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ORIGINAL ARTICLE

Application of Tripod-Beta Approach and Map – Overlaying Technique to Analyze Occupational Fatal Accidents in a Chemical Industry in Iran

IRAJ MOHAMMAD FAM[1], ALI KIANFAR[2] and MOHAMMAD FARIDAN[3]

[1]Department of Occupational Health and Safety, Faculty of Health, Hamadan University of Medical Sciences, Hamadan, Iran; [2]Department of Occupational Health and faculty of Health, Tehran University of Medical Sciences, Tehran, Iran; [3]Department of Occupational Health and Faculty of Health, Kurdistan University of Medical Sciences, Sanandaj, Iran.

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ABSTRACT

The undesirable effects and consequences of occupational fatal accidents have placed a great emphasis on applying preventive measures. This study was aimed to analyze and specify the latent causes of occupational fatal accidents in Exir Chemical Plant, Urmia - Iran in 2008-2009. The analytical Tripod-BETA method was used. A geographic Information System (GIS) was then used to determine a list of the most significant preconditions and active failures contributing to occupational fatal accidents. The total number of recognized preconditions and latent failures were 572 and 852 respectively. The most frequent preconditions and latent failures were determined by overlaying the coded sheets on each other. Results of the study showed that Promoting and enhancement of the company's safety culture, a carrot and stick motivation policy accompanied by comprehensive assessments to prioritize safety training programs, were among recommended preventive actions to control and reduce fatal accidents.

Keywords: *Accident, Chemical Industry, GIS, Tripod – BETA*

INTRODUCTION

Human resource is one of the major elements of production and through cooperation, plays significant part in a sustainable development of communities [1]. Therefore, Human resource is a strategic asset of an organization and lack of such resource or its inefficient use, even with a community own abundant natural resources such as oil and gas does not contribute to a real or sustainable development [2]. It is also considered that promoting health indices is one of the indicators of constituting a healthy and productive population [3].

An occupational fatality is a death that occurs while a person is at work or performing work-related tasks. Occupational fatalities are also commonly called" occupational deaths" or "work-related deaths/fatalities" and can occur in any industry or occupation [4]. Traumatic occupational fatalities represent a public health problem of significant proportion. Each day, an average of 6000 people die as a result of work-related accidents or diseases totaling more than 2.2 million work-related deaths a year [5].

It is important to understand the factors (human, technical, organizational, etc.) may have contributed to the outcome when incidents occur in the workplace in order to avoid similar incidents in the future. Through a good understanding of the occurrence of incidents, appropriate methods for incident prevention can be developed [6].

In spite of considerable development of safety engineering and introduction of system safety as an approach to accident prevention and detection of deficiencies in system components that have a potential for failure, yet accidents still occur and it seems to be impossible to eliminate their occurrence completely [7]. Thus, developing of hazard analysis techniques and utilizing them correctly is a basis for proposing and developing measures to prevent similar accidents or their consequences in future. The studies illustrated the importance of understanding of why accidents/incidents occur and how to prevent them [8, 9, 10, 11]. Most traditional engineering accident/incident analysis

* **Corresponding author:** Iraj Mohammad Fam, Email: mohammadfam@umsha.ac.ir

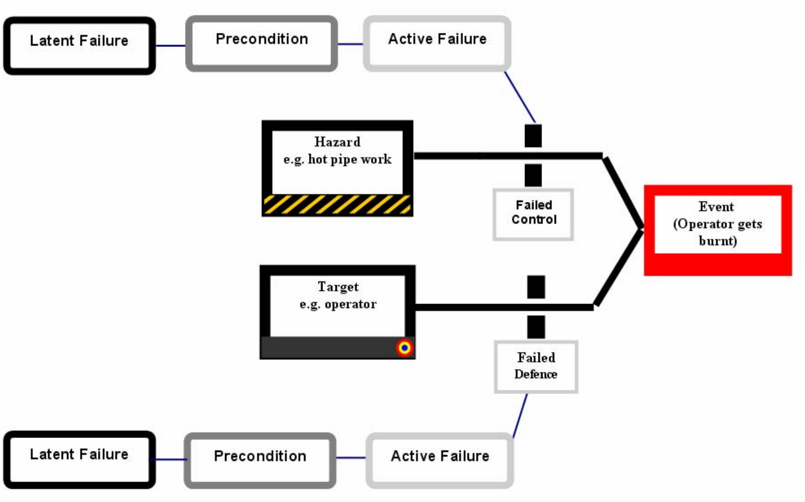

Fig 1. Tripod BETA diagram

techniques focus on the technical components of the system that failed.

The accident analysis process must determine not only the specific unsafe acts and conditions that contributed to the accident, but also the deficiencies in the management system that allowed the accident to occur. On the other hand, the purpose of incident analysis is to determine the causes and the specific factors that contribute to incidents. The analysis gives insight into what went wrong in order to take counter-measures to avoid recurrence. During the analysis, information is collected about the workplace, the work itself, the work process, and the technology involved.

Incident analysis then can provide us an understanding of the previous accidents. There are many ways to analyze incidents. Traditional analytical techniques deal mainly with the identification of event sequences, looking for unsafe acts or conditions leading to the accident. Such techniques include the Why-because analysis, Sequence of events (domino effect), Sequential time and events plotting, Multilinear events sequencing, technique of operations review and change analysis [9]. Causal analysis goes beyond identifying what happened, but looks deeper into why it happened [9].

In this study the TRIPOD BETA method was used to analysis of fatal occupational accident. The Tripod Beta Analysis looks at what caused the sequence of events in an incident. The analysis shows how the incident happened, what barriers failed and why these barriers have failed. The TRIPOD BETA relies on building a tree structure that represents the incident mechanism, the events and their relationships. The Event in a Tripod Beta Diagram is the result of Hazard acting on an Object. A Barrier is something that preventing the meeting of an object and a hazard. When such a barrier fails, a causation path is made to explain how and why this happened. The Tripod method presumes that incidents are caused by human error, which can be prevented by controlling the working environment. The causation path displays this by starting with the Active Failure of the barrier, then under what Precondition or in what contextual state this happened and at last the Underlying Failure of the barrier. The aim of Tripod Beta is to uncover the hidden deficiencies in an organization; the Latent Failures. These can be classified into eleven Basic Risk Factors (BRF's); these are categories that represent distinctive areas of management activity where the solution of the problem lies (Fig 1).

Generally, using and producing chemicals can present dangers to both people and the environment. Operational errors such as pressure and temperature beyond critical limits can cause catastrophic consequences to life and environment and leading to financial loss. Major industrial hazards are generally associated with the potential for fire, explosion or dispersion of toxic chemicals [12].

The main objective of this study was to analyze the fatal accidents and determine the prevalent preconditions and latent failures contributing to work related fatalities in a chemical plant in Iran.

MATERIALS AND METHODS

This is a cross-sectional study in Exir Chemical Plant, Urmia - Iran in 2008-2009. Tripod-BETA method was used to analyze fatal accidents. Tripod-BETA is a structured 'tree' approach to the analysis of accidents and incidents based on the Tripod Theory of Accident Causation (described above) and the Hazard Management Process. The analysis is divided into three distinct phases, and the completion of each phase provides a logical 'tollgate' that can be used to verify the scope of investigation.

Three Phases of technique included:

The first phase involves gathering facts and data related to the event and its consequences and developing a Core Diagram. The core model of a Tripod-BETA tree describes the incident mechanism including the hazards, targets and events in cause-effect terms. The basic building block is a hazard, target and event 'trio' (Fig 1). A hazard is the agent of harm, which causes the harm or change the state; the target is the object of harm which is damaged or changed, and the event is an occurrence where the hazard and target combine to result in an accident (harm) or near miss (potential for harm). Harm is the undesirable change of state. Normally around 3 to 5 of these trios are needed to fully describe an incident. The purpose of this diagram is to understand the conceptual pathways which join hazards and targets with events.

The second phase is to examine the circumstances of the incident to identify what hazard management measures (controls and defenses) failed (Fig 1). Failed or missing hazard management measures are added to the core model of the Tripod-BETA tree. At this phase, trigger events and the other controls and defenses that were make ineffective beforehand are identified.

The third phase aims to identify the underlying causes of the incident. The Tripod-BETA tree is completed by plotting causal paths for each failed or missing hazard management measure, leading from immediate failures to preconditions and underlying causes. Tripod theory emphasizes that active failures do not occur in isolation but are influenced by other external factors such as organizational or environmental preconditions. Latent causes of each control and defense failure are examined, many of them originate from failures elsewhere in the business often in decisions or actions taken by planners, designers or managers remote in time and location from the front line of operators. This leads the investigation into the paths from each active failure to one or more latent failures. The Tripod-BETA model, while acknowledge that human error often features as a trigger to incidents, indicates that organizational deficiencies may have contributed to these errors or magnified the consequences. This model is a simplification of an event which is designed to give an investigation team a mental picture that helps them to recognize relevant facts and likely sequences of events.

As mentioned above, Tripod-BETA method includes three phases which are mainly reflected in the construction of a Tripod-BETA tree. Accordingly, the first step in accident analysis will be the recognition of hazards and at risk targets. In the second step, active failures or unsafe acts that breach the hazard management measures, controls and barriers are determined. This conducted by a team of accident analysis investigators.

As the investigation proceeds to the next phase and based on the technique structure, initially preconditions related to each active failure, are selected from a database of 44 already prepared preconditions. Then, the most likely associated latent failures are chosen from these 11 suggested categories.

- Hardware - where the failures are due to low quality of materials, poor assembly, ageing, etc. (position in life cycle)

- Design – where the deficiencies are due to Design defects that are unreasonably dangerous characteristics of a product resulting from decisions, calculations, drawings, or specification of the design process.

- Maintenance management - where failures come from insufficient, delayed, and improper maintenance and repair.

- Procedures – where the procedures are unclear, unavailable, incorrect or otherwise unusable standardized task information that has been established to achieve a desired result

- Error-enforcing conditions - where factors such as time pressure, changes in work patterns and physical working conditions causes unsafe acts (errors or violations)

- Housekeeping - where tolerance of deficiencies in conditions of untidiness and cleanliness of facilities and work spaces or in the provision of adequate resources for cleaning and waste removal increase the chances of unsafe acts

- Incompatible goals - where there is a failure to manage conflicts between organizational goals (such as safety and production), formal rules (such as company written procedures and the rules generated informally by a work group) and demands of individuals, tasks and their personal preoccupation or distractions.

- Communication – where there are failures in transmitting information that is necessary for the safe and effective functioning of the organization to the appropriate recipients in a clear and non ambiguous or intelligible form. Transmission failures indicate that the necessary communication channels do not exist or the necessary information is not transmitted.

- Organization - where there are deficiencies in the structure of a company or the way company doing business that allow safety responsibilities to become ill-defined and warning signs to be overlooked.

- Training - where there are deficiencies in the system that provides necessary awareness for personnel. In this context, training includes on-the-job coaching mentors and supervisors as well as formal courses. Awareness refers to the process of understanding the hazardous conditions present at the worksite.

- Defenses - are failures in the systems, facilities and equipments in control of hazards or in mitigation of the consequences of human or component failures. These comprise: detection/alarm; control and interim recovery; protection/containment and escape.

It should be mentioned that, these 11 latent causes of accidents are divided into 156 sub categories which have been existed and defined in the technique structure.

Fig. 2 illustrates the most frequent preconditions and latent failures were determined by overlaying the coded sheets on each other. For example 1B in preconditions is "the working environment is not appropriately safe (conflict with worker and tools of his job, unorganized layout, unsafe conditions, etc.)" and 1.06 in latent failures is "financial limits and unseasonable pressures during design and production stages". To facilitate the process, a map overlaying technique, based on GIS software, was employed.

Preconditions coding in relation with an active failure											
		1B					1G	2A			
			2D	3A							
			4B	4C	4D						
		6A	6B		7A	7B	7C	7D			
	7E						9A	9B			
	9C	9D	9E	9F	9G						
		11A	11B								
Latent failure coding in relation with an active failure											
					1.06	1.07				2.01	2.02
2.03	2.04					2.09	2.1				
3.01			3.04		3.06	3.07				3.11	3.12
3.13							4.07	4.08	4.09	4.1	4.11
4.12	4.13	4.14									
								6.02		6.04	
6.06	6.07								7.01	7.02	
7.04	7.05	7.06	7.07	7.08							
								9.01			9.04
				9.09							
				11.08				11.12	11.13	11.14	

Fig 2. An example of preconditions and latent failures coding sheet

RESULTS

Fig. 3 illustrates the process of overlaying completed sheets with the aid of GIS based software for determining the most frequent preconditions and latent failures contributing to accidents. The most frequent preconditions and latent failures in Fig 3 illustrate with red color and the least frequent of those illustrate with white color.

The results indicated that there are 22 active failures for 7 fatal accidents that the most critical ones were:

- Recruitment of inexpert workers
- Lack of appropriate job instructions and requirements.
- Inadequate inspection and monitoring
- Wrong work procedures
- Assigning tasks to employees who have already

Table 1. The frequency of preconditions contributing to accidents

Preconditions	Frequencies
1-The predominant organizational culture of the company is not positive (personnel do not work safely and sincerely)	21
2-Due to the pressure to accomplish the tasks in the shortest period of time, some safety work practice procedures have often been neglected.	19
3-Despite the personnel's knowledge and awareness of unsafe working conditions, work procedures are routinely continued. (Health, safety, environment (HSE) and repair-maintenance related activities have been suspended by the people in charge.)	18
4-Personnel are not knowledgeable enough. They are not fully aware of their duties nor the type of tasks they have been assigned for .(They are inexperienced or have not been trained efficiently)	18
5-There are not safety work practice procedures or they are not readily available.	18
6-Inappropriate supervision. (supervisors are either absent or too busy , permit-to-work forms completed inappropriately, supervisors have not recognized the hazardous combination of operations)	15
7-Environmental factors affect or disturb the operations .(noise , odor , vibration, extreme temperatures, wind , direct sunlight, darkness, dusts, chemicals , violent work atmosphere)	15

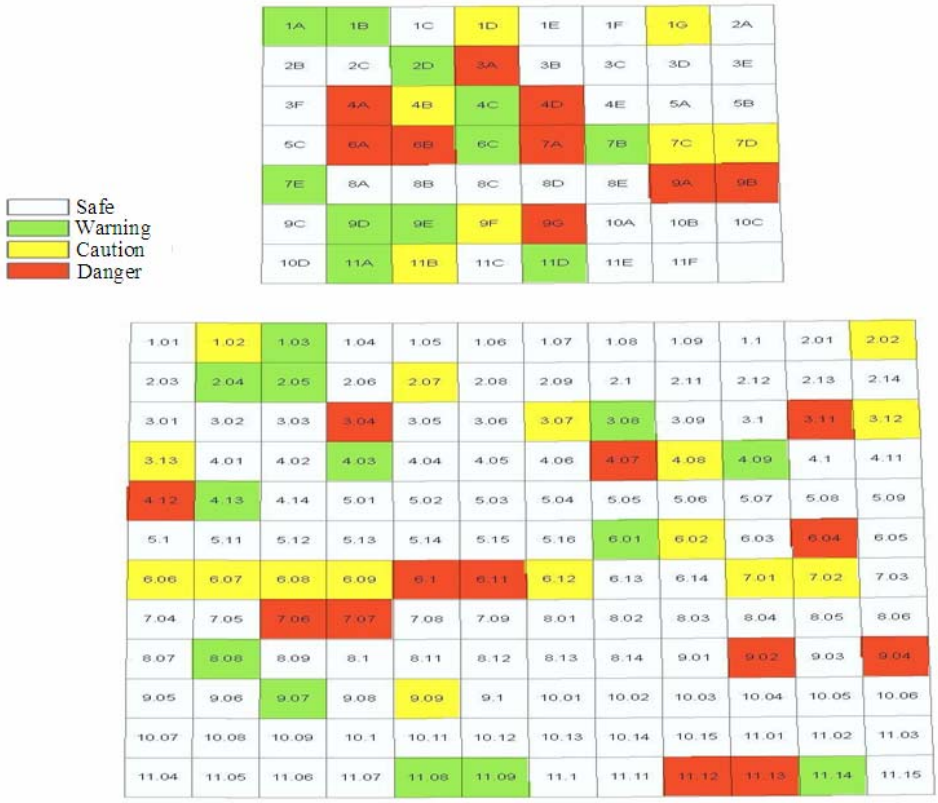

Fig 3. Output of GIS

been targets of accidents (whohave been injured before in accidents)

- Lack of adequate inspection and monitoring on holidays and the days off work.
- Insufficient or inappropriate safely equipment

Tables 1 and 2 illustrate the frequency of preconditions and latent failures in those 22 active failures already identified.

A total number of 572 preconditions and 852 latent failures were detected.

DISCUSSION

From Table 2 the most prevalent precondition contributing to occupational fatal accident in this company is the poor safety culture. Due to ever increasing hazards and harmful agents in different workplaces, and considering the fact that a sole focus on engineering or legislative attempts is not the only strategy to minimize or eliminate unsafe conditions at work place, it is now generally accepted that several other complementary measures are required to be taken [13].

According to international labor organization (ILO) statistics, the significant burden of occupational accidents and diseases is not solely technology-related [5]. The most important element in an integrated sustainable safety development, as a fundamental prerequisite to minimize work-related accidents, is attributed to cultural and societal aspects of work. Furthermore, safety experts have realized that 80 to 90 percent of work related accidents are due to unsafe acts which even strict engineering and legislative attempts have not been able to eliminate their occurrence and consequences [14]. Creation or enhancement of a positive safety culture through deliberate manipulation of various organizational characteristics now seems to be an area of concern for organizations. A number of previous studies have highlighted the role of poor organizational policies and safety culture in increasing accidents rate [15].

For instance following the King Cross fire, judge Fennel stated that A culture change in management is required throughout the organization [16].

Similarly during the piper alpha inquiry Lord Cullen said It is essential to create a corporate atmosphere or culture in which safety is understood to be and is accepted as the number one priority [17].

Investigations of rail industry accidents such as lad broke grove in 1999 have induced organizations to pay much attention to the role of a positive safety culture in minimizing the risks of fatal accidents [18].

The role of poor safety culture in accidents have been proved, Pidgeon mentions the safety culture enhancement in organizations [19].

One of the other major preconditions contributing to accidents was performing the work procedures hastily that resulted in carelessness and overlooking some safety work practice procedures deliberately. In other words, not assigning high priority to safety issues and neglecting safety requirements for the sake of production result in safety rules and procedures violation.

Performing work procedures hastily and not assigning high priority to safety issues increase the risk of accident as a consequence [20].

Table 2. The frequency of Latent failures contributing to accidents

Latent failures	Frequencies
1-There is not appropriate supervision or monitoring to perform the procedures. (Supervision timing is not suitable).	20
2- No assessment to ensure that employees have a good understanding about safety work practice procedures.	19
3-Employees' responsibilities have not been defined. (required tasks have not been covered in employees' list of responsibilities, training activities are limited to general definitions of responsibilities)	19
4-Insufficient supervision to establish safe work conditions.	18
5-Insufficient management commitment to work cognition.	18
6-There is no supervision or corrective measure to improve employees' unsafe behavior.	16
7-There are not sufficient resources, both budget and time, to apply training programs.	16
8-The company does not care about safety matters, when applying changes or taking efficiency enhancement measures. Safety concepts are not evident in work procedures; there is no active policy or strategic objectives to encourage working safely).	15
9-Authorized employees do not receive thorough or appropriate reports about the potential hazards.	15

The following are the three fundamental latent failures contributing to fatalities in this study:

Poor safety supervision

Designing and implementation of safety programs is emphatically considered as one of the important factors in continuous improvement of an organization. Exert accurate supervision of working practices, compare the results with the standards and in case of incompatibilities, take corrective actions are essential to the success of the safety program. To implement a safety program successfully putting a great emphasis on an appropriate supervising system based on a carrot and stick motivation policy is necessary [21, 22].

Assigning safety related responsibilities inappropriately and not holding personnel accountable.

Safety programs cannot be implemented, unless assigning clear and defined responsibilities towards safety both in emergencies and normal working conditions for the personnel in the organization. This not only will encourage the personnel to cooperate and take an active role in safety programs but also prevent them from violating safety rules and procedures. Working safely is every member’s duty in an organization [23]. Researchers refer to lack of a cooperative approach as one of the major causes of safety program failures [24].

Poor management commitment to safety

It is now believed that one of the most important causes of accidents is mismanagement or managerial error [17]. The reason is the fact that managers are responsible for implementation and administering of safety systems [25]. Management commitment to safety is undeniably an integral part of management systems such as OHSAS and Health, Safety and Environment management system (HSE-MS).

Eventually a list of recommendations was proposed to control and minimize work fatalities in the company:

1. HSE strategic management policy arrangement in the company
2. Compiling and implementation of (HSE) comprehensive training program.
3. Determining contractors' competency both before and after contracting with them.
4. Supervising HSE policy requirements sufficiently and accurately based on the management of change approach.
5. Informing all involved employees about the results
6. Determining employees' physical, physiological and mental competencies.

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