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Original

Quantitative Assessment of Risks Caused by Blowout in Yaran with Fuzzy Fault Tree Analysis

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ABSTRACT

Background: Blowout is one of the most significant accidents in the drilling industry. Because of a shared field with a neighboring country and is located on Hur al-Azim wetland, Yaran Oil Field in the west of Ahwaz city needs special attention in terms of blowout control. **Methods:** Four main events including kick prevention, kick detection, failure in the blowout preventer, and blowout occurrence have been identified by expert interviews and field studies as top events. Each top event by fault tree method was analyzed and its intermediate and basic causes were identified. The oil field includes 20 wells and one well was selected for the study. In this study, the fuzzy fault tree analysis method was used to assess the failure rate of events leading to a blowout. **Results:** Based on the obtained results, the failure rate in kick prevention has been estimated to be 0.2863, the failure rate in kick detection 0.3878, the failure rate of blowout preventer 0.08443, the failure rate of a blowout from the first path 0.011, and the failure rate of a blowout from the second paths has been estimated to be 0.0286. In the event of kick prevention, hydrostatic pressure reduction with a failure rate of 0.227, in the event of kick detection, the failure rate of change in mud volume and change in current volume were 0.1462 and 0.133 respectively. **Conclusion:** The results have been used to better understand the blowout and prevention actions and prevent losses due to the blowout.

Keywords: Fuzzy Fault Tree Analysis; Blowout; Drilling; Risk Assessment

Introduction

Oil and gas industries are among the most hazardous industries in today's world. The hazards might occur to human, equipment and environment, and consequently, the highest rates of accidents usually happen in oil and gas drilling operations. [1] Geographical issues, high-pressure and flammable fluids in the presence of an ignition agent, shortage of appropriate response and communication problems are some of the important and vital factors which create threats to the safety of operations and may lead to further incidents. [2] In such an environment, oil and gas leaks not only lead to uncontrollable fire incidents, death and economic damage, but also cause extensive environmental pollution and ecological consequence. [3] One of the most important accidents in the drilling industry is blowout. It is an uncontrolled flow of hydrocarbons into the surrounding environment, and is considered a consequence of kick. Blowout is the most frightening risk threatening human life, environment, property and assets. [4] The oil spill caused by blowout may cause extensive damage to

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the ecosystem and marine environment worse than that; it may cause people's death. [5] On April 20, 2010, blowout of the Macondo well belonging to BP Company took place in the deep waters of the Gulf of Mexico. In this accident, 11 people lost their lives and four million barrels of crude oil spilled into the Gulf of Mexico. [6] Moreover, on August 30, 2019, following a gas explosion in Louisiana, USA, it took 38 days to block the well. [7] Blowout is the unwanted flow of formation fluid into the well as a result of loss of well control, in which the formation fluid pressure surpasses the pressure created by the fluid column at the bottom of the well. [8] Blowout can lead to kick if it is not detected and prevented in time. Well control operations include technical, administrational and organizational measures. They are carried out in order to maintain the stability of the well and reduce the risk of loss of well control through blowout prevention, blowout detection, kick prevention and well killing operations (Figure 1).

The first three stages are for preventing the loss of well control, and the fourth stage is meant to regain control. [9]

Failure in any of the stages of well control operations causes the loss of well control blowout, leading to human, equipment, and environmental consequences. The risk assessment process provides a method for evaluating the probability of safety, health, and environmental impacts. [10] In some studies, the fault tree analysis method has been used to analyze the hazards in drilling operations. [9] In other studies, the fuzzy tree analysis method has been to assess the quantitative risk of leakage in blocked oil and gas. [11] Fault tree analysis has been in deep water drilling when working on gas hydrate also for the probability of occurrence of blowout. [12]

The purpose of this article is to assess and outline the probability of the accidents related to blowout using the fault tree analysis method in order to provide a better understanding of the causes of blowout and use the results to prevent possible accidents.

Methods

The research site was Yaran Oil field in west of Ahvaz and on Horu-alAzim. Yaran oil field includes 20 wells and one well was selected for study. The risks of fire, explosion and release of fluid in the environment are among the consequences of blowout of wells in this field, which can create significant economic, social and environmental impacts. Accordingly, blowout risk assessment is very important and effective in preventing the mentioned impacts. Figure 2 shows the stages of the research.

After outlining the successive stages leading to blowout, each stage was considered an undesirable event. By drawing on books, journals, field research and the opinions of experts in the drilling industry, necessary action has been taken to draw the fault tree analysis of each stage. Four undesired events, including the kick prevention, kick detection, failure in BOP, and blowout from first and second routes have undesired. Then, using the fault tree method, basic and intermediate causes have been identified and outlined. Fault tree analysis Figure 3 uses specific symbols. [13]

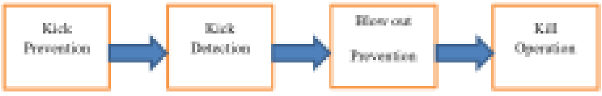

Figure 1. Schematic diagram of well control process

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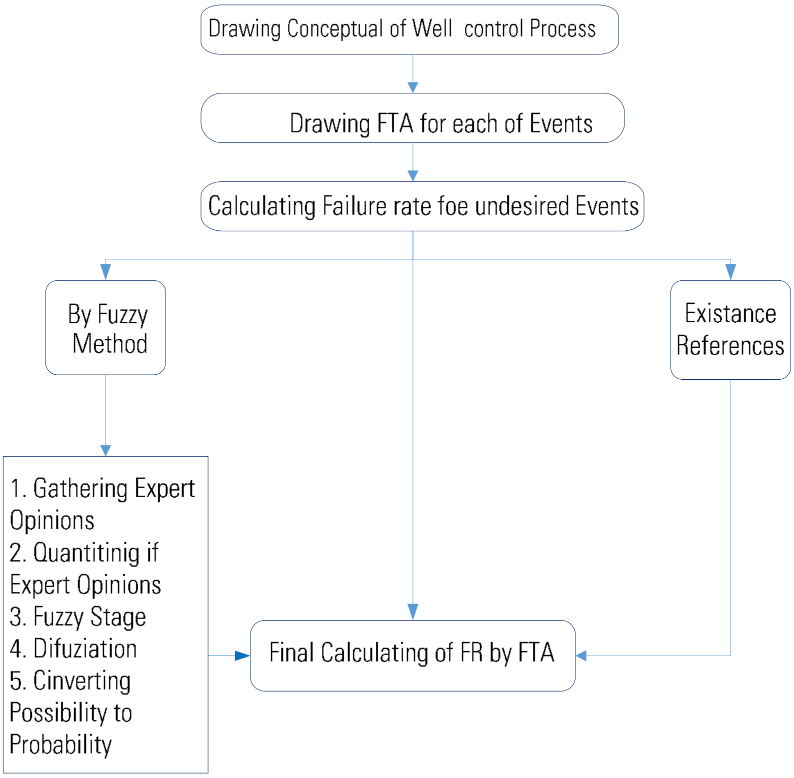
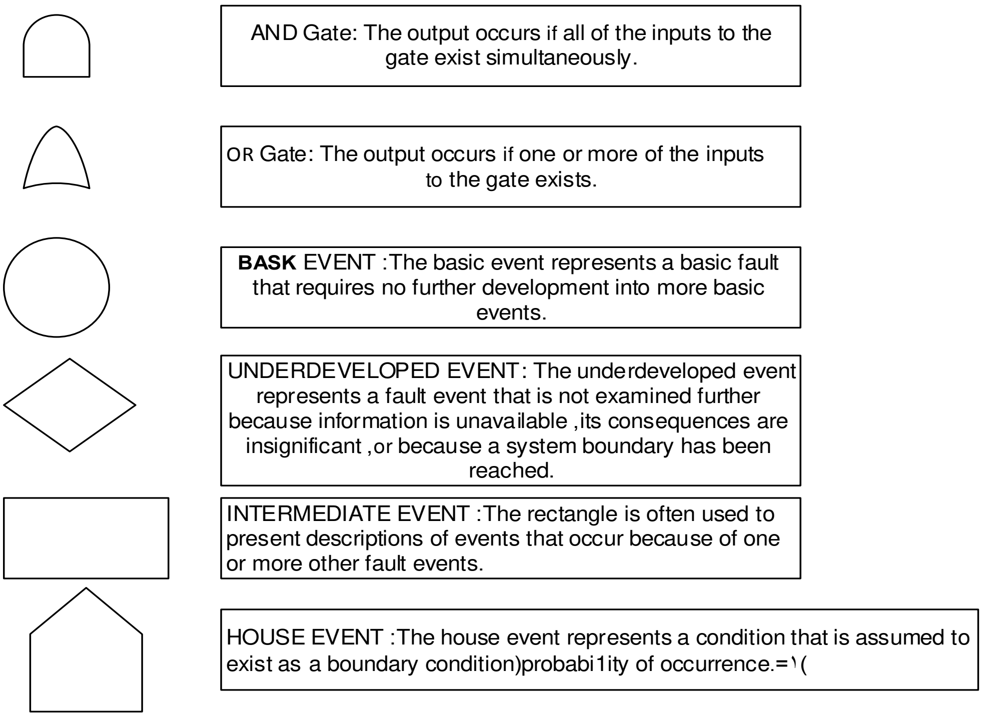


Figure 2. Diagram of stages of the research


AND Gate: The output occurs if all of the inputs to the gate exist simultaneously.

OR Gate: The output occurs if one or more of the inputs to the gate exists.

BASK EVENT :The basic event represents a basic fault that requires no further development into more basic events.

UNDERDEVELOPED EVENT: The underdeveloped event represents a fault event that is not examined further because information is unavailable ,its consequences are insignificant ,or because a system boundary has been reached.

INTERMEDIATE EVENT :The rectangle is often used to present descriptions of events that occur because of one or more other fault events.

HOUSE EVENT :The house event represents a condition that is assumed to exist as a boundary condition)probabi1ity of occurrence.=۱(

Figure 3. Standard fault tree symbols[13]

Due to the lack of sufficient information and the variety and extent of the processes, the failure rate many components were not achievable. Therefore, in order to calculate the failure probability, fuzzy logic has been used to determine the failure. [14] These stages started with selection of a team consisting of

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relevant experts and ended with estimation of the failure rate.

In current research five experts participated. Their expertise were in oil , mechanical and geological engineering .Experts were not of the same degree of expertise. For this reason, the method was used to determine their specialty. [15,16] The criteria of job title, work experience, education and age have been used in determining the importance of experts. Scoring method used for grading the experts has been shown in the Table 1.

After determining assessment criteria of the experts in the previous stage, their weights have been determined. The final weight score of each expert has been obtained by dividing the total scores obtained by him by the total scores obtained by all the experts participating in the study. The weight score of each expert based on the criteria determined in the previous stage, has been shown in the Table 2.

To quantify experts' opinions or to determine the weight of their opinions for basic events, linguistic variables have been used. The five language variables used include Very Low, Low, Medium, High and Very High. To fuzzify this part, trapezoidal fuzzy number has been used. Figure 4 shows the fuzzy range of linguistic variables used in this research.

To use the opinions of the experts, they have been given some forms in which the they have been asked to assign Very Little, Little, Medium, High and Very High scores depending on their personal opinion and the importance of each of the parameters. The value of the linguistic variables of the experts whose opinions have been used in the quantification of each basic event is shown in Table 3.

Table 1. Scoring table based on experts' characteristics

No	Status	classification	Point
1	Job Title	Manager & Deputy	4
		Inspector ،Assistant of manager، Controller	3
		Site supervisor ،Foreman	2
		Operator	1
2	Experience	30	4
		20-30	3
		10-20	2
		5-10	1
3	Education	PhD	5
		Bachelor , Master	4
		Diploma	3
		Holder of occupational diploma	2
		High school dropout	1
4	Age (year)	>50	4
		40-50	3
		30-40	2
		30<	1

Table 2. Weight scores of selected experts

Expert	Tile	Experience	Education	Age	Weight Index	Expert's Weight score
1	Inspector Assistant Manager ، Controller	20-30	Bachelor, Master	-50 40	13	.024
2	Inspector Assistant Manager ، Controller	10-20	Bachelor, Master	-40 30	12	.022
3	operator	10-20	Holder of occupational diploma	-40 30	8	.15
4	Inspector Assistant Manager ، Controller	10-20	Bachelor, Master	-40 30	10	.18
5	Inspector Assistant ، Manager ، Controller	10-20	Bachelor, Master	-40 30	10	.18
	Total				53	

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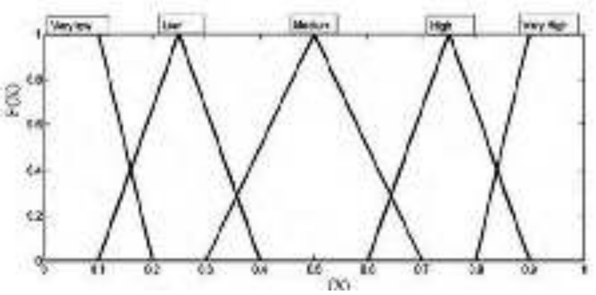

Figure 4. Language variables used by experts

Table 3. The weight of linguistic variables in quantifying the opinion of experts for each basic event

Linguistic variables	Weight of linguistic variables			
Very Little	./2	./1	0	0
Little	./4	./25	./25	./1
Medium	./7	./5	./5	./3
High	./9	./75	./75	./6
Very High	1	1	./9	./8

Consensus of experts:

For the consensus of the experts, the weight score of each expert has been multiplied by the score of his linguistic variables. This is done according to equation (1) .

$$M_i = \sum_{i=1}^{n} W_i A_{ij} \qquad (i=1,2,3.....m) \qquad (1)$$

A_{ij}: Linguistic variable of each basic event i for the expert j

W_i:Weight of expert j

m: number of basic events

n: number of experts

M_i: The fuzzy number of experts consensus regarding each basic event i

De-fuzzification

De-fuzzification of fuzzy numbers is an important method for decision making in fuzzy environment. In this research, the center of gravity method is chosen for de-fuzzification. This method was developed by Sogno in 1985 and it is the most accurate de-fuzzification method. [17] De-fuzzing trapezoidal numbers are obtained using the following equation (2).

$$X=\frac{1}{3} \times \frac{(a_4+a_3)^2-a_4a_3-(a_1+a_2)^2+a_1a_2}{(a_4+a_3-a_2-a_1)} \qquad (2)$$

The numbers obtained from the previous step for each basic event are deemed as the opinion of experts and is still possible. At this stage, using the center of gravity model and the trapezoidal equation, these numbers have been de-fuzzified.

Using conversion formula of possibility to probability

The number resulting from the de-fuzzing step is still a possibility. Since the error tree accepts probability, the number obtained from the previous step must be converted from possibility into probability. For this purpose, the formulas provided by Anisawa's equations (3 and 4) have been used:

$$FP=\begin{cases} \frac{1}{10^k} & CFP = 0 \\ 0 & CFP \neq 0 \end{cases} \qquad (3)$$

$$K=\left[\frac{1-CFP}{CFP}\right]^{\frac{1}{3}} \times 2.301 \qquad (4)$$

Results

Were considered the top ones identified by safety professionals and drilling specialists. They included kick occurrence, kick detection failure, BOP detection failure and hydrocarbon blowout. They were analyzed and the intermediate and events of each of the top events were identified. According to Figure 5, kick fault tree included 45, the three main were efficient hydrocarbon formation ‘ negative diffraction pressure, and sufficient permeability. Efficient hydrocarbon formation and sufficient permeability as were not analyzed. Negative diffraction pressure was analyzable including 32 and 10 intermediate causes. To identify probability of for each , fuzzy fault tree was used and qualitative opinion of the experts became quantitative. Probability of each cause related to kick occurrence is shown in Table 4. Based on the Boolean algebra rules, in each tree, probabilities will be multiplied by each other and constitute the probability of each . will be connected by And and Or gates. OR gates will be accumulated and And

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gates will be multiplied together. Negative diffraction and low hydrostatic pressure entailed the most failure rates of .25 and .22 .Based on the calculations, final probability was evaluated as 0.2863.

Figure 6 demonstrates fault tree of kick detection. 16 causes were identified as the and 11 as the intermediate, and the fault tree of kick detection failure was constructed. Mud volume with a rate of 14, circulation pressure change with 13 and failure of flow meter with the rate of 14 had the highest failure rates in kick detection. Probabilities are shown in Table 5. Based on calculations, final probability occurrence of kick detection failure was evaluated as 0.3879. Figure 7 shows BOP fault tree. 9 causes as the intermediate and 9 causes as the were identified .Choke line, kill line, kill valve and accumulator line with 34 ,34 , 24, 14 rates had the most failure rates in BOP system respectively. Table 6 shows related probabilities and final probability of BOP, which was evaluated to be . Blowout hydrocarbon was predictable in two paths whose fault trees are presented in Figures 8, 9. Three causes included kick, well control failure and kick detection failure shown as the blowout in first path. They were connected by AND gate, and meanwhile, three causes of well control failure were analyzed. Accordingly, 12 intermediate and 22 were identified. Figure 8 shows blowout hydrocarbon fault tree in second path, and unlike figure 7, it was formed by two main causes. It included Kick and well control failure, and covered 13 intermediate causes and 21 ones. Probabilities of causes in Tables 7 and 8 indicate probability of occurrence of blowout in two paths. Regarding fault tree in Figure 8, it was 0.11, and for fault tree figure 9, it was 0.286. The rates of kick detection and killing operation in first path were 38, and .012 and kick, power system and BOP system failure in second path were 028, .001,and .084 respectively, being the highest failure rates .

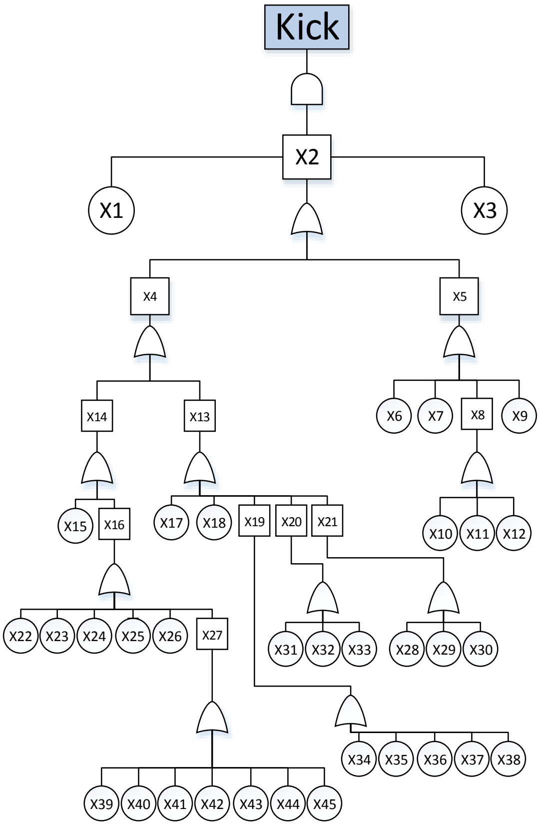

Figure 5. Kick fault tree

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Table 4. Components of the kick fault tree and their probabilities in Figure 5

Event	Description	Probability		Description	Probability
X1	Efficient hydrocarbon formation	0.005	X25	Bad cementing	0.0055
X2	Negative diffraction pressure	0.2518	X26	Casing failure	0.0055
X3	Sufficient permeability	0.0292	X27	Surging-piston effect	0.029
X4	Low hydrostatic pressure	0.227	X28	Failure in centrifuge	0.0003
X5	Low AND lost APL	0.0248	X29	Failure in degasser	0.0015
X6	Surface line failure	0.0042	X30	Mud cleaner equipment in adjustment	0.0006
X7	Power failure	0.0055	X31	Power failure	0.0055
X8	Pump failure	0.0107	X32	Agitator(mixer) failure	0.0001
X9	Operator failure to notice adjustment	0.0044	X33	Settlement of mud weight substance	0.0061
X10	Pump control failure	0.0055	X34	Pulling the pipe too fast	0.0175
X11	Flied end lost in	0.0033	X35	Using Mud high viscosity and high gel strength	0.0090
X12	Blowing	0.0019	X36	Having balled up bit	0.0166
X13	Density reduction	0.044	X37	Having thick wall cake	0.0085
X14	Volume reduction	0.0664	X38	Having small clearance between the string and hole	0.0127
X15	Inadequate hole's fill up	0.0445	X39	Having and plugged drill string	0.001
X16	Mud lost	0.022	X40	Run in to hole too fast	0.0049
X17	Gas cut mud	0.0395	X41	Using mud of high viscosity &high gel strength	0.0067
X18	Abnormal pressuresize	0.0445	X42	Having balled up	0.0055
X19	Swabbing while tripping	0.063	X43	Having Thick wall cake	0.0004
X20	Mud weight reduction	0.0116	X44	Having small clearance between the string and hole	0.0090
X21	Failure in Mud treatment equipment	0.0262	X45	Using the float valve /non return safety valve	0.0019
X22	Formation	0.0055			
X23	Increasing MW	0.0058			
X24	Annular losses	0.0055			

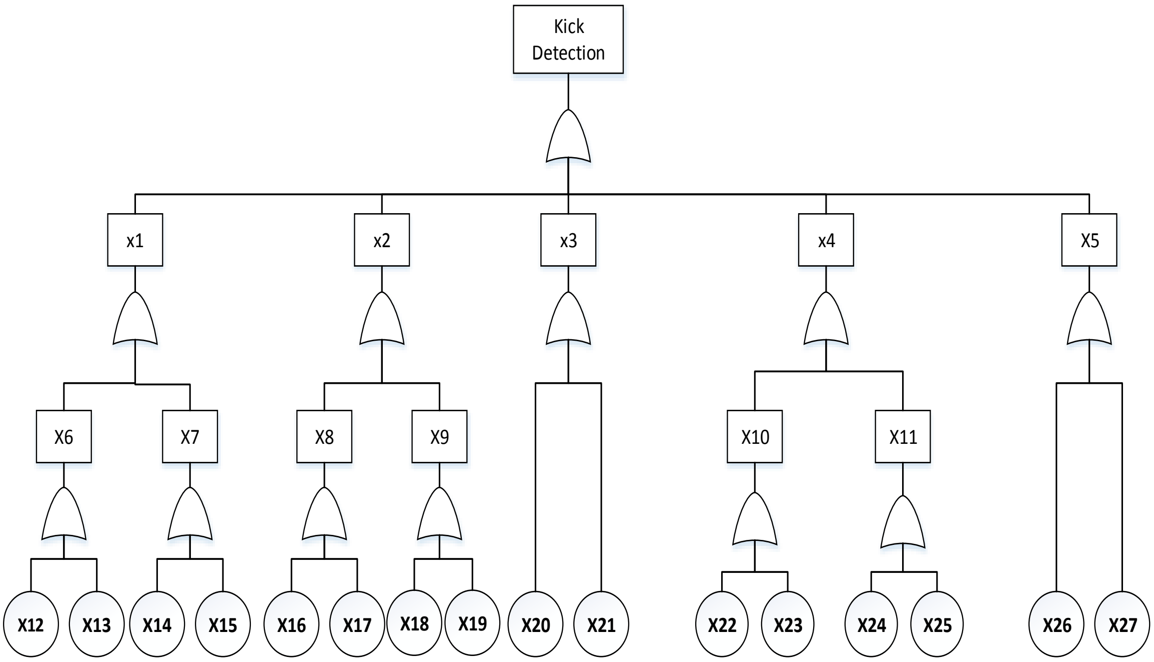

Figure 6. Kick detection fault tree

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Table 5. Components of the kick detection fault tree and their probabilities in Figure 6

Event	Description	Probability	Event	Description	Probability
X1	Mud volume/ flow change	0.146	*X17*	Failure of operator to notice change in SPM	0.0019
X2	Circulation pressure change	0.133	*X18*	Failure of stroke meter	0.0008
X3	Gas cut	0.07	*X19*	Failure of operator to notice change in P.R	0.0019
X4	Mud property change	0.032	*X20*	Failure of gas detector	0.0003
X5	ROP change	0.006	*X21*	Failure of operator to notice gauge	0.073
X6	Mud tank	0.0002	*X22*	Failure of density meter	0.015
X7	Flow Metering	0.014	*X23*	Failure of operator to density meter	0.015
X8	Pump	0.131	*X24*	Failure of resistivity	0.0006
X9	Pump Rate(SPM)	0.002	*X25*	Failure of operator to notice conductivity change	0.015
X10	Mud density	0.051	*X26*	Failure of ROP indicator	0.0045
X11	Mud conductivity	0.015	*X27*	Failure of ROP change	0.0021
X12	Failure of tank level indicator (float system)	0.04			
X13	Failure of operator to notice the tank level change	0.00002			
X14	Failure of flow meter	0.14			
X15	Failure of operator to notice flow meter	0.006			
X16	Failure of pressure gage	0.001			

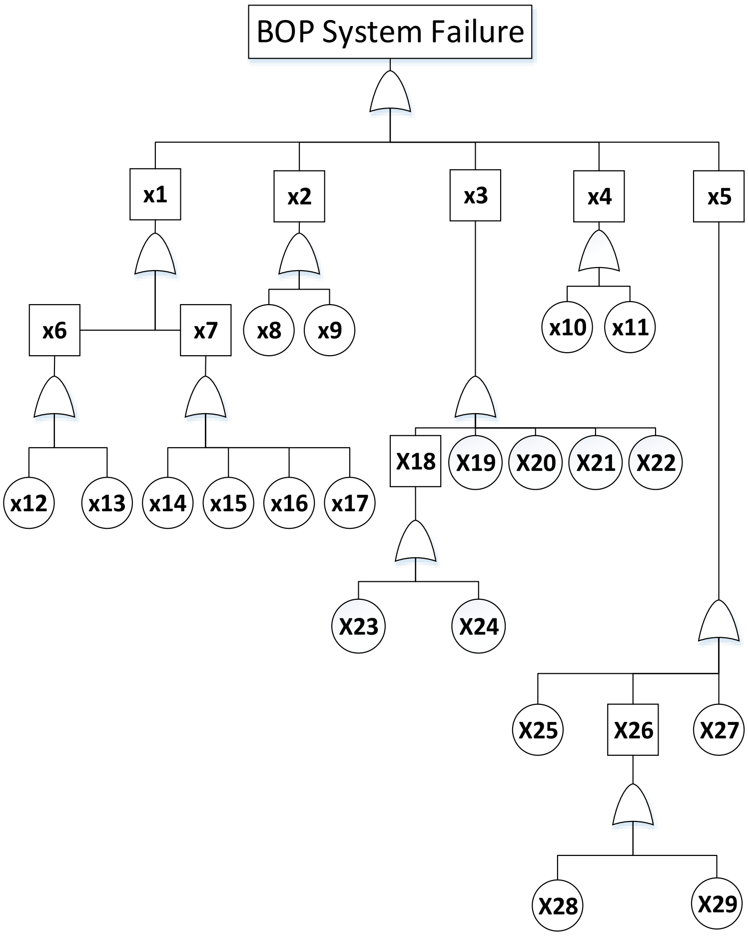

Figure 7. BOP fault tree

Table 6. Components of the BOP fault tree and their probabilities in Figure 7

Event	Description	Probability	Event	Description	Probability
X1	BOP stack failure	0.00009	*X16*	Lower pipe ram failure	0.0245
X2	Valve failure	0.00009	*X17*	Blind shear ram failure	0.014
X3	BOP control system failure	0.0629	*X18*	Power system failure	0.0057
X4	Line failure	0.0007	*X19*	4Way valve failure	0.0128
X5	Choke manifold failure	0.0206	*X20*	Remote panel valve failure	0.0148
X6	Annular preventer	0.00004	*X21*	Signal line failure	0.0148
X7	Ram preventer	0.0001	*X22*	Accumulator line failure	0.0148
X8	Kill valve fail	0.242	*X23*	Air driven pump failure	0.0025
X9	Choke valve fail	0.0002	*X24*	Electric pump failure	0.0032
X10	Choke line fail	0.346	*X25*	Choke valve failure	0.0002
X11	Kill line fail	0.346	*X26*	Hydraulic choke valve failure	0.0097
X12	Upper annular preventer fail	0.246	*X27*	Gate valve failure	0.0105
X13	Lower annular preventer fail	0.0245	X28	Choke remote panels failure	0.0097
X14	Upper pipe ram fail	0.0245	X29	Hydraulic choke valve failure	0.0097
X15	Middle pipe ram fail	0.0245			

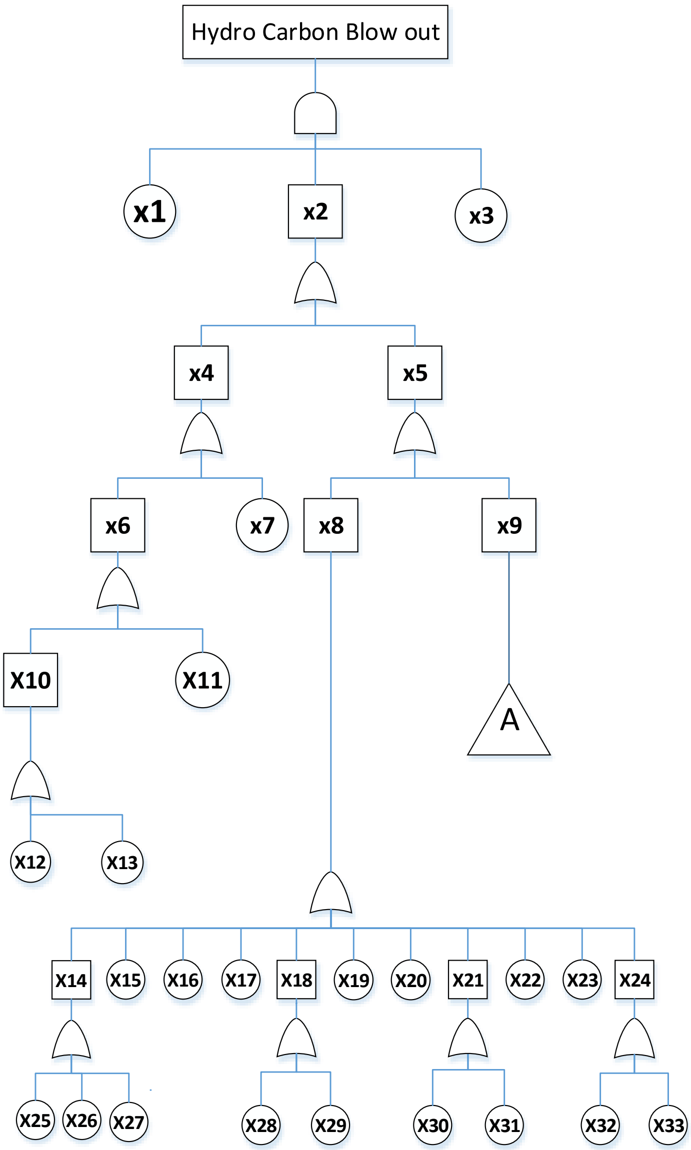

Figure 8. Blowout hydrocarbon fault tree by the first path

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Table 7. Components of blowout hydrocarbon by first path and their probabilities in Figure 8

Event	Description	Probability	Event	Description	Probability
X1	Kick	0.0286	X18	Power system failure	0.001
X2	Well control failure	0.099	X19	Gauge failure	0.0093
X3	Kick detection failure	0.387	X20	Casing failure	0.00006
X4	Above BOP	0.0025	X21	Rig Mud pump failure	0.00002
X5	Inadequate well control	0.0972	X22	Drill pipe failure	0.00005
X6	Catastrophic	0.0025	X23	Bad cementing	0.0005
X7	Rig collapse	0.0025	X24	Well head system damaged	0.00002
X8	Kill	0.0128	X25	Pit level indicator failure	0.0002
X9	BOP System failure	0.0844	X26	Pump stack failure	0.0002
X10	artificial	0.00006	X27	Mud flow indicator failure	0.0002
X11	Natural	0.00003	X28	Primary power failure	0.0005
X12	War	0.00003	X29	Secondary power failure	0.0005
X13	Terrorism	0.00003	X30	Mud pump failure	0.0002
X14	Indication system failure	0.0006	X31	Back up pump failure	0.0043
X15	Choke and kill line failure	0.0003	X32	Causing head housing failure	0.00001
X16	Drill pipe not returned to valve	0.00005	X33	Well head connection failure	0.00001
X17	Operator error	0.003	A	BOP system failure	0.08443

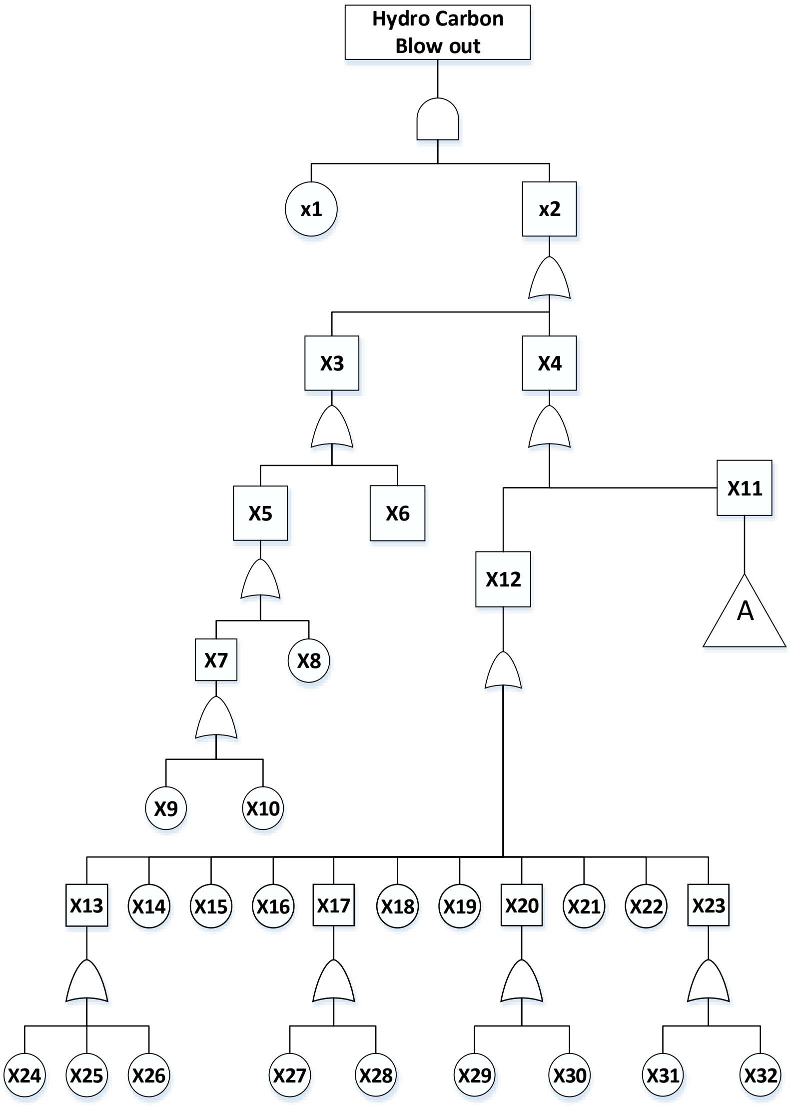

Figure 9. Blowout hydrocarbon fault tree by the second paths

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Table 8. Components of blowout hydrocarbon by second paths and their probabilities in Figure 9

Event	Description	Probability	Event	Description	Probability
X1	Kick	0.0286	X19	Casing failure	0.0006
X2	Well control failure	0.0999	X20	Rig Mud pump failure	0.0086
X3	Above BOP	0.0025	X21	Drill pipe failure	0.00005
X4	Inadequate well control	0.0972	X22	Bad cementing	0.0005
X5	Catastrophic	0.0025	X23	Well head system damaged	0.00002
X6	Rig collapse	0.0025	X24	Pit level indicator failure	0.0002
X7	Artificial	0.00006	X25	Pump stack failure	0.0002
X8	Natural	0.00003	X26	Mud flow indicator failure	0.0002
X9	War	0.00003	X27	Primary power failure	0.0002
X10	Terrorism	0.00003	X28	Secondary power failure	0.0002
X11	BOP system failure	0.0844	X29	Mud pump failure	0.0002
X12	Kill operation	0.0128	X30	Back up pump failure	0.0043
X13	Indication system failure	0.0006	X31	Causing head housing failure	0.00001
X14	Choke &Kill line failure	0.0003	X32	Well head connection failure	0.00001
X15	Drill pipe not returned to valve	0.00005	A	BOP system failure	0.08443
X16	Operator error	0.0003			
X17	Power system failure	0.001			
X18	Gauge failure	0.0093			

Discussion

The four stages of well control included kick prevention, kick detection, ,and blowout prevention and equipment, the first three of which are related to the loss of well control, and the last one, to the recovery of well control. [4,9] In current research, the fuzzy fault tree analysis method was used to evaluate the blowout risk of the well. These four stages were identified as undesired and their and intermediate causes were specified using the fuzzy fault tree analysis method. The fault tree for the prevention of the occurrence of kick included 34 and 11 intermediate , a total of 45 causes were identified, and the probability of a total failure was estimated to be 0.3682. The reduction of hydrostatic pressure against abandonment pressure was the main cause of kick occurrence with 26 basic and 7 intermediate causes, and the probability of its failure was calculated as 0.227. It had a major contribution to the occurrence of kick. Kick detection fault tree included 16 and 11 intermediate , and the probability of failure in kick detection was estimated as 0.3778. In this tree, Mud volume changed with a failure rate 0.1462, and flow pressure changed with a rate of 0.5 .These were the highest failure rates, and had the greatest impact on the overall failure probability. The fault tree of blowout prevention equipment included 20 occurrences and 9 intermediate ones, and the probability of failure in prevention equipment was estimated to be 0.08483. The probability of failure of blowout prevention control system with the failure rate of 0.629 made the largest contribution to the final probability of the fault tree regarding the blowout prevention equipment. The probability of failure of hydrocarbon blowout was drawn from two paths. The first path included 33 and 11 intermediate , and the final probability of its failure was estimated to be 0.011. The three causes of failure of kick, failure of well control equipment and failure of kick detection related to each other with AND gate, were the main and effective causes in the final of the blowout. The probability of failure of hydrocarbon blowout in the second path included 20 and 12 intermediate, and the probability of the final failure was estimated at 0.0286. In this path, failure of the kick and failure of blowout equipment with connection AND gate was enough to lead to the final hydrocarbon blowout. Among the four identified, the probability of failure in kick detection was estimated at 0.3878, which had the highest failure rate. It was followed by occurrence of kick with a failure probability of

0.2863, BOP failure with a probability of 0.08443, and hydrocarbon blowout from the second paths with the failure probability of 0.0286 and hydrocarbon blowout from first path with the probability of 0.011constituted the lowest failure rates.

Conclusion

Risk assessment is a main part of proactive approach to prevent accident in workplace .Having clear understanding of and intermediate help to predict failures leading to top. FTA provides such vision against blowout in oilfield.

Conflict of interest

The authors declared no conflict of interest.

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Authors' contributions

All authors equally contributed to preparing this article.

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