Selecting the Appropriate Physical Asset Life Cycle Model with a Multi-Criteria Decision-Making Approach (Case Study: Petroleum Pipelines)

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ARTICLE INFO

Keywords:

Physical Asset Management (PAM)

Life Cycle Cost (LCC)

Risk

RAM

Received: 4 Oct. 2018
Revised: 13 Dec. 2018
Accepted: 20 Jan. 2018

ABSTRACT

Companies need to exactly manage their assets to balance performance, risk, and cost. The ability of equipment to provide a certain level of performance is influenced by its design, utilization, deterioration, and life. On the other hand, in order to obtain the desired level of performance and reduce risk, proper planning of maintenance activities during the period must be done. To manage this issue, organizations must develop a suitable method for their assets from the acquisition stage to the disposal to obtain the required processes and, ultimately, to earn the desired profit. In this study, petroleum pipelines have been considered as a case study, and life cycle cost (LCC), risk, and key performance indicators (KPI) have been identified as the criteria for decision making. KPI is itself composed of three sub criteria, including reliability, availability, and maintainability. They are weighted by using the opinions of eight expert and DANP method. The final weights of LCC, risk, and KPI (reliability, availability, and maintainability) are 0.269, 0.301, and 0.429 respectively. Considering different strategies in each phase of the asset life cycle, different scenarios are described for the asset life cycle as follows: 1) RCM-replacement, 2) RCM-overhaul, 3) CBM-replacement, 4) CBM-overhaul, 5) TPM-replacement, and 6) TPM-overhaul. Finally, based on the gained experts’ viewpoint from questionnaire and MOORA technique to rank the scenarios, the desired scenario, namely Buy-TPM-Replacement, is selected. Due to the use of experts’ opinions, these results will vary with the change of people, and due to the lack of relevant data, it is not possible to avoid this issue.

1. Introduction

The creation of many principles of integration, life cycle, and optimization of physical asset management in the oil and gas industry during the 1980s and 1990s resulted from a series of threatening events of the survival of this industry. Oil prices fell below the price of production, and new reserves were discovered in less expensive regions of the world such as Kazakhstan and South China; moreover, the easy oil extraction was coming to an end, and the Piper Alpha at the top of the financial and technical challenges of the threats was

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caused by the combination of several minor human mistakes and resulted in deaths of many people. A general review was undertaken by the British government under Lord Cullen. In this way, Publicly Available Specification (PAS) 55 was first released in April 2004. PAS 55 is an asset-based approach to managing physical assets by placing risk management as the main platform and collecting all the levels of asset management in the form of an integrated classification system. In recent years, efforts have been made by those who are active in this area, leading to the creation of a formal approach to asset management systems and the publication of the ISO 55000[2] International Standard in 2014.

Asset Management in ISO 55000, Section 1.3.3, is defined as follows: "coordinated and systematic activities of the organization to realize the value of assets". The concept of value is in line with the goals and strategy of the organizations. For example, in financial areas, the highest value can be short-term profit, and in environmental fields, it can mean long-term ecological sustainability. Using what is expressed in ISO, a deeper and more understandable definition can be made. With regard to business or organization goals, in order to effectively and efficiently meet the desired goals, asset management is a set of activities related to:

- Identifying required assets;
- Identifying financing requirements;
- Asset acquisition;
- Providing logistics support and maintenance for assets;
- Asset decommission and overhaul.

From this definition, we infer out that asset management involves a wider set of activities than maintenance, which is essentially related to the maintenance of assets in operational terms. Asset management is about the usage of financial and technical guidance and exact management approaches to deciding on the needed assets to meet the organization's goals, acquiring, and logical retaining assets throughout its life cycle until decommission by balancing cost, risk, and performance. In other words, achieving more added value while providing services at the highest level is possible by managing physical assets.

Life cycle according to PAS 55 is the "time interval that commences with the identification of the need for an asset and terminates with the decommissioning of the asset or any associated liabilities". Of course, the main stages of assets life-cycle can include acquisition/creation, operation, maintenance and repair, and reconstruction/retirement. Understanding each phase of the asset life cycle and the impact of each one on the final output is very important.

Asset acquisition is the first stage of the asset life cycle process. Equipment is one of the items to which the most capital of the company is assigned, and it has a significant impact on the working capital and increases profits. For this reason, it is very important to carry out appropriate analyses and adopt the right policies before the asset acquired. There are different ways to obtain assets, including buying, renting, leasing, and manufacturing.

Maintenance and repair are a set of various activities to maintain and survive parts, equipment, and machinery, to protect capital and assets used in the industry until required, and to prevent as much as possible incidents that lead to device failure and interruption in the production process or exploitation procedure for the related equipment and factories. The selection of an optimal maintenance policy can increase production and efficiency of industrial units with the reduction of a sudden drop in equipment, as well as reducing other limitations such as cost and manpower. Today, with the rapid advancement of technology and the expansion of industrial automation as well as the increase in the number of machineries, the volume of investment in machinery and physical assets of organizations has grown.

Maintenance as a system plays a key role in reducing costs, improving quality, minimizing equipment failure, increasing productivity, and delivering reliable equipment. The most important maintenance strategies mentioned in the related literature are emergency maintenance, break-down maintenance, preventive maintenance, corrective maintenance, condition-based maintenance, predictive maintenance, reliability-centered maintenance, total productive maintenance, and risk-based maintenance.

All assets will be exhausted over time, and failures will increase the need for maintenance. Proper

[2] ISO 55000 Asset management. Overview, principles and terminology. ISBN: 978 0 580 86467 4
ISO 55001 Asset management. Management systems requirements. ISBN: 978 0 580 75128 8
ISO 55002 Asset management. Management systems guidelines for the application of ISO 55001. ISBN: 978 0 580 86468 1.

maintenance can result in a longer lifespan of the physical asset. However, at the end of the useful life of assets, organizations need to replace them with good new ones. Substitution of assets requires large amounts of investment, so most organizations try to increase the assets life span through maintenance. However, in some circumstances, even when the asset is in a desirable situation, organizations decide to replace it. According to previous researches, many of existence assets in the industry have been exploited more than their original design life, and in many cases, the lack of replacement for them has led to more energy consumption, higher maintenance cost, and increased risk of accidents. On the other hand, organizations experience negative feedback due to the unnecessary replacement of physical assets. Therefore, decision making between these two opposite options is a major challenge for asset owners. Deciding whether to repair/replace physical assets requires a logical choice and determines the option that is best for a particular situation.

A general approach to asset life cycle management makes it possible to manage a large amount of asset data. With this manner, you can achieve the appropriate cost and risk profile and improve asset performance. Considering all the phases of the asset life cycle in an integrated framework provides condition that managers not only consider their decisions solely to optimize cost, risk, and performance at each stage of the asset life cycle, but also make the right decisions by knowing how decisions affect each stage over the entire life cycle. The present research seeks to answer the following question:

What is the proper strategy in each phase of the petroleum pipelines?

Given the recency of this issue in our country and the lack of attention paid by researchers, the innovation of this work is to study the factors which are effective in managing the organization's assets in order to make the maximum utilization of assets and in earning the most value for the organization.

2. Literature Review

Ali Sayyah has presented an effective model that demonstrate the effect of manageable changes on valuation factors. The physical asset management strategy should include how to supply and determine assets factors as well as how to operate, repair, and maintain them during utilization. By combining the ANP and PROMETHEE methods, the researcher has ranked the strategies and determined the best ones based on decision preferences.

In a work of examining the impact of physical asset management system components on productivity growth, Dezhangah and Seifimoradi have evaluated the factors affecting productivity from a physical asset management perspective. In this regard, the concepts of efficiency, effectiveness, productivity, and components of the uptime are first mentioned and the impact of physical asset management on productivity has been examined separately by elements of the uptime[3].

Salimi et al., in an essay of a comprehensive model for codification the roadmap of physical asset management excellence in large and challenging organizations, have presented a step-by-step model for the implementation of asset management and maintenance management using strategic management concepts. For this purpose, the concepts of physical asset management and strategic management as well as the requirements for the successful implementation of transformation plans are considered. Utilizing the proposed model enables the organization to codify a roadmap for the implementation of physical assets management in a few key steps and significantly increase the likelihood of the success of the asset management project.

Competition among all types of utilities (water, electricity, or gas suppliers) has never been more intense than recent years, and utilities face more challenges today than ever before. Changing policies, pricing, and performance constraints, increasing environmental standards, and so on have resulted in a new challenge about the need to increase the level of customer service while reducing costs. Therefore, these companies have to manage their systems and equipment in a way that reduces costs in all phases of the system's lifespan. Nikju et al. (2009) outlined firstly the economic and commercial challenges of utilities and the overview of the asset management system and then pointed out the benefits of asset management system in utilities. Finally, the role of information technology (IT) in upgrading the asset management system is described.

When deploying preventive maintenance, we will find a huge amount of data on operations and maintenance. Companies and asset management units store a lot of data, but the stored and existing data created by the equipment are not almost used while they can lead to increased efficiency and organizational performance

[3] Strategies for excellence in maintenance management

of asset management performance. Analyzing the generated data will be crucial to improving the decision-making process. Jaime Campos et al. (2017) highlighted the characteristics of data analysis in the manufacturing sector, especially for industrial asset management, as well as the visualization aspects of data analysis results. Finally, an overview of the dimensions and requirements of the big data technology application system for asset management objectives is provided. At present, the issues discussed in this work, namely equipment health, reliability, impacts of unplanned failures, etc., have great importance for manufacturing companies. The successful performance of asset management plays a significant role in the manufacturing industry, the success of which depends heavily on information and communication technology (ICT) support.

Success in complex, highly interconnected industries today depends on meeting customer expectations at the highest level or operating purely economically. One of the ways to achieve competitive performance is the effective management of physical assets. In the current business environment, physical asset management is becoming a major challenge for business organizations and has become more important as a management function than before. Damjan Maletič et al. (2017) examined the role of two potential factors, namely the uncertainty and competitiveness regarding physical asset management methods as well as the key performance indicators of the maintenance. The research is based on the premise that physical asset management (PAM), which is defined by risk management practices, performance appraisals, life cycle management, policies, and strategies, has become an essential component of strategic thinking of asset owners as well as asset and maintenance managers. The results have shown that organizations with high levels of uncertainty and competitiveness are more involved in developing PAM methods. In addition, when organizations face higher levels of competitiveness, they use KPIs in a broader context than organizations with less competitiveness.

Today, tangible change in thinking is formed from maintenance management to asset management which focuses on reliability, operational equipment, and cost-effective assets. One of the challenges in the manufacturing industry is to create an asset management model that is integrated with the business plan and related strategies. Wyhan Jooste (2004) developed a model for performance management.

Most companies which use physical assets to create value have a limited budget to manage these assets. In the PAM environment, risk management means maintaining the equipment properly, increasing its reliability, and leading to the proper acquisition of assets. The high reliability of the equipment used can have a positive impact on the risks involved, which is the reason why having the right strategy for maintaining and executing the right tactics is so important. In order to comply with the PAS 55 framework, risk management implementation is required from the outset. Since education and forecasting are the supporting tools for risk management, it seems reasonable to allocate a large portion of the funds for risk management; even if more capital is needed in one of the two areas, it can be provided through the risk management budget. J. S. Schoeman and P. J. Vlok provided a closer look at the physical asset management environment in an essay and gave the reader some advice on how to divide the organization's PAM budget. Their purpose was to highlight the potential effects of risk management, forecasting, and personnel training in the physical asset management environment.

The lack of rich literature in this area is due to the emergence of this issue. Given the novelty of the subject, the present paper can be considered as one of the first works in this field in Iran. This research can be a starting point for managers to pay attention to the protection of assets while maintaining their performance as well as guidance for further research.

3. Methodology

Strategy is a general plan to achieve one or more long-term or overall goals under conditions of uncertainty. In the sense of the "art of the general", which includes several subsets of skills such as tactics, siege craft, logistics, etc., strategy is important because the resources available to achieve these goals are usually limited.

Alfred Chandler (1962) reported that "strategy is the determination of the basic long-term goals of an enterprise and the adoption of the courses of action and the allocation of resources necessary for carrying out these goals." Michael Porter (1980) defined strategy as the "broad formula for how a business is going to compete, what its goals should be, and what policies will be needed to carry out those goals" and as the "combination of the ends (goals) for which the firm is striving and the means (policies) by which it is seeking to get there."

The life cycle of each of equipment consists of four stages, namely acquisition, operation, maintenance, and replacement. The methods available in the acquisition, maintenance, and replacement phases (according to the above definitions) can be considered as a kind of strategy. Each of these strategies will create different costs, risks, and performance for the asset. The strategies in the equipment life cycle are shown in Table 1.

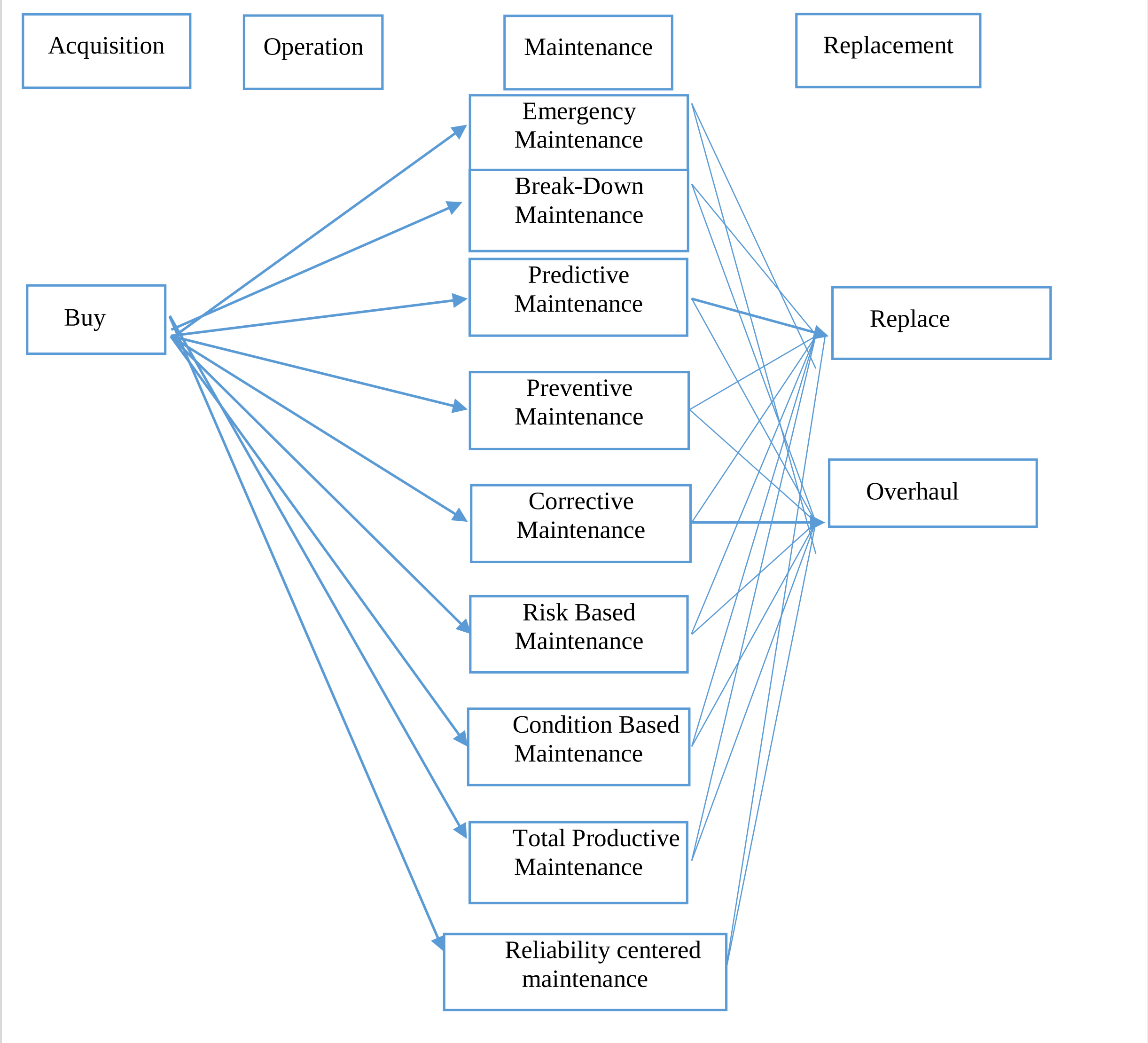

Figure 1. Strategies in each phase of life cycle.

Different scenarios will be created by selecting different strategies in each phase of the life cycle. However, due to the consideration of oil and gas pipelines as a case study, it is not possible to use the rental strategy. On the other hand, due to the lack of numerical data and the use of the experiences of experts, considering many strategies will lead to problems such as the fatigue of the respondents which can lead to incorrect results.

For the reasons mentioned above, a number of existing scenarios, which have been more applicable according to the views of the experienced have been selected.

1. RCM-Replacement
2. RCM-Overhaul
3. CBM-Replacement
4. CBM-Overhaul
5. TPM-Replacement
6. TPM-Overhaul

In order to select the most appropriate strategy and rank the other ones, life cycle cost (LCC), risk, and key performance indicator (KPI) are chosen as the criteria. The equipment life cycle cost has five sub-criteria that are composed of different phases of the life cycle, namely acquisition cost, installation and commissioning cost, operating cost, maintenance cost, and replacement cost. Further, asset management risks according to ISO

55000 can be classified under six categories of physical failure risks, operational risks, risks associated with natural environmental events, risks associated with the factors outside the organization's control, stakeholders related risks, and risks associated with different lifecycle phases of assets. We also consider the key performance indicator in terms of the three sub-criteria which are reliability, availability, and maintainability (RAM) of the equipment.

Relative weight of the identified criteria can be obtained using the dematel-based analytic network process (DANP) technique. The approach to implementing this technique is summarized below.

A survey was conducted via questionnaires distributed to eight experts in relation to each stage of asset life cycle. The assessment is accomplished by interaction between the criteria by pair-wise comparisons and scoring the direct influence. The scale used changes from 0 to 4, with scores represented by natural language: no influence (0), low influence (1), middle influence (2), high influence (3), and excessive influence (4). After comparison, the direct-influence matrix can be obtained from the convergence of experts' opinion where n × n matrix D, is denoted as the degree to which criterion i affects criterion j. Matrix $\boldsymbol{D}$ is acquired by using Equation (1). Thus, matrix $\boldsymbol{D} = [d_c^{ij}]_{n\times n}$ of the direct relationships can be obtained by:

$$\boldsymbol{D} = \begin{bmatrix} d_c^{11} & \cdots & d_c^{1j} & \cdots & d_c^{1n} \\ \vdots & & \vdots & & \vdots \\ d_c^{i1} & \cdots & d_c^{ij} & \cdots & d_c^{in} \\ \vdots & & \vdots & & \vdots \\ d_c^{n1} & \cdots & d_c^{nj} & \cdots & d_c^{nn} \end{bmatrix} \tag{1}$$

The following equation is then used to measure the data compatibility;

$$g = \frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\left| d_c^{ij(p)} - d_c^{ij(p-1)} \right|}{d_c^{ij(p)}} \times 100 \tag{2}$$

Reliability is also given by the following relationship:

$$\text{Reliability} = \left(1 - \frac{g}{100}\right) \times 100 \tag{3}$$

If the g value is less than 5% (reliability above 95%), the reliability of the data is confirmed.

The normalized matrix ($\boldsymbol{N}$) is acquired by using Equation (4).

$$\boldsymbol{N} = V\boldsymbol{D}$$
$$V = min\left\{ 1\Big/\max_i \sum_{j=1}^{n} d_c^{ij} \,, 1\Big/\max_j \sum_{i=1}^{n} d_c^{ij} \right\} \tag{4}$$
$$, i\,, j\, \epsilon \{1,2, \dots, n\}$$

When the normalized direct-influence matrix $\boldsymbol{N}$ is obtained, the total-influence matrix $\boldsymbol{T}$ can be obtained from Equation (5), in which $\boldsymbol{I}$ denote the identity matrix.

$$\boldsymbol{T} = \boldsymbol{N} + \boldsymbol{N}^2 + \cdots + \boldsymbol{N}^k = \boldsymbol{N}(\boldsymbol{I} - \boldsymbol{N})^{-1}, \quad when \ \lim_{h\to\infty} \boldsymbol{N}^h \tag{5}$$

The $\boldsymbol{T_c} = [\boldsymbol{T}_c^{ij}]_{n\times n}$ pertains to n criteria, while $\boldsymbol{T_D} = [\boldsymbol{T}_D^{ij}]_{m\times m}$ is devoted to m dimensions from total influence matrix $\boldsymbol{T}$.

$$\boldsymbol{T_c} = \begin{array}{cc} & \begin{array}{ccccc} \boldsymbol{D}_1 & & \boldsymbol{D}_j & & \boldsymbol{D}_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{j1}\cdots c_{jm_j} & \cdots & c_{n1}\cdots c_{nm_n} \end{array} \\ \begin{array}{cc} \boldsymbol{D}_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ \vdots & \\ \boldsymbol{D}_i & \begin{array}{c} c_{i1} \\ c_{i2} \\ \vdots \\ c_{im_i} \end{array} \\ \vdots & \\ \boldsymbol{D}_n & \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} & \begin{bmatrix} T_c^{11} & \cdots & T_c^{1j} & \cdots & T_c^{1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{i1} & \cdots & T_c^{ij} & \cdots & T_c^{in} \\ \vdots & & \vdots & & \vdots \\ T_c^{n1} & \cdots & T_c^{nj} & \cdots & T_c^{nn} \end{bmatrix} \end{array} \tag{7}$$

$$\boldsymbol{T_D} = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1m} \\ \vdots & \ddots & \vdots \\ t_D^{m1} & \cdots & t_D^{mm} \end{bmatrix}$$

The total influential dimensions matrix $\boldsymbol{T_D}$ needs to be normalized by dividing it using the following formula:

$$\boldsymbol{T_D} = \begin{bmatrix} T_D^{11} & \cdots & T_D^{1j} & \cdots & T_D^{1m} \\ \vdots & & \vdots & & \vdots \\ T_D^{i1} & \cdots & T_D^{ij} & \cdots & T_D^{im} \\ \vdots & & \vdots & & \vdots \\ T_D^{m1} & \cdots & T_D^{mj} & \cdots & T_D^{mm} \end{bmatrix} \begin{array}{l} t_D^1 = \sum_{j=1}^{m} T_D^{1j} \\ t_D^i = \sum_{j=1}^{m} T_D^{ij} \\ t_D^m = \sum_{j=1}^{m} T_D^{mj} \end{array} \tag{8}$$

Therefore, a total influential matrix $\boldsymbol{T_D}$ can be normalized and represented as $\boldsymbol{T_D^\alpha}$, where $\boldsymbol{T_D^\alpha} = \left[T_D^{ij} \Big/ T_D^i \right]_{n\times n}$, as expressed in Equation (9). Then, each row of the normalized $\boldsymbol{T_D^\alpha}$ can be summed to equal one, so that $\sum_{j=1}^{m} T_D^{\alpha ij} = 1$.

$$\boldsymbol{T_D^\alpha} = \begin{bmatrix} T_D^{11}/t_D^1 & \cdots & T_D^{1j}/t_D^1 & \cdots & T_D^{1m}/t_D^1 \\ \vdots & & \vdots & & \vdots \\ T_D^{i1}/t_D^i & \cdots & T_D^{ij}/t_D^i & \cdots & T_D^{im}/t_D^i \\ \vdots & & \vdots & & \vdots \\ T_D^{m1}/t_D^m & \cdots & T_D^{mj}/t_D^m & \cdots & T_D^{mm}/t_D^m \end{bmatrix} = \begin{bmatrix} T_D^{\alpha 11} & \cdots & T_D^{\alpha 1j} & \cdots & T_D^{\alpha 1m} \\ \vdots & & \vdots & & \vdots \\ T_D^{\alpha i1} & \cdots & T_D^{\alpha ij} & \cdots & T_D^{\alpha im} \\ \vdots & & \vdots & & \vdots \\ T_D^{\alpha m1} & \cdots & T_D^{\alpha mj} & \cdots & T_D^{\alpha mm} \end{bmatrix} \tag{9}$$

The normalized total-influence criteria matrix $\boldsymbol{T_C^\alpha}$, can be obtained using Equation (10).

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{c_{ij}}^{11}, i = 1,2,\dots,m_1 \tag{10}$$

$$\boldsymbol{T_c^{\alpha 11}} = \begin{bmatrix} T_{c_{11}}^{11}/d_{c_1}^{11} & \cdots & T_{c_{1j}}^{11}/d_{c_1}^{11} & \cdots & T_{c_{1m_1}}^{11}/d_{c_1}^{11} \\ \vdots & & \vdots & & \vdots \\ T_{c_{j1}}^{11}/d_{c_i}^{11} & \cdots & T_{c_{ij}}^{11}/d_{c_i}^{11} & \cdots & T_{c_{im_1}}^{11}/d_{c_i}^{11} \\ \vdots & & \vdots & & \vdots \\ T_{c_{m_1 1}}^{11}/d_{c_{m_1}}^{11} & \cdots & T_{c_{m_1 j}}^{11}/d_{c_{m_1}}^{11} & \cdots & T_{c_{m_1 m_1}}^{11}/d_{c_{m_1}}^{11} \end{bmatrix} = \begin{bmatrix} T_{c_{11}}^{\alpha 11} & \cdots & T_{c_{1j}}^{\alpha 11} & \cdots & T_{c_{1m_1}}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ T_{c_{11}}^{\alpha 11} & \cdots & T_{c_{11}}^{\alpha 11} & \cdots & T_{c_{im_1}}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ T_{c_{m_1 1}}^{\alpha 11} & \cdots & T_{c_{m_1 j}}^{\alpha 11} & \cdots & T_{c_{m_1 m_1}}^{\alpha 11} \end{bmatrix} \tag{11}$$

Unweighted super-matrix $\boldsymbol{W}$ is the matrix transposed from $\boldsymbol{T_C^\alpha}$.

$$\boldsymbol{W} = (\boldsymbol{T_c^\alpha})' = \begin{matrix} D_1 \\ \vdots \\ D_i \\ \vdots \\ D_m \end{matrix} \begin{matrix} c_{11} \\ \vdots \\ c_{1n_1} \\ \vdots \\ c_{i1} \\ \vdots \\ c_{in_1} \\ \vdots \\ c_{m1} \\ \vdots \\ c_{mn_m} \end{matrix} \overset{\begin{matrix} D_1 & & D_j & & D_m \\ c_{11}\cdots c_{1n_1} & \cdots & c_{j1}\cdots c_{jn_j} & \cdots & c_{m1}\cdots c_{mn_m} \end{matrix}}{\begin{bmatrix} W^{11} & \cdots & W^{i1} & \cdots & W^{m1} \\ \vdots & & \vdots & & \vdots \\ W^{1j} & \cdots & W^{ij} & \cdots & W^{mj} \\ \vdots & & \vdots & & \vdots \\ W^{1m} & \cdots & W^{im} & \cdots & W^{mm} \end{bmatrix}} \tag{12}$$

$$\boldsymbol{W^\alpha} = \boldsymbol{T_D^\alpha} \times \boldsymbol{W} = \begin{bmatrix} t_D^{\alpha 11} \times W^{11} & \cdots & t_D^{\alpha i1} \times W^{i1} & \cdots & t_D^{\alpha m1} \times W^{m1} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1j} \times W^{1j} & \cdots & t_D^{\alpha ij} \times W^{ij} & \cdots & t_D^{\alpha mj} \times W^{mj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1m} \times W^{1m} & \cdots & t_D^{\alpha im} \times W^{im} & \cdots & t_D^{\alpha mm} \times W^{mm} \end{bmatrix} \tag{13}$$

A weighted super-matrix $\boldsymbol{W^\alpha}$ can be obtained by the product of $\boldsymbol{T_D^\alpha}$ and $\boldsymbol{W}$ as given by Equation (13).

We limit the weighted super-matrix by raising it to a sufficiently large power φ until it converges and becomes a long stable super-matrix term to obtain global priority vector, which defines the influential weights $w = (w_1 \dots, w_j \dots, w_n)$ from $\lim \varphi \to \infty\, (w^\alpha)$ for the criteria.

Eventually scenarios should be ranked using the MOORA method, but due to the lack of the participation of the authorities and the lack of access to the data needed to perform the multi-objective optimization on the basis of ratio analysis (MOORA), questionnaires were used to generate qualitative data on the value of each indicator relative to the scenario. The approach to implementing this technique is described below.

The first step of the MOORA method is constructing the decision matrix of the problem. The criteria (objectives) and alternatives are listed in the columns and rows of the decision matrix respectively. The decision matrix shows the performance of different alternatives with respect to the various criteria.

$$\boldsymbol{X} = [x_{ij}]_{mn} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (14)$$

where X_{ij} presents the performance value of *i*th alternative on *j*th criterion, and *m* and *n* are the numbers of alternatives and criteria respectively.

The following formula is used to make the decision matrix dimensionless:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \quad (15)$$

where x_{ij} is the response of alternative *i* to objective *j* $(i = 1, 2, \dots, m)$, *m* is he number of alternatives$(j = 1, 2, \dots, n)$, and *n* is the number of objectives,

x_{ij}^{*} indicates a dimensionless number representing the normalized response of alternative *i* to objective *j*; these normalized responses of the alternatives to the objectives belong to interval [0, 1].

Given that each indicator is positive or negative, the ideal reference points are the lowest for the negative indicators and highest for the positive indicators. *g* numbers of criteria (maximized values) are beneficial criteria as *n-g* criteria (minimized values) have negative effects on the performance as seen in the formula. Normalized performance values of the beneficial criteria are added. Then, the same procedure is repeated for the nonbeneficial criteria. Finally, the sums of the nonbeneficial criteria are subtracted from the sums of the beneficial criteria as expressed by Equations (2)–(15). The result is the overall performance score of each alternative (y_i^*).

$$y_i^{*} = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*} \quad (16)$$

Given the weight of the criteria, the values of utility and disutility of each criteria can also be obtained from the following relation:

$$y_i^{*} = \sum_{j=1}^{g} r_{ij}^{*} * w_j - \sum_{j=g+1}^{n} r_{ij}^{*} * w_j \quad ; i = 1, \dots, m \quad (17)$$

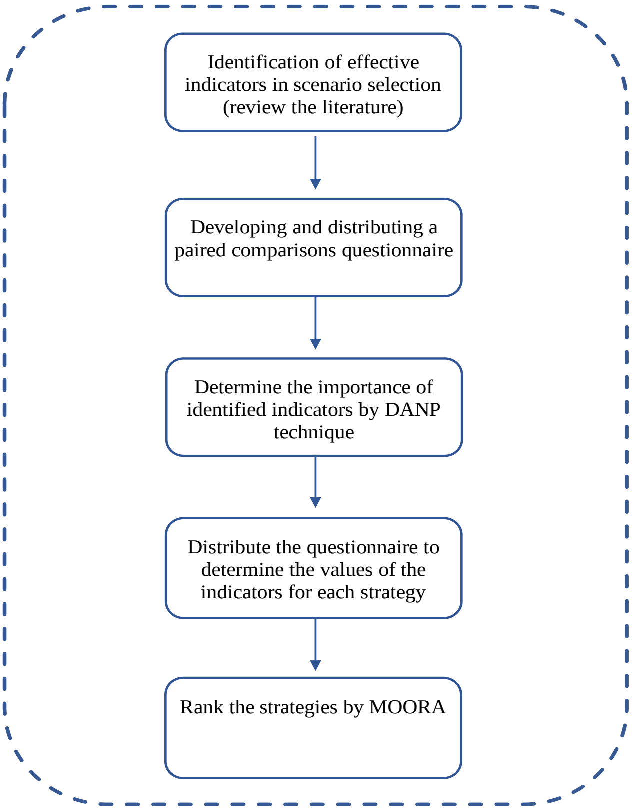

Figure 2. Research procedure.

4. Research Findings

After getting acquainted with the research method and determining the effective indicators and sub-indicators presented in Table 1, we first prepared a questionnaire with five verbal expressions to compare the criteria with each other for weighting the identified indicators and distributed them to eight experts. Afterward, using the DANP technique, we figure out the weight of each indicator.

Table 1. Indicators and sub-indicators used in this work.

Dimension	Abbreviation	Criteria	Abbreviation
Life Cycle Cost	LCC	Acquisition cost	C_A
		Installation and Commission Cost	C_{ic}
		Operation cost	C_O
		Maintenance cost	C_M
		Disposal cost	C_D
Risk	R_i	Physical failure risks	R_1
		Operational risks	R_2
		Risks associated with natural environmental events	R_3
		Risks associated with the factors outside of the organization's control	R_4
		Stakeholders related risks	R_5
		Risks associated with different lifecycle phases of assets	R_6
Key Performance Indicator	KPI	Reliability	R
		Availability	A
		Maintainability	M

After collecting the experts' opinions and following the steps mentioned above, matrix ***TD*** and $(R + C)$ and $(R – C)$ values for the criteria were obtained. Given these numbers, the intensity and vector of impact for each criterion was determined as shown in Figure 1.

Table 2. Total-influence dimensions of matrix ***TD***.

TD	LCC	Risk	KPI	*C*
LCC	0.09979	0.12877	0.17994	0.408497
Risk	0.15306	0.14707	0.22637	0.526501
KPI	0.11783	0.13416	0.18477	0.436761
R	0.370679	0.409996	0.591084	
$R + C$	0.779176	0.936497	1.027846	
$R – C$	0.037818	0.116505	-0.15432	

According to the following graph, LCC and risk dimensions are the effective dimensions, and KPI is the impressible dimension. Furthermore, KPI has the utmost importance while LCC has the least. Finally, the following weights (Table 3) were obtained for each of the criteria about the pipeline by completing a questionnaire by eight experts of oil and gas industry.

Table 3. Weights of the dimensions.

Dimensions	Weights
LCC	0.2692
Risk	0.3010
RAM	0.4298

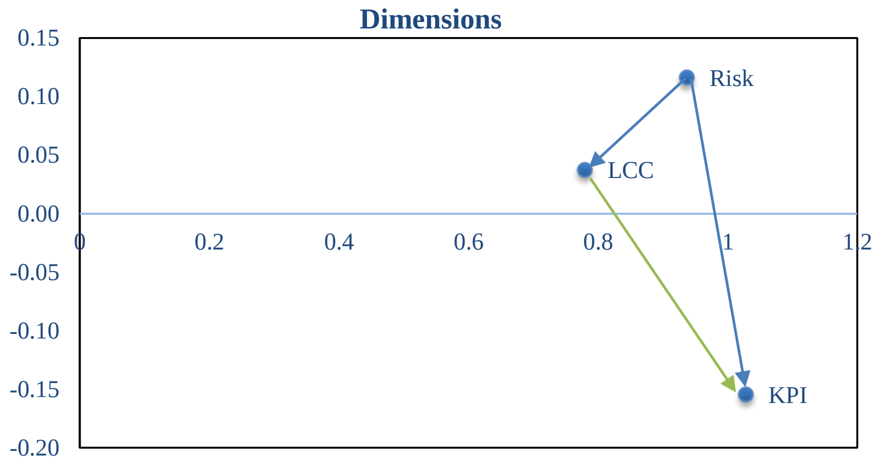

Figure 3. A network relation map of dimensions.

According to the obtained weights, these experts believe that improving asset management in an organization will depend on improving the performance of the equipment (RAM index). Subsequently, considering the importance of the safety of people and equipment in this industry, identification, management, and control of the associated risks will be required. The life cycle cost of equipment should also be taken into account and controlled to an acceptable level and reduced to the extent possible.

At the end, we will seek to rank the scenarios using the MOORA method, but due to the lack of participation of the authorities and the lack of access to the data needed to perform the MOORA, questionnaires were used to generate qualitative data on the value of each indicator relative to the scenario. After collecting the questionnaires and gathering the experts' opinion, the decision matrix was formulated.

The maximum values obtained for y_i^* are set to alternative i, and then the values are ranked in a descending order. Finally, using Equation (16) the target function values are calculated for each scenario as shown below.

Table 4. The decision matrix.

No.	Scenario	LCC	Risk	KPI (RAM)
1	Buy-RCM-Replacement	3.75	4.5	5.5
2	Buy-RCM-Overhaul	3.5	5.5	5.25
3	Buy-CBM-Replacement	4.5	5.5	6.25
4	Buy-CBM-Overhaul	4	6	6.25
5	Buy-TPM-Replacement	3.5	4	5.5
6	Buy-TPM-Overhaul	3.25	4.25	5

Table 5. Target function values and scenario ranking.

Scenario	y_i^*	Rank
Buy-RCM-Replacement	–0.05007	3
Buy-RCM-Overhaul	–0.07505	6
Buy-CBM-Replacement	–0.07317	5
Buy-CBM-Overhaul	–0.07082	4
Buy-TPM-Replacement	–0.03051	1
Buy-TPM-Overhaul	–0.04498	2

5. Result and Discussion

The management structure and content of each company or firm, especially in the upstream sector of the oil industry, consist of two parts: first, how the hidden values and potentials that can lead to the creation of value and revenue are identified, and, second, according to risk and uncertainty together with the process of creating value, how this risk and uncertainty are managed. This is where the importance and necessity of the “integration and management of assets” is manifested to combine the correct sources and factors of production in the shortest possible time so that we maximize the creation of value and manage the risks existing in this direction, which are in the upstream segment too.

Managing the physical asset life cycle can be effective in increasing productivity and increasing the rate of return on capital. For example, using smarter techniques for maintaining and repairing equipment and working properly can increase production capacity, availability, and reliability of equipment at an affordable cost, which leads to an increase in the rate of return on capital. Also, in another example, by studying the operational and climate conditions that dominate an industrial site, one can buy equipment that has less permanent depreciation rate and consequently reduce fixed costs altogether. By utilizing proper management practices in maintenance and repair, one can gain more by using less resources, or maintaining the performance of the equipment at appropriate levels leads to an increase in the quality of production products or to the provision of services that can increase sales prices. By properly recognizing the equipment performance and operating conditions, we can increase the efficiency of the equipment in terms of consuming raw materials or energy.

As mentioned before, by conducting proper analysis before deciding on the strategy of each of the phases of the equipment life cycle and adopting appropriate policies, suitable solutions can be provided for the purchase, for how to operate and maintain the equipment, and even for its disposal. In this study, considering the three criteria of cost, risk, and performance, we examined six scenarios related to the life cycle of petroleum pipelines and ranked them according to these three criteria. According to the results, in order to protect equipment and extend its service life, the best strategy for maintaining and repairing is a total productive maintenance, and with the expiry of the useful life of the equipment, replacing it with the new pipeline will be more economical than overhauling it while reducing the potential risks. Nevertheless, due to the lack of actual data, the results are based on the opinions of the selected experts, and if they change, the results can be modified. Therefore, it is recommended that this study should be done by collecting actual industry data so that the condition of the equipment can be improved with the results obtained.

6. Suggestion for Future Research

Based on this research, the following topics are suggested for future research:

- Investigating the optimal life of equipment using LCC, Risk, and KPI estimation;
- Using other methods of decision making;
- Evaluating the scenarios by classifying the equipment as critical, essential, important, and normal and suggesting a suitable scenario for each class;
- Surveying other scenarios;
- Assessing and evaluating the safety and economic efficiency (RAMS-e) instead of reliability, availability, and maintainability (RAM) as the KPI.

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