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Influencing the Human and Organisational Factors in Process Safety Risk Assessments

Arthur Groot

DSM Resins & Functional Materials, Sluisweg 12, Waalwijk, The Netherlands
arthur.groot@dsm.com

The PSRA (process safety risk assessment) is the most important element of an effective process safety management program. A PSRA is an organized and systematic effort but there are also highly complex tasks related to it. The effort is to create a complete identification of causes and consequences and subsequently set of effectiveness of barriers to manage the risk to acceptance level.
The critical task is that the information to be compiled about the chemistry needs to be comprehensive enough for an accurate assessment of the reactivity hazards, fire and explosion characteristics and toxic releases. A successful PSRA also requires an unambiguously Risk Assessment Metric or risk graph, the availability of reliable clean (failure) data and must be organized properly. The organizational part of the PSRA's have to deal with demanding circumstances like time pressure, culture, workload, costs, motivation, procedures of classification and competent resources to complete the risk assessment in time. These elements together are typical ingredients introducing the human factor in PSRA's and the presence of so-called cognitive biases. These biases can have a negative influence on the validity of the risk assessment and can lead to incorrect and hence ineffective recommendations. Cognitive biases are defined by Kahneman as the tendency of systematic deviations when assessing risk instead of objective and rational judgment. The occurrence of these cognitive biases can be clarified by the understanding the dual-system of thinking (system 1 and system 2), Kahneman.
The objective of this paper is to identify what kind of human factors and organisational factors are present in a PSRA and what can be done to prevent them? To identify these biases, we have evaluated multiple PSRA's from our company. The results of this evaluation show that human and organisational factor can be avoided, and more important incorrect conclusions and implementation of ineffective recommendations can be prevented.

1. Introduction process safety management

Process Safety Management (PSM) is the application of management principles and systems to the identification, understanding and control of process hazards to prevent process-related injuries and incidents. The PSM system originally suggested by CCPS contains 14 main elements. In 2005, the CCPS introduced the next generation of the process safety management framework – Risk Based Process Safety (RBPS).
A pillar or foundation block of the PSM system is 'the understanding of hazard of risks'. One of the elements in this pillar is the hazard identification, the process safety risk assessment, which is an important part of the PSM system. The PSRA (process safety risk assessment) is applied across the chemical industry and has been reinforced by requirements under legislation of the Seveso guideline in Europe.
Until now, many methods and approaches have been proposed to assess the risk of the identified scenarios. A study carried out by Khan et al (2015) identifies an overview of PSRA methods from 1996 to 2014, which includes qualitative, quantitative methods as well as a combination of these. However, despite the availability of many PSRA methods, an evaluation of multiple PSRA's conducted in our company showed that the quality of the PSRA's appears to stagnate.

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The people that facilitate PSRA's are expected to follow a well-structured and approved process, supported by relevant guidelines and information to make finally a rational judgment. In practice we recognized that cognitive biases such as substitution, curse of knowledge, optimism, pessimism, etc. play a significant role in the outcome (quality) of the process safety study. What we need in a PSRA is an objective and rational judgment of the scenarios and no involvement of cognitive biases that affects the final outcome.
Next to that, we concluded that we didn't not give enough support to our people how we want them to organize the PSRA and that we didn't do enough training and coaching how to obtain the quality in the PSRA.

2. Introduction to cognitive biases

Cognitive biases are systematic deviations of a specific judgment in the same direction. In a PSRA we expect the presence of cognitive biases for different reasons: time pressure, availability of resources, lack of data and cognitive biases have been proven to be made by all type of people, independent of intelligence. The occurrence of cognitive biases in PSRA's can be clarified by the dual-system of human cognition; system 1 (fast) and system 2 (slow), Morewedge and Kahneman (2010).

2.1 System 1 and system 2

System 1 produces the fast, intuitive judgments and instantaneous decisions. System 1 is 'always on', is an automated process, is prone to cognitive biases and results in systematic deviations of judgments. System 2 is in contrast slow, lazy and inefficient and is a deliberate type of thinking involved in focus, deliberation, reasoning or analysis. Typical examples of system 2 thinking are calculations of complex mathematics problems or performing a demanding physical task or procedure. But system 2 thinking is also careful and rational. A visual summary of the differences in system 1 and system 2 thinking is shown in Table 1.

Table 1: a summary of system 1 and system 2 thinking

	System 1		System 2
	Fast		Slow
	Automatic/ always on / quickly / no effort / generally operating		Must be switched on / requires time and energy / effortful
	Unconsciousness		Consciousness
	Prone to error		Reliable

What is happening when our system 1 is not finding the answer to the question? In an ideal situation, our system 2 kicks in automatically. Our system 2 is subsequently trying to find the correct answer to the question but it takes time and energy. Finally, a well-overthought answer or judgment will be the result. If we are under time pressure or we are tired (at the end of the day during a risk assessment), it takes more effort for our brain to switch between system 1 and system 2. The problem is at that moment, that our system 1 is answering the complex question with error to prone. Another problem is that we do not recognize the need for system 2 and we accept the answer generated by system 1 thinking. This is the moment when a cognitive bias occurs.
What is needed for a PSRA is at least the awareness of the process of system 1 and system 2 thinking and how we can activate system 2 thinking as much as possible when we are dealing with complex questions during a risk assessment.

2.2 System 1 and system 2 thinking when using a RAM

In general, the chemical industry using different methods used to understand the risks related to the process: HAZID, PHR, HAZOP, FME(C)A, SIL, LOPA, Bow-Tie, etc. Most methods make use of a Risk Assessment Matrix (RAM) to estimate the likelihood and assess the expected consequences of the identified scenarios.
In a RAM, the likelihood can be assessed (semi)-qualitatively. The consequences are assessed for the potential impact on people, environment, asset damage (financial) and reputation. The use of the RAM is broadly accepted in high hazard industry but is also controversial for the logic behind the scoring system and the reproducibility and consistency of the scoring method. Still the main benefits attributed to the RAM are the intuitive appeal and simplicity.
Duijm (2015) published an overview of the critical issues that are related to cognitive biases when applying the RAM:

- The consistency between the risk matrix and quantitative measures and the corresponding appropriateness of decisions based on risk matrices;
- The subjective classification of likelihood and consequence;
- The definition of risk scores and its relation to the scaling of the categories;
- The limited resolution of risk matrices;
- The aggregation of scenarios and consequences for a single event on different areas of concern, and for multiple hazards originating from a single activity;

And the problems with the use of corporate-wide risk matrix designs.
Thomas et al (2014) reviewed more than 520 papers published by the SPE in the last 15 years on the use of the risk matrix. Finally, a representative group of 30 papers was analysed, the limitations were discussed and inconsistencies of working with the RAM were addressed. Thomas et al identified in their evaluation the effect of the cognitive biases that is known as the centring bias. The centring bias is the tending by people of the judgment for the likelihood, which is in the middle of the risk matrix. Or in other words, the people avoid choosing for the columns with the extreme values (highest and lowest likelihood and consequences). This cognitive bias exists due to system 1 thinking.

2.3 System 1 and system 2 thinking when using a Risk Graph

The Risk Graph is a (semi) qualitative method and was published in 1994 by the German Institute for Standardization. The method was subsequently included in IEC 60508-5 and the IEC 61511-3. The method consists of a tree-like graph, see figure 1 for a visualization of the graph.
When the Risk Graph is applied, the result is the selection of the correct Safety Integrity Level (SIL) level that belongs to the risk of the identified scenario. A Risk Graph intends to make an assessment of a scenario based on a series of parameters (C, F, P and W) that represents the risk considering that there is not a SIF (Safety Integrity Function) in place. The parameters used in the graph are:

- C (consequence, range Ca - Cd). This parameter represents the potential number of fatalities and serious injuries when the affected area is occupied.
- F (frequency and exposure, range Fa- Fb). The probability that the exposed area is occupied at the time of the hazardous event. Mostly defined as: less than 10% of the time and 10% of the time or more.
- P (probability, range P1-P2), the probability of avoiding the hazard. This factor represents the likelihood of personnel being able to avoid the hazard
- W (demand rate, W1-W3). This is the likelihood of the initiating event occurring in the absence of a SIF, usually in frequency per year. This frequency is determined by including all failures that can lead to the hazardous event and estimating the overall rate of occurrence.

The target SIL is determined by following the path as per the selected parameters. The value in the box under the W parameters indicates the target SIL. If the box shows an "a" there is no specific requirement for a SIL value. If it is a “b”, a single SIF is not sufficient.
At our company we use the Risk Graph to assess the risks of the identified scenarios. In our evaluation, also the effect of the cognitive biases that is known as the centring bias was identified. As also was concluded when using the RAM, the people avoid choosing for the columns with the W3 and W1 values (highest and lowest likelihood and consequences). This cognitive bias exists due to system 1 thinking.In addition to the centring bias, as demonstrated by Thomas and in the analysis of applying the Risk Graph, we expected more cognitive biases when PSRA’s are conducted and when the RAM is used.

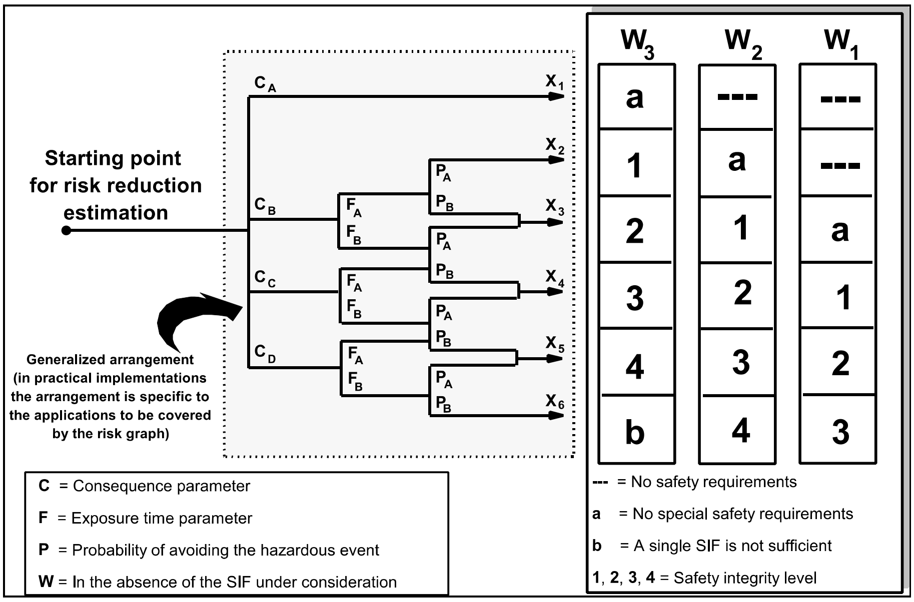

Figure 1: Risk Graph from the IEC-61511(2017), Functional safety – Safety instrumented systems for the process industry sector – part 3.

2.4 System 1 and system 2 thinking in a PSRA

Most of the time system 1 runs automatically during a risk assessment and system 2 is in a comfortable low-effort mode in the background. When both systems agree, a risk assessment gets turned into the right direction. In case that system 1 runs into trouble, because there is no easy answer to assess the risk, it asks for processing help from system 2. But sometimes system 1 has systematic errors. For instance, when conducting a PSRA and irrelevant information and/or insufficient information is provided about an incident that happened recently on a chemical site nearby, you will see in practice (if not corrected by the facilitator) that it takes direct effect on the risk assessment. While in fact, it doesn't say much about the incident rate on your site due to that both companies maybe have a different background or other barriers to prevent such incidents. In general, for occupational safety risk assessments, relevant information comes into your mind via system 1 quickly (due to the relative high frequency of occurrence), while you have to search effortful with system 2 to search for information in case of PSRA's (due to the relative low frequency of occurrence).
System 2 is in fact a lazy controller and doesn't like to expend much effort. One of its main functions is to monitor and control thoughts and actions suggested by system 1 which is not very helpful for hazard identification for low frequency scenarios and the so-called black swan scenarios. If we want to generate initiating events and/or threats, we need to get system 2 into the action. If it doesn't because it is lazy, then we only get a bunch of standard initiating events/threats, barriers and consequences. However, if we can use some other external mechanism to activate system 2 then we are in the game. _The goal of this paper was to identify what kind of cognitive biases (human factors) due to system 1 thinking are present in a PSRA and what can be done to prevent them (switching over to system 2 thinking)? To identify these biases, we have evaluated multiple PSRA's.

3. Results of human factors in PSRA

The following cognitive biases were identified as highly possible during the evaluation wherein system 1 thinking has affected the results of the PSRA:

1. Curse of knowledge;
2. Combination of availability, optimism and pessimism bias;
3. Substitution bias.

<u>The curse of knowledge</u>
The curse of knowledge is a cognitive bias that occurs when someone, communicating with other individuals, unknowingly assumes that the others have the same knowledge to understand the topic, Bhandari and Barth

(2013). That means in a PSRA, that it is difficult (or even not possible) for this person to think about this topic from a less-informed perspective, which is automatically closing discussions about the identification of new or alternative scenarios (threats – consequence pairs). Also, in the discussion of a scenario itself (threats – consequence pair) it takes effect. The persons in the risk assessment do not know that their outcome knowledge is affecting the risk assessment, and, if he did know, he could still not ignore or defeat the effects of the bias. In other words, he cannot successfully reconstruct his previous, less knowledgeable states accurately, which directly relates to the cognitive bias curse of knowledge. In the incident investigation process, Burggraaf (2016) identified that the curse of knowledge also plays a significant role in defining the underlying cause and the lesson learned from incidents.

<u>Combination of availability, optimism and pessimism bias</u>
The availability of statistics plays a significant role when applying a RAM. Sometimes is for the risk assessment no objective or 'clean' data available and people have to rely on their 'own' statistics. In the process of judgment you will see, especially for the high-risk scores that people looking for justification of such scores. In PSRA, you have to deal with such scores due to the rare likelihood and the extreme consequences. Due to a lack of or a limited availability of objective data, our system 1 thinking creates a situation of a typical related to that risk. In case of available data in a later phase, an analysis will show that there can be huge difference between the created typical and the objective data. The optimism bias is a cognitive bias that causes a person to believe that there is a lower risk. Due to this, there can bear a relation to the realistic frequency. While the pessimism bias represents the opposite. Both play a role in PSRA's and it can differ per scenario that is discussed. In case of the optimism bias the following factors effects the person in his or her optimism; the degree of confidence, the information he or she has about themselves versus others and the overall mood.

<u>Substitution bias</u>
The substitution bias kicks in when an easy answer is not available for a complicated question, Kahneman (2010). What happens is that system 1 is answering a substitute question instead of a satisfactory answer for the complicated question. For example, in a PSRA the people are making judgments about the following complicated issues:

1. The likelihood must be assessed for a pipe rupture of a vertical piping in a process plant.
2. The effectiveness of the barrier, emergency response team, must be assessed during a high hazard incident in perspective of saving lives and protecting the environment.
3. An effect must be assessed about an explosion and fire followed by a pollution of the soil.

Due to demanding circumstances like time pressure, costs and the right resources to complete the PSRA in time you will see that people tend to answer with a substitute answer instead of activating system 2 thinking. You often recognize these substitution biases when you are doing a review on the results of a PSRA. What you see is a missing logic in the development of a scenarios, that defined measures/barriers are not affecting the likelihood or mitigating the consequence, that barriers are not truly independent of other barriers, etc. In case a substitution bias is recognized during a PSRA, it is important to reserve time directly and not postponing the question to the end of the risk assessment.

4. Results of organizational factors in PSRA

The quality of a PSRA can also be influenced by poor organization, Gambetti (2012). Based on our evaluations it was getting clear that the following factors contribute to the quality:

- The alignment of expectations with the (internal) client, such as: scoping, explaining the boundaries of used PSRA technique, the reporting tool, minimum availability of information needed, the correctness of needed information, planning, etc.
- The PSRA facilitator; minimum of experience, the people skills and competences of the proposed PSRA facilitator versus the scope of the PSRA.
- The PSRA team; minimum of competences, experience and knowledge versus the scope of the PSRA.

The alignment of expectations can be covered with a solid work process based on checklists and mandatory consultation for verification of the higher risk scenarios.
The selection of the (external as internal) facilitator for the PSRA study is often based on availability. In fact, it should be based on softer criteria like cultural fit, skills fit, behavioural fit in combination with harder criteria like experience with related PSRA's, relevant references, working experience and knowledge which makes it more complex. The softer selection factors are also applicable for the selection to the PSRA team members. The

final goal is to have a diverse PSRA team with different backgrounds of 4 up to 7 people that have a good understanding of the (chemical) process.
It is finally up to the PSRA facilitator to decide whether the team is good enough to start the PSRA. In case that during the facilitation PSRA team members are lagging or do not fill in their role properly, it is up to the PSRA facilitator to stop the study. Also this part of the facilitation process needs to be trained.

5. Conclusions

This paper shows that next to the centering bias, three other types of cognitive biases play a role in a PSRA. Although the presence of other cognitive biases cannot be excluded based on the limited numbers of reports and other exercises that were evaluated. This paper shows also that:

- Complex psychological processes play a role in conducting a PSRA and having effect on the quality of the assessment.
- When we conduct a PSRA under demanding circumstances (like time pressure, costs and the right resources to complete the risk assessment in time), you will see that people tend to answer based on system 1 thinking (error to prone).
- Cognitive biases associated with system 1 thinking can be avoided.
- When you are aware of cognitive biases, you can prevent implementing ineffective recommendations and incorrect conclusions from the risk analysis.
- Next to human factor play organizational factors an important role to achieve a high quality PSRA study. It is now understood that both, hard and soft criteria, play a role for a successful PSRA.

The general recommendation is to create awareness amongst the people that facilitates the PSRA's. The facilitator of the PSRA can be trained to recognize these biases and act upon these biases during the risk assessment. What can be helpful is to peer review the PSRA for errors based on these cognitive biases. This is asking a lot from the peer reviewer because he or she is also sensitive for the same cognitive biases and can make the same mistake. The same recommendation is applicable to the organizational factors.

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