Systemic Accident Analysis Methods: A Comparison of Tripod-β, RCA and ECFC

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Abstract

Introduction: The adverse outcomes of major accidents have led to development of accident analysis techniques to fully investigate such incidents. However, each method has its own advantages and deficiencies, which makes it very difficult to find a single technique capable of analyzing all types of events. Therefore, the comparison of accident analysis methods would help find out their status in different specifications and select a more suitable method. In this research, RCA and ECFC were compared with Tripod β in order to determine a superior technique for the analysis of major accidents in manufacturing industries.

Methods and Materials: In the first step of the study, comparison criteria were developed using literature reviews and Delphi method. In the second step, the relativeimportance of each criterion was qualitatively determined and then applying Fuzzy triangular numbers, the qualitative values were converted to the quantitative values. Finally, using TOPSIS, the techniques were prioritized in terms of the criteria and the superior technique was determined.

Results: The results of the study showed that ECFC is superior to CBA and AABF.

Conclusions: Available techniques should be compared based on proper criteria in order to select the best one for the analysis, because inappropriate selection of accident analysis techniquesmay lead to misguided results.

Keywords: Accident, safety, manufacturing,TOPSIS

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Introduction

Costs arising from accidents, even in developed countries, have crippling effects on not only industries but also the national economy of the country [1]. Based on national safety council reports, accidents cost 263.8 billion dollars in 2011 accounting for 35% of the total accidents costs including motor vehicle crashes, home and publicinjuries [2].Unfortunately, thereisnoaccurateandclear-cut data in Iran on the rate of fatal occupational injuries, but it is estimated that this in developing countries is 3–4 times higher than in the developed countries [3]. Based on this relationship, it can be remarked that the cost of accidents in the developing countries is much more than what it is in developed countries. In addition to financial loss, social and environmental impacts of accidents are undeniable [4]. The consequences of Bhopal and Chernobyl accidents addressed these topics[5].Therefore, occupational accidents impose huge costs on individuals, companies and on the society. As a result, a high number of techniques were introduced for accident investigation and their number and applications are rising. The purpose of these techniques is to look for the causes that led to the undesirable consequences. The output of the accident investigation is usually a description of chains of interacting causes. Understanding the root causes of incident is critical for safety specialists [6]. Various techniques have been developed to achieve this aim. In the recent years, different methods with strengths and weaknesses have been developed to improve the effectiveness of accident analysis techniques. Similarly, the selection of appropriate method, according to proper criteria is considered so important that inaccurate and inappropriate information could mislead the analyst.

The study was conducted in the MAPNA Group in 2011 and 2012. MAPNA Group is a group of Iranian companies involved in construction and installation of energy production machinery, including boilers, gas and steam turbines, electrical generators, as well as industrial scale petroleum processing installations, railway locomotives and wind power. The company was founded in 1993 with the aim of developing indigenous knowledge production capacity for petroleum facilities, power plants and other industrial facilities, and as a contract management company.

In this group, three techniques including Tripod-β, ECFC and RCA are used for accident analysis. The following sections describe briefly the mentioned techniques:

- Events and Causal Factors Charting (ECFC)

The ECFC provides a graphical display of the incidents chronology, and is used primarily for organizing evidence to depict consequences of accidental events. It is useful when accident involves multiple causes. The method can demonstrate graphically triggering conditions and events, which is necessary and sufficient for an incident to occur. In other words, the ECFC is used to determine causal factors by identifying significant events and conditions leading to accident [7].

- Root Cause Analysis (RCA)

The RCA is a systematic technique aiming at finding the root causes of a problem instead of the symptoms of the problem. It is one of the tools in the accident analysis "toolbox" employed by the safety committee members whenever the accident analysis is completed prior to the submission of the recommendations for mitigation action. This technique should only be used by the safety committee members during the post-accident analysis[7].

- **Tripod-β**

A Tripod-β analysis looks for the main cause(s) of the sequence of events in an incident. The analysis detects show the incident is happened, what and why barriers have failed. It is based on building a tree structure representing the incident mechanism, the events, and relationship between them. The event in a Tripod-β is the result of hazard acting onan object. A barrier is something that prevents achieving the object and a hazard. A causation path is made to explain how and why this happened whenever such a barrier fails [8].

Considering that the main purpose of performing an accident investigation is to prevent its recurrence, the present study aimed to find out which of these three methods is the most successful in determining main causes of accidents in MAPNA Group.

Methods and Materials

This descriptive analytical study was carried out in MAPNA group in Iran. The first step was the selection of appropriate criteria for the comparison of those techniques. The comparison criteria were selected based on the viewpoints of the Delphi panellists, literature reviews, as well as interview with HSE experts. The accident sequence, analysis scope, primary/secondary technique, analytical approach, accident model, and training needs were suggested by Sklet in 2003[7]. In addition, other criteria were introduced by Benner in 1985 consisting accuracy, persuasion, independency, exploration and investigation,etc.[9].

The comparative criteria for the purpose of prioritization of accidents analysis methods in Mapna group were selected with the focus on being understandable, quantification capability, and commonness.

The identified criteria in the form of a specific questionnaire were sent for 61 Iranian safety experts to select appropriate technique using method of paired comparisons. Of which 37 assessed the identified criteria. Experts selected have the following characteristics:

1. Education:M.Sc. and Ph.D.
2. Relevant work experience: at least five years
3. At least 3 time experience of involvement in incident analysis of the construction industries
4. Area of interest: occupational hygiene, safety and HSE management.

After analyzing the results, the following six criteria were selected:

- Model running cost (RC)
- Time required to run the model (RT)
- Training courses required for implementation (TN)
- The ability of being quantified (QA)
- The graphical description of event sequence (GD)
- The analysis levels (AL)

In order to accurately prioritize accident analysis methods in construction industries, it is required to determine the relative importance of each criterion. For this purpose, a questionnaire was developed and completed by 28 experts. Finally, the relative importance of each criterion was quantitatively determined using triangular fuzzy numbers.

Then, the values of m, α, and β for each qualitative option at three different levels of response were determined as follows [10]:

High= (1, 0.4, 0)   Medium= (0.5, 0.3, 0.3)
Low= (O, 0, 0.4)

By replacing qualitative options with the values of m, α, and β in the formula $\mu_T(x) = \frac{m+\beta}{2(1+\beta)} + \frac{m}{2(1+\alpha)}$, the quantitative values for each option were obtained as follows: [10]

Low=0.143   Medium=0.5   High=0.857

The triangular fuzzy numbers method was used to convert qualitative values to quantitative ones in order to enter the model. Then, techniques were prioritized by TOPSIS method.

In the first step, normal decision-making matrix was calculated (Equation 1).

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},$$

$i = 1, \text{t step, normal decision} -$ making matrix Equ. 1

In the second step, the weighted decision-making matrix was calculated and positive-ideal as well as negative-ideal solutions were determined.

In the third step, the separation criteria were calculated using n-dimensional Euclidean distance (Equation 2):

$$d_i^- = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2 \right\}^{1/2},$$

$$i = 1, \ldots, m$$

$$d_i^+ = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2 \right\}^{1/2},$$

$i = 1, \ldots, m$ Equ. 2

In the fourth step, the relative closeness to the ideal solution was calculated according to the Equation 3.

$$R_i = \frac{d_i^-}{(d_i^+ + d_i^-)}, i = 1, \ldots, m$$ Equ. 3

Results

The determination of relative importance of the criteriashowed that analysis levels and training needs are the most and the least important criteria, respectively (Table 1)

As mentioned above, the obtained results were used in order to determine the relative importance of each criterion in the form of a matrix. Considering the nature of criteria in this matrix, triple qualitative options (high, medium, low) or Yes/No options were used for rating (Table 2).

The triangular fuzzy numbers method was used to convert qualitative values to quantitative ones in order to enter the model. In order to prioritize the techniques by TOPSIS method, normal decision-making matrix was calculated. Then the following results were obtained by calculating the weighted decision-making matrix. The results of the calculation of positive and negative ideal solution are shown in Table 3. The lower numerical values of implementation cost, time and training needs will lead to more positive ideal solution. However, the higher numerical value of quantification ability, the presentation of events sequence (graphical presentation ability), and analysis levels (depth of analysis) will lead to the formation of a positive one.

After the calculation of separation criteria using n-dimensional Euclidean distance, the relative closeness to the ideal solution, prioritization and precedence of techniques were calculated. The results are shown in Table 4.

Table 1: The relative importance of criteria

Criterion	Quantified values
Model running cost (RC)	0.56
Time required to run the model (RT)	0.64
Training courses required for implementation (TN)	0.51
The ability of being quantified (QA)	0.71
The graphical description of event sequence (GD)	0.62
The analysis levels (AL)	0.79

Table 2: Qualitative ranking matrix of techniques based on criteria

Criteria / Technique	RC	RT	TN	QA	GD	LA
Root Cause Analysis (RCA)	High[7, 11]	High[7, 12]	High [7]	Medium[12]	No [13, 14]	High [13, 14]
Event and Causal Factors Charting (ECFC)	Low[7, 11]	Medium[11,12]	Low [11]	[12]	Yes [13, 14]	High [13, 14]
Tripod - β	Medium[7, 11 and 12]	Medium[11, 112]	High[7, 12]	Medium [12]	Yes [13, 14]	High [13, 14]

Table 3: Positive-ideal solutions and negative-ideal solutions

Criteria / Ideal solutions	RC	RT	TN	QA	GD	LA
Positive-ideal	0.05	0.19	0.05	0.44	0.47	0.41
Negative-ideal	0.30	0.32	0.29	0.07	0	0.07

Table 4: Quantified values of techniques ranking based on criteria and their prioritization and precedence

Criterion / Technique	LA	GD	QA	TN	RT	RC	LA	GD
Tripod-β	0.857	1	0.5	0.857	0.5	0.5	0.66	2
RCA	0.857	0.857	0.857	0.5	0	0.857	0.38	3
ECFC	0.143	0.5	0.143	0.5	1	0.857	0.80	1

Discussion

The accident analysis techniques should provide appropriate inputs to corrective actions, but it is hard to find a single technique that is capable of determining all types of causes [15]. In this regard, prioritization and selection of proper techniques for accident analysis is of significant importance. This should be performed regarding to a variety of criteria including the industry type, time limits, costs, and availability of expert team, etc.[16]. Although, many researchers have compared accident analysis techniques based on different criteria, there is no model to prioritize the current methods in accordance to their applicability for specific industrial applications [17].

Following the prioritization of techniques for accident analysis in process industries, it was revealed that ECFC and RCA technique have the highest and lowest preferences, respectively. The ECFC method needs lower cost and training for implementation, and can illustrate the risky events in a graphical manner. This method entails all four levels ranging from technological system up to organizational level.It seems the RCA and Tripod-β methods developed to cover Level 1 to 4.

The second characteristic is whether the methods give a graphical description of the event sequence. The Tripod-β and RCA methods give a graphical illustration of the whole accident scenario. The Tripod-β illustrates graphically a target (e.g. worker), a hazard (e.g. hot pipe work) and the event (e.g. worker gets burned) in addition to the failed or missing defenses caused by active failures, preconditions and latent failures (BRF) (event trios).

This is consistent to the findings of Sklet's study [7,13].

However, RCA techniques lack this capability. The fourth characteristic assessed is the need of education and training in order to use the methods. RCA and Tripod-β falls into the "expensive" category and ECFC falls into the "cheap" category.

The priority of the considered techniques in this study is as follows: ECFC, Tripod-β and RCA.

In a study, Sklet used seven criteria for the comparison of several accident analysis techniques including RCA, ECFC, and Tripod-β [7, 12, and 13]. This study revealed that Tripod-βtechnique covers analysis levels of 1 and 2 while RCA and ECFC techniques cover 1-3 and 1-4 levels, respectively. In addition, training needs of ECFC, Tripod-β and RCA techniques are respectively low, medium, and high[11,13].

Conclusions

Available techniques should be compared based on proper criteria in order to select the best one for the analysis, because inappropriate selection of accident analysis techniquesmay lead to misguided results.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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