how it is applied is crucial (i.e. its ownership) . Facilitators should know enough about the properties and rationale of each method to anticipate out what could happen when using it (e.g. discrepancies, unintended reactions of participants, gap between what is done and what is planned...). It is so easy for any method to drift and then become a farce. In their relationship with the system studied, participants of risk analysis review, even if they are subjects of their activity, are objects of the action of the facilitator. Even if participants are highly skilled professionals and got a strong commitment to safety, their primary motivations are *de facto* seldom focused on risk management. Their concerns are frequently related to their relationships with other members of the organization - managers, supervisor, financial, coworkers ... - rather than the system studied. The activity of the risk manager as facilitator of a risk review, therefore, includes the following elements:

- Engaging participants in the implementation of the method,
- Tracing the cognitive route designed to provoke participants' reaction to : (1) a chain of potential symptoms, (2) entry points for hazard identification and (3) risk characterization by developing plausible scenarios,
- Being a mediator between the participants and the system studied.

To clarify outlines of this mediating function, the relationship between methods and models is explored in the next paragraphs.

## 4.3. Definition of an object as triangulation

Whatever the system, defining an object can be done by triangulation combining a functional definition (what the object does), an ontological definition (what the object is), and a genetic definition (what the object becomes). The systemic approach (Simon 1965) (Simon 1996) involves the development of a dedicated framework, that is to say "no more explaining mechanisms themselves, but understanding or interpreting behavior with a permanent reference to projects of modeled phenomenon. These projects must be described regarding environments in which they work and become. Functioning and processing are seen within temporality. " (Le Moigne 1977)

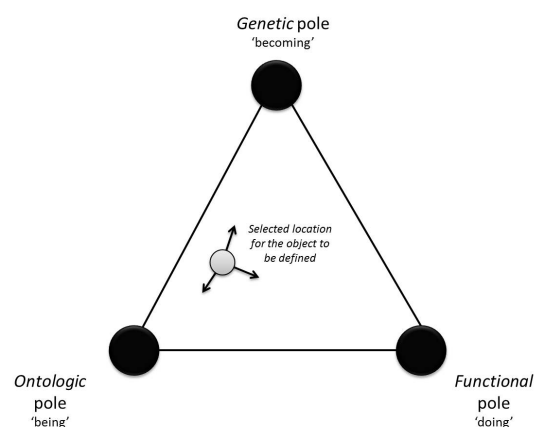


Fig. 2 : definition of an object by triangulation (Le Moigne 1977)

#### 4.4. Model proceeding methods

It is consequently possible to have a fresh look at the methods of risk analysis:

- HAZOP: The symptom of hazard flux is the “deviation” from the nominal conditions. The method deals with the research of causes and consequences of the deviation. The system is defined in accordance with functions of state (i.e. pressure, temperature, volume ...) compared to what it is or what it should be.
- FMEA: In the acronym of the method itself, the symptom is the “*failure mode*”. The failure mode is the expression of the failure (i.e. the phenomenon that prevents an entity from performing a function). So, the system is observed within a functional approach.
- PHA: The study begins with a description of the organization of the system (structure and program). The study highlights the potential hazards in order to identify critical sub-systems, (e.g. vulnerable equipment). “*Vulnerability*” is then the symptom, resulting in the concept of a feared event. The common thread is, what the system becomes when exposed to a particular stress. The perspective is polarized towards the genetic pole.

| Method | Stated objective                | System description              | Symptom                              | Core Concepts       | Workshop course                                 | Perspective            |
|--------|---------------------------------|---------------------------------|--------------------------------------|---------------------|---|------------------------|
| FMEA   | Ensure reliability & safety     | Function                        | Failure mode                         | Function            | Co-construction of a cause-consequence scenario | Functional<br>“doing”  |
| HAZOP  | Process safety                  | Functions of states<br>P,V,T°,Q | Deviation                            | Nominal conditions  |   | Ontological<br>“being” |
| PHA    | Selection of critical scenarios | Hazard – activity association   | Hazardous situation<br>Vulnerability | Structure & Program |   | Genetic<br>“becoming”  |

Table 1: methods, symptoms and perspectives

#### 4.5. Methods on purpose

Choosing a method is to choose a place of observation in the *-doing, being, becoming-* triangulation. The risk manager should be aware that the choice of method implicitly makes the working group focus on the system. In order to conduct his exercise, it is essential that the practitioner keeps this in mind. This combination of three definitions is specific to each single observer. This viewpoint must be communicated intelligibly and cannot be imposed because of its presupposed evidence or objectivity. The choice of method seems to be a significant marker of the relationship of the observer modeling (i.e. the sponsor of the study or its delegates) with the system.

To conclude, we therefore propose locating each method according to the definition of the object by triangulation. Note that what we locate is not where each method stands but where the system appears when looked at by each method. The major advantage of the elicitation of this point is to enable to assess whether the purpose serves the purpose. Being aware of where minds are looking, certainly allows the knowledge of what is observed, but also the knowledge of what is beyond our field of vision. Even with committed people, technically skilled and professionally experienced, which facilitator has not felt uncomfortable while conducting his review and feeling a kind of offset framing, and then missing the point? How many participants have never had the impression of *much ado about nothing* after several long days of workshop? Based on results from feedback debriefing and semi-directive interviews of participants of more than fifty workshops over the last decade for the Oil & Gas, mining, pharmaceutical and engineering industries, we argue that the unfamiliarity of each participant concerning their own choice of perspective is a factor of confusion and misunderstanding. The role of the facilitator is, however, crucial for the development of consensus and shared representations. Thus, "The more he theorizes methods, the more he restores his freedom. The more he ensures the performance of its instruments, the more he has the choice of his tools".(Le Moigne 1977)

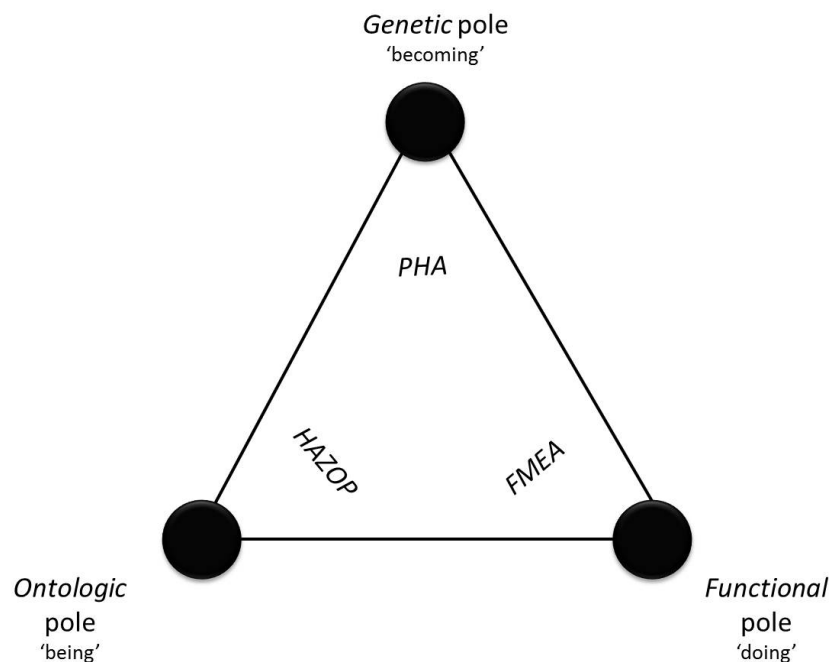


Fig. 3: Situation of the system within the triangulation (be, do, become) regarding each given method

## 5. Conclusion and perspectives

The approach proposed in this paper provides risk analysis stakeholders, on the one hand, bases allowing them to enrich and refine their own mental representation of a system and on the other hand, keys to understanding some of the determinants of mental representation of other participants (Simon 1978). To conclude, the three methods presented are particularly suitable for the risk assessment of technical systems. Depending on who is taking ownership (e.g. operator, engineer, designer, manager...) and depending on the project stage, the perspective changes within a frame (being, doing, becoming). The method used will be more or less ergonomic. Identifying this point of view during action: (1) gives a better understanding of the limitations of each method within a given context, (2) facilitates the effective running of the risk workshop and (3) provides a valuable indicator of the level of guarantees that can be associated with recommendations coming from the risk assessment. Even if it is not a new result that a single method cannot cover the whole spectrum of risk (N. G. Leveson 2002), but we propose here a fresh formal explanation by referring to the idea that a definition of a system is the combination of three definitions (functional, genetic and ontological). The key point is that a method is the result of a choice of perspective and cannot allow at the same time a comprehensive set of point of view. As already stated, risk assessment should be based on a model of the system studied and its behavior. It must be consistent with the complexity of the system itself (Rasmussen 1997). We can conclude that one can not have a chance to cover a risk as a whole, if one do not combine at least three complementary methods of Risk Assessment. We have illustrated this point by checking three methods used by energy sector to analyze the technical risks of their industrial projects. We suggest that this analysis could be done for any type of Risk Assessment that combines several methods. By doing so, it will be possible to check that each blending of method do not forget a viewpoint and that at least the system analyzed is seen from several perspectives.

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