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# Hazard Matrix Application in Health, Safety and Environmental Management Risk Evaluation

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## 1. Introduction

In occupational safety one of the most complicated and harder to achieve goals is to prioritize actions towards risk prevention and mitigation. There are several methodologies to do that. Some of them are expensive; demand some extensive structure for its application and so on. Some others are either weak in results or lack technical or scientific basis. (Haddad *et al*, 2008). The research presented in this chapter emerged in between these methodologies for being not expensive and requiring resources, most of the time, already available in a company's documentation.

More specifically, this chapter focuses on the development and usage of a risk assessment methodology called Hazard Matrix (HM) and its application in Health, Safety and Environmental Management (HSE). The HM is a prioritization methodology suitable to be used in the analysis phase of a risk management program. The application of HM in HSE is a very powerful methodology to highlight critical hazards and sectors/areas in a business unit or company under study.

We will present and explore the HM concept, features, relevance and implementation, under the scope of a risk management process. In order to achieve this, the chapter will follow this sequence, organized in sections:

- HSE aims and structure (Section 2);
- Aspects of risk management necessary for a HSE Program (Section 3);
- The HM concept, structure and applications; (Section 4)
- Two case studies for the clarification of the methodology and to highlight its possibilities of use (Section 5).

The case studies presented come from two different types of industries, in order to demonstrate the comprehensive application of HM and details. Although the methodology lacks a refined or complex mathematical structure, we can refine the presented approach and develop other implementations leading to a high detailed usage. Here we refrain to do that; this is something for future work.

## 2. HSE aims and structure

Basically, HSE deals with the anticipation and recognition, analysis, evaluation, treatment and communication of hazards and treats in the occupational safety aspect of any company,

and by an expanded or more comprehensive perspective, to all surrounding environments. HSE is becoming increasingly important, as well as demanded, in any company's effort towards sustainability and legal adequacy. It is becoming part of its regular operations and is commonly required by regulatory bodies, clients and society.

In order to organize a HSE Program one needs to develop and structure (ISO 14.001:2007, 2007) a set of activities in a close relation with a Risk Management Program (ISO 31.000:2009, 2009). Determination of scope and objectives are necessary for the establishment of such a Risk Management Program. In this phase, each step of this management process must be defined, as well as its expected results. After that, the mapping of all organization's processes and also their interactions must be performed (the ones that interfere in risk management). On this phase of the HSE effort, all activities, operations and the relations between them must be clearly identified, as they represent potential sources of hazard. Moreover, in order to achieve enough knowledge to underlie adequate action of HSE process, data must be collected from the activities and operations, about its **Processes** (inputs and outputs), its **People** who work there, and generally about the **Organization** itself.

After data collection and the processes mapping are done, the management process is able to perform a **Hazard Mapping and Identification**, which consists in identification, localization and classification of the hazards involved in each process activities of the organization. This classification is performed according to two aspects: type of hazard existent, such as physical, chemical, biological etc., and the severity of its impact. The second one is traduced mathematically by weights that can be represented in a boarding selection.

After these entire actions have been performed one can establish the necessary set of information in order to develop the HM (Haddad *et al*, 2008) application in the next stage. With the sequential implementation of the concepts and tools listed one should be able to apply these concepts, use the HM, recognize and prioritize risks, and implement a useful tool in the development of a Risk Management Program addressing HSE issues.

### 3. Aspects of risk management necessary for a HSE program

System Safety can be described as a sub-discipline of systems engineering that applies scientific, engineering and management principles to ensure adequate safety, the timely identification of hazard risk, and initiation of actions to prevent or control those hazards throughout the life cycle and within the constraints of operational effectiveness, time, and cost (Vincoli, 2006).

One of the key aspects of safety management is the proper management of risk. There are several ways of defining risk, but all of them share a common core: they define risk as combination of its independent variables likelihood and severity. The new ISO 31.000:2009, entitled "Risk Management", presents a series of guidelines and principles for its management. ISO 31.000:2009 defines risk as:

*"Risk - effect of uncertainty on objectives"*

*NOTE 1 an effect is a deviation from the expected – positive and/or negative.*

*NOTE 2 Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process).*

NOTE 3 Risk is often characterized by reference to potential events and consequences), or a combination of these.

NOTE 4 Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

NOTE 5 Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood"

The concept of risk indicates that it relates to activities or tasks to be performed, being intimately related to a human behavior or environment. As an example, a fuel, such as gasoline, isolated from its context, does not present any level of risk by itself. However, when this fuel is considered to be handled at an environment where sources of ignition are present, for example, dealing with gasoline becomes a hazardous activity. The associated risk will vary according to the behavior of the handler and environmental where it is done. As stated by (Ciocoiu and Dobrea 2010) "even apparently insignificant risks have the potential, as they interact with other events and conditions, to cause great damage. "

Due to the very nature of risk, it is present in almost every activity, job or task performed in the modern world. The accelerating pace of business, globalization, the financial crisis, all contribute to the growing number and complexity of risks and to the greater responsibility for managing risks on an enterprise-wide scale (Ciocoiu and Dobrea, 2010). This leads to the need of managing occupational risks ahead in order to assure minimum casualties and optimum performance. However, the risk is also a very complex entity, which directs to difficulties when understanding and managing.

It is commonly accepted that a proper method for assessing and managing risks pass through decomposing the "risk" in its independent variables: *frequency*, *severity*, and *scenario*. Therefore, the dependent variable "Risk" can be written as:

$$\text{Risk} = f(\text{frequency}, \text{severity}, \text{scenario})$$

Decomposing the risk in independent variables and further analyzing each variable is the core method presented in the MIL STD 882 for preliminary Hazard analysis. This concept has proved to be successful , since it is still used by many standards, including the forth review of MIL STD 882 (United States, 2003), OHSAS 18.001:2007 (OHSAS, 2007) and ISO 31.000:2009 (ISO, 2009)

### 3.1 The risk management process

Before human's development of *risk management* process and the clear concept of *system safety*, the common technique used to deal with risk was mainly based on a *trial and error* approach. This culture led mankind to fix problems only after its consequences were observed at the already designed running system. In opposition, the idea of minimizing risks until acceptable levels by trying to predict the occurrence of accidents and taking measures in order to avoid them is widely diffused nowadays. This approach characterizes the concept of risk management.

Risk management can be defined as the collection of culture, processes and structures that are directed towards realizing potential opportunities whilst managing adverse effects (Australia, 2004). In this context, it is a complex process and can be understood as a systematic application of management policies, procedures and practices.

The NZS 4360:2004 guideline (AUSTRALIA, 2004) determines that a proper overall risk management process incorporates several other tasks, such as:

- Communication,
- Identification,
- Analysis,
- Evaluation,
- Treatment,
- Monitoring; and
- Reviewing.

The ISO 31.000:2009, in its turn, defines risk management as:

*“Risk management:*

*process of systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analyzing, evaluating, treating, monitoring and reviewing risk”*

Fig. presents an overview of the entire risk management process, based upon the process described in the NZS 4360:2004 guideline (Australia, 2004), using a block diagram representation.

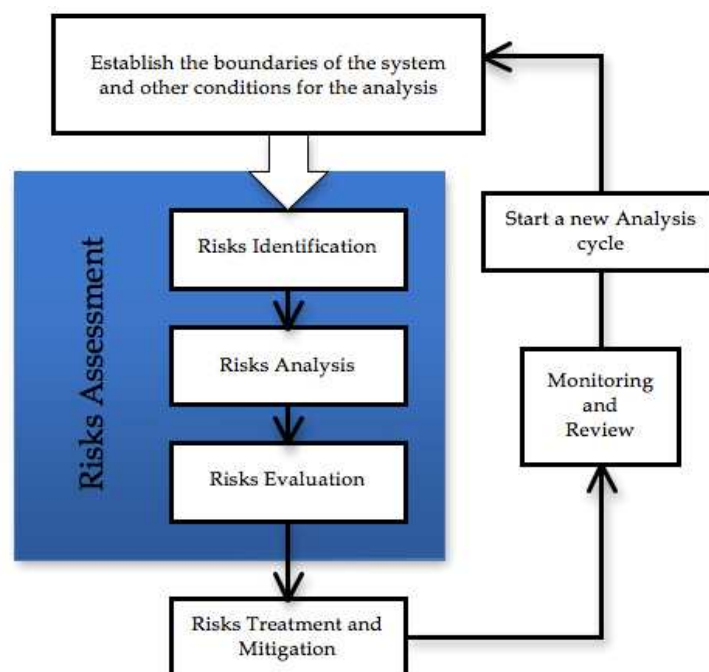


Fig. 1. Risk Management overview (based on ISO 31000: 2009)

At this point, it is important to highlight that the success of risk treatment depends directly on how complete its preliminary analysis, which identifies, describes and classifies them. Risk identification of any organization requires the previous knowledge of its activities and processes, of the external market conjuncture and the legal, social, political and cultural environment in which the company is inserted, and for that, it must be clearly defined its strategic objectives (Muniz, 2011).

Within the risk management, which is an interactive process where the risk is studied again after all the mitigations are in place (as indicated by the arrow linking “treat risk” and “monitoring and review” in figure 01), one major phase in the overall process is assess the risk. The Australian and New Zealand Standards AS NZS 4360:2004 defines that this phase comprehends: Identify the risk, analyze the risk and evaluate the risk, and defines its steps as follow:

- Risk analysis: systematic process to understand the nature of the risk and deduce its level;
- Risk identification: the process of determining what, where, when, why and how something could happen;
- Risk evaluation: the process of comparing the level of risk. In many cases the risk evaluation involves establish a priority among several risks.

Furthermore, due to resources limitation, which is unavoidable, addressing all indentified risks becomes a non-realistic approach. As resources can be limited financially, technically, or even related to time or personnel, one will need to implement a system to highlight the most critical hazards and sectors, so that appropriate resources application can be assured. The important role of a prioritization system highlighted above is efficiently accomplished by HM, since its main objective is to establish a priority ranking among risks and sectors.

### 3.1.1 The importance of prioritization

Companies have one primary goal: profit. This is the reason for their existence and thus almost all decisions taken at business environment unavoidably aim at profits increase (Mello, 2004). In this context, hazard minimization and mainly the prevention and mitigation of its consequences must be established in a systemic and optimized way.

As it is clear that any company works with limited resources, there ought to be a prioritization tool able to identify such as which risks or company's sectors are more critical, on which the plan of risks mitigation can be based and oriented. Therefore, the best utilization of financial, labor or time resources can be assured.

In this context, must be emphasized that there are many aspects in which prioritization can be established. It can be financial aspect, so that more money is spent on the priority issue and it is assigned a larger proportion of the available budget. Alternatively, 'priority' may be temporally defined, as all risk issues cannot be tackled simultaneously. An identified priority issue would thus be address in precedence to another, which may be deferred until a later time. Temporal prioritization is fundamental to the development of long-term strategic risk management plans. (Centre for Environmental & Risk Management, 1997)

Situated right between the Evaluation and the Treatment phases at Risk Management Process, described by Figure 1, risks prioritization becomes a strategic part of this process when it is taken for its real application, since, after risk analysis and evaluation, it is possible that resources limitations naturally lead to a necessary chose of more critical measures to be taken at a first moment, as well as demand a temporal ordination.



Further, studying risk management, one can conclude that risk prioritization is a key aspect of the overall procedure. As risk prioritization and treatment are intrinsically connected to risk analysis and evaluation, the next section briefly presents and discusses methods commonly used to evaluate risks.

3.2 Risk evaluation schemes

In the risk management process one important aspect is the risk analysis, which is done using a chosen methodology, which is sometimes called “risk assessment scheme”.

Despite the fact that Hammer’s book (reference) is an old reference, it still is quoted and cited in many recent works and manuals of risk assessment, due to its clear ideas and concepts. Although the risk assessment schemes presented by Hammer might be somehow obsolete, the concepts are not.

There are an unlimited number of schemes. Each one has its strengths and weakness. Hammer, in his book, presents several possible schemes, which can be folded into 4 greater categories:

- Analysis in trees
- Analysis in spreadsheets
- Qualitative Analysis
- Quantitative Analysis

It is important to remark that every risk assessment method will fall into two of the four categories. A risk assessment tool will be qualitative or quantitative and formatted as tree or spread sheet. This leads to a classification matrix as shown in Table 1.

	Analysis formatted as tree	Analysis formatted as Spread Sheet
Qualitative Results		
Quantitative Results		

Table 1. Risk Assessment – Classification Table

The schemes of risk analysis under the **tree concept** focus on establishing a chain of events, as well as assess the risk occurrence likelihood. The TNO Red Book (Committee For The Prevention of Disasters, 1997) presents some fault tree analysis methods. Risk assessment performed using fault trees technique can provide a result as simple as a series of causes and effects (**qualitative approach**) or as complex as the evaluation of risk occurrence probability (**quantitative approach**). It is also important to remark that the analysis complexity varies at the same rate as the analyzed system complexity.

The other category of risk assessment is the spreadsheet. Some of the most used risk assessment schemes fall into the spreadsheet category. This category counts widely used methods like HazOp (Committee For The Prevention of Disasters, 1997), FMEA (United States. MIL-STD-1629, 2000), Hazard Preliminary Analysis (HPA) (United States, MIL-STD 882-D, 2003) and the HAZARD MATRIX (Haddad, 2008).

The majority of the risk schemes available approach the problem using the principle of compartmentalization, studying sub-systems and sub-components, on behalf of simplicity in more complex systems.

This “compartmentalization” is done setting borders in the scenario. These borders can set sub-areas for analysis, sub-system, and sub-component or split the “target” of the analysis using nodes. The main representative tool of this technique that places nodes in the flow of matter and energy flows and analyze the risks in each node is the HazOp. (Committee For The Prevention of Disasters, 1997),

Irrespective of the chosen method to assess risk, a quantitative analysis is to be preferred over any qualitative, mainly because a quantitative approach establishes a hierarchy between risks. The HM is an example of a risk assessment method designed to prioritize risks, hazards and environmental (sectors).

In summary, the risk assessment schemes should be selected matching the strengths and weakness of each scheme with a given scenario and the output requirements:

- **HazOP** - This scheme suite perfectly a scenario where the productive process can be represented (drawn) as a flow chart, due to the easiness of cutting the flow applying nodes on it. It is known that a block diagram can be used to represent a “flow chart” and, therefore, allow application of HazOP to a discontinuous process (such as an assembling line), if the level of risk justifies this approach. (Committee For The Prevention of Disasters, 1997),
- **FMEA** - The FMEA is the risk assessment scheme published by the MIL STD 1629 (UNITED STATES, 2000) and used spreadsheets to decompose the risk in its failure modes, causes and consequences. This FMEA suites best when applied to machinery or equipment's.
- **Tree Analysis** - All the assessment methods that fold into this category assess the risk by set a chain of events (causes and consequences). These methods regard to determine the frequency (number) for the likelihood of the risk to occur.
- **Matrix Schemes** - These schemes provide a very flexible approach to the risk and hazards analyses. As a general rule, these tools compensate the lack of deep by decomposing the risk in its independent variables (likelihood and severity) and analyzing each variable separately. These methods are also indicated to assess risk of a particular task in hand. **The hazard matrix proposed in this chapter is one example of this category.**

This section provided an overview about risk management in a general approach. However, risk management procedures may differ depending upon scenario and applications. The next section addresses the risk management and evaluation when applied specifically to environmental risks.

### 3.3 Environmental risk management and evaluation

When it comes to environmental risk, the scenario is a key part of the entire risk assessment routine. In general, the hazards identification process is the same for both environmental and occupational risk management. The main difference between them will be related to the scope utilized to determine the scenario.



At his point, considering this risk scenario context, it is important to clearly define a limit that, in a simplified way, represents the interface between the industry internal and external environment. This limit is well represented by a key concept: the *industry walls*, which defines a separation between occupational and environmental hazards.

During an occupational risk management process, one is concerned with the effects of the hazard within the boundaries of the enterprise, company, unit or industry. This scope guides all decisions, from which methodology use to what consequences should be neglected.

On the opposite, the scope applied over the scenario when an environmental risk management process is undertaken focus on risks source effects on the external area, which means beyond the *industry walls*. Figure 2 represents the difference between environmental and occupational risk management approaches.

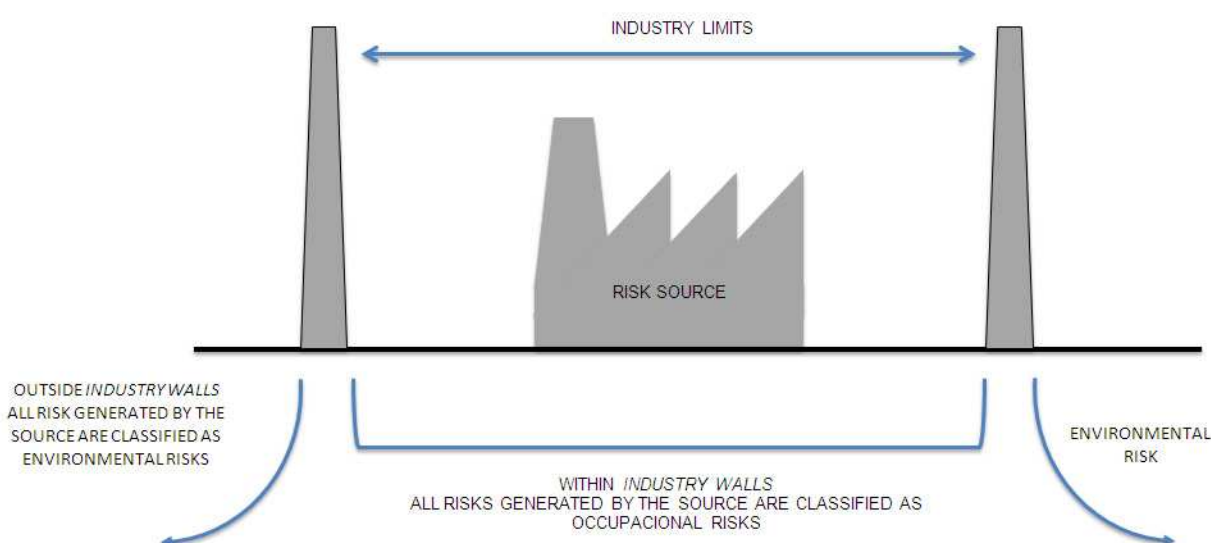


Fig. 2. Environmental Risk versus Occupational Risk

#### 4. The Hazard matrix (HM) concept, structure and applications

The HM methodology, based on the work done by (Haddad *et al* 2008), is a valuable tool to allow determination of prioritization among several risks, hazards and sectors within a given system or environment. This complex system can be anything that held more than a single hazard to be prevented or mitigated, from an industry to an office building.

The HM approach is based on the already cited concept of risk as a function of its severity and probability of occurrence. In a simplified view, as seen before, risk can be defined by the product of its two variables. In the HM, the probabilistic factor is represented by the number of workers exposed to the hazard. The severity factor, in turn, is mathematically traduced by a numerical classification of hazards, which will be more specified later.

The analysis starts by dividing the company in sectors, identifying the hazards and sectors its respective sectors of exposure. Due to that, it is likely to use the hazard matrix combined with other risk identification and assessment tools, like FMEA (MIL STD 1629) or HPA (MIL

STD 882). Each sector constitutes a line (from 1 to y) in the hazard matrix, followed by a column that stands for the number of workers on that sector. As for the other columns, they take all the hazards identified in all the sectors, drawing column from 1 to x.

After building the matrix, the hazards identified are preliminarily assessed though out the use of a “Risk Assessment Code” (RAC). This RAC follows a simple criterion, which varies according to the scenario, availability of data or even precision required. The important is that the criteria must be the same for the entire matrix, as well as be able to provide a numerical number.

When it comes to occupational hazards, one valid criterion is presented (as example) in Table 2.

Risk Assessment Code	Description
0	This hazard is NOT present in the sector evaluated
1	The exposure of this hazard occurs bellow the action level AND it is occasional
3	The exposure of this hazard occurs bellow the action level AND, continuously
6	The exposure level is between the action level and the Threshold Value Limit (TVL-TWA) or equivalent.
9	The exposure level is above Threshold Value Limit (TVL-TWA) or equivalent.

Note: Action level is half the TVL-TWA value

Table 2. Risk Assessment Codes for Hazardous agents (chemicals, physical or Biological agents).

Therefore, the HM is completed by evaluating the hazards using the RAC pre-selected for a given scenario. Each given position within the matrix corresponds to the hazard in a given sector. That means that the value written in the position (i,j) stands for the RAC () which best represents the exposure to the Hazard “j” faced by the workers in sector “i”.

In the HM, the Sectors (S) and Number of Workers (W) forms the lines and the hazards (H) the columns that draws the borders of the RAC. Table 3 presents a general HM.

Sector	Hazards identified					
Description/ Name	Number of people working	H <sub>1</sub>	H <sub>2</sub>	H <sub>3</sub>	...	H <sub>x</sub>
S <sub>1</sub>	W <sub>1</sub>	R <sub>1,1</sub>	R <sub>1,2</sub>	R <sub>1,3</sub>	...	R <sub>1,x</sub>
S <sub>2</sub>	W <sub>2</sub>	R <sub>2,1</sub>	R <sub>2,2</sub>	R <sub>2,3</sub>	...	R <sub>2,x</sub>
S <sub>3</sub>	W <sub>3</sub>	R <sub>3,1</sub>	R <sub>3,2</sub>	R <sub>3,3</sub>	...	R <sub>3,x</sub>
...	...	...	...	...	...	...
S <sub>Y</sub>	W <sub>Y</sub>	R <sub>Y,1</sub>	R <sub>Y,2</sub>	R <sub>Y,3</sub>	...	R <sub>Y,x</sub>

Table 3. Hazard Matrix – General Construction model

The next stage of the HM approach is to calculate the **hazard frequency of recurrence**, the **exposure frequency** and the **relevancy percentage**.

The hazard frequency of recurrence measures how intense is the overall exposure to a given risk, while the exposure frequency evaluates which sector represents a more hazardous environmental to work in. Both frequencies take into account the number of works exposed and the intensity of the hazard.

The relevancy percentages are a mathematical composition of both hazard frequency of recurrence and exposure frequency to allow easier understanding and prioritization. Next, we present the hazard frequency calculation in more details.

#### 4.1 Hazard frequency calculation

Taking the first Hazard (H1) in the matrix (Table ), its hazard frequency of recurrence is determined by the following calculation:

$$f_{H1} = W_1 * R_{1,1} + W_2 * R_{2,1} + W_3 * R_{3,1} + \dots + W_y * R_{y,1}$$

Similar calculations are performed to all the other hazards to determine their hazard recurrence frequency:

$$f_{H2} = W_1 * R_{1,2} + W_2 * R_{2,2} + W_3 * R_{3,2} + \dots + W_y * R_{y,2}$$

$$f_{H3} = W_1 * R_{1,3} + W_2 * R_{2,3} + W_3 * R_{3,3} + \dots + W_y * R_{y,3}$$

$$f_{Hx} = W_1 * R_{1,x} + W_2 * R_{2,x} + W_3 * R_{3,x} + \dots + W_y * R_{y,x}$$

This allows the establishment of a general rule for determining the **recurrence frequency** of any hazard within a HM as follows:

$$f_{Hj} = \sum_{i=1}^y W_i * R_{i,j} ,$$

where

$$1 \leq j \leq x$$

After all the **hazard recurrence frequencies** are determined, a global hazard frequency can be determined as follows:

$$F_H = \sum_{j=1}^x f_{Hj}$$

The global hazard frequency is used to calculate the relevancy percentages. The other key figure of a hazard matrix is the exposure frequency, which is further presented in the next section.

#### 4.2 Exposure frequency calculation

Following the determination of all the hazard recurrence frequencies, comes the determination of the **exposure frequencies**. Taking the first sector (S1) in the HM (Table ???) the exposure frequency is determined as follows:

$$f_{s1} = W_1 * R_{1,1} + W_1 * R_{1,2} + \dots + W_1 * R_{1,x}$$

The other exposure frequencies are determined using similar equations:

$$\begin{aligned} f_{s2} &= W_2 * R_{2,1} + W_2 * R_{2,2} + \dots + W_2 * R_{2,x} \\ f_{s3} &= W_3 * R_{3,1} + W_3 * R_{3,2} + \dots + W_3 * R_{3,x} \\ f_{sy} &= W_y * R_{y,1} + W_y * R_{y,2} + \dots + W_y * R_{y,x} \end{aligned}$$

Analyzing the method to determine each **exposure frequency**, it is possible to determine a general rule for their determination:

$$f_{si} = \sum_{j=1}^x W_i * R_{i,j}$$

, where

$$1 \leq i \leq y$$

The global exposure frequency is determined as follows:

$$F_S = \sum_{i=1}^y f_{si}$$

Similarly to the global hazard frequency, the global exposure frequency will also be used to calculate the relevancy percentages. This is done next.

#### 4.3 Relevancy percentage calculation

The next stage of the hazard matrix method is determining the **relevancy percentage**, which can be calculated via the following set of equations:

$$\%_{Hj} = \frac{f_{Hj}}{F_H} * 100 = \frac{\sum_{i=1}^y W_i * R_{i,j}}{\sum_{i=1}^x f_{Hj}} * 100,$$

where

$$1 \leq j \leq x,$$

$$\%_{si} = \frac{f_{si}}{F_S} * 100 = \frac{\sum_{j=1}^x W_i * R_{i,j}}{\sum_{i=1}^y f_{si}} * 100$$

where

$$1 \leq i \leq y$$

With these calculations performed, we are ready to assemble the entire HM. This is discussed next.

4.4 The complete hazard matrix

Once all the calculations are concluded, the HM from Table 3 can be updated to incorporate these percentages. Table 4 Hazard Matrix – Relevancy Percentages presents this newer and complete matrix.

5. Hazard matrix applications in HSE

Like risk management, hazard matrix application also varies depending upon scenario and scope of analyses. This section addresses these differences and customization required when one applies HM to HSE as well as other applications.

Sector	Hazards identified							
Description/ Name	Number of people working	H <sub>1</sub>	H <sub>2</sub>	H <sub>3</sub>	...	H <sub>x</sub>		
S <sub>1</sub>	W <sub>1</sub>	R <sub>1,1</sub>	R <sub>1,2</sub>	R <sub>1,3</sub>	...	R <sub>1,X</sub>	f <sub>s1</sub>	% <sub>0s1</sub>
S <sub>2</sub>	W <sub>2</sub>	R <sub>2,1</sub>	R <sub>2,2</sub>	R <sub>2,3</sub>	...	R <sub>2,X</sub>	f <sub>s,2</sub>	% <sub>0s,2</sub>
S <sub>3</sub>	W <sub>3</sub>	R <sub>3,1</sub>	R <sub>3,2</sub>	R <sub>3,3</sub>	...	R <sub>3,X</sub>	f <sub>s3</sub>	% <sub>0s3</sub>
...	...	...	...	...	...	...	...	...
S <sub>Y</sub>	W <sub>Y</sub>	R <sub>Y,1</sub>	R <sub>Y,2</sub>	R <sub>Y,3</sub>	...	R <sub>Y,X</sub>	f <sub>sY</sub>	% <sub>0sY</sub>
		f <sub>H1</sub> % <sub>0H1</sub>		f <sub>H2</sub> % <sub>0H2</sub>	f <sub>H3</sub> % <sub>0H3</sub>	f <sub>Hx</sub> % <sub>0Hx</sub>		100%

Table 4. Hazard Matrix – Relevancy Percentages

5.1 Environmental risks prioritization

The main difference between applying the HM to prioritize occupational hazards and environmental hazards is the understanding of the scenario. As already discussed in figure 2, one addressing the occupational hazards will analyze risk, frequencies and exposure within the boundaries of an enterprise, Industry or site, while the environmental risk assessment will regard the effects on the exterior of this same enterprise.

Hence, in cases on which the HM is intended to be applied to prioritize and assess environmental risks, some small adaptations are due.

Firstly, the sectors of an enterprise will be replaced to vulnerable areas already identified on the neighborhood (or areas of influence) of a given enterprise, industry or unit. Subsequently, the number of workers will be replaced by an average number of people living / working in that given vulnerable areas. Secondly, the hazards identified will concern to risks that can create effects outside the enterprise, industry or unit boundaries. From these adaptations, the environmental HM is adapted as shown in table 5.

Vulnerable area	Hazards identified							
Description/ Name	Number of people Living/ working	H <sub>1</sub>	H <sub>2</sub>	H <sub>3</sub>	...	H <sub>x</sub>		
A <sub>1</sub>	P <sub>1</sub>	R <sub>1,1</sub>	R <sub>1,2</sub>	R <sub>1,3</sub>	...	R <sub>1,x</sub>	f <sub>s1</sub>	% <sub>0s1</sub>
A <sub>2</sub>	P <sub>2</sub>	R <sub>2,1</sub>	R <sub>2,2</sub>	R <sub>2,3</sub>	...	R <sub>2,x</sub>	f <sub>s2</sub>	% <sub>0s,2</sub>
A <sub>3</sub>	P <sub>3</sub>	R <sub>3,1</sub>	R <sub>3,2</sub>	R <sub>3,3</sub>	...	R <sub>3,x</sub>	f <sub>s3</sub>	% <sub>0s3</sub>
...	...	...	...	...	...	...	...	...
A <sub>Y</sub>	P <sub>Y</sub>	R <sub>Y,1</sub>	R <sub>Y,2</sub>	R <sub>Y,3</sub>	...	R <sub>Y,x</sub>	f <sub>sY</sub>	% <sub>0sY</sub>
		f <sub>H1</sub>	f <sub>H2</sub>	f <sub>H3</sub>		f <sub>Hx</sub>		
		% <sub>0H1</sub>	% <sub>0H2</sub>	% <sub>0H3</sub>		% <sub>0Hx</sub>	100%	

Table 5. Environmental Hazard Matrix

Thirdly, the risk levels need to be re-designed to match environmental events. Due to the complexity of assess effects and predict damages, it is recommended to keep the description of environmental risks as simple as possible. Table 6 presents one suitable example.

Risk Assessment Code	Description
0	This hazard is NOT percept in that given vulnerable area
1	This Hazard can damage the environment in a reparable way, without any permanent damage to structures, environmental or people, and without victims.
3	This Hazards can severely damage the environmental and harm people, without loss of lives
9	This hazard can cause immediate death of at least one person within the vulnerable area

Table 6. Environmental Risk Assessment Codes, based upon MIL STD 882 Severity categories.

The mathematical determination of the hazard frequency, exposure frequency, relevancy percentages remains the same as presented in the section 3.

This section presented an application of the Hazard Matrix tool to Environmental Risk Analysis. However, HM is a valuable tool for other scenarios as well. One example of such application of HM is in project management, which is further explored in the next section.

5.2 Projects/temporal applications

One of the most useful and enriching results of a Risk Prioritization tool, which specially includes the HM, is the global and comparative view of the organization’s sectors (as well as their interactions) that it provides. Nevertheless, some productive sectors, such as the Construction Industry, have its operation based on projects, where the final product is the main goal of the production activities, which are finished when the product is completed.



Such kind of activities, in terms of risk assessment and prioritization, may demand a specific approach, in order to provide to project’s managers its global understanding and the associated risks related to each temporal stage, as well as their interactions along time and its effects on the project.

In this context, in order to meet such demands, a convenient adaptation of HM is suggestively developed. Initially, the **SECTOR** column will be replaced by a **STAGE** column, where will be allocated each stage of the project. Alternatively, it is quite acceptable to create sub-stages, if it seems applicable. The probabilistic factor continues to be well represented by the number of employees who is going to be involved with each stage.

It is important to emphasize that these analysis do not intent to replace the objectives and results of conventional HM, but it only provides, when it is possible and convenient, a different and complementary view of the whole process in a temporal approach. Therefore, the combined use of both types is quite possible.

6. Case studies

In this section, two study cases are presented. Each of the cases of study deals with a different aspect and application of the hazard matrix method.

6.1 Chemical process unit

Urbanski (1964) and (Meyer 1977) present a method to produce lead azide via precipitation using lead nitrate and sodium azide as reactants. This method is largely used in the explosive industry, been lead azide is a chemical compound with explosives properties and largely used as a primer explosive (payload of blasting caps) in mining activities. Due to its (lead azide) explosive properties, “explosion” is expected to be the most relevant hazard. However, the hazard matrix method proves that “perception” alone is not a suitable risk assessment technique.

Since lead azide manufacture involves chemical compounds, the RAC (Risk assessment codes) should take into account the threshold exposure limits as a parameter. Table 7 presents the RAC used in this case of study.

		Risk Assessment Codes
TVL-TWA		9
Action Level		6
		3
		1
		0

Table 7. RAC for a chemical process unit

Taking the work done by (Galante 2008), in which a hazard matrix methodology was applied to this very kind of manufactory, a hazard matrix for a lead azide unit can be written as in table 8.

SECTOR		HAZARDS				Fs	%s
Description	Number of Workers	Exposure to Chemicals (Lead salts)	Physical Hazard - Noise	Accident - Explosion	Accident - Electrical Discharge		
Pb(NO3)2 preparation workshop	2	9	1	0	1	22	23%
Na(OH) preparation workshop	2	0	1	0	1	4	4%
Na(N3) preparation workshop	2	0	1	0	1	4	4%
Precipitation reaction workshop	4	6	1	3	1	44	46%
Drying	2	3	1	6	1	22	23%
	Fh	48	12	24	12		
	%H	50%	12.5%	25%	12.5%		100%

Table 8. Hazard Matrix for Lead Azide manufactory

Analyzing the results achieved by calculating the hazard matrix, it is possible to prioritize the sector and the hazards using the relevance percentage:

Sectors:

- Precipitation reaction workshop - 46%
- Pb(NO3)2 preparation workshop - 23%
- Drying - 23%
- Na(OH) preparation workshop - 4%
- Na(N3) preparation workshop - 4%

Hazards:

- Exposure to Chemicals (Lead salts) - 50%
- Accident - Explosion - 25%
- Physical Hazard - Noise - 12.5%
- Accident - Electrical Discharge - 12.5%

From the analysis, it is possible to conclude that the most relevant hazard is related to deal with lead salts. This relates to the toxicity of lead and its effects once within the human body. Since the exposure to lead involves more people, it got a higher relevance percentage, which differs from the “initial guess” that “explosion” would be the most relevant hazard.

As for the sector, the precipitation workshop got the higher relevance, mainly due to the higher number or workers in the sector.

In summary, according to the HM written for this scenario, the top priority when comes to mitigate and control hazards would be address the lead exposure (50% of all the hazards relevancies are due to lead exposure) in general, and in particular its exposure within the precipitation workshop (this area counts for 46% of the exposure relevancies).

6.2 Oil Extraction – Offshore platform

Nowadays modern society and economy is heavily dependent upon oil and its derivatives. From that, it is just logical to assume that oil industry is a major player within the international economy, being present worldwide, from prospection, extraction and processing. At the same time, oils are fuels and by that reason they represent a hazard to be managed. Even more, the large amounts of oil dealt with worldwide exponentially increases the hazard, both occupational (intense labor, heavy machinery, pumps, chemical hazards, fire hazard, and accidents in general.) and environmental (major fires, explosions, major leaks both in land and water).

In a greater scope, there are the oil extraction operations off shore. Extraction platforms stationed off shore are one important representative of this group. These platforms are very complex installations, being capable to drill and build the oil wells, extract, produce and hold both oil and high pressure gases, as well as perform the entire set of required maintenances (Freitas *et al* 2001; Booth and Butler,1992).

Due to the off shore environment in which oil platform operate and the hazards of its operations and products dealt with, as well as economical relevance in modern society, they constitute an extremely important scenario for risk assessment, including hazard matrix ranking system. Muniz (2011) developed his work having an off-shore oil extraction platform as a case of study. The chosen platform is set at the Brazilian coast, near the city of Vitoria.

The work performed by (Muniz 2011), the RAC used were as in table 9

Risk Assessment Code	Description
0	Exposition un-existence
1	Low level of exposition.
3	Medium Level of Exposition
9	High Level of Exposition

Source: Translated from (Muniz 2011)

Table 9. Environmental Risk Assessment Codes.

Using the criteria for RAC as presented in Table 9, (Muniz 2011), it was drawn two hazard matrixes, one analyzing a platform in general (Table 10) and a second one analyzing the drilling system (Table 11), among others.

As a complex system, oil extraction platforms in an off-shore environment have a large number of areas and hazards to be dealt with. The data presented in Tables 10 and 11 are nothing but a small portion of the work developed by (Muniz 2011). Therefore, a HM is a remarkable tool to guide the risk assessment process, as well as, the team responsible for risk control and mitigation.

In the early stages of the risk management program, by the use of HM, several hazards can be ignored, sectors and areas of lower relevance percentages can be neglected and all the effort and resources can be oriented to those hazards and areas that represent the most relevant within this vast and complex system.

SECTOR		HAZARDS																				
Description	Number of Workers	Physical	Chemical	Biological	Ergonomic	Accidents		Metal dust and fumes	Organic Vapors	Cleaning Products	Chemical Products	Contami- nated Air	Chemical Intoxica- tion	Position and Movement	Lighting	Machinery and Equipment	Fire and Explosion	Falling Objects	Trans- portation People and Cargo	Electricity	Fs	%s
			Noise	Heat	H2S, CH4																	
Administration	6		1	0	0	0	0	0	0	1	0	1	0	1	1	0	1	0	0	1	42	14
"Hoselling"	13		1	3	0	0	0	0	0	3	0	1	0	3	1	3	3	0	0	1	247	8
External Area	16		3	1	0	9	9	0	0	0	0	0	0	1	0	9	3	9	9	1	720	23.5
Drilling System	20		3	3	3	0	0	9	0	0	3	0	1	9	1	9	9	3	9	3	1300	42
Engine Room	10		9	9	0	0	0	9	3	3	9	1	3	9	1	3	9	1	1	9	760	24.8
Fh	217	205	60	144	270	75	150	331	49	363	214	185										
%H	7.1	6.7	2	4.7	8.8	2.4	4.9	10.8	1.6	12.8	7	6										100%

Source: Translated from (Muniz 2011)

Table 10. Hazard Matrix – GENERAL

SECTOR	HAZARDS													
	Physical	Chemical	Biological	Ergonomic	Accidents									
Description	Number of Workers	Noise	Heat	H2S, CH4	Metal dust and fumes	Organic Vapors	Cleaning Products	Chemical Products	Contaminat ed Air	Chemical Intoxication	Position and Movement	Lighting	Machinery and Equipment	Fire and Explosion
Driller's Cabin	4	1	0	0	0	1	0	0	1	0	0	0	0	9
Energy Room	4	1	0	0	0	0	0	0	0	0	0	1	0	3
Probe Floor	10	3	1	3	0	9	0	1	0	1	9	0	3	9
Sieves Area	10	9	9	1	0	9	0	3	0	3	9	3	9	3
	Fh	128	100	40	0	184	0	40	4	40	180	34	120	168
	%H	10.8	8.5	3.4	0	15.6	0	3.4	0.3	3.4	15.3	2.9	10.2	14.2

Source: Translated from (Muniz 2011)

Table 11. Hazard Matrix – DRILLING SYSTEM

## 7. Limitations and aspects of hazard matrix

Since Hazard Matrix is a prioritization tool, as it aims to provide a priority ranking among identified hazards and sectors, they must be previously identified and inserted in the HM. Therefore, HM utilization in combination with a Risk Identification tool, such as Preliminary Hazard Analysis (PHA) is essential. In this sense, failures in the risk identification phase, as well as the exclusion of some specific risk or sector identification will certainly jeopardize the accuracy and reach of HM prioritization results and global analysis.

Under the approach of decomposing risk into its independent variables, as discussed earlier, HM prioritization of hazards are intrinsically related to the factors severity and probability of occurrence. As HM prioritizes the most critical hazards, the ones whose product of severity  $\times$  probability have a high value would be, at a first moment, a priority for the treatment phase highlighted by HM. However, at a second moment, after risks mitigation under the orientation of HM prioritization is done, hazards whose severity and probability were lower initially will appear as priorities in a second HM utilization. The transition happens because, during the risk mitigation phase, severity and probability factors of the most critical risks are reduced. Consequently, in a second HM utilization, they will not appear in the top of priority ranking provided by the method.

In addition, even though the HM Environmental application provides an efficient alternative analysis, one of the most relevant limitations of the methodology is related to the difficulty to compare efficiently in prioritization terms both Environmental and Occupational risks in the same HM.

Besides, although HM provides a relative comparison between hazards or sectors that ordinates, in percentage, the most critical sectors/hazards to be prioritized, when the difference between percentages are very small, the differentiation of relevance between this sectors/hazards and its effects on the risks mitigation plans must be analyzed carefully, since this numerical analysis is relative. Therefore, in this situation, other factors that concern at these sectors/hazards must be evaluated and combined to the HM's result.

In this sense, the role of HM alternative applications, such as Project and Environmental presented earlier become a useful complementary analysis. By providing an auxiliary view of the global situation, they may compensate the conventional HM restrictions and limitations such as the ones listed above, reducing the probability of errors.

## 8. Closure and future work

Some future aspects of the application of the HM methodology should be listed as: 1) a deeper study in the application of the weights used inside the HM; 2) improvements done in the data collection of hazards and sectors, in order to enhance the results achieved (having the burden of a higher price of investment) and 3) the development of a better integration between risks pertaining the occupational aspect of the analysis (said to be inside the walls) and those risks which expose a larger community (said to be outside the walls).

As it stands, the HM concept and application in HSE is a powerful yet simple form of decision making in an occupational risk assessment. It is fully integrated in the Risk Management Program of any company. Resources and structure to do this are quite commonly already available.



The strategic role of a risk prioritization stage at HSE is justified by the inherent limitation of resources with which any company works, as well as the difficulty to compare, in a relevance scale, predicted accidents. As shown in the first study case, human's impression of risk's relevance is not a reliable reference to make decisions and prioritize risk mitigation. In this context, the utilization of the HM, combined with some risk identification tool, such as Hazards Preliminary Analysis (HPA), enables such prioritization, ordering in a critical scale both sectors and hazards already identified and classified.

As there are different applications of HM, it is important to notice that their combined utilization with the original HM model is in a complementary approach. Thus, for the HSE of a company, for example, there can be developed both an occupational and an environmental Hazard Matrix. However, comparison between both environmental and occupational risks, in order to orient the prioritization of risk mitigation plans is still a challenge.

One may say that HM is the chosen method to prioritize risks and to determine strategic resources utilization within risk management. However, HM approach and effects transcend the mere aspect of risk prioritization: It must be considered as an efficient, global and multidisciplinary analysis, connected to plenty aspects of risk management, optimization and resources utilization.

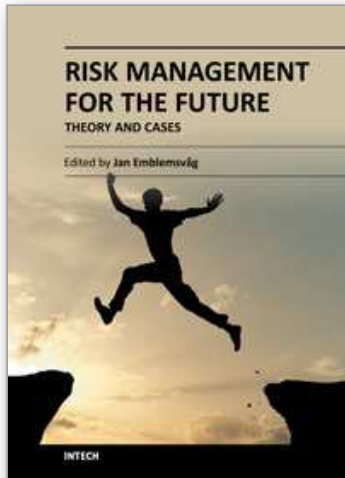
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## **Risk Management for the Future - Theory and Cases**

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A large part of academic literature, business literature as well as practices in real life are resting on the assumption that uncertainty and risk does not exist. We all know that this is not true, yet, a whole variety of methods, tools and practices are not attuned to the fact that the future is uncertain and that risks are all around us. However, despite risk management entering the agenda some decades ago, it has introduced risks on its own as illustrated by the financial crisis. Here is a book that goes beyond risk management as it is today and tries to discuss what needs to be improved further. The book also offers some cases.

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