



## Analysis of the Causes of Industrial Accidents using Tripod Delta Technique: A Case Study in a Chemical Process Industry



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### ABSTRACT

**Background:** Chemical process industries are among the most important industries which have been faced with many catastrophic accidents. This study aimed to analyze the root causes of the accidents in a chemical process industry.

**Methods:** This study has been implemented in a chemical process industry using Tripod Delta technique in 2019. The implementation steps included forming an accident analysis team, reviewing accident documents and records, compiling Tripod Delta questionnaires, and determining the general failure types (GFTs) involved in the accident.

**Results:** The results showed that procedures (PR), training (TR), and maintenance management (MM) have the most discrepancies in the accident (213, 212, and 202 respectively). In addition, communication (CO), hardware (HW), and design (DE) have the least discrepancies (33, 40, and 76 respectively).

**Conclusion:** The findings indicated that training, standard, and safe procedures as well as maintenance management are determining factors in preventing industrial accidents. Therefore, in order to reduce the accident rates in industries, close attention should be paid to these areas and its indicators with a process and risk based approach.

## 1. Introduction

The global advancement of complex and important technologies in various industries, especially in hazardous industries, has led to the development of proactive safety approaches instead of reactive ones. In fact, the new approach is based on identifying, evaluating, and controlling the root causes of accidents before occurrence [1, 2]. The analysis of major accidents has shown that much of the damages are not only preventable, but also they are

predictable. However, this is conditioned to identify the root causes as well as timely control measures [3-6]. Analyzing the root causes of accidents such as the release of flammable, explosive, and toxic chemicals is one of the most essential steps to improve the safety level in various industrial units, especially in chemical process industries [2, 7]. Furthermore, investigating the past accidents has revealed that catastrophic accidents are never dependent on one cause, but rather they are associated with multiple cause factors. [8].



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In this regard, collecting and analyzing relevant data, are the most important steps in preventing accidents. Without gaining full knowledge of the root causes of accidents and their consequences, managers will be unable to make a conscious decision to implement preventive measures. Therefore, analysis and modeling the causes of accidents, determining the nature, type, and consequences of the accidents could help us determining related cause factors and how can other similar accidents be prevented [9, 10]. Several accident analysis techniques are used to identify direct, indirect, and root causes as well as reducing the incidence and severity of the hazardous consequences in industrial environments [11]. Tripod Delta technique is one of the most widely used methods in analyzing accidents in chemical process industries. This technique can be used to analyze accidents and assess the ability of the existing safety system. Tripod Delta technique has a forward-looking perspective which can be considered as a positive point against retrospective techniques. This technique does not rely on past accidents and instead focuses on factors that have played a key role in all recent accidents. The Tripod Delta technique considers eleven factors in future accident and investigate each of them separately [12, 13]. Therefore, this study aimed at analyzing the causes of accidents in a chemical process industry based on Tripod Delta technique.

## 2. Materials and Methods

This article is taken from an analytical and cross-sectional study conducted in a chemical process industry in 2019. In this study, the root causes of five fires, resulting by hexane leakage, were analyzed for the period 2014-2018 using eleven factors of Tripod Delta technique including Hardware (HW), Design (DE), Maintenance management (MM), Procedures (PR), Error enforcing conditions (EC), Housekeeping (HK), Incompatible goals (IG), Organization (OR), Communication (CO), Training (TR), and Defenses (DF). It is noteworthy that the fires resulting by hexane leakage was analyzed in the chemical industry. The main reason for choosing the fire is its recurring nature as well as catastrophic consequences.

The steps of research methodology presented as follow (figure 1).

The implementation steps included forming an accident analysis team, reviewing accident documents and records, compiling Tripod Delta questionnaires, and determining the general failure types (GFTs) involved in the accident (Figure 1). The study team consisted of 15 people including senior management representative, health, safety and environment (HSE) director, safety officers, occupational health and environmental experts, operational, and process technicians. The required data were collected based on the accident records (during five years) and field study (interview with HSE team).

Following that, eleven GFTs related to Tripod Delta technique were defined. Five out of eleven GFTs including CO, OR, TR, PR, and IG belonged to the general preventive indicators group because of their organizational perspective. Other five GFTs including HW, DE, EC, HK and, MM were among the special preventive indicators. Moreover, the reaction of the failure type was known as the defense (DF). Therefore, based on the GFTs, a questionnaire consisting of 110 questions was developed (10 questions for every GFTs). The content validity of the questionnaire was confirmed by the accident analysis team. Regarding the reliability Cronbach's alpha coefficient was reported 0.74 in response to past corrective actions, 0.72 for existing control measures, and 0.73 for suggested control measures.

Finally, the fires were analyzed. Furthermore, control strategies with a preventive approach were suggested by the accident analysis team. According to the accidents records of the chemical process industry, the most significant and common accident that occurred in the last five years was hexane-leak fires. The description of the accident was as follows:

Hexane leakage occurred due to earlier opening of the nozzle valve containing a combination of silicon and hexane during discharge. Because of using the electric shovels and sparking, the fire begun and rapidly spread after the leakage of hexane liquids on the floor. Fire extinguisher capsule was used to reduce the damage and consequences. Then, the fire was completely extinguished by fire agency. However, this accident had a significant financial and environmental consequences.

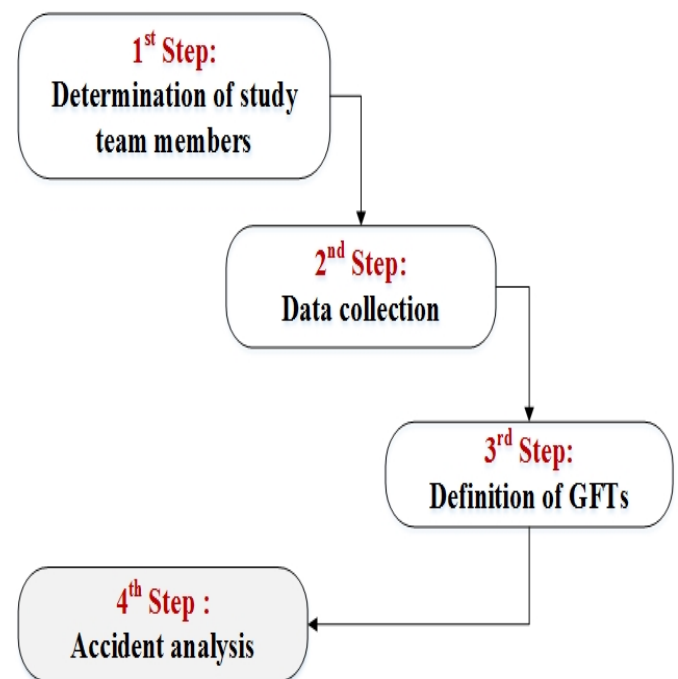


Figure 1: Flowchart of research methodology steps

### 3. Results and Discussion

The completed Tripod Delta worksheet in the fire accidents is presented in Table 1.

The discrepancies for 11 GFTs in the three groups of past, present and future are presented in Table 2 and Figure 2. As indicated by results, there were huge discrepancy related to TR, PR, and MM in the three phases before corrective actions, existing corrective actions, and proposed corrective actions (213, 212, and 202 respectively). The findings indicated the importance of these three GFTs. Therefore, in completing the accident analysis worksheet, corrective measures were taken with a preventive approach to eliminate and reduce the mentioned GFTs.

Moreover, CO, HW, and DE had the lowest discrepancy (33, 40, and 76 respectively). In addition, the findings indicated that much attention has been paid to these GFTs in the industry. Another important point is to reduce the number of discrepancies from the pre-implementation to the existing and proposed corrective measures. This indicated that the number of discrepancies were high in the past and before the implementation of corrective measures, and gradually have decreased with the implementation of their frequency.

According to the considered measures by the accident analysis team, it was expected that the frequencies would be minimized in the proposed measures phase. Therefore, as the number of discrepancies among the 11 GFTs in the Tripod Delta decreases, the accident rate will subsequently reduce in the future. The effectiveness of the corrective actions determine this process DE, HW, and CO are ranked ninth to eleventh of GFTs.

Moreover, the results showed that the procedures in the organization had many weaknesses including lack of transparency, unavailability, lack of information and, communication of these procedures as well as their incompatibility with working conditions. There are also weaknesses in training that lead to low levels of safety knowledge, awareness, safety culture, lack of motivation in employees, lack of commitment and, safety attitude at the organizational levels.

Inefficiency in maintenance management include non-compliance with maintenance instructions equipment, temporary repairs, lack of continuous monitoring, lack of reporting, and documenting defects.

The findings of this study revealed that promoting safety culture is the main root of accidents and human errors. Designing a new structure and system is required to provide safety culture, safety commitment, and job motivation. Training and culture are complementary, and the failure in each of them has adverse effects on the other component. Fires and explosions hazard take place in all industries; therefore, it seems necessary to provide new technical and managerial solutions to find out the root causes. In the present study, factors such as lack of systematic documentation and procedures, knowledge deficiencies in management system, communication between working groups, insufficient supervision, and inefficiency in the educational system have caused repeated human errors. As a result, these factors can cause irreparable human, financial, and environmental damages to the chemical process industry [14-16].

**Table 1:** Tripod delta worksheet for hexane leak

Failure type	Failure causes	Secondary failure causes	Failure location	Failure time	Responsible Person(s)	Active failure (danger)	Suggested control measures
PR	Lack of transparency, unavailability, lack of information, incompatibility with working conditions	Lack of knowledge management system structure in the organization	Old Custer line	2015	Line wash operator, Balance tank filling operator, Laundry operator	Carry out the task without regard to safety (use of electric flooring on hexane liquids, careless washing of the floor with ethanol alcohol)	Training and information, developing relevant guidelines, holding TBM
TR	Lack of education, lack of awareness, low level of safety	Lack of training system in the organization, lack of cooperation with expert staff to teach safety issues	Old Custer line	2015	Head of education, senior management, public relations officer, HSE expert	Lack of awareness of the dangers of hexane liquids (flammability)	Establishment of educational system, collaboration with expert teachers in the field of HSE, development of practical headings along with maneuver
MM	Fault in connection between tank and nozzle balance (leakage)	Insufficient inspection and supervision, lack of long-term maintenance	Old Custer line	2015	Facility technician, instrument technician, process expert	Hexane leakage between tank and nozzle coupling connection during pumping of materials	Ongoing supervision and inspection, identification of defects and breakdowns and notification to the production supervisor and HSE officer, application of up-to-date and defective designs

Procedures (PR), Training (TR), Maintenance management (MM).

**Table 2:** Frequency of discrepancies

Corrective action phase	General failure types (GFTs)								
	DF	IG	PR	TR	OR	CO	MM	HK	HW
Past	75	75	90	90	64	15	90	75	21
Present	15	51	68	66	24	11	67	15	13
Future	11	24	55	56	20	7	45	12	6
<b>Total</b>	<b>101</b>	<b>150</b>	<b>213</b>	<b>212</b>	<b>108</b>	<b>33</b>	<b>202</b>	<b>102</b>	<b>40</b>

Defenses (DF), Incompatible goals (IG), Procedures (PR), Training (TR), Organization (OR), Communication (CO), Maintenance management (MM), Housekeeping (HK), and Hardware (HW).

In this regard, the results of the study by Lali-Dastjerdi and Mohammadfam (2012) showed that 97 preconditions and 115 latent causes were involved in the coke gas leakage explosion [17]. Furthermore, Soltanzadeh *et al.* (2019) showed that accidents in the chemical industry have been affected by individual, organizational, training, risk management, unsafe acts, unsafe conditions, and the type of accidents [18]. In a similar study, Xin *et al.* (2019) by using the Tripod Delta technique found that the most important latent problems in the control system include improper use of equipment, lack of sufficient resources, failure to identify inappropriate working conditions, non-implementation of the annual training programs due to financial problems, and workload [19].

It should be noted that although the analysis of accidents in similar industries has been investigated in some studies, however a few studies have been had a comprehensive view on accidents in the chemical process industry. In the present study, we used three approaches to consider the past (before taking control measures), present (existing control measures) and future (required control measures) besides

and future (required control measures) besides applying and localizing them in conjunction with the 11 GFTs related to Tripod Delta technique by designing a questionnaire in chemical process industries. Therefore, the results of this study could be considered as an initiative in the accident analysis [14, 20, 21].

#### 4. Conclusion

The findings of the current study revealed that different risk factors are associated with occurrence of accidents in the chemical process industry. Therefore, accidents analysis, which is usually done to provide control strategies and to reduce accident rates, should be performed carefully.

Although, a suitable design was used for accidents analysis based on Tripod Delta technique, however this study had some limitations that should be considered in future studies.

To conclude, comprehensive studies with large sample size and analysis of major accidents could provide thorough investigations and more accurate analyses.

#### Authors' Contributions

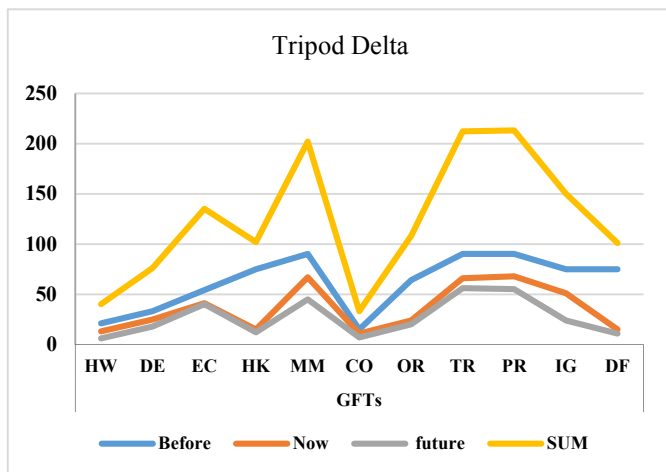
All the authors contributed to the preparation of this article. A.S., and B.O., designed the study. F.H., and B.O., drafted the manuscript, and contributed to data collection and data analysis. Additionally, A.S., confirmed the final version of the manuscript.

#### Conflicts of Interest

The Authors declare that there is no conflict of interest.

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Hardware (HW), Design (DE), Error enforcing conditions (EC), Housekeeping (HK), Maintenance management (MM), Communication (CO), Organization (OR), Training (TR), Procedures (PR), Incompatible goals (IG), and Defenses (DF).

**Figure 2:** Comparison of identified contradictions for tripod delta questionnaire indices

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