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Fault Tree Analysis of Hazardous Conditions and Near Misses in a Company: A Case Application

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ABSTRACT

This paper presents a fault tree application to analyze hazardous conditions and near misses in a company, which could lead to accidents and catastrophes. Based on past information, data is 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 were 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.

1. 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 human life may be jeopardized. 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 tool 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 [1-12]. In this paper, we have considered a fault tree application to analyze hazardous conditions and near misses in a company, which could lead to accidents and catastrophes. Data has 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 were also carried out to determine possible accident prevention costs.

The reporting team in the company had the most of the data that were needed for analysis. However, the data was in huge numbers of files, from which specific values had to be extracted. As it was mentioned previously, two conditions have been taken into consideration: The hazardous conditions and the near-miss condition. By using the FTA approach, it was possible to identify all evens and sub-events that lead to each condition. Finally, 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. These analysis help to determine the ways of eliminating or reducing the risk if possible. Next section describes each case independently.

2. 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 3 years were found from the company reports, from mid-year to mid-year, as follows: 3750 near misses in 2011/2012, 3100 near misses in 2012/2013, and 3416 near misses in 2013/2014. As the company only categorizes their problems according to the working operation and directorate, we could not do much. We wanted to find the causes of the near misses in each working operation, so we read around 1000 samples of near miss reports

in order to categorize them into causes. The working operations that we could get samples of represent around 50% of company's total near misses. Our next step was to find sub-causes of the causes, as we wanted to dig in to find as much details as we could get. We also determined the probability 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 causes of each near miss condition was determined. For example, by reading samples of the reports in the construction working operations, we found that the near misses occur 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 for each category of operations in the company. Number of cases observed for each cause in each category are shown in the tables. 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 %

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
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	50.0
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

As we 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
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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

3. 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 3 years was as follows 5807 in 2011/2012, 5581 in 2012/2013, and 6371 in 2013/2014. We faced the same problem that we faced in the near misses, which is the categorization of problems. Therefore, we had to read samples of the hazardous conditions reports in order to find the causes, sub-causes, and dig into the reports as much as we could in order to perform the same steps as done for the near misses.

According to the reports that were investigated, we categorized the hazardous conditions 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 number of cases were obtained. Finally, percentages were determined based on the total number of cases in each category. The related results are summarized in tables 8 to 13 for all categories. For example, in case of construction, 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) as shown in table 8.

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

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). We estimated this cost as 15,000 KD/month according to samples of the reports that we read. By doing the same type of analysis as we did for the near misses, we also found the expected cost for the Hazardous conditions 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 2 main causes were “equipment related” and “electrical

hazards", which contributed 17% of the total hazardous condition costs. These significant costs in were:

- Equipment Related: 1550 KD/month
- Electrical: 1016 KD/month

4. 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, we have developed fault trees and tried 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 equations [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.

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

5. PREVENTION METHODS AND COSTS

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:

Prevention Methods for Near Misses: In order to prevent Near Misses, we concentrated on two main causes, 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 costs of 1000 KD/supervisor * 6 supervisors + 600 KD/working staff * 18 Staff Members = 16,800 KD/month
Signs: 3000 KD (fixed initial cost) for 10 years. By using Engineering Economy, (interest, I = 15%, N = 10 years). Annual costs would be about A = 600 KD/year or 50 KD/month. The total costs for supervision and signs would be 16,850 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 KD/year or 830 KD/month is estimated. Combining all these prevention costs results in a total cost of 17,680 KD/month.

5. CONCLUSION

Safety issue is one of the most important consideration 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 not 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, we have considered a large oil company and proposed risk assessment and cost analysis for several categories of near miss events and hazardous conditions. We have quantified various conditions and events that result in each final event by reading several hundreds of records that were kept in the files. Furthermore, we have developed fault trees 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. We concentrated 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. We have come up with some prevention methods, for which the total cost was 17,680 KD/month. Thus, by incurring this cost, we are avoiding 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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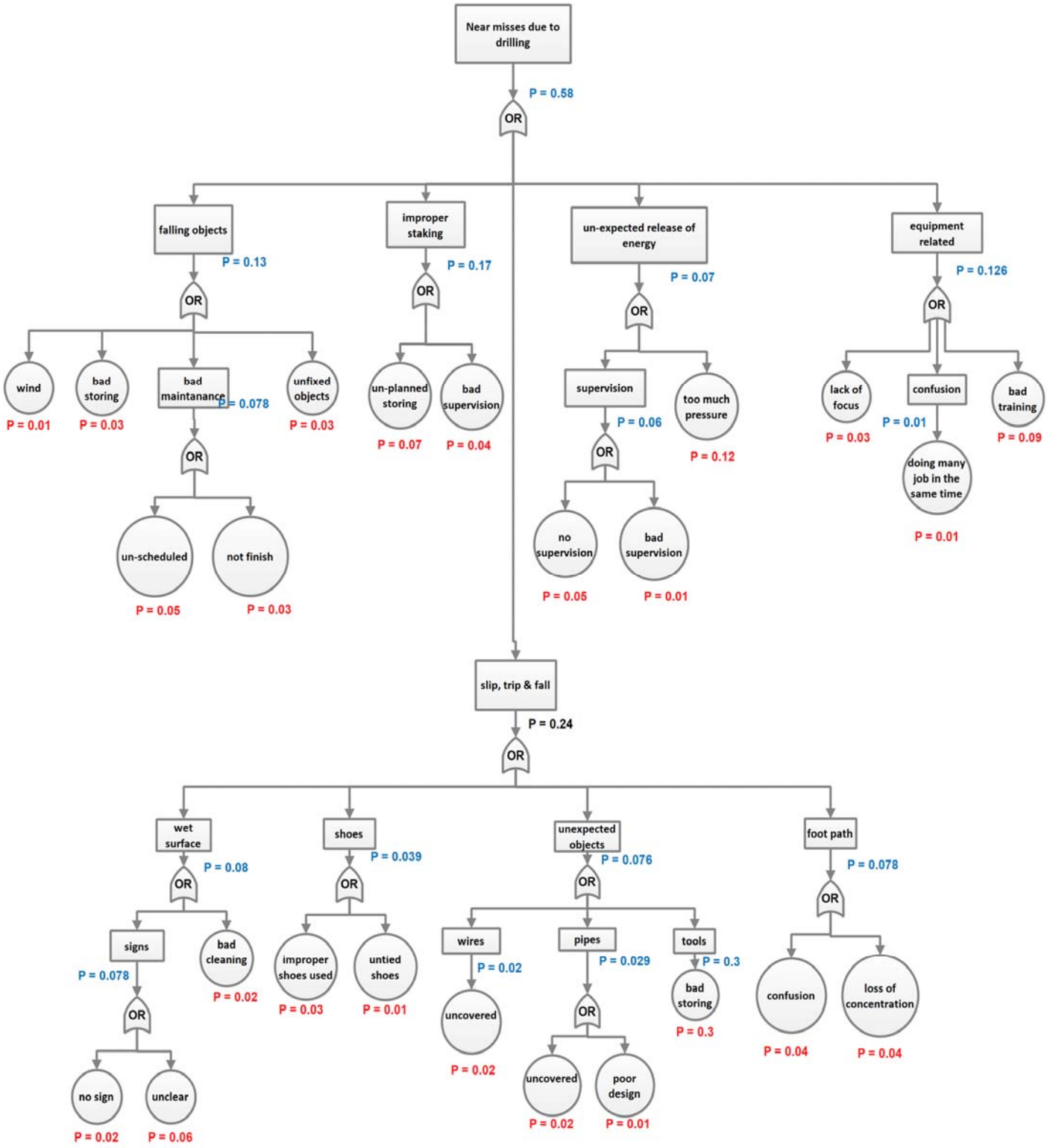

Figure 2. Fault tree for the top event "Near misses due to drilling"

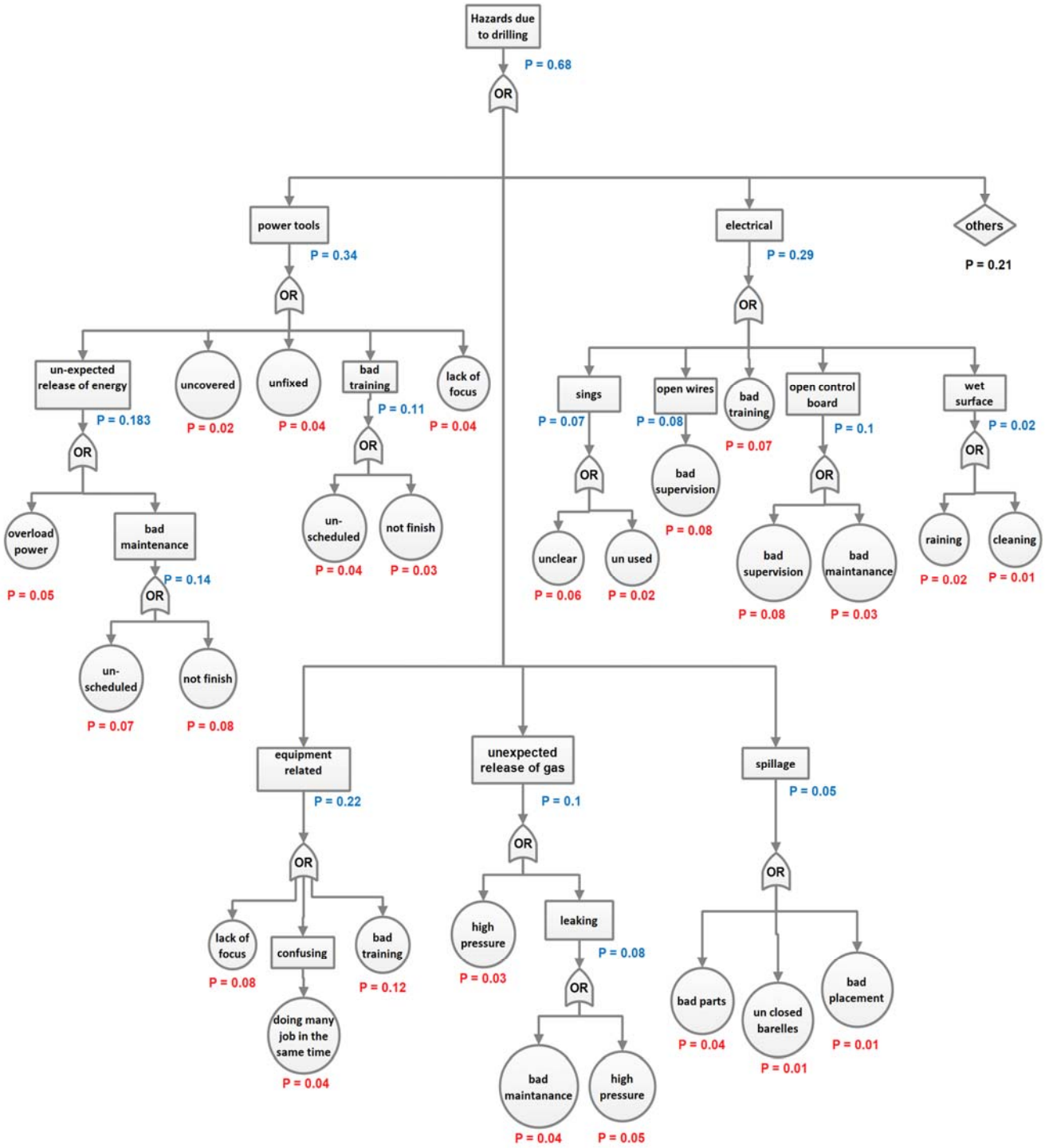

Figure 3. Fault tree for the top event "Hazards due to drilling