PRIORITISATION OF CRISIS TREE DIAGRAMS WITH AHP

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ABSTRACT

Disasters happen regularly and it is essential to learn from them in order to prevent new ones. This paper presents a new graphical representation, the Crisis Tree Analysis (CTA), to map the combination of basic events leading to a crisis. Then, the criticality of each event is assessed using the Analytic Hierarchy Process (AHP), which permits to prioritise tangible and intangible basic events on the same scale. The technique is briefly illustrated with the Bhopal disaster.

Keywords: Analytic Hierarchy Process, Crisis Tree Analysis, Risk Management, Bhopal Disaster.

1. Introduction

The management of most companies is concerned mainly with profitability. Investment in safety appears a drain in resources with no return even in the long run. However, industrial incidents regularly happen, and even sometimes repetitively in the same organisation, leading potentially to severe human and environmental consequences. This paper will present a successive utilisation of two methods in order to facilitate the identification and quantification of the risks.

The first method is a Crisis Tree Analysis (CTA), which graphically display the combination of facts or basic events that leads to an incident. The undesired event is placed on the top of a tree and its children represent the basic events. The second method is an adaptation of the Analytic Hierarchy Process in order to quantify the likelihood a basic event will happen. An application on the Bhopal disaster will be briefly presented.

2. Crisis tree analysis

The crisis tree analysis (CTA) represents graphically the combination of basic events or facts leading to a crisis. This technique is a further development of the fault tree analysis (FTA). FTA has been widely used as a safety and reliability tool for complex systems (Lee, Grosh et al. 1985). In both analyses, the undesired event is placed on the top of a tree and its children represent the basic events. These basic events are due to human errors, equipment failure or environment interference. Tree analysis provides a logical representation of the relation between the top event and the basic events. Its construction is always top-down, starting from the main undesired event and then developed downwards with the causes making the basic events of the tree. A tree is made of a number of elements which are:

Top event: The undesired event (crisis)

Basic event: The basic causes of the undesired event which are usually component failures, human errors or environment interference

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Undeveloped event: This fault event is not developed downwards due to lack of information or insignificance

Gates event: It indicates the outcomes of a combination of basic events or other gate events, which is the release or not release leading to the upper basic or main event. The gate events are also referred to as intermediate events

In order to achieve a rational and precise analysis, the undesired event should be defined clearly. The boundary of the analysis should be set in order to define which environmental influences are included and the level of resolution and depth of the analysis. Then, the tree is constructed top-down by identifying the basic events leading to the upper event. These basic events are combined with gates. In a fault tree diagram, the AND and OR gates are sufficient to describe most of the situations: a machine works or does not work (table 1). However in a crisis analysis, the output is not always binary. The magnitude of the crisis can be very different depending on the number of active inputs. For example, consider the three following events and consequences:

an uncontrolled manipulation lead to a lethal explosion (crisis level 1),

location is close to habitations therefore a higher number of persons are killed (crisis level 2),

no evacuation procedure is in place then the number of victims is much higher (crisis level 3).

The number of events occurring has clearly an impact on the severity of the crisis. Therefore, we have introduced the new gate REVOLVING, where the output indicates the level of the crisis. The logic tables of these three gates are given in table 2.

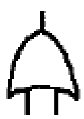
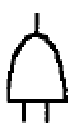
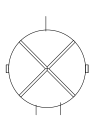
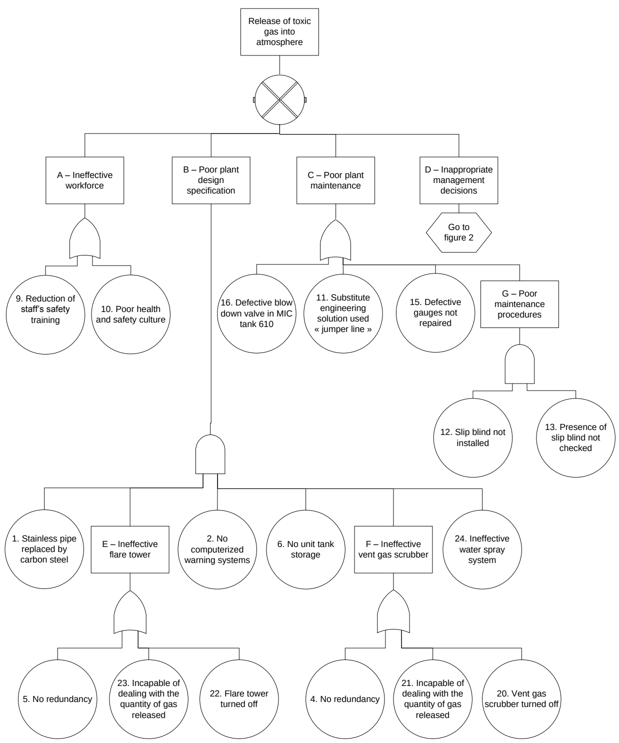
Symbol	Gate name	Description	Inputs
	OR	The output event occurs if any of its input event happen	≥ 2
	AND	The output event occurs if all input event happen	≥ 2
	REVOLVING	The output occurs if any of its input event happen and is amplified with its number	≥ 2

Table 1: OR and AND logic gates

Input 1	Input 2	Output AND	Output OR	Output REVOLVING
0	0	0	0	0
1	0	0	1	1
0	1	0	1	1
1	1	1	1	n (number of the inputs at 1)

Table 2: Logic table of the gates OR, AND and REVOLVING

The CTA is a powerful method for diagnostics and problem finding because it follows a logical and systematic process of breaking down a complex system into its root causes (figure 1 and 2). It does not only analyse the traditional physical parts of the system but intangible events can be considered in the tree (e.g. human skill, quality of the procedure, etc). The CTA is inherently a qualitative analytic tool, therefore a quantitative method must be further utilised because each basic event does not have the same probability to occur. This hierarchical analysis, focusing on the top event and then cascading deductively on basic event, can be easily reused in the Analytic Hierarchy Process in order to quantify the priority of each basic event.



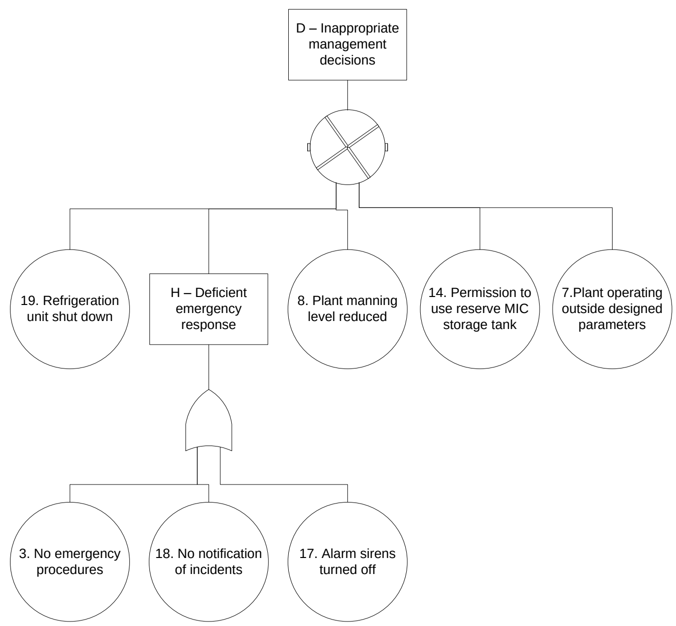


Figure 1 and 2: Crisis tree diagram of the Bhopal disaster

3. Reliability Block Diagrams

Reliability Block Diagrams (RBD) are systems substantially equivalents of crisis tree diagrams. Fault trees model system failure combinations. RBD is a success oriented model: it looks at the combinations that will lead to system functionality. Each block in the RBD represents an actual functioning component. Any failure is represented by removing the block from the diagram. If the connection between input and output is totally interrupted trough any path then the system fails (Corporation 2007). Blocks could be arranged either in parallel or series. A parallel structure corresponds to an AND logic gate in the crisis tree diagram, whilst the series format corresponds to an OR logic gate. The new REVOLVING gate indicates the level of the crisis. Its representation in an RBD is a block series as in the OR gate but with an additional hyperblock covering each entry. The hyperblock is green if all blocks are there. If a connection between the input and the output of the hyperblock is missing, it will turn red. The number of red hyperblocks indicates the level of the crisis. Table 3 summarizes the conversion.

Crisis Tree Diagram		Reliability Block Diagram	
Gate name	Symbol	Structure	Representation

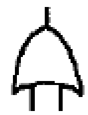
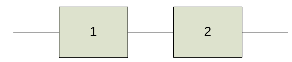
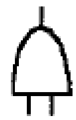
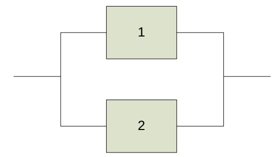
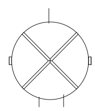
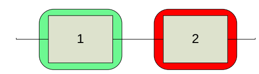
OR		series	
AND		parallel	
REVOLVING		Green or red hyperblock	

Table 3: CTD gates and corresponding RBD representation

4. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making (MCDM) method that helps the decision-maker facing a complex problem with multiple conflicting and subjective criteria (Saaty 1977; Saaty 1980; Ishizaka and Labib 2009). Several papers have compiled the AHP success stories in very different fields (Zahedi 1986; Golden, Wasil et al. 1989; Shim 1989; Vargas 1990; Saaty and Forman 1992; Forman and Gass 2001; Kumar and Vaidya 2006; Omkarprasad and Sushil 2006; Ho 2008; Liberatore and Nydick 2008). New applications integrate AHP with other methods as mathematical programming techniques like linear programming, Data Envelopment Analysis (DEA), Fuzzy Sets, House of Quality, Genetic Algorithms, Neural Networks, SWOT-analysis (Ho and Emrouznejad 2009). In this paper, we will describe a new integration of AHP simultaneously with the CTA (figure 1).

AHP has the advantage of permitting a hierarchical structure of the problem, which provides users with a better focus on specific criteria and sub-criteria when allocating the weights. The goal of the decision is located on the top of the hierarchy. The children of the tree are the criteria and sub-criteria to satisfy. The leaves are the alternatives to consider. At the exception of the leaves, the AHP structure is similar to the CTA one: the goal is the undesired event and the criteria are the basic events. Therefore, AHP can easily be adopted to measure the criticality of the basic event.

The main feature of AHP is the pairwise comparison of criteria of the same hierarchic level, which provides more accurate results than a direct evaluation as the decision-maker concentrates only on two elements at the time (Millet 1997; Ishizaka, Balkenborg et al. 2010). The comparisons are entered in a positive reciprocal matrix **A**. The eigenvalue method is used to calculate the priorities from this matrix:

$$\mathbf{A} \cdot \mathbf{p} = \lambda_{max} \cdot \mathbf{p} \qquad (1)$$

where **A** is the comparison matrix

p is the priorities vector

λ_{max} is the maximal eigenvalue

In order to declare the comparison matrix consistent enough for calculating credible priorities, it must pass a consistency check (2). If the Consistency Ratio (CR) is less than 10%, then the matrix can be considered as having an acceptable consistency.

$$CR = CI/RI, \qquad (2)$$

where RI is the Random Index (the average CI of 500 randomly filled matrices)

CI is the Consistency Index

$$CI = (\lambda_{max} - n)/(n-1), \qquad (3)$$

where n is the dimension of the matrix

λ_{max} is the maximal eigenvalue

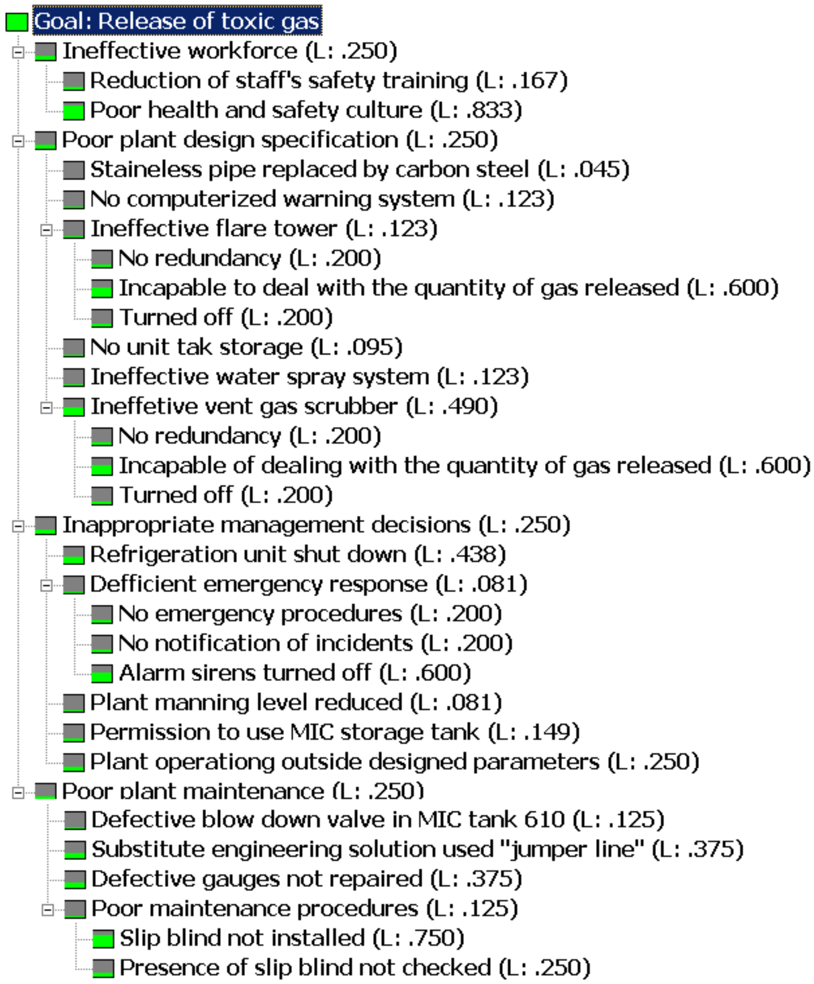


Figure 1: Criticality of each event in the Bhopal disaster

5. Conclusion

Catastrophes can sometimes lead to beneficial transformations. Experience with failure has proven to be more likely than experience with success to produce conditions for learning, to challenge existing knowledge and to extract meaningful knowledge from it (Haunschild and Rhee 2004). Aftermath of these events, companies, organisations, societies and researchers are obliged to act in order to prevent new crisis.

In this paper, a new graphical analysis has been combined with advanced techniques of the Operational Research in order to prioritise risks. Finally, let us stress that the combined technique with the Crisis Tree Analysis and AHP is generic and can be easily use to prevent disasters in any field. From this paper, we can propose three meta-dimensions to enhance learning from crisis:

- Re-examine processes, determine what went wrong and learn from their failures,

- Develop new methods to identify, evaluate and mitigate risks,

- Learn vicariously from other fields failures because lessons are often generic and transferable.

Disasters happen regularly and probably it will not change in the future. However, it would be unforgivable not to learn from them and to have a repeat disaster even in another field.

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