Chapter 7

Prioritizing Human Factors in Emergency Conditions Using AHP Model and FMEA

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Additional information is available at the end of the chapter

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Abstract

One of the most critical issues related to safety in industrial plant is to manage accidents that occur in industries. In general, the causes of accidents are twofold: the presence of dangerous equipment and human errors. The aim of this study is to propose a novel approach to ensure safety in emergency conditions in industrial plant considering both of these factors. The proposed idea aims to integrate the human reliability analysis (HRA) and the failure modes and effects analysis (FMEA). The human errors and failure modes are categorized using a multicriteria approach based on analytic hierarchy process (AHP). The final aim is to present a novel methodological approach based on AHP to prioritize actions to carry out in emergency conditions taking into account both qualitative and quantitative factors. A real case study is analyzed. The analysis allowed to identify possible failure modes connected with human error process.

Keywords: AHP, HRA, FMEA, emergency, human errors

1. Introduction

In recent years, various emergency events have caused loss of lives. The potential for major industrial accidents required a clearly and systematic approach to control the human errors and failure modes to ensure a proper approach in emergency conditions. One of the most important significant sources useful to monitor the emergency events is the database EM-DAT (http://www.emdat.be/). The database is a potential tool to investigate industrial accidents and disaster events worldwide. For instance, **Figure 1** shows the total number of industrial accidents, in Europe, between 1900 and 2015. As it is possible to note, during the period 1990–2008, there has been a growth in the number of accidents. This result is not a surprise as a consequence of growth on industrial processes and technology.

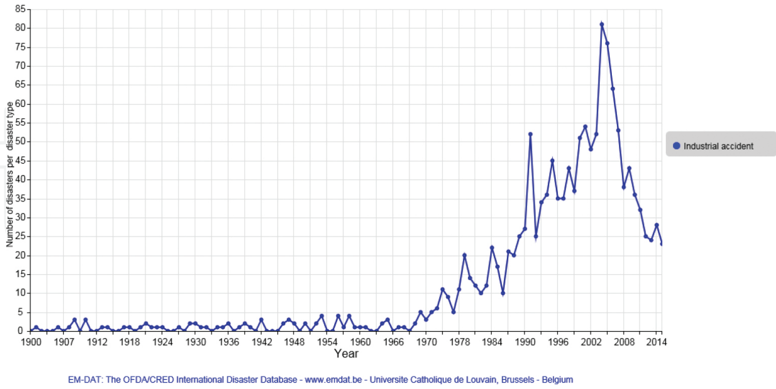

Figure 1. The total number of industrial accidents between 1900 and 2015 (source "http://www.emdat.be/").

Of course, the growth of industrial accidents, highlighted above, behave in accordance with an increase of the total number of economic damage as it is shown in **Figure 2**.

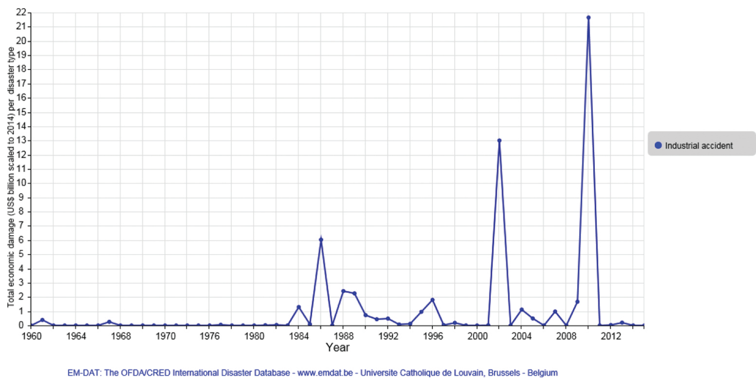

Figure 2. The total economic damage between 1900 and 2015 (source http://www.emdat.be/).

Among the major disasters that occur worldwide are the *Seveso disaster in Italy* (July 1976), caused by the release of dioxins into the atmosphere; the *Chernobyl disaster* in Ukraine (April 1986) happened after a test on a reactor; the *Shell Oil refinery* explosion in the USA (May 1988), caused by hydrocarbon gas leak; and the *Fukushima I* nuclear accidents in Japan (March 2011).

These undesirable events increased the importance of risk assessment and a good operational planning decisions [1, 2]. In this context, the critical elements to take into account are human factors and failure modes to design a systematic approach to improve the role of human element in a system performance. Thus, *what is the point?* In our opinion, it is necessary to provide a structured framework to prioritize risks taking into account the failure mode and the human errors.

For this reason in the present research, an integrated approach is proposed. In particular, the approach is based on three fundamental aspects that, in our opinion, help to analyze the problem globally: the *human reliability analysis* (*HRA*), the *failure modes and effects analysis* (*FMEA*), and the multicriteria approach using *analytic hierarchy process* (*AHP*). Here below, a brief overview of the above approaches is provided.

The HRA is a critical issue because the human errors involve the use of qualitative and quantitative aspects [3]. In literature, a great number of tools are proposed for human reliability analysis [4]. The limit of the HRA techniques is related to the uncertainty to consider organizational factors and errors of commission. One of the most important issues related to human errors is the performance shaping factors (PSFs). PSFs allow to assess all the environmental and behavioral factors that influence the decision and actions of man. In particular, the use of PSFs allows to simulate different scenarios. HRA tools include failure modes and effects analysis (FMEA), developed in the late 1950s. FMEA is one of the most popular methods used to perform the risk assessment [5]. The traditional FMEA approach has been extensively criticized due to the limitations in calculating the risk priority number (RPN) [6, 7].

Several methods have been suggested to improve the traditional HRA and FMEA. Among these methods, the multicriteria methods such as analytic hierarchy process (AHP) are very promising. AHP, developed by Saaty [8], is a useful approach to manage the complexity of decision problems. AHP technique is very suitable to determine the weights for each risk factor. With AHP, it is possible to evaluate the ambiguity of human perception and to transform it into a mathematical formula.

In this paper, the AHP technique is proposed to weigh and to prioritize failure modes and human factors that characterize actions in emergency conditions. AHP is used to assess the relative importance among human factors and failure modes. As a result, a new methodological approach to calculate the risk priority number using weighting method integrating with human factors is presented. To validate the application of the model and to examine its effectiveness, the proposed methodology is used for analyzing an emergency scenario in a petrochemical plant.

The rest of the paper is organized as follows. The literature review on emergency management is presented briefly in Section 2. The methods are introduced in Section 3. Section 4 is about the proposed evaluation methodology. Furthermore, a numerical example is presented. Conclusions are analyzed in Section 5.

2. Literature review on emergency management and human errors

In emergency management, it is necessary to collect many and different types of information to deal with emergency tasks in different phases and to deal with emergency situation such as stress, lack of time, and adequate training [9].

A systematic literature review was carried out to search if a similar study has already been published in the literature. We looked for studies in the *emergency management* area in Scopus database (www.scopus.elsevier.com). In particular, we investigated the “engineering field,” in which 8,445 documents came out during the period of 1925–2016. **Figure 3** shows the number of documents by year. Results point out that there is a growing interest on emergency management issue.

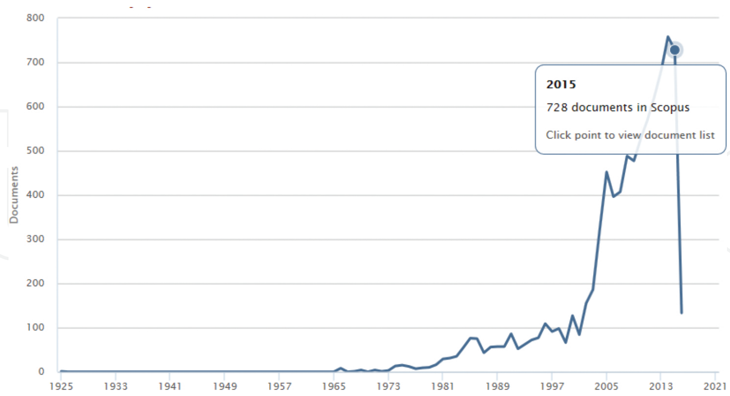

Figure 3. Documents by year.

A depth analysis shows that the majority of the researches are developed in the USA (**Figure 4**).

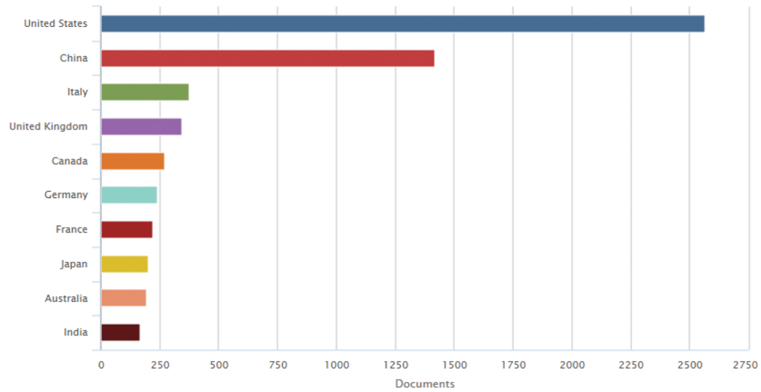

Figure 4. Documents by country/territory.

In recent literature, several approaches and models have been proposed to manage emergency conditions. For instance, Pérez et al. [10] in their study proposed a fleet assignment model for the Santiago Fire Department to maximize the number of incidents successfully attended. Omidvari et al. [11] developed a model based on analytical hierarchy process and failure modes and effects analysis logic to determine the factors influencing the fire risk of an education center. Bariha et al. [12] proposed the analysis of hazards associated with accidental release of high pressure from gas-pipeline transportation system. A probabilistic risk assessment from potential exposures to the public applied for innovative nuclear installations has been analyzed by Dvorzhak et al. [13]. While Shi et al. [14] used a technique plan repository and evaluation system based on AHP group decision-making for emergency treatment and disposal in chemical pollution accidents, Ergu et al. [15] applied the analytic network process, a generalization of the AHP, in risk assessment a decision analysis. Liu et al. [16] present a novel approach for FMEA based on AHP and fuzzy VIKOR method.

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The above works relate to emergency management in the sense that they analyze multiple approaches to manage emergency conditions. However, no specific systematic approach is presented to take into account both qualitative and quantitative factors in the emergency management. Our work focuses in understanding the failure modes and human errors in emergency conditions, following a strict and standardized protocol to identify and to prioritize risks.

3. Methods

To design the model, a novel approach including HRA, FMEA, and AHP is defined. In this section, a short description of these methods is given.

3.1. The failure modes and effects analysis (FMEA): the traditional approach

According to the American Society for Quality [17], FMEA is a procedure that is performed after a failure modes and effects analysis to classify each potential failure effect according to its severity and probability of occurrence. Traditional FMEA method is based on risk priority number (RPN) for analyzing the risk associated with potential problems. RPN is calculated by multiplying the scores of severity (S), occurrence (O), and detection (D). In details:

- Occurrence (O) represents the probability that a particular cause for the occurrence of a failure mode occurs (1–10). The range of occurrence scale is from score 1 (failure is unlikely) to score 10 (failure is very high and inevitable).
- Severity (S) represents the severity of the effect on the final process outcome resulting from the failure mode if it is not detected or corrected. The severity scale is from score 1 (none effect) to score 10 (hazardous without warning).
- Lack of detectability (D) represents the probability that the failure will not be detected. The detectability scale is from score 1 (detection almost certain) to score 10 (absolute uncertainty).

Generally, it will give more importance to the failure modes with higher RPNs. The RPN method has been criticized due to its limitations, among which are:

- The relative weights of risk factors are not taken into account.
- S, O, and D indexes have the same relevance.
- Different sets of O, S, and D scores produce the same value of RPN.
- They are ordinal type of scale (not cardinal). Thus, no arithmetic operation among them is permitted.

To avoid some of the drawbacks mentioned above, some different approaches have been proposed in literature. For instance, Narayanagounder and Gurusami [18] used analysis of variance (ANOVA) to prioritize failure modes or using additional characteristic indexes to define the order to analyze (from a design point of view) the failure mode. However, this proposal are very complex, and it is not simple to apply it in industrial context. For this reason, our study aims to propose a simple application using AHP technique according to human reliability analysis that is explained in the next sections.

3.2. The human reliability analysis (HRA)

The development of human reliability methods occurred over time in three stages [19]: (1) the first stage (1970–1990), known as the *first human reliability method generation*; (2) the second phase (1990–2005), known as *the second human reliability method generation*; and (3) finally, the *third generation*, started in 2005 and still in progress [20, 21].

Among the several approaches that have been proposed and developed for error classification, we remember the Systematic Human Error Reduction and Prediction Approach (*SHERPA*) [22], the Cognitive Reliability Error Analysis Method (*CREAM*) [23], the Human Error Identification in Systems Tool (*HEIST*) and Human Error Assessment and Reduction Technique (*HEART*) [24], and the Human Factors Analysis and Classification System (*HFACS*) [25], among others.

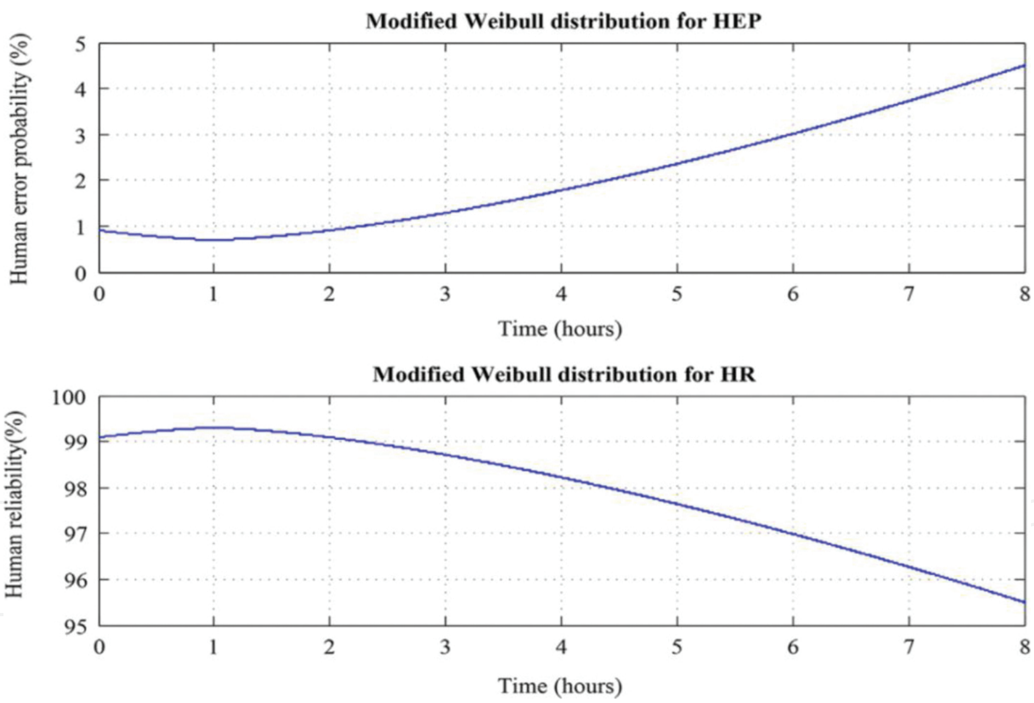

Figure 5. The Weibull function.

The common basis for all techniques is the assessment of the human error probability (HEP) representing the index of human error and its variation according to PSFs. The analysis of human error starts with a definition of HEP. Obviously, the probability of error is a growing function of the time. The HEP value can be calculated as:

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$$HEP_{nom} = 1 - e^{-\alpha t^{\beta}} \tag{1}$$

The above formula can be changed in relation to the working hours. Since the operator's reliability is highest in the first hour of work and descending gradually, it gets closer to the eighth hour, and the unreliability decreases with the time (**Figure 5**).

$$\begin{cases} HEP_{nom}(t) = 1 - k * e^{-\alpha(1-t)^{\beta}} & \forall t \in [0;1] \\ HEP_{nom}(t) = 1 - k * e^{-\alpha(t-1)^{\beta}} & \forall t \in [1;\infty] \end{cases} \tag{2}$$

where α is the scale parameter and β is the shape parameter. The β parameter is defined as 1.5 by the scientific literature of the HEART method.

The α parameter is calculated by the following formula:

$$\alpha = \frac{-\ln\left[\frac{k(t=8)}{k(t=1)}\right]}{(t-1)^{\beta}} \tag{3}$$

Using (Eq. 2), it is possible to define the trend of reliability associated to specific generic task or human errors, as it is shown in **Table 1**.

#	Human errors/generic task	Limitations of unreliability for operation (%)	k (t = 1)	k (t = 8)
1	Total unfamiliar	0.35–0.97	0.65	0.03
2	Shift or restore system to a new or original state	0.14–0.42	0.86	0.58
3	Complex task	0.12–0.28	0.88	0.72
4	Fairly simple task	0.06–0.13	0.94	0.87
5	Routine highly practiced	0.007–0.045	0.993	0.955
6	Restore or shift a system to original or new state	0.008–0.007	0.992	0.993
7	Completely familiar	0.00008–0.009	0.99992	0.991
8	Respond correctly	0.00000–0.0009	1	0.9991

Table 1. Human errors scale.

One of the most important aspects is the study of factor interactions that increase the probability of error and interdependencies of performance shaping factors (PSFs). Specifically, the context in which humans make errors is analyzed. The PSFs allow the inclusion, in the model, of all the environmental and behavioral factors that influence the decision and actions of man [26]. In particular, the use of PSFs allows to simulate different scenarios. Analytically, the PSFs are modifying the value of the error probability because they introduce external factors that strain and distract the decision maker [27]. The PSF and their values are obtained from the literature, as is shown in **Table 2**. The PSFs considered are (1) *available time, (2) stress/stressor, (3) complexity, (4) experience and training, (5) procedures, (6) ergonomics, (7) fitness for duty, and (8) work processes.*

# PSFs	Levels	Values
1 Available time	Inadequate time	1
	Time available = time required adequate time	10
	Nominal time	1
	Time available > 5 time required (extra time)	0.1
	Time available > 50 time required	0.01
2 Stress	Extreme	5
	High	2
	Nominal	1
3 Complexity	Highly complex	5
	Moderately complex	2
	Nominal	1
4 Experience/training	Low	3
	Nominal	1
	High	0.5
5 Procedures	Not available	50
	Incomplete	20
	Available, but poor	5
	Nominal	1
6 Ergonomics	Missing	50
	Poor	10
	Nominal	1
	good	0.5
7 Fitness for duty	Unfit	1
	Degraded fitness	5
	Nominal	1
8 Work processes	Nominal	1
	Good	0.5

Table 2. PSFs scale.

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It is important to note that four main sources of deficiencies can be identified in current HRA methods:

- No empirical data for model development and validation
- Lack of inclusion of human cognition
- Large variability in implementation
- Heavy reliance on expert judgment in selecting PSFs and the use of these PSFs to obtain the HEP in human reliability analysis

The limitations characterizing the FMEA and HRA methods are the motivation under our study and provide the reason to integrate them with AHP technique.

3.3. The analytic hierarchy process (AHP)

AHP uses mathematical objectives to process the inescapable, subjective, and personal preferences of an individual or a group making a decision [28]. In the AHP process, firstly, the hierarchy is defined. Secondly, judgments on pairs of elements with respect to a controlling element are expressed to derive ratio scales that are then synthesized throughout the structure used to select the best alternative [29]. The modeling process can be divided into different phases; to provide a better understanding of the main phases, they are described as follows:

1. *Pairwise comparison and relative weight estimation.* Pairwise comparisons of the elements in each level are conducted with respect to their relative importance toward their control criteria. Saaty suggested a scale of 1–9 when comparing two components. For example, a score of 9 represents an extreme importance over another element, while a score of 8 represents an intermediate importance between "very strong importance" and "extreme importance" over another element. The pairwise comparisons can be represented in the form of a matrix. Score 1 represents equal importance of two components, and score 9 represents extreme importance of the component i over the component j.

2. *Priority vector.* After all pairwise comparisons are completed, the priority weight vector (w) is obtained.

3. *Consistency index estimation*. The consistency index (CI) of the derived weights could then be calculated by $CI = (\lambda_{max} - n)/n - 1.$, where λ_{max} is the largest eigenvalue of the judgment matrix A and n is the rank of the matrix. In general, if CI is less than 0.10, the satisfaction of the judgments may be derived.

4. Research framework: Human reliability model based on AHP

In this section, a human reliability model is proposed to analyze the human reliability in emergency conditions, based on failure modes and effects analysis. Here, below is a brief description of the phases and steps characterizing the model.

4.1. The rationale

As reported in the previous sections, a quantitative method was developed to prioritize failure modes and human errors using AHP technique. The logic model is depicted in **Figure 6**. Each model phase is discussed in brief, as follows:

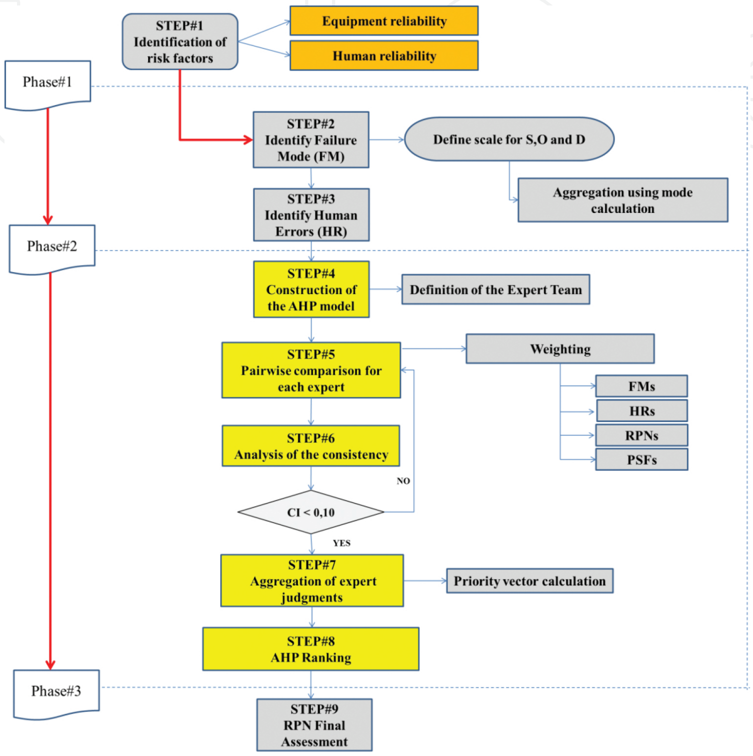

Figure 6. Methodological approach.

Phase #1: Preliminary analysis. The aim of the first phase was to identify scenario under study defining failure modes and human errors characterizing the accident. This phase represents the most critical phase because an incorrect assessment could determine the inappropriateness of the overall model. Three main steps were identified, as follows:

- Step #1: Identify of risk factors
- Step #2: Identify failure modes (FMs)
- Step #3: Identify human errors (HRs)

Phase #2: Multicriteria analysis. One of the crucial elements in measuring the effectiveness of a decision model is to obtain consistent results according to common standards. Thus, the aim of the second phase was to define the AHP model according to prioritize failure modes (FMs) and human errors (HRs), when there is a disagreement in ranking scale for severity, occurrence, detection, human errors, and PSFs. The final purpose of this phase was to define the final score for each criteria and subcriteria according to the AHP model and according to the expert team.

Four main steps were identified, as follows:

- Step #4: Construction of the AHP model
- Step #5: Pairwise comparison for each expert
- Step #6: Analysis of the consistency
- Step #7: Aggregation of expert judgments
- Step #8: Ranking

Phase #3: Synthesis. The aim of the last phase was to define the final assessment for RPN according to the expert team. One step was identified to carry out the phase, as follows:

- Step #9: Final assessment

4.2. Case study: the model validation

To demonstrate the proposed approach, a real-world application is employed in this section. The example is related to an emergency shutdown valve (ESDV) in a petrochemical plant. Of course, reliability is crucial to safety (**Figure 7**). An emergency shutdown valve is an actuated valve designed to stop the flow of a hazardous fluid upon the detection of a dangerous condition, protecting people, equipment, or the environment.

Figure 7. Example of emergency shutdown valve.

4.2.1. Phase #1: preliminary analysis

According to Step #1, the identification of risk factors were carried out. In detail, an expert team, composed by five engineers, was selected to develop the model.

According to Step #2, the main failure modes characterizing the malfunction of an ESDV were identified: valve open (FM1), partially open (FM2), closed (FM3), partially closed (FM4), and wobble (FM5). The main failure causes were identified in broken and corrosion.

Scales for S, O, and D were defined by each expert, as is shown in **Table 3**.

Failure mode	S	O	D	RPN
Expert#1				
FM1	2	4	7	56
FM2	3	5	6	90
FM3	2	6	4	48
FM4	4	7	5	140
FM5	4	7	2	56
Expert#2				
FM1	3	5	7	105
FM2	2	4	8	64
FM3	3	7	6	126
FM4	6	3	8	144
FM5	7	7	1	49
Expert#3				
FM1	1	8	3	24
FM2	4	4	6	96
FM3	5	8	7	280
FM4	3	3	5	45
FM5	2	4	5	40
Expert#4				
FM1	3	8	7	168
FM2	4	2	6	48
FM3	5	7	6	210
FM4	6	3	5	90
FM5	2	4	5	40
Expert#5				
FM1	3	8	7	168
FM2	1	4	4	16
FM3	5	4	6	120
FM4	6	4	2	48
FM5	2	4	5	40

Table 3. Failure mode – for each experts.

The aggregation of values expressed by each experts was made *computing the mode* or in other words identifying the value that appeared most often in the set of data. For instance, if we consider the set data for FM1 related to the severity scale, the most frequent value or the mode value is 3. The final set of data used is shown in **Table 4**.

Failure Mode	S	O	D	RPN initial
FM1	3	8	7	168
FM2	4	4	6	96
FM3	5	7	6	210
FM4	6	3	5	90
FM5	2	7	5	70

Table 4. Calculation of the mode values for the five experts

Frequently, human errors are overlooked. Because the FMEA examines individual faults of system elements taken singly, the combined effects of coexisting failures are not considered. Thus, according to Step #3, the human errors (HR) were identified by the expert team. For the scenario under study, three HRs and three PSFs were selected, as is shown in **Tables 5** and **6**.

#ID	Human errors/generic task	Limitations of unreliability for operation (%)	k (t = 1)	k (t = 8)
2HR1	Shift or restore system to a new or original state	0.14–0.42	0.86	0.58
5HR2	Routine highly practiced	0.007–0.045	0.993	0.955
7HR3	Completely familiar	0.00008–0.009	0.99992	0.991

Table 5. Human errors selection.

# ID	PSFs	Levels	Values
1 PSF1	Available time	Inadequate time	1
		Time available = time required adequate time	10
		Nominal time	1
		Time available > 5 time required (extra time)	0.1
		Time available > 50 time required	0.01
2 PSF2	Stress	Extreme	5
		High	2
		Nominal	1
3 PSF3	Complexity	Highly complex	5
		Moderately complex	2
		Nominal	1

Table 6. PSFs scale.

Scales for PSFs were defined by each expert. In **Table 7**, a synthesis is shown.

Human error	PS1	PS2	PS3
HR1	10	1	1
HR2	1	5	1
HR3	5	1	2

Table 7. PSF scale—experts—synthesis.

4.2.2. Phase #2: AHP model

According to Step #4, the AHP model was built to determine the criteria and subcriteria weights. The model consists of eight criteria and six subcriteria. In **Figure 8**, the AHP model is shown.

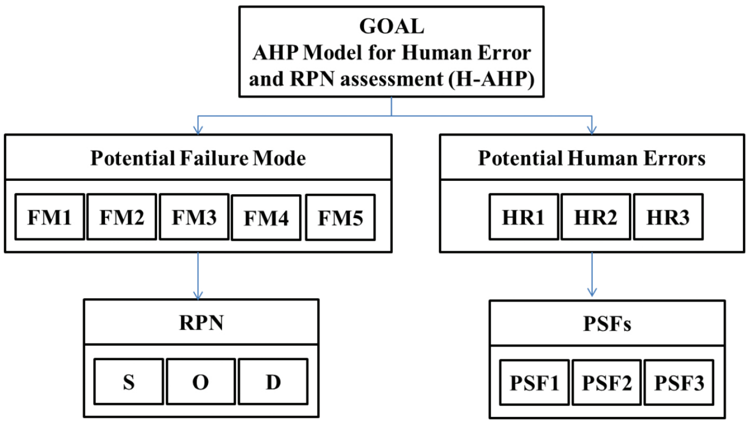

Figure 8. R-AHP model.

	FM1	FM2	FM3	FM4	FM5	Weight
FM1	1	5	5	6	6	0.547
FM2	1/5	1	3	4	4	0.215
FM3	1/5	1/3	1	3	3	0.121
FM4	1/6	1/4	1/3	1	2	0.065
FM5	1/6	1/4	1/3	1/2	1	0.050
Consistency: 0.078 < 0.10.						

Table 8. Example of pairwise comparison for potential failure modes criteria.

In this phase, according to Step #5, pairwise comparison matrices were filled out by the expert team to define the weights of criteria and subcriteria. It is worth noting that the same importance was attributed to the main criteria or 50 % potential failure mode and 50 % potential human errors. **Tables 8** and **9** show two examples of pairwise comparison. For each pairwise comparison, according to Step #6, consistency analysis was carried out.

	HR1	HR2	HR3	Weight
HR1	1	1/3	1/3	0.139
HR2	3	1	1/2	0.332
HR3	3	2	1	0.527

Consistency: 0.051 < 0.10.

Table 9. Example of pairwise comparison for potential error criteria.

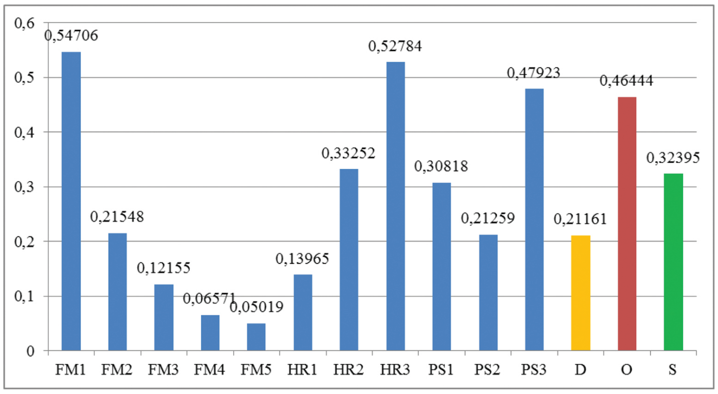

Figure 9. Final weights.

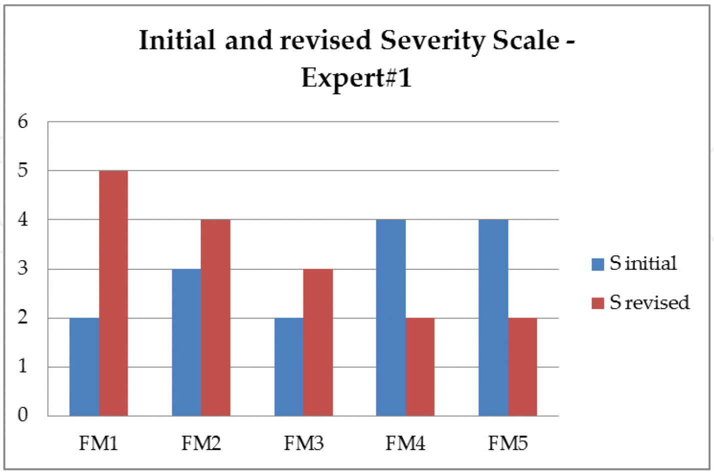

Figure 10. Example of initial and revised severity scale for Expert #1.

The determination of relative weights in AHP model is based on the pairwise comparison conducted with respect to their relative importance toward their control criterion. In detail, evaluation expressed in **Tables 4–7** was used. Furthermore, Saaty's semantic scale was used for the comparison.

Failure mode	S	O	D	RPN revised
Expert #1				
FM1	5	7	3	105
FM2	4	5	4	80
FM3	3	5	4	60
FM4	2	5	4	40
FM5	2	5	2	20
Expert #2				
FM1	4	5	7	140
FM2	3	6	5	90
FM3	3	6	5	90
FM4	6	3	4	72
FM5	6	7	1	42
Expert #3				
FM1	5	8	3	120
FM2	5	5	4	100
FM3	5	5	4	100
FM4	4	4	3	48
FM5	4	4	3	48
Expert #4				
5	8	3	120	5
4	5	4	80	4
5	7	2	70	5
4	3	2	24	4
2	4	4	32	2
Expert #5				
3	8	5	120	3
5	5	4	100	5
5	4	5	100	5
5	5	2	50	5
2	4	4	32	2

Table 10. Revised failure mode—for each expert.

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Furthermore, according to Step #7, the *geometric mean* was used to synthesize the set of judgments given by the expert team.

According to Step #8, the ranking was obtained. The aim of the present step was to define the final score for each criteria and subcriteria according to the AHP model and according to the expert team. One step was identified to carry out the phase, as follows. The scores of these each weighted criteria and subcriteria are shown in **Figure 9**.

Results pointed out that, according to expert judgments, the occurrence is the most important parameter with a score of 46.4 % than the other (severity with a score of 32.4 % and detectability with a score of 21.2 %). Furthermore, the most critical failure mode is FM1 with a score of 54.7 %, the most critical human error is HR3 with a score 52.7 %, and the most important performance shape factor is PS3 with a score of 47.9 %.

4.2.3. Phase #3: a new approach for prioritizing human errors and failure modes

Phase #3 is a crucial phase in the proposed methodological approach. In fact, it is important to note that, for instance, for Expert #1, FM1 and FM 5 had the same RPN (56) with different ranking values for occurrence, severity, and detection. For determining the most significant failure mode H-RPN, the weights defined through AHP model were used, as is shown in **Table 9**.

In detail, according to the final weights obtained with AHP, each expert expressed a reassessment judgments for S, O, and D scales. **Figure 10** shows an example of revised severity scale for Expert #1.

In a similar way, revised scales for occurrence and detectability were obtained by each expert, as shown in **Table 10**.

The aggregation of values expressed by each expert was made computing the mode, as shown in **Table 11**.

Failure Mode	S	O	D	RPN revised
FM1	5	8	3	120
FM2	4	5	4	80
FM3	5	5	4	100
FM4	4	5	4	80
FM5	2	4	4	32

Table 11. Revised calculation of the mode values of five experts.

Table 12 shows an example of new RPN.

	Severity	Occurrence	Detection	New RPN
Initial	3	8	7	168
Revised	5	8	3	120
Multicriteria RPN = % reduction in RPN = (RPN initial—RPN revised)/RPN initial				29 %

Table 12. Example of calculation of RPN.

Figure 11 shows a comparison between initial and revised RPNs, highlighting the *RPN reduction* for each FM. It is significant to point out that in general **Figure 11** shows, for the specific case study, a reduction of the RPN because usually the expert team have overestimated one parameter. But an *increase of RPN* could happen also.

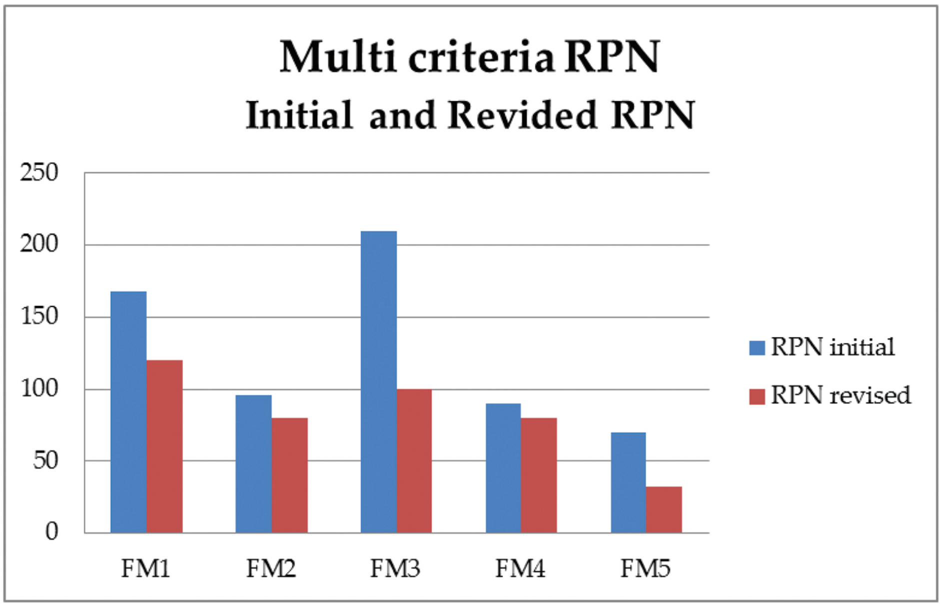

Figure 11. Comparison between initial and revised RPN.

Of course, in our opinion, the above assessment allows to evaluate the RPN more precisely and objectively with respect to the traditional approach.

5. Conclusion

This paper proposes a novel approach to prioritize failure modes taking into account human errors. The final aim was to improve the evaluation of risk priority number integrating human errors in the calculation. The goal was achieved through a multicriteria model, based on AHP. The method allowed us to weigh the failure modes integrating with human errors and to prioritize failure modes. The model can be applied when there is a disagreement in ranking scale for severity, occurrence, and detection. The novelty of the method is because there is no evidence in literature of this kind of approach using AHP. In our opinion, the proposed method

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ensures several benefits, as detailed follows: (1) it is a generic method that can be applied in several industrial processes; (2) it can be used to identify human errors that can become single points of failure; and (3) it can be used to define potential human errors that are the most critical by revealing the severity and probability of occurrence. Future research will investigate a great number of failure modes and human errors. Furthermore, several scenarios will be taken into account to compare results.

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