Classification and Analysis of Hazardous Conditions and Near Misses by Using Fault Trees: A Case Application in Oil Industry

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This paper presents a study which deals with the analysis of hazardous conditions and near misses using the fault trees. These conditions may lead to accidents and catastrophes. In particular, specific data are collected on the situations or disorders that could lead to hazardous and near miss conditions in a company. A near miss is an occurrence of an event that could almost result in a catastrophe. Based on the collected data, approximate probabilities are assigned to various basic events and a risk assessment is made for the final events, such as the hazardous and the near-miss events. The analysis was useful in identifying all the related sub-events and basic events in a fault tree structure in addition to determining the probability of final events. In addition to evaluation of associated risks, cost analysis was also carried out to determine possible accident prevention costs. These types of analysis help the managers to visually see all the possibilities and to take the necessary actions for eliminating possible causes of accidents and increasing the safety to a maximum possible level.

Keywords: hazardous conditions, risk assessment, fault trees, basic events, accident prevention, risk analysis

Introduction

Safety is a major issue that companies face in today's industry. Particularly, if the industry is prone to accidents and hazardous conditions, catastrophes can happen, which may result in millions of dollars in losses or jeopardizing human life. As workers at oil companies could be exposed to various incidents that could lead to facing significant health and safety risks, necessary prevention actions should be taken in advance in order to avoid any undesirable incidents. In this paper, a fault tree application was taken into consideration to analyze hazardous conditions and near misses in a company, which could lead to accidents and catastrophes.

Data have been collected on the situations or disorders that could lead to hazardous and near miss conditions. A near miss is an occurrence of an event that could almost result in a catastrophe. Based on the collected data, approximate probabilities are assigned to various basic events and a risk assessment is made for the final events, such as the hazardous and the near-miss events. The analysis was useful in identifying all the related sub-events and basic events in a fault tree structure in addition to determining the probability of final events. In addition to evaluation of associated risks, cost analysis was also carried out to determine possible accident prevention costs.

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Literature Review

Extensive research has been carried out on safety analysis in different areas and organizations. Various statistical methods and other quantitative tools have been used. One of the most widely used tools is fault tree analysis (FTA), which has been proved to be useful in assessing risks and determining probability of an accident occurring. Literature abounds with research in these directions: Javadi, Nobakht, and Meskarbasheh (2011) utilized fault tree analysis approach for assessment of power system reliability. Baig, Ruzli, and Buang (2013) presented a literature review on reliability analysis using fault trees. Glickman (2007) discussed assessment of hazardous material risks for rail yard safety. Batzias, Bountri, and Siontorou (2011) presented a procedure for solving river pollution problems by means of fuzzy fault tree analysis. Lee (1985) also presented a literature review for fault tree analysis, methods, and applications. Hauptmanns, Marx, and Knetsch (2005) also presented a methodology for analyzing occupational hazards based on fault trees. Wang, Teague, West, and Mannan (2002) presented a new algorithm for computer-aided fault tree synthesis. Magott and Skrobaneck (2012) discussed timing analysis of safety properties using fault trees with time dependencies. Doytchev and Szwillus (2009) presented a procedure for combining task analysis and fault tree analysis for accident and incident analysis. They presented a case study from Bulgaria. Shalev and Tiran (2007) presented a new method for improved fault trees, reliability and safety calculations using condition-based fault tree analysis (CBFTA). Dutuit and Rauzy (2005) also used fault trees for approximate estimation of system reliability. Contini and Matuzas (2011) used functional decomposition for analysis of large fault trees.

Research Method

In this research, data were analyzed by investigating about 1,000 reports in an oil company. These reports which were reviewed as reporting team in the company had the most of the data that were needed for analysis. However, the data were in huge number of files, from which specific values had to be extracted. As it was mentioned previously, two conditions have been taken into consideration: the hazardous condition and the near-miss condition. By using the FTA approach, it was possible to identify all events and sub-events that lead to each condition. After assigning probabilities to final basic events, it was possible to determine the probability of the top event, which was either a hazardous condition or a near-miss condition. Calculation of the associated probabilities, leads to determination of risks, which include damage level and financial risks. This analysis helps to determine the ways of eliminating or reducing the risk if possible. Finally, several prevention methods were recommended with cost estimation.

Data Classification and Analysis

Analysis of Near-Miss Conditions

A near miss could be described as an unplanned event that results in no injury, illness, but has the great potential to do so. The unplanned event could result in costing the company though. The number of near misses for the past three years was found from the company reports, from mid-year to mid-year, as follows: 3,750 near misses in 2011/2012, 3,100 near misses in 2012/2013, and 3,416 near misses in 2013/2014. As the company only categorizes their problems according to the working operation and directorate, the challenge of this study was to find a way to conduct a reliable study to find the causes of the near misses in each working operation. About 600 samples of near miss reports were reviewed in order to categorize them into causes. The samples represent around 50% of company's total near misses. The next step was to find sub-causes of the causes; as

further data were required to find as much details as possible. The probability was also determined for those sub-causes that helped us in analyzing the data.

After detailed investigation of near misses in company reports, they were first categorized by operations as: Construction, Drilling, Lifting Crane Operations, Maintenance, Offices, and Production/Process Operations. Next, the cause of each near miss condition was determined. For example, by reading samples of the reports in the construction working operations, the findings of the near misses were occurring due to *slip, trip & falls, falling objects, explosive ordinance, equipment related causes, soil collapse, other causes* (which included radiation, electrical, improper stacking, abrasive wheels or climate). These causes are given in Tables 1 to 6.

Table 1

Causes of Near Misses for Construction

Construction	No. of reports	Percentage
Slip, trip & falls	80	34.6
Falling objects	58	25.1
Explosive ordinance	27	11.7
Equipment related	24	10.4
Soil collapse	15	6.5
Others	27	11.7
Total	231	37.2

Table 2

Causes of Near Misses for Drilling

Drilling	No. of reports	Percentage
Equipment related	15	28.3
Unexpected energy release	12	22.6
Falling objects	11	20.8
Slip, trip & falls	5	9.4
Improper staking	3	5.7
Others	7	13.2
Total	53	8.5

Table 3

Causes of Near Misses for Lifting Crane Operation

Lifting crane operations	No. of reports	Percentage
Falling objects	22	59.5
Equipment related	10	27.0
Slip, trip & falls	3	8.1
Improper staking	2	5.4
Others	0	0.0
Total	37	6.0

Table 4

Causes of Near Misses for Maintenance Operations

Maintenance	No. of reports	Percentage
Slip, trip & falls	42	42.0
Falling objects	38	38.0
Improper staking	6	6.0

Table 4 to be continued

Electrical	5	5.0
Equipment related	5	5.0
Others	4	4.0
Total	100	16.1

Table 5

Causes of Near Misses for Offices

Offices	No. of reports	Percentage
Slip, trip & falls	67	67.0
Falling objects	20	20.0
Improper staking	8	8.0
Electrical	5	5.0
Others	0	0.00
Total	100	16.1

Table 6

Causes of Near Misses for Production/Process

Production/process	No. of reports	Percentage
Slip, trip & falls	45	45.0
Falling objects	28	28.0
Improper staking	10	10.0
Oil spillage	7	7.0
Electrical	5	5.0
Others	5	5.0
Total	100	16.1

Table 7

Expected Cost of Various Near-Misses Categories

Working operation	Cost KD/month
Construction	6,500
Drilling	3,100
Lifting crane operations	1,500
Maintenance	6,560
Offices	2,750
Production process	7,100

Numbers of cases observed for each cause are shown in the Tables 1-6 for each category of operations in the company. Furthermore, based on the total number of cases, related percentages have been calculated and included in the last column of each table. For the first case, it is $80/231 = 34.6\%$. Note that the total in each table is divided by the total of all five causes in each case and percentage is determined for each case. For example, the total in Tables 1 to 6 is 621 cases. Thus, $231/621$ gives a percentage of 37.2. As mentioned previously, the near misses costs are mainly asset damage costs, which happen from the occurrence of a near miss, which cause no injury or human damage. The costs of the concerned near misses categories related to working operations were expected values, which were calculated by multiplying the cost of each cause with its probability. The results are shown in Table 7. Total cost was 25,710 KD/month. It was found that two main

causes, namely “slip, trip, and fall” and “falling objects” in construction category contributed 71% of the total near misses costs. The related costs were:

- Slip, trip, and fall: 10,000 KD/month
- Falling objects: 9,400 KD/month

Analysis of Hazardous Conditions

A hazardous condition could be described as dangerous or unsafe work condition, which could later on result in a loss or an injury. The number of hazardous conditions for the past three years was as follows 5,807 in 2011/2012, 5,581 in 2012/2013, and 6,371 in 2013/2014. The same problem was encountered in the near misses, which is the categorization of problems. Therefore, around 500 samples of the hazardous conditions reports were revised in order to find the causes, sub-causes, and dig into the reports as much as possible in order to perform the same steps as done for the near misses. The related results are summarized in Tables 8 to 13 for all categories.

Table 8

Causes of Hazardous Conditions for Construction

Construction	No. of reports	Percentage
Open manhole	20	21.0
Open excavation	23	24.0
Electrical	12	13.0
Equipment related	16	17.0
Unsafe working platform	5	5.0
Others	19	20.0
Total	95	19.1

Table 9

Causes of Hazardous Conditions for Drilling

Drilling	No. of reports	Percentage
Electrical	15	15.0
Equipment related	22	22.0
Power tools	20	20.0
Spillage	12	12.0
Unexpected release gas	10	10.0
Others	21	21.0
Total	100	19.1

Table 10

Causes of Hazardous Conditions for Lifting Crane

Lifting crane operation	No. of reports	Percentage
Open excavation	3	0.13
Electrical	5	0.217
Equipment related	12	0.522
Signage	3	0.13
Others	0	0.0
Total	23	0.052

Table 11

Causes of Hazardous Conditions for Maintenance

Maintenance	No. of reports	Percentage
Open manhole	10	10.0
Open excavation	16	16.0
Equipment related	18	18.0
Power tools	18	18.0
Unsafe working platform	12	12.0
Others	26	26.0
Total	100	19.1

Table 12

Causes of Hazardous Conditions for Offices

Offices	No. of reports	Percentage
Electrical	15	0.15
Signage	15	0.15
Waste	22	0.22
Access	11	0.11
Improper material storage	12	0.12
Others	25	0.25
Total	100	0.191

Table 13

Causes of Hazardous Conditions for Production

Production/process	No. of reports	Percentage
Electrical	16	16.0
Equipment related	21	21.0
Power tools	14	14.0
Waste	8	8.0
Unsafe working platform	14	14.0
Others	27	27.0
Total	100	19.1

According to the reports that were investigated, the hazardous conditions were categorized of each working operation into a cause. Just like the near misses, by reading samples of the reports in each category of six work operations, causes of hazardous conditions and the number of cases were obtained. Finally, percentages were determined based on the total number of cases in each category. For example, in case of construction (Table 8), hazardous conditions are due to open manholes, open excavation, electrical hazards, equipment related causes, unsafe working platform, and other causes (including improper stacking and climate).

Similar to construction, causes and probabilities of all other categories are given in related Tables 9 to 13. Each hazardous condition category had its own causes. Hazardous conditions do not have costs in a direct way. When a hazardous condition takes place, the only cost concerned is cost of fixing of what is reported as a hazardous condition (maintenance cost). This cost was estimated as 15,000 KD/month according to samples of the reports. By doing the same type of analysis as conducted for the near misses, the expected cost for the hazardous conditions was found by multiplying the costs concerned in each operation with the probabilities of the main causes. The summarized cost results are shown in Table 14.

Table 14

Expected Cost of Various Hazardous Conditions

Working operation	Cost KD/month
Construction	2,850
Drilling	2,850
Lifting crane operations	600
Maintenance	2,850
Offices	2,850
Production process	2,850

The total cost was 15,000 KD/month as mentioned above. The two main causes were “equipment related” and “electrical hazards”, which contributed 17% of the total hazardous condition costs. These significant costs were:

- Equipment related: 1,550 KD/month
- Electrical: 1,016 KD/month

Fault Tree Analysis of Main Events

A fault tree diagram is a graphical technique that can provide a clear and systematic description of all occurrences of events and the basic events that cause the final events. The occurrences might result in unwanted outcomes. In order to further investigate the main events that are categorized in Tables 1 to 6 and Tables 8 to 13, a fault tree was developed in order to investigate the risks for each of the 12 subcategories. Fault trees are used to determine causes of events through detailed analysis of basic events. OR and AND logical relations are used to determine final probabilities of main events. Figure 1 illustrates symbols and logical relations used in fault trees. AND and OR relations are used with Eqs. (1) and (2) respectively to determine the probability of a resulting event based on the probabilities of sub events or basic events.

Figure 1. Logical relations and symbols used in fault trees.

$$\text{AND: } P(E) = \prod_{i=1}^n P(Q_i) \quad (1)$$

$$\text{OR: } P(E) = 1 - \prod_{i=1}^n [1 - P(Q_i)] \quad (2)$$

where, E = Resulting event, Q_i = Basic event that results in event E.

In case of AND relation, all sub events must occur for the resulting event to occur. In case of OR relation, occurrence of one or more sub events cause the occurrence of the resulting event. In the examples considered, mostly OR relation existed. All fault trees could not be shown in this paper due to space restrictions. Only two cases are shown for illustration. Figure 2 illustrates the fault tree for the final near miss event for drilling operations and Figure 3 illustrates the fault tree for the final hazardous conditions event for the drilling operations. Similarly, all fault trees, for other near misses and hazardous conditions have been constructed. Based on the available data, probabilities were estimated for the basic events for each fault tree. These basic

event probabilities were then used to determine the probability of the top event for each condition. As it can be seen from the fault trees, the top event probabilities are calculated using the tree structure from bottom to the top. Fault trees were constructed and final event probabilities were calculated for the ten events described above. Table 15 summarizes the final probabilities, or the risks associated with each event in the near miss and hazardous conditions.

Figure 2. Fault tree for the top event “Near misses due to drilling”.

Figure 3. Fault tree for the top event “Hazards due to drilling”.

Table 15

Probabilities (Risks) Associated With Top Events

Operation event	Near miss	Hazardous condition
Construction	0.720	0.850
Drilling	0.580	0.680
Lifting crane	0.643	0.682
Maintenance	0.690	0.760
Offices	0.630	0.690
Production	0.650	0.770

Research Results

After some investigation of the events, it was recognized that possible solutions could be implemented as suitable prevention methods for the near misses and hazardous conditions. While the near misses require a lot of work for correction, hazardous conditions need some preventive maintenance in order to solve the related problems. Also near misses have higher impact as injury or financial loss as compared to hazardous conditions. Possible prevention methods for each case are discussed below.

In order to prevent Near Misses, two main causes were considered, namely Slip Trips & Falls and Falling Objects, which contributed 71% of the near misses. The prevention methods suggested for the Slip, Trip & Falls were basically to work on two issues: Supervision and Adding Signs. For the Falling Objects, the proposed preventions included: Providing Overhead Protection; and Supervisors to organize lifting times and conditions. The related costs for each prevention method are estimated as follows.

Slips Trips & Falls

Supervision: Supervisors responsible for each working Operation + Staff would have an estimated cost of $1,000 \text{ KD/supervisor} * 6 \text{ supervisors} + 600 \text{ KD/working staff} * 18 \text{ Staff Members} = 16,800 \text{ KD/month}$

Signs: 3,000 KD (fixed initial cost) for 10 years. By using Engineering Economy (interest, $I = 15\%$, $N = 10$ years). Annual costs would be about $A = 600 \text{ KD/year}$ or 50 KD/month . The total costs for supervision and signs would be $16,850 \text{ KD/month}$.

Falling Objects

Creating a walking path and overhead protection is estimated to cost 50,000 KD over the next 10 years. By using Engineering Economy and interest, $I = 15\%$, number of years $N = 10$, equivalent annual cost of $A = 9,960 \text{ KD/year}$ or 830 KD/month is estimated. Combining all these prevention costs results in a total cost of $17,680 \text{ KD/month}$.

Conclusion

Safety issue is one of the most important considerations in industrial systems. It is important to study each system systematically and assess the safety of each operation. Related unsafe conditions and risks have to be determined using appropriate tools. Unsafe events could be injuries that occur, near miss events that result in damage to property and financial loss, with no injury to human life. However, they pose threats as potential for serious injuries. Hazardous conditions are also events that are situations or conditions that could result in serious injuries or losses. Each situation has to be analyzed in the industrial facility under consideration and associated risk has to be determined. Furthermore, possible preventions should be proposed.

In this paper, a large oil company was considered and proposed risk assessment and cost analysis for several categories of near miss events and hazardous conditions. The work of this study quantified various conditions and events that result in each final event by reading several hundreds of records that were kept in the files. Furthermore, fault trees analysis was conducted for each near miss event and for each hazardous condition. Using the estimated probabilities of basic events at the lowest level of fault tree, it was possible to determine the probability or the risk associated with each event. These quantified risks show the importance of the event and how dangerous it is for each case.

The annual near misses costs were 27,510 KD/month for the organization considered. The intensity in this study was taken on the main cause of the near misses, which were the slip trip and fall, and the falling objects.

They added up to be 19,400 KD/month. Some prevention methods were recommended, for which the total cost was 17,680 KD/month. Thus, by incurring this cost, the company can avoid the payment of 19,400 KD/month in addition to most importantly eliminating or reducing the risk of having a near miss event to occur. A near miss event could sometimes result in losses amounting to millions of dollars, fatalities, and even loss of human life. Therefore, the savings in figures may not be significant as compared to the elimination or reduction of risks.

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