Journal of Industrial and Systems Engineering
Vol. 12, No. 2, pp. 46-60
Spring (April) 2019

Identification and ranking risks of horizontal directional drilling for oil & gas wells by using fuzzy analytic network process: A case study for Gachsaran oil field wells

Abbas Sheikh Aboumasoudi[1*], Omid Behvandi[1]

[1]*Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

a_sh_edu@pin.iaun.ac.ir, Omid_behvandi@yahoo.com

Abstract

Risk ranking of Horizontal Directional Drilling (HDD) for gas and oil wells is a key criterion in the project feasibility, pricing and for introducing a risk management strategy that aims to reduce the number of failures in the installation phase and its negative consequences. HDD is currently widely used in drilling wells in Iran, but research in the area of identification and risks ranking of these projects have not been done so far. Therefore, this research will identify and ranks the HDD risks in the field of Gachsaran as the case study, by helping literature review and drilling experts and using statistical techniques and Multi-Criteria Decision Making (MCDM) methods. The method of the network analysis process is a powerful tool in deciding uncertain topics for ranking the risks. The offered approach allows decision-makers to involve in the ranking process and use linguistic assessment in the ranking of HDD risks.

Keywords: Horizontal Directional Drilling (HDD), Analytic Network Process (ANP), fuzzy set theory.

1- Introduction

Horizontal Directional Drilling (HDD) technology is used to install water, gas, heating, drain, sewers pipes and cables under obstacles such as rivers, busy streets, highways, airport runways, areas congested with buildings or underground utilities, and environmentally sensitive areas (Gierczak, 2014 (1)). It is an ideal technology because it does not require large excavation pits nor does it greatly interfere with traffic. When drilling the initial borehole, the drill can be easily tracked and its path altered unlike other trenchless technologies such as jack and bore. HDD is also versatile as it can be used for large diameter pipelines and pipelines spanning a large distance (Hashash and Javier, 2011). Many contractors who install underground utilities applying HDD technology are not able to carry out risk assessment in the project planning phase, as they do not have any mathematical model which allows doing it for various sizes of HDD installations (Gierczak, 2014 (2)). Risk dimensionality and severity is generally greater in the case of HDD because the equipment, labor and material that is used in the process are all selected to match the predicted soil condition, ground water table, and location of other utilities, which are all determined from limited sampling done during the pre-planning phase of the projects (Skogdalen and Vinnem, 2012).

The experts emphasize the necessity of risk assessment before starting the realization of the investment, as the estimation of the risk level is the starting point to analyze the project feasibility and cost estimation.

*Corresponding author

Thanks to carrying out a risk assessment, a lot of serious economic and legal consequences connected with HDD failure e.g. the damage of other existing underground utilities, the damage of expensive HDD down-hole equipment, the damage to the installed pipeline, etc. can be avoided.

Currently, there is also no risk management strategy available, which could be an effective tool to reduce the risk level (Moganti, 2016).

Any deviation from the predicted project parameters will escalate the risk leading to possible accidents. Many accidents have occurred on HDD projects due to various factors that include but not limited to uncertain soil conditions, inappropriate drilling practices, inaccurate locating of existing utilities, inappropriate worker apparel, and lack of effective communication among crew members on the jobsite. Some of these accidents have resulted in severe injuries and even deaths of workers (Ma et al., 2010). These consequences present a need for evaluating the safety risk on HDD projects through investigating the current practices in the industry (KarimiAzari et al., 2011).

This study attempts to identify and rank the Horizontal Directional Drilling (HDD) in the field of Gachsaran using of the linguistic preferences. The presented approach, inclusive thirteen risk in four categories of grand, environment, machine and management which are identified by expert opinions and One-Sample T-Test and their relative ranks are calculated by using Fuzzy Analytical Network Process (FANP) with considering the interdependency between them. Meanwhile, in order to remove the waste calculation in FANP method, the relationships of criteria are specified by expert opinions and Pareto principle. The rest of the paper is organized as follows: in section 2 the literature review would be presented. The methodology of research would present in sections 3 and a numerical application of the proposed approach will present in section 4 and finally conclusion and future works would be presented in section 5.

2- Literature review

Digging the ground to reach the desired target is called drilling. Drilling can be done to reach oil, water, gas, etc. The drilling operations are carried out at a great speed, since using a drill rig for a long time is very costly. Drilling operations are very dangerous and always used by the most experienced people to do (Carlin, 2014). The oil well is a cylindrical hole that is created on the ground for exploration, operation, etc. of oil resources, and may be vertical or oblique. Wang et al. (2012) and Zhang et al. (2011) describe the methods used for drilling as follows: vertical drilling, horizontal drilling, horizontal directional drilling, multilateral drilling and under balance drilling.

In the phrase of drilling, the drilling of a well in the direction of a predetermined path to achieve a given goal is called horizontal directional drilling. On the other hand, it has been interpreted as a curved, oblique and guided excavation (Bennett and Ariaratnam, 2008). Figure 1 shows the schematic state of horizontal directional drilling (Mawford, 2009):

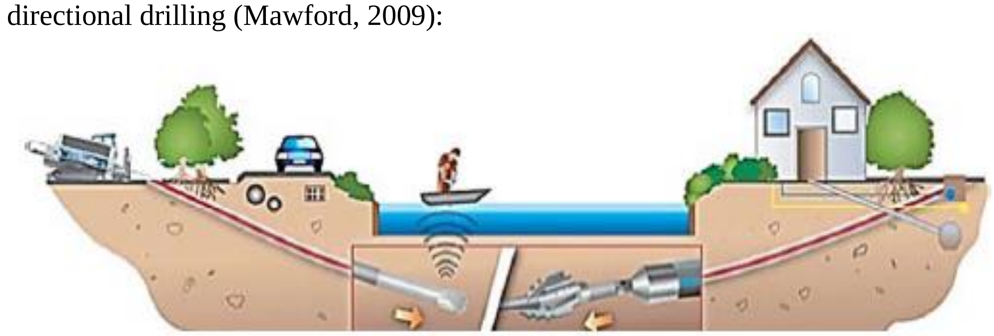

Fig1. Schematic state of horizontal directional drilling (Mawford, 2009)

Risk management is a pivot of management, risk assessment is a risk management tool that can help you investigate the potential risks and decide on their reduction. Drilling of oil and gas wells is always faced with operational hazards and problems that lead to a lot of damage. Therefore, management and assessment of safety, health and environment risks are essential for drilling operations, which should be considered more in the drilling industry (must be selected). In the literature no risk assessment model for HDD technology was found, which takes into account the risk management strategy. It indicates the need to develop a new mathematical model for the risk assessment in HDD technology, taking into consideration the important risk factors (Abdelgawad et al., 2010).

Van Staveren (2007) states that there are four main types of risk that they should be recognized: pure and potential risk, predicted and unpredicted risk, information and interpretation risk, direct and indirect risk. Pure risk relates to unwanted hazards or events that always lead to unwanted occurrences. It is advisable to eliminate this type of risk as quickly as possible. Risk is defined as the possibility of loss. Risk cannot be eliminated on an HDD installation. It must be managed. To be managed, HDD risk must be understood. Categorizing risk aids in understanding risk.

Several decision-making approaches to rank have been introduced in the past three to four decades, including the matrix method, Analytical Hierarchical Process (AHP), Artificial Neural Networks (ANN), TOPSIS, Case Based Reasoning (CBR), fuzzy set theory, data envelopment analysis (DEA), the Genetic Algorithm (GA), Mathematical Programming (MP), Simple Multi-Attribute Rating Technique (SMART), GRA, and their hybrids (Hashemi et al., 2015). Nieto-Morote et al. (2010) presented a new method for risk analysis for a construction project that addresses the complexity of dealing with risk in which information is either incomplete or unacceptable for risk assessment. Kang et al. (2005) presented a model to evaluate by using a multivariate dynamic programming approach. The researchers solved the proposed model through a duplicate algorithm. Zheng et al. (2007), using the modified hierarchy analysis process, have presented a structure for the risks of construction projects.

3- Material and methods

3-1- One-Sample T-Test

One-Sample T-Test introduced as a statistical tools, which used to examine the mean difference between the sample (n<30) and the known value of the population mean. In One-Sample t-test, the population mean was known. A random sample is selected from the population, and then the mean of sample is compared to the average of the population, and statistical decision is made about whether or not the sample mean is different with the population mean. [19].

The statistical hypothesis for One-Sample T-Test is: $\begin{cases} H_{.}: \mu = a \\ H_1: \mu \neq a \end{cases}$ (1)

Where, "a" is a numerical value. The examination statistic equal to: $t = \frac{\bar{x}-\mu}{\frac{s}{\sqrt{n}}}$ (2)

Hypothesis testing: In hypothesis testing, statistical decisions are made to decide whether or not the population mean and the sample mean are different. Here, the calculated values are compared to the value of the table. If the calculated value is greater than the table value, then the hypothesis is rejected and the alternative hypothesis is accepted (Winter, 2013).

3-2- Pareto principle

A principle, named after economist Vilfredo Pareto that specifies an unequal relationships between inputs and outputs. The principle states that, for many phenomena, 20% of invested input is responsible for 80% of the results obtained. Put another way, 80% of consequences stem from 20% of the causes (Bi et al., 2012).

3-3- Fuzzy Analytic Network Process (FANP)

ANP is a general form of the Analytical Hierarchy Process (AHP) which was proposed by Saaty (1996) for extending the AHP to address restrictions of the hierarchical structure where criteria are independent from each other. In FANP, pair-wise comparison matrices are formed between various attributes of each level with the help of triangular fuzzy numbers. The FANP can easily accommodate the interrelationships existing among the functional activities (Önüt et al., 2009).

Önüt et al. (2009) proposed the following four main steps of FANP as follows:

Step 1: Model problem structuring: The problem should be clearly defined and decomposed into a logical system like a network.
Step 2: Pair wise comparison matrices and priority vectors: the geometric mean is used to aggregate the expert opinions and to obtain eigenvectors of each pair wise tables, the logarithmic least squares method can be used as follows:

$$\widetilde{w}_k = \left(w_k^l, w_k^m, w_k^n\right) \ \ k = 1,2,3, \dots, n \tag{3}$$

Where:

$$w_k^s = \frac{\left(\prod_{j=1}^{n} a_{kj}^s\right)^{1/n}}{\sum_{j=1}^{n}\left(\prod_{j=1}^{n} a_{ij}^m\right)^{1/n}} \quad s \in \{l, m, n\} \tag{4}$$

Step 3: Forming the super-matrix (w_{ij}): these matrixes include the eigenvectors which obtained from step 2.
Step 4: calculating final weighs of levels: final weights of elements for each level (w_i^*) is calculated using equation 4:

$$w_i^* = w_{ii} \times w_{i(i-1)} \times w_{i-1}^* \tag{5}$$

3-4- Methodology

The proposed combined approach to identify and rank the Horizontal Directional Drilling (HDD) in the field of Gachsaran consists of seven steps, as shown in figure 2. In the first step, HDD risks are specified by reviewing the literature. In the second step, a decision making team (DMT) is organized. In the third step, the identified risks of first step are investigated in Brainstorming meetings and are finalized. Experts of study are determined by DMT in the fourth step. In the fifth step, a structured questionnaire which its validity confirmed by drilling experts and its Reliability is equal to 0.752 according to Cronbach's Alpha method, is used to select the relevant HDD risks based upon those suggested in third step. In the sixth step, the experts are asked to provide their opinions in linguistic terms on whether a risk was relevant or not to rank the Horizontal Directional Drilling (HDD). Next, the relevant risks are selected by one-sample t-test and using SPSS Software. In the seventh step, the experts are asked in a structured questionnaire which its validity confirmed by drilling experts and its Reliability is equal to 0.802 according to the Cronbach's Alpha method, to determine the relationship between the risks. After receipt of the filled out questionnaire, number 1 will be inserted in case there is a relationship between two selected risks and 0 if no relationship is assumed, then the related Pareto chart is drawn. Relations between the pair of risks that are covered by 80 percent of the expert opinions frequency are accepted and elected as the relationships among the risks. Finally, using pairwise comparisons in order to determine the relative importance of the risks, ranks of the HDD risks using a super-matrix which is part of the FANP are calculated.

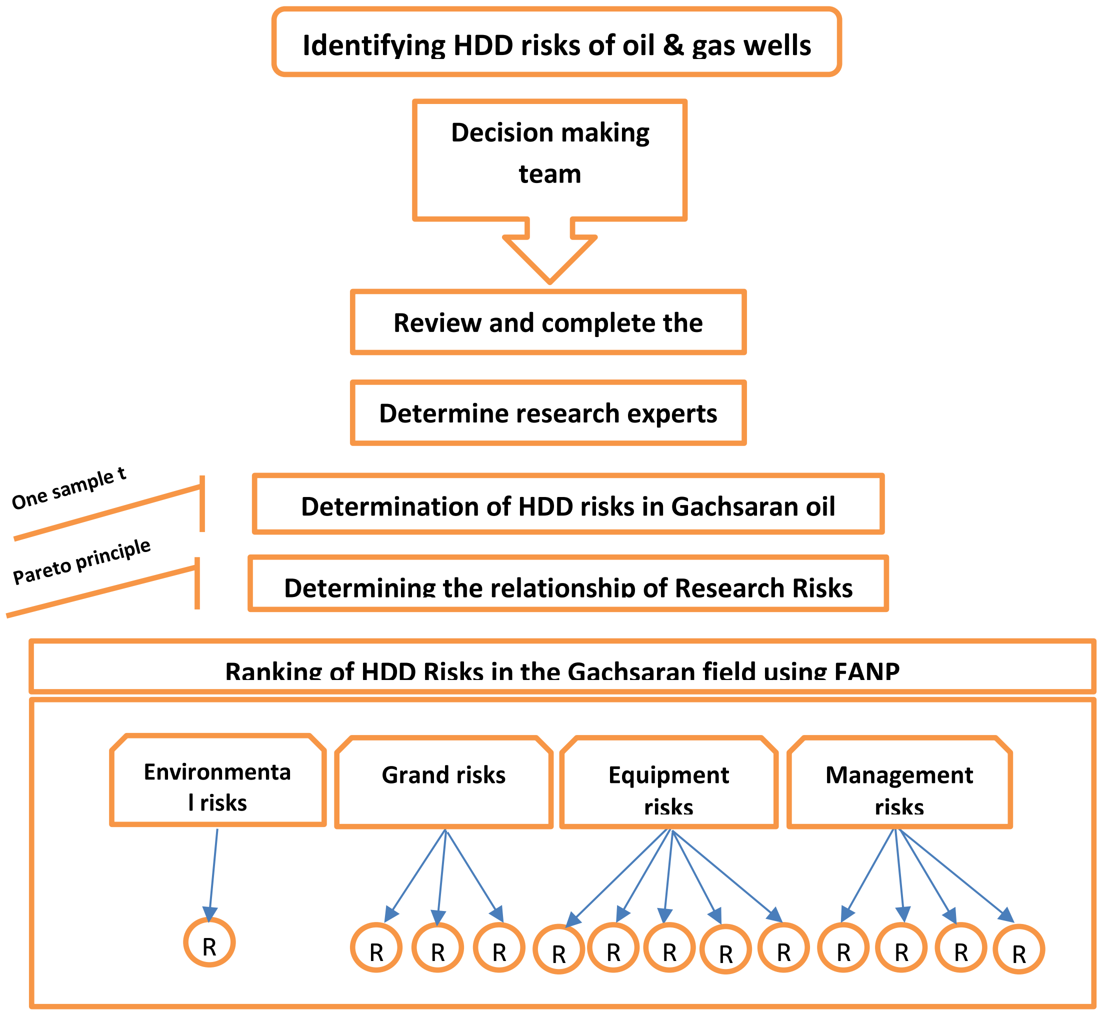

Fig 2. Diagram for proposed approach

3-5- Numerical example

The Gachsaran oil field is an Iranian oil field located in Kohgiluyeh and Boyer-Ahmad Province and is around Gachsaran city or Dogonbadan. It was discovered in 1928 and developed by Anglo-Persian Oil Company. It began production of Crude oil in 1930. The total proven reserves of the Gachsaran field are around 52.9 billion barrels (9394×106tonnes), and production is centered on 560,000 barrels per day (89,000 m3/d).

3-5-1- Identifying HDD risks of oil and gas wells drilling

In order to identify the appropriate risks in the ranking process, in the first step, by conducting library studies, the risks identified in the literature as horizontal diversion drilling risks are collected.

3-5-2- Forming decision making team

The decision-making team is formed consists of experts in the field of drilling in Gachsaran oilfield, which has both management and drilling experiences (table 1).

Table 1. Decision making team

Item	Position	Experience (year)
1	Area Chief	30
2	Head of drilling operations	27
3	Owner representative and Supervisor of drilling operations	27
4	Senior expert of drilling directional	20
5	Senior expert of operations and researcher drilling	20

3-5-3- Review and complete the identified risks

The decision-making team, through the formation of brain storm meetings, takes action on examining the risks identified in the literature review and eventually finalizing the research risks list (table 2). Bent Ariatanam (2008) and Gierezacca (2014), have used management, ground, equipment and environmental risk grouping to categorize drilling risks, the same are also used in current research.

3-5-4- Determining the list of experts

The decision making team, identifies research experts among experts in the Gachsaran oil field. Having at least a bachelor's degree and experience of at least 5 years in HDD projects are the criteria to select the experts (table 3).

Table 2. Research experts

Item	Position	Total No. of expert	Number of eligible expert based on criteria		No. of Research Experts
			Bachelor Degree criteria	Experience criteria (At least 5 years of experience in drilling operations)	
1	Heads of drilling operation	5	5	5	5
2	OperationsلگHeads of	2	2	2	2
3	Heads of geological operation	4	3	3	3
4	Senior expert of geophysics	2	2	2	2
5	Representatives of the Owner in drilling operation	2	2	2	2
6	Head of directional drilling operation	2	2	2	2
7	Senior expert on directional drilling	8	8	5	5
8	Senior expert in Orientation	8	8	5	5
9	Senior expert of mechanical engineering of drilling machines	6	6	2	2
10	Senior expert of electrical of drilling machines	5	5	2	2

Table 3. Identified HDD risks

item	risk	Code	item	risk	Code
1	Unexpected natural subsurface obstacles	R1	37	Release of drilling mud and gasoline and related environmental damages	R37
2	Man-made subsurface obstacles	R2	38	Inappropriate calculation of load on drill and tension, which exceeds the tube capacity during operation	R38
3	Blocking of the drilling pipe or product pipe installation due to the swelling of clay and silt	R3	39	Not taking into consideration the allowable bending radius of drill pipes or the product pipe	R39
4	Shallow gas probability	R4	40	Inappropriate selection of external tube coating	R40
5	Total/partial losses in formation layers	R5	41	Operator lacking the required skills	R41
6	Crew exposed to H2S	R6	42	Fatigue of workers	R42
7	Wells instability	R7	43	Lack of proper supervision	R43
8	Increase the well cavity and cementing problems	R8	44	Not testing water for the drilling fluid preparation	R44
9	Plugging of Transmitters and Electronic Pulse Transmitter	R9	45	Not testing the mud properties	R45
10	Inappropriate entry into the tank with error angle and failure to obtain exploitation calculated	R10	46	Delay in the materials delivery and transportation	R46
11	Loss of radio communication with a drill rig	R11	47	Type of contract	R47
12	Pipe damage due to the material's fatigue & low quality	R12	48	Improper cost calculations for the investment	R48
13	Failure of drilling rig for mechanical and electrical reasons	R13	49	Insufficient available capital	R49
14	Drilling mud engine failure	R14	50	High interest rate	R50
15	Mud Washing System Failure	R15	51	Imbalance of exchange rates	R51
16	Roller blocks failure	R16	52	High inflation	R52
17	Roller cradles failure	R17	53	Inappropriate choice of project implementation method	R53
18	Side cranes breakdown	R18	54	Failure to predict the exact time to run the project	R54
19	Ballasting system breakdown	R19	55	Contractor's error	R55
20	Faulty pipe connections: the improper fusion/welding of pipes	R20	56	Drill a diversion away from the main hole	R56
21	Excessive noise	R21	57	Failure to achieve the main target point	R57
22	Drill pipes Pre-hit	R22	58	The mistakes of the angles received from the bottom of the well arising from wrong pre-hitting	R58
23	Tight hole stuck pipe	R23	59	Inaccurate calculations of the orientation and azimuth angles and the geographic coordinates of the tank	R59
24	Equipment failure due to H2S gas	R24	60	Eclipse of drilling tools through drilling mud additive	R60
25	Creating torque in BHA and mismatching engine axes and navigation system	R25	61	Wrong angle setting and computational errors	R61
26	Cutting the inside of the well during rotation due to the torque on the drill bi	R26	62	The inability of the navigational engineer to identify the correct pulses and the resulting computational errors	R62
27	Problems with the power supply of in-well navigation equipment	R27	63	Pre-estimated mistake in the amount of power needed	R63
28	Calibration of navigation sensors	R28	64	Computational mistake of drill jets and loss of pressure	R64
29	Failure and incomplete performance of electromechanical actuators	R29	65	Computation of lags with high variance.	R65
30	Problems of Flow Switches & Pressure indicator Relays	R30	66	Failure to reach the final Target point	R66
31	disconnecting the various modules of the in-well navigation tools	R31	67	Lack of proper formation of different groups	R67
32	wrong pulses generating and transitions to the surface	R32	68	Problems due to the financial burden of expensive equipment and related stress	R68
33	in-well motor breakdown including static and rotor	R33	69	Ergonomic problems due to fatigue and pressure of non-stop activities	R69
34	Problems with the building permission	R34	70	Conclusion of inappropriate contracts and risks of native workers using	R70
35	Severe weather conditions	R35	71	Extreme dependency to offshore supply and sanction	R71
36	Lack of access to natural water for drilling operations	R36	72	Problems due to a short or long distance of the resting camp and the location of the drilling machine	R72

3-5-5- Determine the research risks using One-Sample T-Test

In the second stage, by issuing a questionnaire, experts are asked to specify the importance of the risks using linguistic preferences. In this phase, the linguistic terms of “very good”, “good”, “moderate”, “weak” and “very weak” were used [29]. Then, to change the qualitative data to quantitative data, the values: 5~1 were allocated to the importance levels of “very high” to “very weak”, respectively. The quantitative data were inserted to the SPSS software in order to perform One-Sample T-Test. The selected statistics for the test were shown in (table 4).

According to equation 1, the statistic hypotheses are defined as: $\begin{cases} H_\circ : \ \mu = 3 \\ H_1 : \ \mu \neq 3 \end{cases}$

For all the risk significance level is less than 0.05 (the level of significance which usually used for the test) and the significance level less than 0.05 Leads to rejection of the null hypothesis($\mu = 3$). So, the pollution mean of these risks are lower or upper than the test value (i.e., $\mu \neq 3$). However, the risks with positive values for lower and upper limits of Confidence Interval of the Difference have population mean more than test value (i.e., $\mu > 3$). Therefore, the accepted risks to rank HDD risks, which are obtained from expert’s opinions and One-Sample T-Test are: R4, R5, R6, R12, R23, R28, R31, R33, R36, R57, R60, R69 and R71 (figure 3).

3-5-3- Determining the risks relationship using Pareto principle

To determination the relationships between the research’s risks, the experts were asked to assess the relationship or lack of relationship between the pair-risk by a questionnaire. After receipt of the filled out questionnaires, the qualitative data were changed to quantitative data by inserting number 1 in case, there was a relationship between two selected risks and 0 if no relationship was assumed. Then, the frequency percent of expert opinions were calculated and sorted in descending. In following, cumulative frequency of expert opinions were calculated and related Pareto chart was drawn (figure 4). As it shown in figure 4 and according to the Pareto principle, number of 22 relations between the pair-risk that were covered by 80 percent of the expert opinions were accepted and selected as relationships among risks. Figure 5 shows relationships among all 13 risks of this study.

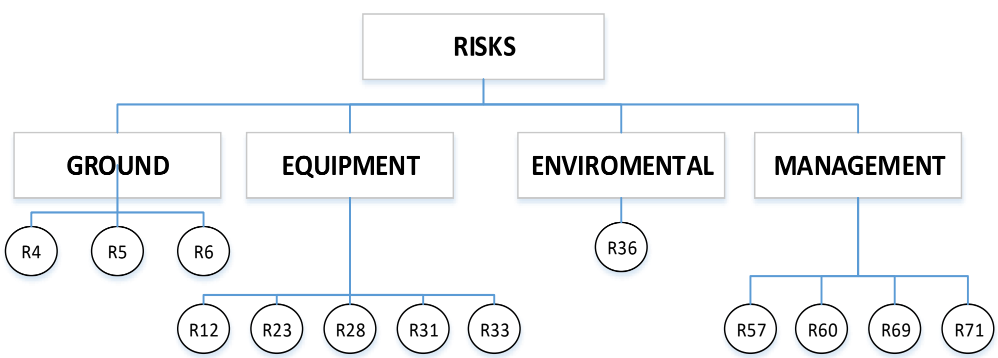

Fig 3. HDD risk in the Gachsaran oilfield

Table 4. One-Sample T Test

	Test Value = 3					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
R1	-41.74	29	0	-1.93333	-2.0281	-1.8386
R2	-17.03	29	0	-1.56667	-1.7549	-1.3785
R3	-9.109	29	0	-1.13333	-1.3878	-0.8789
R4	19.039	29	0	1.66667	1.4876	1.8457
R5	22.494	29	0	1.76667	1.606	1.9273
R6	19.977	29	0	1.7	1.526	1.874
R7	-9.866	29	0	-1.16667	-1.4085	-0.9248
R8	-9.542	29	0	-1.5	-1.8215	-1.1785
R9	-17.03	29	0	-1.56667	-1.7549	-1.3785
R10	-21.11	29	0	-1.73333	-1.9013	-1.5654
R11	-10.43	29	0	-1	-1.1961	-0.8039
R12	22.494	29	0	1.76667	1.606	1.9273
R13	-16.28	29	0	-1.73333	-1.9511	-1.5155
R14	-6.952	29	0	-1	-1.2942	-0.7058
R15	-41.74	29	0	-1.93333	-2.0281	-1.8386
R16	-11.79	29	0	-1.56667	-1.8385	-1.2949
R17	-9.109	29	0	-1.13333	-1.3878	-0.8789
R18	-17.59	29	0	-1.6	-1.7861	-1.4139
R19	-29.57	29	0	-1.86667	-1.9958	-1.7376
R20	-10.5	29	0	-1.56667	-1.8718	-1.2615
R21	-9.522	29	0	-0.96667	-1.1743	-0.759
R22	-41.74	29	0	-1.93333	-2.0281	-1.8386
R23	59	29	0	1.96667	1.8985	2.0348
R24	-21.11	29	0	-1.73333	-1.9013	-1.5654
R25	-10.43	29	0	-1	-1.1961	-0.8039
R26	-34.11	29	0	-1.9	-2.0139	-1.7861
R27	-9.337	29	0	-1.46667	-1.7879	-1.1454
R28	22.494	29	0	1.76667	1.606	1.9273
R29	-6.44	29	0	-1.06667	-1.4054	-0.7279
R30	-29.57	29	0	-1.86667	-1.9958	-1.7376
R31	21.108	29	0	1.73333	1.5654	1.9013
R32	-21.11	29	0	-1.73333	-1.9013	-1.5654
R33	24.233	29	0	1.8	1.6481	1.9519
R34	-9.95	29	0	-1.23333	-1.4868	-0.9798
R35	-29.57	29	0	-1.86667	-1.9958	-1.7376
R36	19.977	29	0	1.7	1.526	1.874

	Test Value = 3					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
R37	-10.25	29	0	-1.53333	-1.8393	-1.2274
R38	-24.23	29	0	-1.8	-1.9519	-1.6481
R39	-29.57	29	0	-1.86667	-1.9958	-1.7376
R40	-8.068	29	0	-1.36667	-1.7131	-1.0202
R41	-11.79	29	0	-1.56667	-1.8385	-1.2949
R42	-29.57	29	0	-1.86667	-1.9958	-1.7376
R43	-9.95	29	0	-1.23333	-1.4868	-0.9798
R44	-29.57	29	0	-1.86667	-1.9958	-1.7376
R45	-11.24	29	0	-1.5	-1.773	-1.227
R46	-8.462	29	0	-1.1	-1.3659	-0.8341
R47	-24.23	29	0	-1.8	-1.9519	-1.6481
R48	-14.1	29	0	-1.6	-1.8321	-1.3679
R49	-7.309	29	0	-1.16667	-1.4931	-0.8402
R50	-29.57	29	0	-1.86667	-1.9958	-1.7376
R51	-12.32	29	0	-1.53333	-1.7878	-1.2789
R52	-8.61	29	0	-0.96667	-1.1963	-0.737
R53	-22.49	29	0	-1.76667	-1.9273	-1.606
R54	-9.109	29	0	-1.13333	-1.3878	-0.8789
R55	-29.57	29	0	-1.86667	-1.9958	-1.7376
R56	-7.616	29	0	-1.33333	-1.6914	-0.9753
R57	29.571	29	0	1.86667	1.7376	1.9958
R58	-9.109	29	0	-1.13333	-1.3878	-0.8789
R59	-9.109	29	0	-1.13333	-1.3878	-0.8789
R60	22.494	29	0	1.76667	1.606	1.9273
R61	-8.61	29	0	-0.96667	-1.1963	-0.737
R62	-10.25	29	0	-1.53333	-1.8393	-1.2274
R63	-21.11	29	0	-1.73333	-1.9013	-1.5654
R64	-29.57	29	0	-1.86667	-1.9958	-1.7376
R65	-9.146	29	0	-1.43333	-1.7539	-1.1128
R66	-7.413	29	0	-1.2	-1.5311	-0.8689
R67	-29.57	29	0	-1.86667	-1.9958	-1.7376
R68	-7.918	29	0	-0.96667	-1.2164	-0.717
R69	26.492	29	0	1.83333	1.6918	1.9749
R70	-22.49	29	0	-1.76667	-1.9273	-1.606
R71	41.738	29	0	1.93333	1.8386	2.0281
R72	-29.57	29	0	-1.86667	-1.9958	-1.7376

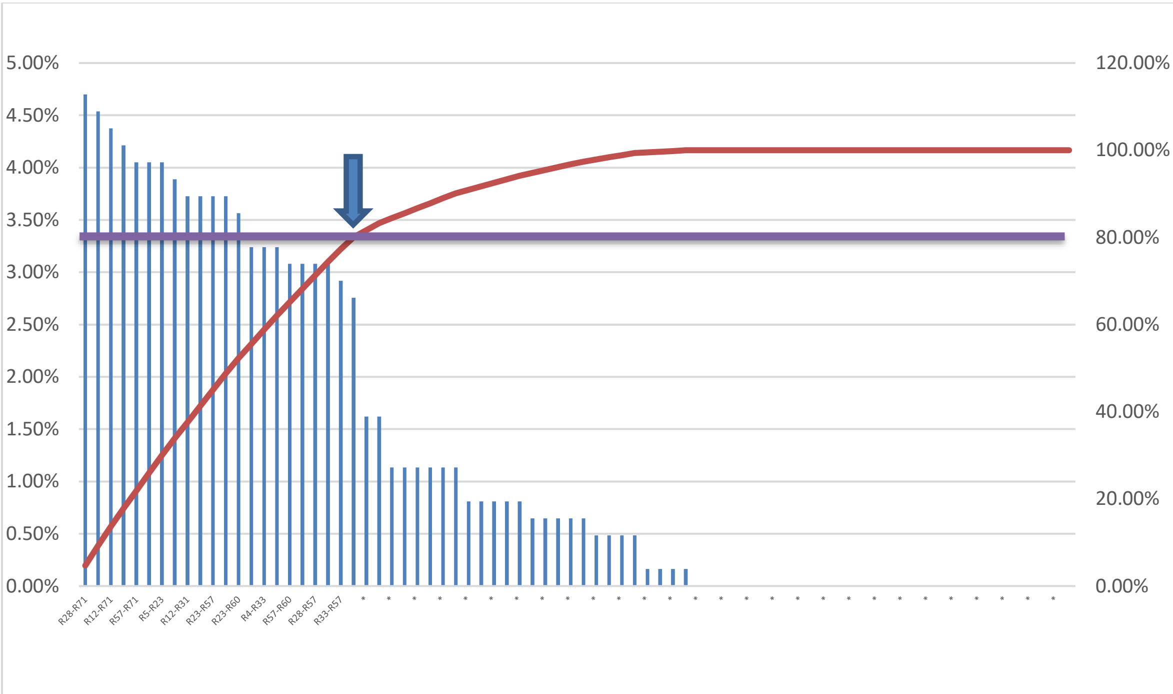

Fig 4. Pareto chart of risks relationship

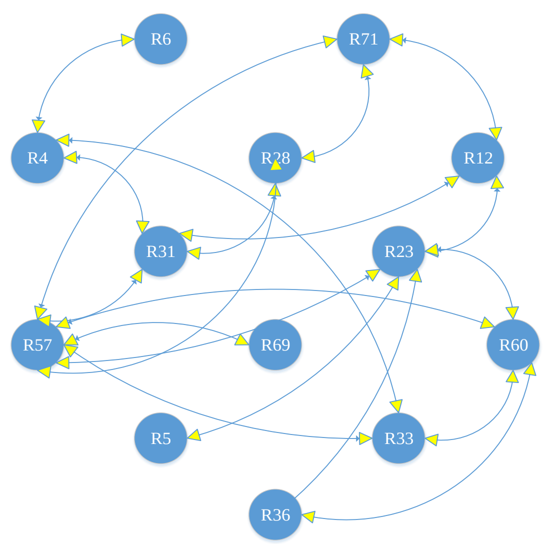

Fig 5. Risks relationship of research

3-5-4- Ranking risks of HDD of oil and gas wells in Gachsaran oilfield using FANP method

First step: In order to determine the weights of risks by using FANP, network structure of problem was provided according to figure 6.

Second step: According to the figure 6, the experts were asked to specify the importance level of risks by pairwise compression questionnaire and using linguistic terms. The linguistic terms used in this step are "equal importance", "weak importance", "string importance ", "demonstrated importance " and "absolute importance ". Helping scale of table 5 the expert opinions were changed to quantitative values and geometric mean was used to aggregating expert opinions.

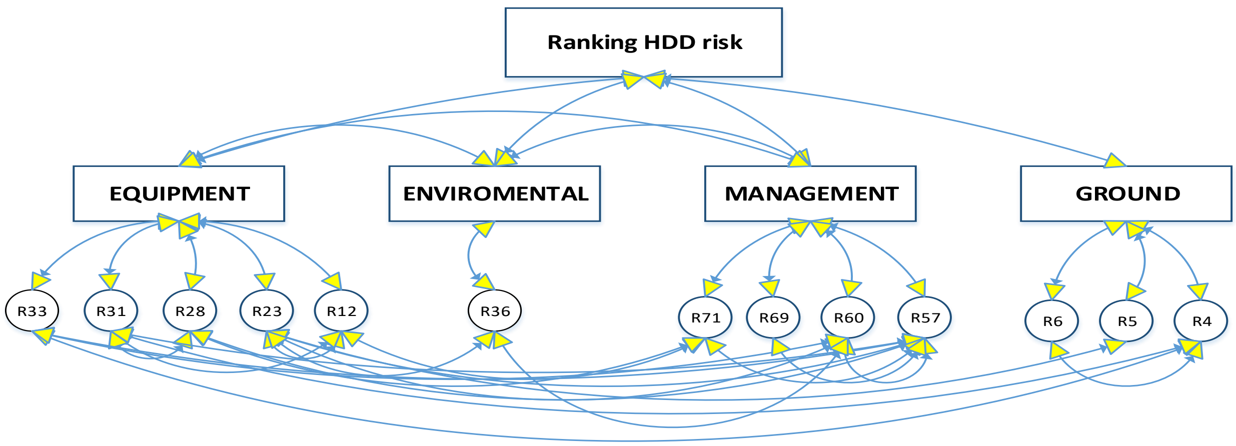

Fig 6. Problem network structure in FANP stages

Third step: In this step, as it shown in table 6-9, eigenvector matrixes were constructed including eigenvectors of the previous steps.

Table 5. Comparison scale (Onüt et al, 2009)

1,1,1	Equal importance
2,3,4	Weak importance
4,5,6	Strong importance
6,7,8	Demonstrated importance
8,9,10	Absolute importance

Table 6. Eigenvector matrix of level 2 respect to level 1

	Ranking of HDD Risk
EQUIPMENT	(0.392,0.429,0.463)
ENVIROMENT	(0.032,0.035,0.039)
MANAGEMENT	(0.125,0.146,0.176)
GROUND	(0.342,0.39,0.43)

Table 7. Eigenvector matrix of level 2 respect to level 2

	EQUIPMENT	ENVIROMENT	MANAGEMENT	GROUND
EQUIPMENT	(0.5,0.5,0.5)	(0.33,0.37,0.40)	(0.42,0.45,0.47)	(0,0,0)
ENVIROMENT	(0.02,0.03,0.03)	(0.5,0.5,0.5)	(0.05,0.05,0.05)	(0,0,0)
MANAGEMENT	(0.16,0.18,0.19)	(0.12,0.13,0.14)	(0.5,0.5,0.5)	(0,0,0)
GROUND	(0.27,0.30,0.32)	(0,0,0)	(0,0,0)	(1,1,1)

Table 8. Eigenvector matrix of level 3 respect to level 2

	EQUIPMENT	ENVIROMENT	MANAGEMENT	GROUND
R33	(0.05,0.05,0.06)	(0,0,0)	(0,0,0)	(0,0,0)
R31	(0.17,0.21,0.25)	(0,0,0)	(0,0,0)	(0,0,0)
R28	(0.12,0.15,0.18)	(0,0,0)	(0,0,0)	(0,0,0)
R23	(0.06,0.07,0.09)	(0,0,0)	(0,0,0)	(0,0,0)
R12	(0.42,0.51,0.60)	(0,0,0)	(0,0,0)	(0,0,0)
R36	(0,0,0)	(1,1,1)	(0,0,0)	(0,0,0)
R71	(0,0,0)	(0,0,0)	(0.08,0.09,0.11)	(0,0,0)
R69	(0,0,0)	(0,0,0)	(0.03,0.037,0.04)	(0,0,0)
R60	(0,0,0)	(0,0,0)	(0.27,0.3,0.34)	(0,0,0)
R57	(0,0,0)	(0,0,0)	(0.50,0.57,0.62)	(0,0,0)
R6	(0,0,0)	(0,0,0)	(0,0,0)	(0.06,0.06,0.07)
R5	(0,0,0)	(0,0,0)	(0,0,0)	(0.69,0.76,0.83)
R4	(0,0,0)	(0,0,0)	(0,0,0)	(0.15,0.17,0.20)

Table 9. Eigenvector matrix of level 3 respect to level 3

	R33	R31	R28	R23	R12	R36	R71	R69	R60	R57	R6	R5	R4
R33	(0.5,0.5,0.5)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.11,0.13,0.15)	(0.10,0.12,0.15)	(0,0,0)	(0.39,0.42,0.46)	(0.28,0.33,0.37)
R31	(0,0,0)	(0.5,0.5,0.5)	(0.13,0.14,0.17)	(0,0,0)	(0.3,0.35,0.39)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.14,0.18,0.212)	(0,0,0)	(0,0,0)	(0.13,0.14,0.17)
R28	(0,0,0)	(0.05,0.06,0.07)	(0.5,0.5,0.5)	(0,0,0)	(0,0,0)	(0,0,0)	(0.04,0.047,0.06)	(0.08,0.09,0.10)	(0,0,0)	(0.04,0.05,0.06)	(0,0,0)	(0,0,0)	(0,0,0)
R23	(0,0,0)	(0,0,0)	(0,0,0)	(0.5,0.5,0.5)	(0.11,0.12,0.14)	(0.07,0.07,0.08)	(0,0,0)	(0,0,0)	(0.05,0.056,0.07)	(0.02,0.03,0.03)	(0,0,0)	(0.07,0.08,0.09)	(0,0,0)
R12	(0,0,0)	(0.11,0.13,0.15)	(0,0,0)	(0.1,0.12,0.15)	(0.5,0.5,0.5)	(0,0,0)	(0.10,0.12,0.15)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
R36	(0,0,0)	(0,0,0)	(0,0,0)	(0.02,0.02,0.02)	(0,0,0)	(0.5,0.5,0.5)	(0,0,0)	(0,0,0)	(0.02,0.02,0.03)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
R71	(0,0,0)	(0,0,0)	(0.04,0.04,0.05)	(0,0,0)	(0.03,0.03,0.03)	(0,0,0)	(0.5,0.5,0.5)	(0,0,0)	(0,0,0)	(0.01,0.01,0.02)	(0,0,0)	(0,0,0)	(0,0,0)
R69	(0,0,0)	(0,0,0)	(0.02,0.02,0.02)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.5,0.5,0.5)	(0,0,0)	(0.01,0.01,0.01)	(0,0,0)	(0,0,0)	(0,0,0)
R60	(0.13,0.14,0.17)	(0,0,0)	(0,0,0)	(0.07,0.08,0.1)	(0,0,0)	(0.39,0.43,0.46)	(0,0,0)	(0,0,0)	(0.5,0.5,0.5)	(0.08,0.09,0.11)	(0,0,0)	(0,0,0)	(0,0,0)
R57	(0.23,0.28,0.32)	(0.25,0.29,0.33)	(0.25,0.29,0.33)	(0.18,0.23,0.28)	(0,0,0)	(0,0,0)	(0.27,0.33,0.38)	(0.36,0.41,0.46)	(0.25,0.29,0.33)	(0.5,0.5,0.5)	(0,0,0)	(0,0,0)	(0,0,0)
R6	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(1,1,1)	(0,0,0)	(0.03,0.03,0.03)
R5	(0.05,0.05,0.06)	(0,0,0)	(0,0,0)	(0.03,0.04,0.05)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.5,0.5,0.5)	(0,0,0)
R4	(0.09,0.02,0.02)	(0.02,0.02,0.02)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.5,0.5,0.5)

Fourth Step: In the last step, final weights of the risks were calculated using equation 5. Therefore, the final relative weights of Risk of in-well motor breakdown including static and rotor (R33), risks of total/partial losses in formation layers (R5), disconnecting the various modules of the in-well navigation tools R31), section TD not reached (R57), Pipe damage due to the material's fatigue and low quality(R12), tight hole stuck pipe(R23), tool plugging with LCM material(R60), shallow gas probability(R4), crew exposed to H_2S (R6), calibration of navigation sensors(R28), lack of access to natural water for drilling operations (R36), extreme dependency to offshore supply and sanction (R71) and ergonomic problems due to fatigue and pressure of non-stop activities (R69) are 0.222, 0.198, 0.120, 0.105, 0.088, 0.068, 0.051, 0.045,0.036, 0.031, 0.02, 0.013 and 0.003, respectively (table 10).

Table 10. Relative final weights of HDD risks

Criteria	Final fuzzy weight	Final weight
R33	(0.153,0.22,0.299)	0.222
R31	(0.077,0.118,0.171)	0.12
R28	(0.022,0.031,0.044)	0.031
R23	(0.048,0.068,0.095)	0.068
R12	(0.062,0.088,0.119)	0.088
R36	(0.017,0.02,0.023)	0.02
R71	(0.011,0.015,0.021)	0.013
R69	(0.003,0.004,0.006)	0.003
R60	(0.038,0.051,0.07)	0.051
R57	(0.071,0.104,0.15)	0.105
R6	(0.028,0.036,0.047)	0.036
R5	(0.156,0.199,0.243)	0.198
R4	(0.035,0.046,0.059)	0.045

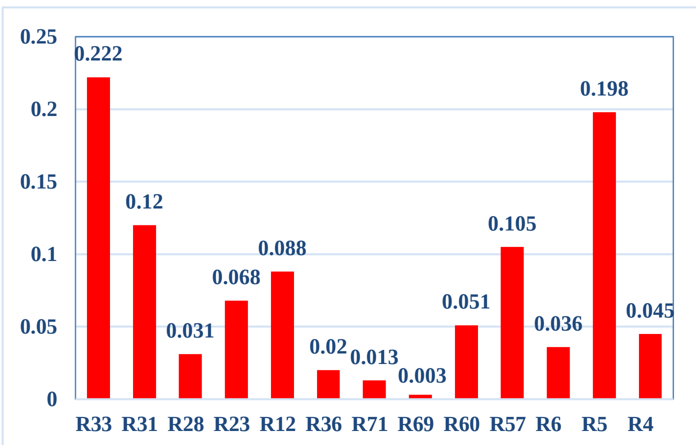

Fig 7. Final weights of HDD risks

Figure 7 shows the final weights of HDD risks in the Gachsaran oil field as well.

5- Results and conclusion

Identifying and ranking the risks of a project provides the possibility of planning and designing an appropriate plan for responding and controlling the risk in the project and has a significant effect on the successful implementation of the project. This paper, present an approach including One-Sample T-Test, Pareto principle and Fuzzy ANP methods, in order to identification and ranking HDD risks in the Gachsaran oil field. HHD risks were determined by aggregating the research expert opinions regarding the importance level of the submitted risks and using One-Sample T-Test. One-Sample T-Test is a statistical procedure used to examine the mean difference between the sample (n<30) and the known value of the population mean. The Pareto principle was applied to determine the relationships between the risks as well. At least, the Fuzzy ANP method was used to obtain relative weights of risks considering the risks interdependences.

The results of the research indicate that in the process of ranking HDD risk of oil and gas wells, Risk of in-well motor breakdown including static and rotor has highest rating an followed by Risks of total/partial losses in formation layers, disconnecting the various modules of the in-well navigation tools, section TD not reached, Pipe damage due to the material's fatigue and low quality, tight hole stuck pipe, tool plugging with LCM material, shallow gas probability, crew exposed to H2S, calibration of navigation sensors, lack of access to natural water for drilling operations, extreme dependency to offshore supply and sanction, ergonomic problems due to fatigue and pressure of non-stop activities, respectively. One of the advantages of the presented approach is using of the One-Sample T-Test to determine the HDD risks in Gachsaran oil field, the others are: determination of relationships between risks Led to the removal of waste calculations in Fuzzy ANP stages, considering the interdependences between risks in determination of risks relative weights using fuzzy ANP method.

In the end, (i) Ranking the HDD risks of oil and gas wells using other methods, except the multi-attribute decision making methods in order to reduce the impact of expert opinions on the decision-making process; (ii) Developing the scope of research and ranking the HDD risks for all oilfields of the country, are suggested for future studies.

References

Abdelgawad A.M., Watanabe K, Mohammed M and Takeuchi, S 2010. Estimating groundwater residence time using multiple regression model based on fluoride dissolution: an exploration of possibilities, *Environmental Earth Sciences* 60(3), 449-462.

Bennett, R.D., and Ariaratnam, S.T., 2008. Horizontal Directional Drilling Good Practices Guidelines (3rd ed.). *Virginia: HDD Consortium*, Arlington.

Bi, G., Feng, C., Ding, J., Khan, K. R. 2012. Estimating relative efficiency of DMU: Pareto Principle and Monte Carlo oriented DEA approach. *Infor,* 50(1), 44-57.

Carlin, M. C. 2014. A Comparative Analysis of Horizontal Directional Drilling Construction Methods in Mainland China. *A Dissertation Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy*.

Gierczak, M, 2014 (1). The quantitative risk assessment of MINI, MIDI and MAXI Horizontal Directional Drilling Projects applying Fuzzy Fault Tree Analysis. *Tunnelling and Underground Space Technology* 43 67–77.

Gierczak, M, 2014 (2). The qualitative risk assessment of MINI, MIDI and MAXI horizontal directional drilling projects. *Tunnelling and Underground Space Technology*. 44 148–156.

Hashash, Y. M. A., & Javier, J. 2011. *Evaluation of horizontal directional drilling (HDD)*. Urbana, Ill: Illinois Center for Transportation.

Hashemi, S.H., Karimi, A, Tavana, M. 2015. An integrated green supplier selection approach with analytic network process and improved Grey relational analysis, *Int. J. Production Economics*, 159, 178-191.

Kang, C.C., Feng, C.M. and Khan, H.A., 2005. Risk assessment for build-operate-transfer projects: A dynamic multi-objective programming approach. *Computer and Operations Research*, *32*, 1633-1654.

KarimiAzari, A.R, Mousavi, N, Mousavi, S.F, Hosseini, S.B. 2011. Risk assessment model selection in construction industry. *Expert Systems with Applications* (38), 9105–9111.

Ma, B., Najafi, M., Shen, H., and Wu, L. 2010. Risk Evaluation for Maxi Horizontal Directional Drilling Crossing Projects. *Journal of Pipeline Systems Engineering and Practice*, 1(2), 91-97.

Mawford, N, 2009. Avoid Wellbore Stability Problems with Casing Drilling. *E&P Journal*, 18.

Moganti, P.Y., 2016. Safety Risk Investigation of Horizontal Directional Drilling Projects, *Clemson University*.

Nitro-Morote, A, Ruz-Vila, F. 2011. A fuzzy approach to construction project risk assessment. *International Journal of Project Management*, 220-231.

Önüt, S, Kara, S. S., Isik, E. 2009. Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert System with Applications*, 36, 3887-3895.

Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process* (Vol. 4922). RWS Publication.

Skogdalen, J.S, Vinnem, J.E, 2012. Quantitative risk analysis of oil and gas drilling, using Deepwater Horizon as case study, *Reliability Engineering and System Safety*, 100 58–66.

Van Staveren, M. 2007. Uncertainty and ground conditions. A risk management approach. Burlington, Butterworth-Heinemann.

Wang F, Ren T, Tu S, Hungerford F, Aziz N, 2012. Implementation of underground long-hole directional drilling technology for greenhouse gas mitigation in Chinese coal mines. *11*, 78-96.

Winter, J.C.F., 2013. Using the student's t-test with extremely small sample sizes, *Practical Assessment, Research & Evaluation, 18(10).*

Zhang, P, Luo, P, Wu, Y, and Huang, Y, 2011. The Status, Development, and Key Technologies of Pipeline Directional Drill Project. *Proceedings of the International Conference on Pipelines and Trenchless Technologies* (pp. 2338-2349). Beijjing: American Society of Civil Engineers.

Zheng, J., An, M., and Smith, N.J., 2007. Application of a fuzzy based decision making methodology to construct project risk assessment. *International Journal of Project Management*, *25*, 589-600.