Decision making using human reliability analysis

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Brazil Regulatory Agencies have a risk criteria which have been defined based on quantitative risk approach. The most well-known regulations are defined for São Paulo and Rio de Janeiro cities which have a strong relationship with IBAMA Agency (Brazilian Environmental Agency). Their standards establish the activities to be developed defining the use of human reliability techniques to calculate the human error probability. Human errors are the main factors of the industrial accidents and their effects are not being assessed systematically with the level of details that are used during a typical human reliability assessment.

The objective of this paper is to analyse some methodologies of human reliability considering the external (observable) and internal (cognitive) human factors. The calculation of the human failure frequency during development of QRA studies by consulting companies are being performed in a subjective and conservative manner when compared to failure of equipment analysis.

In this paper, the human error probability quantification was developed using standardised methods and hence the calculated risk is more accurate and closer to the actual values. The development was based on the evaluation of some methodologies of human reliability and decision making. The method was assessed through a case study of an accident occurred in 2004 at Formosa Plastics Corp. Illiopolis. Initially, an analytical methodology oriented was developed as Hierarchical Task Analysis (HTA), followed by human error analysis using Predictive Human Error Analysis (PHEA) and a qualitative analysis using Systems for Predicting Human Error and Recovery (SPEAR). To complete the study and reduce the uncertainties a quantitative assessment using Fault Tree Analysis (FTA) and Human Error Assessment and Reduction Technique (HEART) was developed. The recommendations generated from the methodologies were assessed in two different categories: First, using the Weighed Score Method based on the management point of view and second, through the HEART and FTA methods representing the point of view of the operators.

The paper concludes that results based on operational focus were more objective and transparent when compared to results from management techniques. This is due to the fact that the operational indicators were easier to interpret and less subjective with less financial concerns involved. Also, the methodologies used provided a thorough understanding of the events in each phase of the accident and several improvements can be raised during each analysis based on the identified vulnerabilities.

Keywords: decision making, human reliability, accident in Formosa-IL, human error probability, performance factors influence.

Introduction

There are numerous studies related to human behavior and each one possesses specific characteristics. Basically, they are differentiated in external (observable) and internal (cognitive) factors and the selection of analytical method depends on the availability of information and the viability of cognitive analysis. Nowadays, in Brazil, the frequency of human error is evaluated in a subjective and conservative way when compared to equipment failure and its quantification, which can be developed using methods that represents the risk closer to reality. This study was based on the evaluation of human reliability and decision making methodologies, followed by a practical application of human reliability assessment of an accident which occurred in 2004 at Formosa Plastics Corp. Illiopolis.

Methodology

The description of the accident which occurred at the Formosa-IL plant was extracted and summarized from the investigation report (Chemical Safety and Hazard Investigation Board, 2007). The plant layout of Formosa-IL is presented in Figure 2.1.

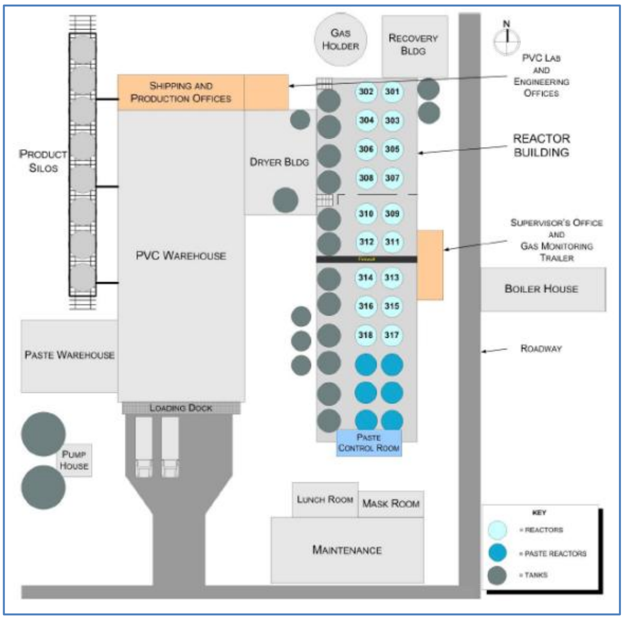

Figure 2.1: Layout of the plant of Formosa-IL (Chemical Safety and Hazard Investigation Board, 2007)

The method for human reliability assessment used in this study is presented in Figure 2.2.

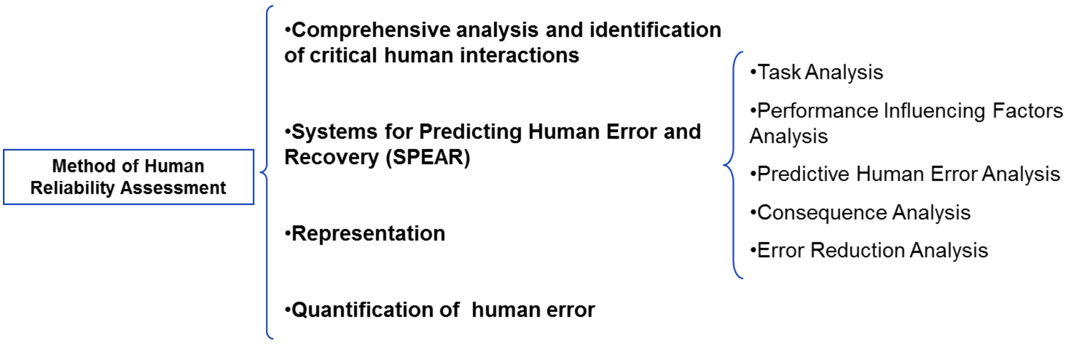

Figure 2.2: Method of human reliability assessment (AICHE/CCPS, n.d.)

The first step of human reliability evaluation consists of general analysis and identification of human interactions. The cleaning of reactors was identified as the critical activity by the Chemical Safety and Hazard Investigation Board (CSB) at the Formosa-IL plant. Normally, before an installation, it is necessary to get information about the most critical operational and maintenance activities directly from the operational team through meetings to stimulate transparent communication about work activities.

The second step consists of the SPEAR methodology application. Initially, the action oriented technique HTA was used in chart and tabular format to represent the activity i.e. reactor cleaning. Following the completion of the task analysis, the Performance Influencing Factors (PIF) analysis was developed in accordance to AICHE/CCPS classification. The last three steps of SPEAR were completed using the Predictive Human Error Analysis (PHEA) where consequences and error reduction analyses were developed. The results were obtained in tabular form preserving the logic between the type of human errors, its consequences and the measures for risk reduction.

The third step of the human reliability assessment, defined as Representation, was developed using Fault Tree Analysis (FTA) and Influence Diagram Analysis (IDA) to represent the accident at Formosa-IL.

In the last step which the human error was quantified, the Human Error Assessment and Reduction Technique (HEART) was used to estimate the probability of human error to quantify the FTA and the IDA developed in the previous step.

Results and Discussion

The human reliability assessment results for the accident at the Formosa-IL PVC plant is presented in this section. The first step of the human reliability assessment consisted of the comprehensive analysis and identification of human interactions, previously identified by the CSB. The second step consisted of the application of the SPEAR and the results are presented in the following section.

SPEAR (Systems for Predicting Human Error and Recovery)

Hierarchical task analysis (HTA) of the Formosa-IL accident

The simplified HTA presented in Figure 3.1 was developed to verify the reactor cleaning activity. It does not consider all of the steps of reactor cleaning in detail. A detailed analysis, which requires significant time and effort, should be prepared involving operators and engineers in charge of the area. The considerations in Plan 0 were extracted from the CSB report while activities considered in Plan 1 were assumed to be more realistic.

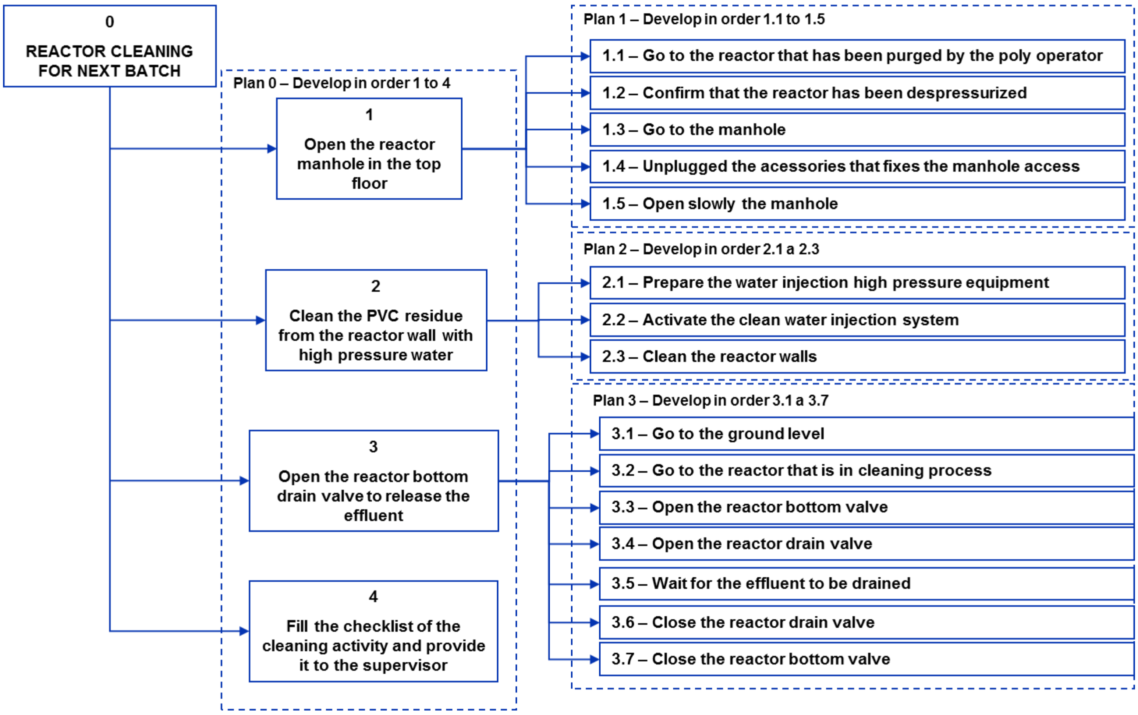

Figure 3.1: Hierarchical Task Analysis of Reactor Cleaning

It is reported in the accident report that the blaster operator went to the wrong group of reactors, this activity corresponds to step 3.2 i.e. go to the reactor that is in cleaning process. The HTA shown in Table 3.1 was developed to detail this step. The CSB report presented the communication system and the location of the reactor only. Therefore, any missing information was considered to be close to reality.

Task Step	Input (registers)	Output (action	Communication	Time and Task dependency	Second function, distraction	Comments
3.2 – Go to the reactor that is in cleaning progress	Identification of reactor tag on reactor bottom and control panel	Operator must check that the reactor tag is in accordance with reactor cleaning progress	By voice, operator on ground level shall go to the other operator to communicate. There is no intercom and radios are not part of routine operation.	Delays in start-up of next batch. Cleaning progress is sometimes not appropriate and should be re-done	Other functions in parallel with cleaning progress	Residual VCM can be released if cleaning process is inappropriate Hazards: operator injuries Operators must use appropriate PPE

Table 3.1: HTA Table for reactor cleaning

The purpose of this exercise was to present some tools to identify where faults were occurring. Ideally, these analyses should be developed for all existing critical activities in an industrial plant. It is observed in Table 3.1 that improper opening of a reactor during cleaning, whilst it is in operation is not considered as part of the task. The HTA developed follows the concept of the method, it addresses with precision and detail the activities to be performed and not the possible deviations. These should be analysed using alternative tools. The development of HTA allows procedures to be more appropriately defined and training to be more efficient. However, it does not show possible errors that may occur.

Analysis of PIFs

After the task analysis, it is important to evaluate the PIFs of the operators during reactor cleaning. The scale used for assessment of PIFs is shown in Table 3.2.

Rating Scale PIF	Procedure	Physical Work Environment
Worse – 1	• There are no written procedures or standards for implementation of activities. • Not integrated with training.	• High level of sound • Poor lighting • High or low temperatures, high humidity or high winds
Average – 5	• Written procedures available, but not always used. • Standardized methods to perform the task.	• Moderate levels of noise • Temperature and humidity variables
Better – 9	• Detailed procedures and checklists available. • Procedures developed using analysis task. • Integrated with training.	• Noise levels at optimal levels • Lighting based on analysis of the task requirements • Temperature and humidity at optimum levels

Table 3.2: Scales used for assessment of PIFs of reactor cleaning

The list of standard PIFs was used to identify factors that could influence the reactor cleaning activity. The list is not a formal definition of PIFs, and depending on the activity, this list should be developed and reviewed by the plant analysts. This evaluation was based on the descriptions of the accident presented by the CSB. Numerous deficiencies were commented and considered in the evaluation. Factors with value of 5 were considered relevant to the study although no information was found in the accident report (Chemical Safety and Hazard Investigation Board, 2007).

- Operating environment
    - Weather: 5
    - Illumination: 5
    - Working hours and breaks: 5
- Work details
    - Place/access: 3
    - Identification:2
    - Displays and controls identification: 3
    - View of critical information and alarms: 3
    - Clear the instructions: 1
    - Quality of controls and warnings: 1
    - Grade of support of diagnosing fault: 1
    - Conflicts between safety and production requirements: 2
    - Training for emergencies: 1
- Characteristics of the operator
    - Skills: 5
    - Risk assumption: 5
- Social and organization factors:
    - Clarity of responsibilities: 3
    - Communications: 1
    - Authority and leadership: 2
    - Commitment of management: 2
    - Overconfidence in technical safety methods: 2
    - Organizational learning: 1

The assessments were conducted after the investigation of the accident, once the faults had already been analysed. If this assessment was performed before the accident, judgement would most likely be different and higher notes would be obtained.

The results demonstrate that there were mainly deficiencies in group task characteristics and organizational and social factors. Within the group task characteristics, specific categories such as clarity of instructions, quality of checks and warnings, degree of support on fault diagnosis presented the worst reviews. These deficiencies could have occurred due to the absence of a supervisor allowing for a hierarchical distance and lack of communication between operations and management. Emergency procedures training were considered the most critical as the effects of the accident would be very different if the operators were adequately trained in evacuation procedures. In the group organizational and social factors, specific categories communications and organizational learning presented the worst results, although authority and leadership, commitment of management, overconfidence in technical safety methods were also considered critical.

These reviews can be justified mainly because there was already evidence of criticality of the bypass procedure of the safety interlock and no effective modification was performed. Also, there was no routine of communication such as radios and intercoms, nor adequate availability of supervisor, and such evidences were not considered by management.

Predictive Human Error Analysis (PHEA), Consequences and Error Reduction

Table 3.3 presents the PHEA methodology that analyses human error and cognitive perspective developed to assess the step of task 3.2. The information was extracted from the CSB accident report, but the logic was developed using the methodology. It is observed that the analysis of consequences of SPEAR is associated with each type of human error defined by PHEA. This way, the consequences are associated with a cause that was identified during the study. A strategy to reduce the error should be developed based on the consequence, that depending on the criticality of the consequence should be mandatory or not.

Task Step	Type of task	Type of error	Description	Consequences	Recovery	Strategy to reduce the error[1]
3.2 – Go to the reactor that is in cleaning progress	Action	Action in the wrong direction	Move in the wrong direction of the right reactors	Operator will be in the wrong group of reactors	Reactor identification at the bottom of reactor and control panel	Optimize layout of the reactors in order to facilitate identification
	Action	Right action on wrong object	Operator performs bypass of interlock system and drains the reactor in operation	Large release of vinyl chloride monometer (VCM) followed by explosion and fire	None	- Evacuation System - Study of protection layers - Historical analysis - Improve procedures and training
	Action	No action	Absence	Delay in drainage	None	
	Action	Omitted action	Absence	Delay in drainage	None	
	Checking	Omission of checks	Operator does not check the reactor identification that should be drained	Impossibility to drain reactor due to interlock activation	Indication of interlock activity in the control panel	Include in checklist the activity verification of reactor to be drained
	Checking	Right check in the incorrect object	Blaster operator confirms that the reactor is in cleaning process, but is on the wrong reactor	Impossibility to drain reactor due to interlock activation	Indication of interlock activity in the control panel	Include in checklist the activity verification of reactor to be drained
	Checking	Wrong check in the correct object	Blaster operator is in the correct reactor but confirms that another reactor is in cleaning process	Operator goes to another reactor and will not drain it due interlock activation	Operator of the upper level will fix the blaster reactor	Improving procedures and training
	Checking	Wrong check in the wrong object	Blaster operator is in the wrong reactor and confirms that another reactor is in cleaning process	Operator goes to another reactor and will not drain it due interlock activation	Operator of the upper level will fix the blaster reactor	Improving procedures and training
	Recovery	No information	Blaster operator has no confirmation about which reactor is in cleaning process	Operator will be in the wrong group of reactors	Operator will go to the upper level and verify which reactor is in cleaning process	

[1] – Strategies to reduce the error should be related mainly to changes in procedures, training, equipment and design.

Table 3.3: Human Error Analysis (PHEA) of the reactor cleaning activity (step 3.2)

The results of PHEA allow the main PIFs contributing to the risk to be analysed. Table 3.4 shows the PIFs related to types of errors evaluated in PHEA.

Type of error	Performance Influencing Factors (PIFs)
Action in the wrong direction	Distraction, practices with unfamiliar situations or poor identification
Right action in the wrong object	Distraction, poor identification, poor lighting, identification of displays and controls or poor communication
No action	Practices with unfamiliar situations or working hours and breaks
Omitted action	Practices with unfamiliar situations, working hours and breaks or distraction
Omission of checks	Distraction or poor communication
Right check in the wrong object	Distraction, poor identification, poor lighting, identification of displays and controls or poor communication
Wrong check in the right object	Distraction, poor identification, poor lighting, identification of displays and controls or poor communication
Wrong check in the wrong object	Distraction, poor identification, poor lighting, identification of displays and controls or poor communication
No information	Poor communication or poor authority and leadership

Table 3.4: Identification of the most critical PIFs during cleaning reactor activity

The interlock pressure system theoretically prevents an undue drainage on the various operator errors on by-pass activation. It is the last protective barrier of the preventive system. However, its actual efficiency should be further evaluated through studies of LOPA.

The list of possible error types with PIFs demonstrates that factors such as distraction and working hours and breaks contribute directly to errors related to the operator's physical state. Identification of displays and controls, poor identification and poor lighting are related to visual factors that influence the decisions of the operator. Poor authority, poor leadership and poor communication refer to organizational policy and practices whilst unfamiliar situations refer to operator experience.

Representation

Fault Tree Analysis

The fault tree analysis representing the development of the accident was developed and is shown in Figure 3.2.

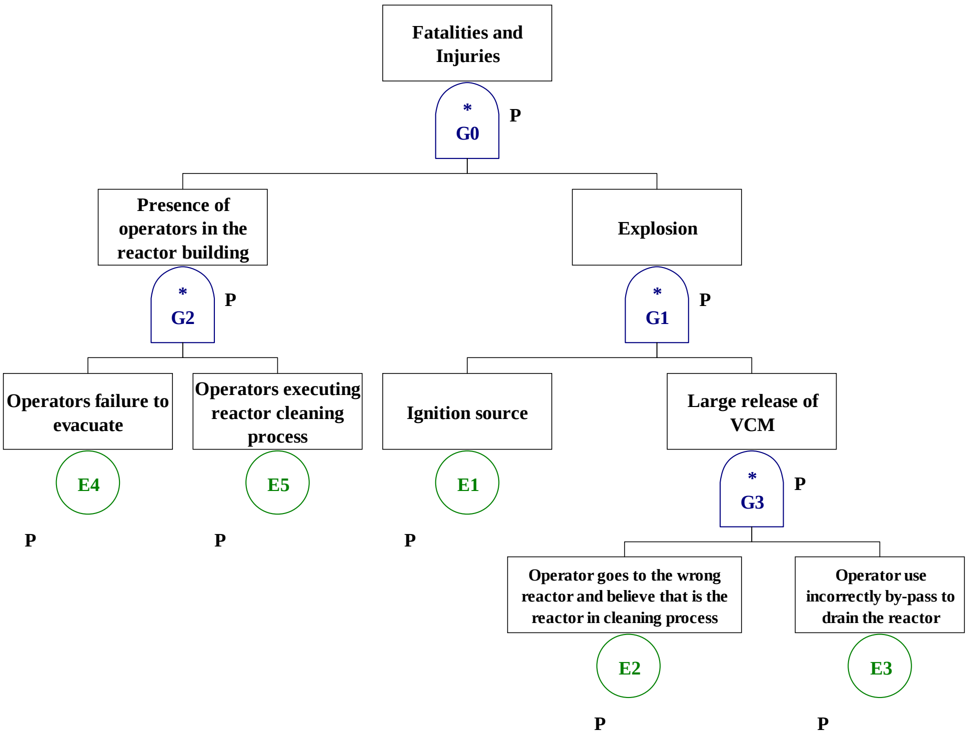

Figure 3.2: Fault tree representation of a large release of VCM scenario followed by explosion and fire causing fatalities

The basic events are directly influenced by the root causes that contribute to the occurrence of the top event (accident). Below is the list of root causes related to each basic event (Chemical Safety and Hazard Investigation Board, 2007).

Basic Event E2 - Operator believes he went to the reactor which required cleaning, when in fact he went to the reactor in operation

- There is no status indicator in the reactor
- Symmetrical layout of reactors
- Similarity of reactors
- Overload of blaster operator

Basic Event E3 - Operator uses the bypass valve to open the bottom valve of reactor in operation

- Bottom valve of the reactor does not open (interlock system - pressure above 10 psi)
- Existing system bypass
- No physical control of air injection hoses of emergency
- No bypass procedure during normal operation
- Supervisor unavailable

Basic Event E4 - Employees fail to evacuate the area

- Ambiguous procedures about how to control large releases of VCM
- Insufficient evacuation training
- No routine drills

IDA (Influence Diagram Analysis)

IDA allows a simplified and detailed view of the factors that influence the event (see Figure 3.4). The main elements that affect the scenario are represented by the ellipse, while the white square represents the uncertainty that led to the accident. The hexagons correspond to the investment possibilities that need to be performed. These investments are shown in blue. The IDA provides a quick and practical decision model and the great value of the diagram is its power of communication since it is easily understood and allows a large amount of information to be considered.

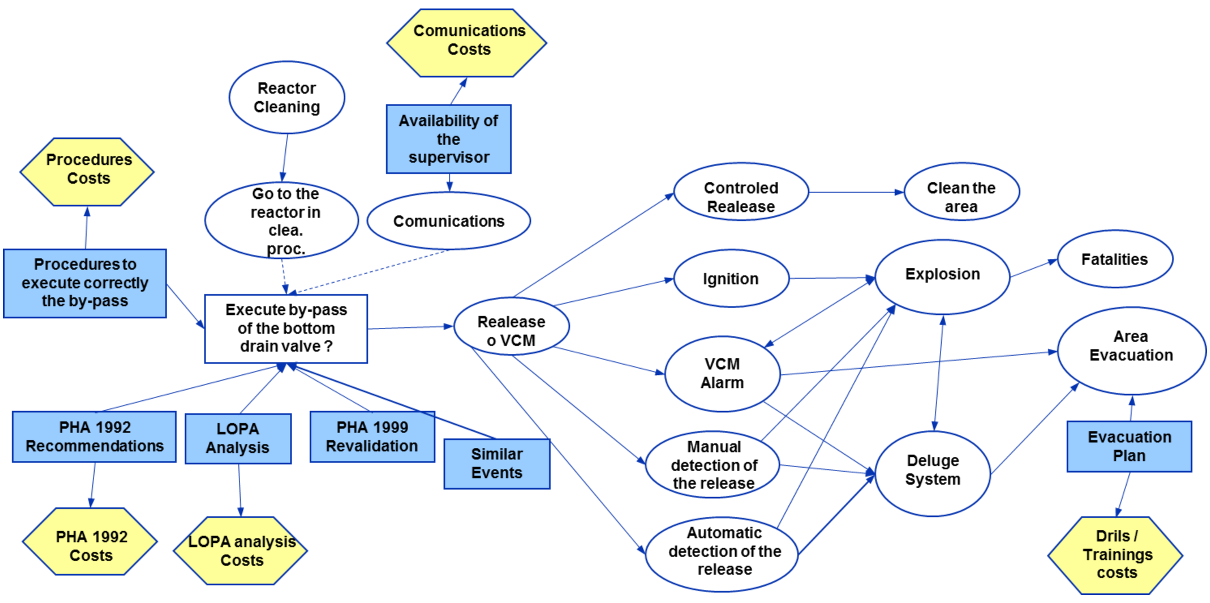

Figure 3.4: Diagram of influences of the Formosa-IL accident

The diagram identifies possible investments, but not the best option. Detailed quantitative studies could show which ones would be the priority investments, although much time, effort and knowledge are required for their development.

The problem of prioritization of the best investments can be treated in two ways. The first one from a management point of view using more general information of the organization, obtained through the analysis of PIFs. The weighted score method for decision making was used due to the following characteristics concerning prioritization of the recommendations:

- Limited financial and resource time
- Investments are independent of one another
- There are factors that may not have been considered, but the diagram logic is consistent
- Evaluation can be developed by a group, but the approval is directed to a single person (the manager)
- Quantification of the whole scenario is not as precise
- Some significant and consistent records need to be presented to justify the selection

The other way is through an operational focus based on the estimated probability of human error through the technique of reduction, evaluation of human errors HEART and quantification of the accidental scenario using the FTA.

The recommendations that were suggested to Formosa-IL are summarized below. Assessments were prepared to prioritize the recommendations.

- Recommendation A - Increase the supervisor availability
- Recommendation B – Implementation of Layer of Protection Analysis (LOPA) studies
- Recommendation C - Implementation of Recommendations from Process Hazard Analysis PHA1992
- Recommendation D - Procedures for use of bypass during normal operation

Quantification of Human Error

Quantification of Basic Events for the FTA

Quantification is an important step in defining the impacts of possible improvements in the reactor design. For quantification of the fault tree, it is necessary to estimate the probability of fault of the basic events. The human error probabilities (HEPS) are estimated using the HEART Methodology.

- Basic Events E2 to E4 have the associated probability of fault presented in Table 3.5:

Basic Event E2	Central	B5	B95
Generic Task E	0.02	0.007	0.045
Errors Producing Conditions (EPC)		**Proportion**	**Calculation**
Pathway capacity overload particularly caused by simultaneous presence of non-redundant information (x 6)		0.2	(6-1) x 0.2 +1 = 2.0
No direct scheduled and clear confirmation of an intentional action (x 4)		0.3	(4-1) x 0.3 +1 = 1.9
Assessed probability of fault	0.02 x 2 x 1.9 = 0.076		
Basic Event E3	**Central**	**B5**	**B95**
Generic Task B	0.26	0.14	0.42
Errors Producing Conditions (EPC)		**Proportion**	**Calculation**
No direct scheduled and intentional action of a clear confirmation. (x4)		0.1	(4-1) x 0.1 +1 = 1.3
Little or non-independent checking or testing of output (x 3)		0.2	(3-1) x 0.2 +1 = 1.4
Assessed probability of fault	0.26 x 1.3 x 1.4 = 0.47		
Basic Event E4	**Central**	**B5**	**B95**
Generic Task I	0.03	0.008	0.11
Errors Producing Conditions (EPC)		**Proportion**	**Calculation**
Lack of familiarity with the situation that is potentially important, but that occurs infrequently or which is unprecedented. (x 17)		0.5	(17-1) x 0.5 +1 = 9
Assessed probability of fault	0.03 x 9 = 0.27		

Table 3.5: Probability of fault of Basic Event E2 to E4

- Basic Event E1 (Source of ignition) has the ignition probability of 30% (Uijt de Haag, 1999).
- Basic Event E5 (Operators present for cleaning process of reactor) has a probability of 4/24 representing 4hr of day (day and night) on the lower level.

Critical analysis of the probabilities of the basic events

ID	Description of Basic Event	Details	Probability
1	Igniting source	The probability of ignition of a flammable fluid depends on parameters such as fluid molecular weight, discharge rate of leakage, temperature of self-ignition, energy and presence of an igniting source. It varies depending on the fluid and operational storage conditions which influence its rate of release. The calculation of ignition could be determined using advanced software, but the value of 30% (Uijt de Haag, 1999) is consistent for the purpose of this study.	30%
2	Operator incorrectly goes to reactor in operation and believes to be in reactor in cleaning process	The displacement of the operator to a reactor for cleaning process is considered part of the routine and occurs in a daily basis. The reactors have indicators at the bottom and on the control panel. The probability of 7.6% relatively low compared to the others can be accepted, since the only deficiency evaluated is the identical arrangement of the reactors.	7.6%
3	Operator uses bypass to open bottom valve of reactor in operation	The probability of use of the by-pass valve to open the bottom of the reactor corresponds to 47% which is a high value for use of bypass security systems. Normal safety standards do not allow security systems to be shut down even during maintenance. Since this procedure of bypass of this safety valve was common in company of Formosa – IL, the value is quite representative.	47%
4	Employees fail to evacuate the area	Normally the fault of operators during evacuation in major accidents should correspond to very low values; the calculated value of 27% that corresponds to almost 1 fault every 3 times is very representative.	27%
5	Operators present for the reactor cleaning process	It is considered that there are operators in the surrounding areas of the reactor during the cleaning process for approximately 4 hours of the day.	16.7%

Table 3.6 summarizes the probabilities of occurrence of the basic events.

Quantification of the scenario of the Formosa-IL accident (FTA)

The probabilities calculated using the HEART method can be used to quantify the fault tree of the accident in Formosa-IL, as shown in Figure 3.3. The purpose of this calculation is to identify the impact of each change in project.

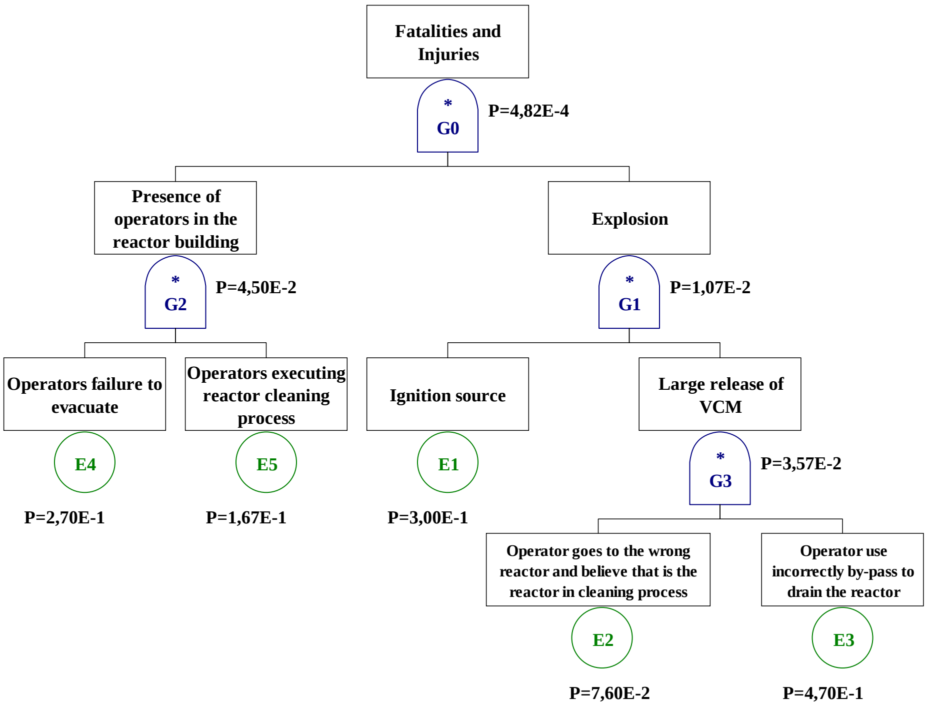

Figure 3.3: Representation and quantification of fault tree of a large release of VCM scenario followed by explosion and fire causing fatalities

Quantification of the IDA (MANAGEMENT FOCUS)

The management has no detailed information of operation; therefore the decision making process is based on general techniques that do not require specific information of the activity in question. The general view allows an evaluation of the system as a whole, ensuring that the interactions of various sectors occur in the best possible way.

Each recommendation was evaluated through a score. This technique can be performed by different managers from different sectors through an individual assessment of the various stakeholders, yielding a final average. Table 3.7 shows the weight of each recommendation considered to quantify the IDA.

Weight of evidence	Effective	Ineffective
What is the weight of evidence of procedures for the use of by-pass in normal operation to ensure bypass of the interlock with safety	0.3	0.7
What is the weight of evidence of the implementation of the recommendations of the PHA 1992 to ensure bypass of the interlock with safety	0.6	0.4
What is the weight of the evidence of implementing LOPA studies to ensure bypass of the interlock with safety	0.8	0.2
What is the weight of evidence for increasing the availability of the supervisor to ensure bypass of the interlock with safety	0.2	0.8

Table 3.7: Weight of evidence

Table 3.8 shows the results of IDA quantification.

Se	E	E	E	Success	Fault	Total Weight	Weighted success	Weighted fault
D The procedures for using the by-pass in normal operation	**C Implementation Recommendations for PHA 1992**	**B Implementing LOPA Studies**	**A Increase the availability of the supervisor**					
Effective	Effective	Effective	Effective	0.95	0.05	0.0288	2.7%	0.1%
Effective	Effective	Effective	Ineffective	0.90	0.10	0.1152	10.4%	1.2%
Ineffective	Effective	Effective	Effective	0.90	0.10	0.0672	6.0%	0.7%
Ineffective	Ineffective	Effective	Effective	0.90	0.10	0.0448	4.0%	0.4%
Ineffective	Effective	Effective	Ineffective	0.85	0.15	0.269	22.8%	4.0%
Effective	Ineffective	Effective	Effective	0.80	0.20	0.0192	1.5%	0.4%
Effective	Ineffective	Effective	Ineffective	0.70	0.30	0.0768	5.4%	2.3%
Ineffective	Effective	Ineffective	Effective	0.60	0.40	0.0168	1.0%	0.7%
Effective	Effective	Ineffective	Effective	0.60	0.40	0.0072	0.4%	0.3%
Effective	Effective	Ineffective	Ineffective	0.50	0.50	0.0288	1.4%	1.4%
Ineffective	Ineffective	Effective	Ineffective	0.50	0.50	0.1792	9.0%	9.0%
Ineffective	Effective	Ineffective	Ineffective	0.40	0.60	0.0672	2.7%	4.0%
Effective	Ineffective	Ineffective	Effective	0.40	0.60	0.0048	0.2%	0.3%
Ineffective	Ineffective	Ineffective	Effective	0.30	0.70	0.0112	0.3%	0.8%
Effective	Ineffective	Ineffective	Ineffective	0.10	0.90	0.0192	0.2%	1.7%
Ineffective	Ineffective	Ineffective	Ineffective	0.01	0.99	0.0448	0.0%	4.4%
							68.2%	31.8%

Table 3.8: Weight of evidence to conduct by-pass of the bottom valve of the reactor with safety

The Weighted Score Method determines the possible combinations between the recommendations and presents a successful weighted acceptance. Combinations that have the higher weighted success should have their cost of implementation verified. The implementation of the recommendations B and C correspond to the combination that attracts most managers and presents a probability of weighted success of 22.8%. The implementation of recommendation B only is very effective, but the weighted success of the activity is only 9%, being the third favourite. The second preferred combination corresponds to recommendations B, C and D with 10.4% probability of success. The implementation of all recommendations, obtaining the highest probability of success is in the eighth position. Recommendation A was considered of low efficiency (weighted success 0.3%) and consequently its implementation makes no significant contribution to the existing combinations. This analysis is based on the subjective judgment of management group members and the values used in this study were estimated.

Recommendation impact using FTA (operational focus)

To each proposed recommendation, the EPC is re-assessed considering the reduction fraction in its value and quantifying the fault tree of the top event once more. This way it is possible to observe how each recommendation can contribute to reducing the probability of occurrence of the top event.

Table 3.9 shows the probability of accident occurrence and their respective relative reduction considering the implementation of each recommendation. From the operational point of the view, recommendation B has the largest 92% reduction in the probability followed by a 50% reduction of recommendation A. The third largest reduction of 34% is related to recommendation D.

ID	Recommendation	E2		E3		E4		FTA	
0	Without recommendations	0.076	Reduction	0.47	Reduction	0.27	Reduction	4.82E-04	Reduction
B	Implement studies of LOPA	0.076	0%	0.34	29%	0.03	89%	3.88E-05	92%
A	Increase the availability of supervisor	0.04	47%	0.45	6%	0.27	0%	2.43E-04	50%
D	Procedures for use of by-pass in normal operation	0.076	0%	0.31	35%	0.27	0%	3.18E-04	34%
C	Implementation of Recommendations PHA1992	0.076	0%	0.35	26%	0.27	0%	3.59E-04	26%
	A+B+C+D	0.04	47%	0.27	42%	0.03	89%	1.65E-05	97%

Table 3.9: Impact of implementation of recommendations

Comparison between management and operational focus

The results of the two focuses are similar showing that if implemented, recommendation B has higher potential for reduction in the prevention of an accident. Although recommendation A is not well qualified in management focus, it is the second best option according to the operational focus. This difference probably derives from the management group's choice to disregard this recommendation. Recommendation C was most prominent in terms of management than operation. Recommendation D presented similar classification in both focus.

Conclusions

There are numerous studies related to human behavior and each one possesses specific characteristics. Basically, they are differentiated in external focus (observable) and internal (cognitive). The method to be selected for analysis depends on the availability of information and the viability of cognitive analysis.

The human error probability was calculated based on both observable and cognitive focus following the structure of the SPEAR method. The observables factors were obtained from the HTA and the cognitive factors were analyzed with the application of PHEA. The most important step that ensured that both factors were considered in the calculation of the probability of human error is the development of the FTA based on the causes and consequences evidenced in PHEA.

The development of IDA is also based on the results of the task analysis and the analysis of human errors, which allows a visualization of variables and uncertainties of the decision process that, must be performed by managers. The results of the management focus can be less transparent than the operational focus, as it is more subjective and may be related to the interests of the decision makers.

The results of the operational focus take more objective factors into consideration with more precise indicators as its assessment is based on mental models of the plant process, which facilitates the evaluation. These different results demonstrate the need to consider the operating environment in decision making and that they are essential for the calculation of the probabilities of human errors. This study shows that cognitive studies are not simple and are not always feasible. The efforts to calculate the probability of human error should be evaluated. Although the objective of this study was to assess the probability of human error, the results of this cognitive study provide information and possible recommendations that may contribute to reducing risks at the industrial plant.

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