Proceedings of the 2015 International Conference on Operations Excellence and Service Engineering
Orlando, Florida, USA, September 10-11, 2015

Economic Risk Management in Oil and Gas infrastructure; A Case study - Low Density Polyethylene (LDPE) production unit of Amir Kabir Petrochemical complex in Iran

Seyed Amirhossein Alavifar
Russian State University of Tourism and Service, Glavnaja str., 99, Cherkizovo, 141221, Pushkinskij r-n, Moskovskaja oblast', Russia
Amir_alavifar@yahoo.com

Victor Makarovich Zaernjuk
Russian State University of Tourism and Service, Glavnaja str., 99, Cherkizovo, 141221, Pushkinskij r-n, Moskovskaja oblast', Russia

Pouyan Banishahabadi
Master of engineering management, Department of mechanical and manufacturing engineering, Faculty of engineering, University Putra Malaysia

Ehsan Aliabadi
Master of Chemical Engineering, Amirkabir petrochemical Complex, Mahshahr, Iran

Abstract

This Research paper is a depiction of the application of the analytical hierarchy process in assigning appropriate and cost effective maintenance methodology to a petrochemical production unit based on Economic risk assessment. The process is employed in making decisions that are geared towards establishing a maintenance strategy to cover the four economic- safety risk zones that the risk-based inspection identifies in a petrochemical complex. The paper will show the process which is to be followed in identifying the areas in the industry that need increased care and maintenance to ensure the safety of the working personnel, the equipment, cater for minimal costs as well as minimize the effect on the environment, while maximizing productivity. Apart from risk areas, four main maintenance strategies are discussed. These strategies include preventive maintenance, corrective maintenance, predictive maintenance and reliability based maintenance. The benefits of these maintenance strategies are also clearly discussed.

Keywords:
Economic risk management, analytical hierarchy, maintenance strategy, petrochemical company, maximizing productivity

1. Introduction

Maintenance strategies in industries are a plan that encompasses managing activities and all aspects of those activities that can be classified as maintenance. This also includes establishing the best path to take in regards to management of all matters involving maintenance. The plan is implemented to help in the delivery of reliable equipment, high plant availability, statutory and regulatory compliance, as well as cost effective maintenance. In most cases prior to 2000, maintenance and safety were two different issues to be handled by an industry. The management strategies after 2000 have included the maintenance techniques and activities (1) (2) (3). Economic Risk based inspection (ERBI) is defined as an assessment that helps in the identification, analysis and planning of future industrial-economical risks that will ultimately compromise the integrity of systems in the industry. This form of assessment considers the likelihood of a risk to occur in the future thus identifying the risk to come up with a comprehensive inspection program (4) (5) (6) (7). ERBI helps a company in addressing issues that are controllable presently to avoid intensified future failures (8). Via proper inspection, the company will easily minimize the costs, failure and criticality associated with an incident. The purposes of ERBI include:

(1) Designing of an appropriate inspection plan for a company
(2) To safeguard the integrity, reliability and availability of a plant via proper inspections
(3) Financial reprieve by conducting inspections that is necessary and governed by operational parameters
(4) Rate the equipment based on the risk of failure and helps mitigate them
(5) Define the inspection techniques needed

The maintenance strategy for the companies is established by the incorporation of an Analytical Hierarchy Process (AHP) to ease making decisions.

The decisions based on LDPE unit of Amir Kabir petrochemical complex in Iran will be covered by two principles:

1- Conduction of a viable ERBI that will aid in the realization of the critical areas in the petrochemical plant
2- Establishment of an AHP model that will help in making sound decisions for maintenance.

2. Literature Review

Analysis has become more popular with the public in the last thirty years, and economic risk analysis has come to the forefront as a great and total procedure that sits aside from and complements the wide-scoped management of nearly every part of our existence. Risk analysis is utilized in decision making by health care managers and those who deal with the environment and cost infrastructure systems. The widespread acceptance of risk analysis by a broad range of industries and organizations, has enabled the growth, expansion, and changing of the theory itself, to be used as an effective solution in many enterprises.

Risk is described as the potential for a person or thing of value to be harmed by a particular danger , while “danger” is any hazardous circumstance or possible trigger for an incident where harm or damage can occur (9). In addition, risk is denoted as a measure under which the severity of a hazard is ambiguous or, in the alternative, as a calculation of the probability and severity of unfavorable effects. The definition of "danger" can be seen as any trait belonging to a substance or process that can be harmful in some way. Humans and machines interacting together can form a complex human/machine system that might correctly take the description of a system model. It's necessary to use the system model to understand how systems might malfunction so that the possibility of accidents can be considered. A big distinction is if an accident happens because of particular malfunctions, or if it occurs because of coincidence. In order to predict and explain accidents, people have always assessed how these events may take place in stereotypical ways.

Additionally, per an Duijne, Aken, & Schouten in 2008, to assess impact, one must utilize risk assessment. This is also true when assessing the consequences and occurrence of human activities on systems that feature characteristics that are hazardous. This is why risk assessment is a very necessary tool in every company's safety policy. What risk analysis system you use has become largely a matter of preference, as there is a plethora of options to choose from (9). We are able to quantify risk, using common measurements and expressing it in mathematical terms, by using information obtained from real accidents (10)This work's purpose has to do with determining, studying, classifying, categorizing, analyzing and doing an overview of the key risk analysis and assessment methodology by going over the scientific literature available. We will cover two main areas; discussion of what risk assessment systems are available, and discussion and review of the works of Elsevier B.V. from the last decade.

Petroleum refineries consist of various equipments which operate in different modes. Such an environment requires selection of the most appropriate maintenance strategy that matches the technical requirements of every unit and meets the overall operational condition. The best maintenance strategy guarantees low and effective cost of management system, safety and optimal operational condition. Maintenance is meant to address issues that are likely to occur such as harmful material leakage, shutdown leading to production losses, formation of explosives, release of toxic liquids or gases and environmental, safety or health deterioration issues (11).

There are four main maintenance strategies; preventive maintenance, predictive maintenance, corrective maintenance and reliable centered maintenance. These strategies are implemented by maintenance engineers. A good maintenance strategy or policy maximizes the availability and efficiency of equipment; it controls failure and deterioration, guarantees safe and correct operation and minimizes the costs (12).

An appropriate regime of planned maintenance should make use of a logical and fact based framework that determines which devices to put in critical devices category. This framework categorizes maintenance areas as

Favorable and Acceptable, Tolerable, Unsatisfactory and Critical areas. Critical areas need preventive maintenance while the unsatisfactory area requires reliable centered maintenance. The Favorable and Acceptable area, and the Tolerable area require corrective maintenance (12).

The main equipment requires inspection process piping, pressure vessels, reactors, heat exchanger, furnace, cooler, safety valves, pumps and compressors (13). As far as maintenance development is concerned, over around 70 years all tools and techniques have been categorized in four different generations. In the first generation of maintenance policy only repair was an issue, the strategy was to run the equipment which should have been fixed if it was broken. This strategy is also called Corrective maintenance (CM). In the next generation during 1960s and 70s taking an action to prevent the equipment failure became an issue; therefore time based maintenance inspections for sensitive parts of industry were developed. After this time in 1980s and 1990s the main focus of maintenance strategy developments turned around equipment condition based maintenance, reliability centered maintenance, computer aided maintenance management and information system and totally proactive tasks instead of passive actions. After this period in recent generation of maintenance policy development since 2000 until now immunizing equipment from each sort of failure or problem has been optimized with risk and cost reduction point of view. For instance preventive maintenance is not cost effective all the time when the consequence of equipment failure is not serious hence risk assessments and maintenance methodologies started to emerge and gained popularity (14). Before 2000, safety and maintenance were considered as separate and independent activities (15)(see Figure 1 for more details).

Table 1: evolution of maintenance policy (16) (14)

First Generation • Fix it when it broke • Basic and routine maintenance • Corrective maintenance	**Second Generation** • Planned preventive maintenance • Time based maintenance • Systems for planning and controlling work	**Third generation** • Condition based maintenance • Reliability centered maintenance • Computer aided maintenance management and information system • Work force multi skilling and team working • Proactive and strategic	**Recent generation** • Risk based inspection • Risk based maintenance • Risk based life assessment • Reliability centered maintenance • Condition based monitoring • Computer aided maintenance management and information system
1940- 1950	**1951-1975**	**1976-2000**	**2001- Present**

2.1. Corrective Maintenance (CM)

Corrective maintenance occurs when the system fails. It means all actions performed as a result of failure, to restore an item to specific condition. It is also referred to as "repair". Preventive maintenance occurs when the system is operating. It means all actions are in an attempt to retain an item I a specified condition for operation by providing systematic inspection, detection, adjustment, and prevention failures. Unlike preventive maintenance, the demand arising from corrective maintenance after a failure has occurred, is stochastic and requires forecasting.

Corrective maintenance involves emergency, repair, remedial and unscheduled activities. Repairs will always be needed. Better maintenance improvement and preventive maintenance, however, can reduce the need for emergency corrections. Troubleshooting and diagnostic fault detection and isolation are major time consumers in maintenance. When the problem is obvious, it can usually be corrected easily. Intermittent failures and hidden defects are more time consuming, but with diagnostics, the causes can be isolated and then corrected.

2.2. Preventive Maintenance (PM).Maintenance involves preventive maintenance (planned) and corrective (unplanned) actions carried to retain a system in or restore it to an acceptable operating condition. Researchers have developed various models and maintenance policies in order to prevent the occurrence of system failures at the lowest possible maintenance costs. The demand arising from preventive maintenance is scheduled and deterministic, at least in principle. Preventive maintenance can be divided into three major categories which include reactive, condition monitoring and scheduled maintenance. Preventive maintenance tasks are intended to prevent unscheduled downtime and premature equipment damage that would result in corrective maintenance. The great challenge lies in detecting incipient problems before they lead to total failures and to correct the defects at the lowest possible cost.

2.3. Reliability Centered Maintenance (RCM). Reliability centered maintenance is a process used to determine the preventive maintenance requirements for a physical asset in its operational environment. RCM is very cost effective and economical. The first task in RCM involves completing a failure mode and effect analysis (FMEA) for major components.

For each failure cause, RCM logic requires the maintenance engineers to answer the following questions

1. Is the failure cause evident to the operator? (Yes or No)
2. What is the failure consequence? (Safety, Operation, or Economic)
3. What tasks should be selected to prevent this failure? (Servicing, Operation monitoring, Functional check, Failure finding, Restoration, or Replacement)
4. What is the reason to select a specific task?
5. What is the suggested interval of the task?

Upon answering such question, RCM analysis provides a clear decision and set of instructions to implement. It does not, however, provide a means of identifying the consequences or the extent of gain to be expected, or otherwise provide an economic justification for the subsequent maintenance expenditure.

2.4. Risk Based Maintenance system (RBM). A RBM system utilizes failure mode analysis and inspection database accumulated over a period of time. Failure modes are determined for each component and the failure scenarios are described as event trees. The probability of failure is expressed in the form of unreliability functions of operation hours or start up cycles through the cumulative hazard function method. Risk based maintenance and also risk based inspection were introduced by American society of Mechanical Engineers (ASME) since 1941 (12). RBM is also possible to use a decision support system for the inspection of staff for oil pipelines based on the decision tree analysis outcome. Oil spillage can be classified and predictions can be made with respect to such classes using selected variables such as system malfunction or mechanical failure. Based on such information, it is important to adopt one of the maintenance strategies outlined below (17) (18).

RBI has been used in Shell facilities by Aller (1995) then Risk Based Maintenance model was modified by Dey, Ogunland et al. (1998) for pipelines (19) (20). The first AHP model to select best methodology for equipment maintenance was presented by Bavilacqua and Braligia (7). Then Dey developed RBI model for pipeline in 2001 (21) and he continued his study on a new AHP model for oil and gas with a case study in 2004 (19) (22) (23) (12).

The main objective of this project will be the application of the analytical hierarchy process in assigning appropriate and cost effective maintenance methodology based on economic risk assessment to a petrochemical production unit where is located in Bandar Imam (south of Iran). The main function of this unit is conversion of ethylene into polyethylene. This unit has an annual capacity of 300,000 tons of light polyethylene and the main feed of this unit is 45 tons per hour ethylene (as input) which is provided by olefin unit. Entered ethylene gas after being compressed in two **Booster & Primary** and **Hyper** compressors goes into reactors and with adding to ethylene starter is converted to polyethylene. After two stages separation Polyethylene from ethylene, the produced molten polyethylene is entered into extrusion and from there after being converted to polymer beads will be transmitted by water to STORAGE SILO.

3. **Methodology**

A RBI irrespective of the type involves the identification and assessment of different areas in an industry. The process in the form of a block diagram is simply shown in figure 1.

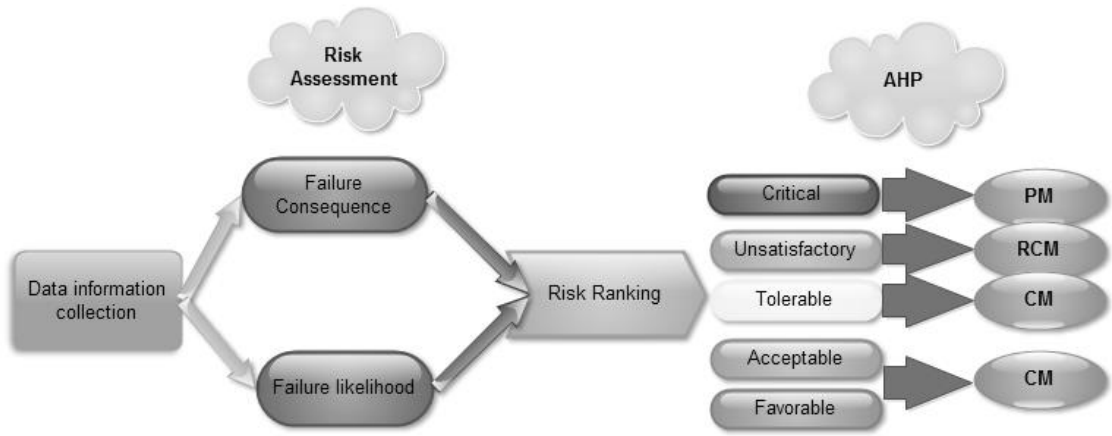

Figure 1- RBI process

The process above represents the ERBI methodology of any industrial plant. This process can be preventive, qualitative or even conditional. The inspection phase will highlight the areas where most damage is to be experienced. The risks in the process have to be defined to successfully integrate an ERBI in a system.

3.1. Risk assessment

The definition of a risk in the ERBI can be in a health, operational, economical or environmental capacity. Risk is expressed as a proportional relationship between the probability of occurrence and the consequence of risk.

Risk = Probability of failure X consequence of failure.

The petrol chemical failures may include explosions, leakage of harmful products or byproducts, health, environmental or safety interference as well as a shutdown. These risks may arise as a result of corrosion of the pipes that is mostly associated with petroleum-based industries. The ERBI methodology of analyses makes use of a risk matrix to compute the possible occurrences (24) (25). The matrix (as shown in table 1) calculates the risks associated with every element of the system, but separately. The matrix calculations are based on two events. The events are the likelihood and consequence categories (10). Calculations based on API 580 use the likelihood and consequence events to categorize the risks involved. The probabilities or likelihood categories are ranked between one and six. The consequence category, on the other hand, is ranked also between one and six to complete the square matrix. Six and six represent the highest probability and consequence (risk) events, respectively whereas the one in consequence as well as one in probability represent the lowest risk events. Since our case regards the use of materials with a petroleum nature then some of the areas that are bound to get a lot of damage include the piping, reactors, furnaces, pumps, compressors, air coolers, pressure vessels, safety vales among other fittings (26).

Table 2- The decision matrix risk assessment technique (10)

	Hazard probability ratings (P)					
Severity of consequences ratings (S)	6	5	4	3	2	1
6	36	30	24	18	12	6
5	30	25	20	15	10	5
4	24	20	16	12	8	4
3	18	15	12	9	6	3
2	12	10	8	6	4	2
1	6	5	4	3	2	1

Table 3-The decision making table **(27)**

	Critical	18-36
	Undesirable	10-16
	Tolerable	5-9
	Acceptable	1-4

The use of the risk matrix calls for a four risk rating scales. The risks involved are rated as acceptable, tolerable, undesirable and critical. This means that the four ratings can be narrowed down to use the AHP method to make decisions on the best form strategy to use. The use of the AHP will ease the discussions and decisions made towards the maintenance plan (28).

3.2. AHP method

The AHP method can easily provide a platform to rationalize discussions and ideas and then it could be improved by ANP method. It helps rating certain elements of the area in question with the solutions as well as risks involved. The AHP method is implemented in five steps, but the general hierarchy tree of the AHP method has three levels. The first level is the goal of the project. The second level consists of the criterion that is used whereas the third level represents the alternative solutions (29). Comparison between the criteria and alternative is linked by a two by two square matrix. The criteria level will help identify the criteria that the petroleum industry will need. In this case, the viable selections include:

1. Health risks; Safety of personnel, equipment and the environment
2. Economic risks; Costs incurred in running the company
3. Accessibility of equipment
4. The operational conditions
5. Added value as a result of failure
6. Feasibility of each policy
7. And toxic emissions from the petroleum plant

When it comes to the policies that are included in the design of the plant, they are categorized into preventive, conditional, corrective or reliable oriented maintenance. Comprising the AHP with the second and third levels, the figure can be represented as:

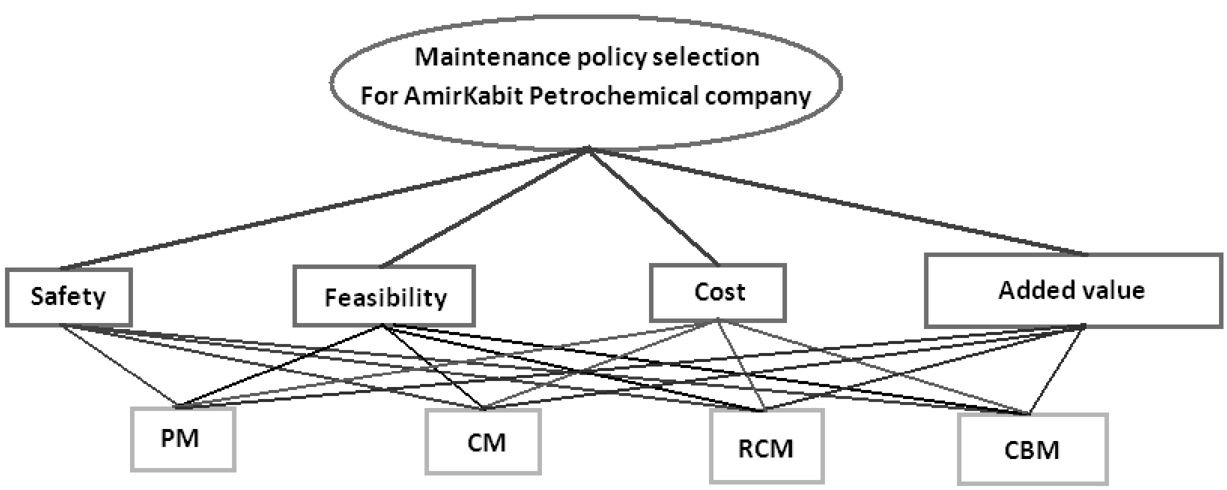

Figure2 -The AHP evaluated model

To make a pair wise decision, one will have to engage the part wise matrixes. The matrixes contain four levels of risk ratings. To make calculations to ascertain the best policy to use in the plant, the Saaty tables have to be used (30) (31). Different values will be obtained from the calculations using the different alternatives offered by the AHP (32) (33). The final step is to calculate a Consistency Index (CI) to measure how consistent the judgments have been relative to large samples of purely random judgments. If the CI is less than 0.1 the judgments are trustworthy. In this study all pair wise comparisons have below 0.1 CI. Consistency index is calculated by following formula:

$$CI=\frac{\lambda max-n}{n-1}$$

Where λ_{max} is the largest eigen value and n is the number of criteria. It is notable that the quality of output of AHP calculations directly related to the consistency of the comparison judgments.

Decision Criteria: Safety, Feasibility, Cost, Added Value
Alternatives: Preventive Maintenance (PM), Corrective Maintenance (CM), Condition Based Maintenance

4. Conclusion

Via the use of the ERBI and incorporation of the AHP - ANP methods of decision-making, it is conclusive to say that all the goals of the maintenance strategy will be met by optimized and cost effective method. As far as maintenance strategies are concerned high reliability policy is always associated with high cost and more expensive maintenance tasks. This paper will indicate that performing economic risk assessment before assigning maintenance policy to equipment can reduce unnecessary costs and increase the level of reliability. If the equipments of the company were located at unsatisfactory area of risk (regarding on probability of failure and also consequence of failure) it’s better that RCM Policy is used and also in Critical, tolerable and acceptable areas of risk respectively PM and CM is more effective and efficient to be used.

References:

1. *"Risk-based maintenance (RBM): a quantitative approach for maintenance/inspection scheduling and planning.* **Khan, F. I. and M. M. Haddara.** 6, 2003, Journal of Loss Prevention in the Process Industries, Vol. 16(6), pp. 561-573.
2. **Straub, D.** *Generic approaches to risk based inspection planning for steel structure.* s.l. : vdf Hochschulverlag AG, 2004.
3. *Criticality evaluation of petrochemical equipment based on fuzzy comprehensive evaluation and a BP neural network.* **Guo, L., J. Gao, et al.** 4, 2009, Journal of Loss Prevention in the Process Industries, Vol. 22, pp. 469-476.
4. **Inspection, R. B.** Base Resource Document. s.l. : API Publication, 581, October, 2000.
5. *"Risk-based inspection and maintenance in power and process plants in Europe.* **Jovanovic, A.** 2, s.l. : Nuclear Engineering and Design, 2003, Vol. 226, pp. 165-182.
6. *Development of Risk-Based Inspection and Maintenance procedures for an oil refinery.* **Bertolini, M., M. Bevilacqua, et al.** 2, s.l. : Journal of Loss Prevention in the Process Industries, 2009, Vol. 22, pp. 244-253.
7. *The analytic hierarchy process applied to maintenance strategy selection.* **Bevilacqua, M. and M. Braglia.** 1, s.l. : Reliability Engineering & System Safety, 2000, Vol. 70, pp. 71-83.
8. *Risk-based inspection and maintenance (RBIM): Multi-attribute decision-making with aggregative risk analysis.* **Khan, F., R. Sadiq, et al.** 6, 2004, Process Safety and Environmental Protection, Vol. 82, pp. 398-411.
9. *Developing an external domino prevention framework: Hazwim.* **Reniers, G. L. L., Dullaert, W., Ale, B. J. M., & Soudan, K.** 2005, Journal of Loss Prevention in the Process Industries, Vol. 18, pp. 127-138.
10. *Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000-200.* **Marhavilas, P., D. Koulouriotis, et al.** s.l. : Journal of Loss Prevention in the Proce, 2011.
11. *Risk-based maintenance strategy and its applications in a petrochemical reforming reaction system.* **Hu, H., G. Cheng, et al.** 4, 2009, Journal of Loss Prevention in the Process Industries, Vol. 22, pp. 392-397.
12. **Tan, Z., J. Li, et al.** *An evaluation of maintenance strategy using risk based inspection.* s.l. : Safety Science, 2011.

13. *Application of risk based inspection in refinery and processing piping.* **Chang, M. K., R. R. Chang, et al.** 4, s.l. : Journal of Loss Prevention in the Process Industries, 2005, Journal of Loss Prevention in the Process Industries, Vol. 18, pp. 397-402.
14. *Risk-based maintenance—Techniques and applications.* **Arunraj, N. and J. Maiti.** 3, s.l. : Journal of hazardous materials, 2007, Vol. 142, pp. 653-661.
15. *Plant maintenance strategy: evidence from four British manufacturing firms.* **Cooke, F. L.** 3, 2003, Journal of Quality in Maintenance Engineering, Vol. 9, pp. 239-249.
16. **Moubray, J.** *Introduction to reliability-centred maintenance.* s.l. : Oxford: Butterworth-Heinemann, 2002.
17. **Speck, J. B., A. T. M. Iravani, et al.** *Industry survey of risk-based life management practices.* s.l. : American Society of Mechanical Engineers, 2002.
18. *Risk-based inspection and maintenance systems for steam turbines.* **Fujiyama, K., S. Nagai, et al.** 10, 2004, International journal of pressure vessels and piping, Vol. 81, pp. 825-835.
19. *"Risk-based inspection for the Petrochemical Industry. In: Risk and Safety Assessments, Where is the Balance?* **Aller, J. E., Horowitz, N.C., Reynolds, J.T. & Weber, B.J.** New York : Pressure Vessels and Piping Division Conference, 1995.
20. *A risk-based maintenance model for cross-country pipelines.* **Dey, P. K., S. Ogunland, et al.** 4, s.l. : COST ENG, 1998, Vol. 40, pp. 24-31.
21. *A risk-based model for inspection and maintenance of cross-country petroleum pipeline.* **Dey, P. K.** 1, 2001, Journal of Quality in Maintenance Engineering, Vol. 7, pp. 25-43.
22. **Hummel, J. M.** *Supporting medical technology development with the analytic hierarchy proces.* s.l. : University Library Groningen, 2001.
23. *Decision support system for inspection and maintenance: a case study of oil pipelines.* **Dey, P. K.** 1, s.l. : IEEE Transactions on, 2004, Engineering Management, Vol. 51, pp. 47-56.
24. *Modeling the probability of losses on the basis of statistical analysis.* **V.M., Zaernjuk.** s.l. : Financial analytics: problems and solutions, 2014, Vol. 14, pp. 17-23.
25. *Asset management and pavement management: Using common elements to maximize overall benefits.* **Falls, L. C., R. Haas, et al.** 1, s.l. : Transportation Research Record, 2001, Journal of the Transportation Research Board, Vol. 1769, pp. 1-9.
26. *Evaluation of risk and cost using an age-dependent unavailability modelling of test and maintenance for standby components.* **Kančev, D. and M. Čepin.** 2, 2011, Journal of Loss Prevention in the Process Industries, Vol. 24, pp. 146-155.
27. **Ayyub, B. M.** *Risk analysis in engineering and economics.* s.l. : CRC Press, 2003.
28. **Shuai, J., K. Han, et al.** *Risk-based inspection for large-scale crude oil tanks.* s.l. : Journal of Loss Prevention in the Process Industries, 2011.
29. **Bhushan, N. and K. Rai.** *Strategic decision making: applying the analytic hierarchy process.* s.l. : Springer Verlag, 2004.
30. **Saaty, T. L.** *Theory and Applications of analytic network process.* s.l. : RWS, publications Pittsburgh, PA., 2005.
31. **Saaty, T. L. and M. Ozdemir.** *The Encyclicon.* s.l. : RWS Publications, 2005.
32. **Figueira, J., S. Greco, et al.** *Multiple criteria decision analysis: state of the art surveys.* s.l. : Springer Verlag., 2005.
33. *Decision making with the analytic hierarchy process.* **Saaty, T. L.** 1, 2008, International Journal of Services Sciences, Vol. 1, pp. 83-98.

Seyed Amir Hossein Alavifar is a PhD candidate in oil and gas economics in Moscow State University of Service and Tourism and a board member of BSTech Engineering consulting Co. He earned B.S in Industrial Engineering from Azad Islamic University of Tehran, Iran, Master in Engineering Management from University Putra Malaysia in field of operational risk management, He also earned certificate of Certified Risk and compliance Management Professional (CRCMP) from International Association of Risk and Compliance Professionals (IARCP), Washington DC, USA. Alavifar has completed several research projects in Urban Risk and Crisis Management with Iranian

Governmental Sections. His research interests include risk assessment, risk management, crisis management, maintenance, project management, Security and Safety.