The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/1355-2511.htm

Received 3 March 2019
Revised 20 August 2019
6 March 2020
Accepted 5 August 2020

Maintenance strategy selection: a combined goal programming approach and BWM-TOPSIS for paper production industry

Soroush Avakh Darestani
Faculty of Business and Law, School of Strategy and Leadership, Coventry University, Coventry, UK and
Department of Industrial Engineering, Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran
Tahereh Palizban
Department of Industrial Engineering, Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran, and
Rana Imannezhad
Department of Industrial Engineering, Bandar e Anzali International Branch, Islamic Azad University, Bandare Anzali, Iran

Abstract

Purpose – Correct and well-planned maintenance based on modern global methods directly affects efficiency, quality, direct production costs, reliability and profitability. The selection of an optimal policy for maintenance can be a good solution for industrial units. In fact, by managing constraints such as costs, working hours and human workforce causing sudden equipment failure, production and performance can increase.

Design/methodology/approach – Therefore, in this research a model was presented to select the best maintenance strategy at Kaghaz Kar Kasra Co of Iran. In this study, it was tried to integrate the two techniques of goal programming and the technique for order of preference by similarity to ideal solution (TOPSIS) to prioritize maintenance strategies. First, all factors affecting maintenance were identified, and based on the Best Worst Method (BWM) the degree of their importance was determined.

Findings – After the evaluation, only 14 criteria in the 4 dimensions of cost, added value, safety and feasibility were selected. The highest points were given to the criteria of equipment cost and depreciation, equipment and personnel performance, equipment installation time and technical feasibility, respectively. In the next stage, using the TOPSIS method the item of maintenance strategy was ranked, and the 3 strategies of preventive maintenance (PM), predictive maintenance (PDM) and corrective maintenance (CM) were chosen. Modeling was performed utilizing a goal programming approach to select the optimal maintenance strategy for 13 devices. All the technical specifications, cost limits and the device time were extracted. After the model was finished and solved the best item for each device was specified.

Originality/value – 1. Developing a goal programming model and decision-making dashboard. 2. Identifying the criteria and factors affecting the selection of the maintenance strategy for paper production Industry

Keywords Maintenance, Maintenance strategy, Best Worst Method (BWM), TOPSIS, Goal programming

Paper type Research paper

1. Introduction

Today, with the advancement of technology and the increasing number of machinery in manufacturing industries, investors and managers consider different ways to decrease

Hereby, authors thank the referees for their valuable comments.

© Emerald Publishing Limited
1355-2511
DOI 10.1108/JQME-03-2019-0022

sudden machinery failure and increase their useful life, aiming to gain the highest possible performance from the equipment at the lowest cost (Can Özcan *et al.*, 2017). Maintenance, as a useful and important tool in various fields, helps manufacturing companies and organizations to have an active presence in competitive manufacturing markets, although it requires a proper implementation in an organization (Gandhare and Akarte, 2012).

Currently, industries are facing great losses due to the lack of comprehensive maintenance systems, improper care and the lack of real-time maintenance for equipment and devices. Therefore, it is necessary to have a complete and effective programmed maintenance system, which makes it possible to continuously control equipment and offer a complete report of their conditions and performance status, while providing the most ideal maintenance services and adopting the best methods to continue the process at the lowest possible cost (Seyed Hosseini, 2005).

Maintenance is regarded as one of the most important topics in industries, which leads to increased performance and efficiency in different ways. Given the limited amount of resources, human workforce and capital, maintenance can greatly contribute to realizing the above-mentioned goals. Maintenance is an important and fundamental concept and its correct implementation results in surviving and continuing the operation of production lines and decreasing costs. The growing complexity of the tools and facilities used by humans to satisfy their increasing needs has highlighted the optimal use and economic efficiency of these items (Ebrahimi *et al.*, 2010). Also, the complicated manufacturing methods, facilities and machinery used in this area require enhancing the performance at the least amount of costs, increasing the useful life of machinery as much as possible and decreasing the total costs related to the prime cost of products (Safari *et al.*, 2010). Since there are optimal reliability and performance levels for machinery and equipment, increasing this level requires spending high expenses, which makes products economically inefficient. However, precise and consistent planning can be developed to acquire the highest efficiency from existing facilities and ensure maximum performance and accessibility in machines (Horizons and Cavalieri, 2013). Accordingly, the selection of an optimal maintenance policy can be a good solution for industrial units to reduce sudden failure of equipment, increase production and performance and decrease other constraints such as costs and the working hours of the human workforce. So far, different strategies have been proposed for maintenance, each of which has its advantages and disadvantages (Jain *et al.*, 2013). Hence, this research seeks to provide a method for selecting the most suitable strategy for maintenance and prioritizing maintenance strategies by integrating the two techniques of goal programming and the technique for order of preference by similarity to ideal solution (TOPSIS). For this purpose, all factors affecting the maintenance are characterized and then, the rate of their importance is specified according to the decision-making technique, followed by prioritizing maintenance strategies and selecting the most appropriate strategy.

For this work, six types of the significant maintenance strategies were considered as decision-making alternatives such as: corrective maintenance (CM), preventive maintenance (PM), predictive maintenance (PDM), condition-based maintenance (CBM), reliability-centered maintenance (RCM) and total productive maintenance (TPM).

However, keeping the safety and the operational state of manufacturing equipment, machinery and installations are among the major problems for manufacturing companies and using a programmed maintenance system, particularly a PM system, is a fundamental solution to this problem (Ding and Kamaruddin, 2015). The basis of this system is to implement a programmed inspection and maintenance on manufacturing or service equipment and devices after a certain period of operation. It is evident that the number of and interval between inspections and maintenance depend on the structure and operational status of the equipment, to prevent depreciation in mechanical parts and perform the necessary predictions for purchasing or manufacturing required spare parts (Gonçalves *et al.*, 2015).

Now, the research question is raised that how to use a combined goal programming approach, the Best Worst Method (BWM) method and TOPSIS to select the maintenance strategy for the company?

The main purpose of this study is to present a combined method of goal programming, BWM and TOPSIS, to select the maintenance strategy for the studied company. By evaluating various maintenance strategies for the studied company, a series of secondary objectives are also presented in this paper. The main research objective is to identify the criteria and sub-criteria affecting the selection of a maintenance strategy, evaluating the importance degree of the criteria affecting the selection of the best maintenance strategy, determining various maintenance strategies and investigating their characteristics and assessing the maintenance strategy selection model.

The rest of the paper is organized as follows. Section 2 explains the theoretical foundations and literature review. Section 3 evaluates the methodology and analyzes data. Finally, Section 4 concludes and presents suggestions for future research.

2. Literature review

First, we define the applied terms in this work. Maintenance process includes all the plans, activities and operations performed under an acceptable standard operating procedure (SOP) to preserve, control and increase the useful life of machinery, equipment, installations and structures in suitable conditions or change them to suitable conditions to be present in the operating cycle. The desirable result of these measures is to preserve the preparedness, operational capability and the operational continuity of the equipment for predefined conditions (Raoofi, 2009). Companies are heavily dependent on their machinery and equipment in securing a competitive advantage. Maintenance, in its wide sense, is the function that is mostly concerned with that aspect of the business. Therefore, it is essential to have a long-term plan for maintenance that takes into consideration the vision, mission and objectives of the organization and the anticipated changes in technology. Maintenance in its narrow meaning includes all activities related to maintaining a certain level of availability and reliability of the system and its components and its ability to perform to a standard level of quality (Al-Turki, 2011). Effective planning and scheduling contribute significantly to reduced maintenance costs, improved utilization of maintenance resources and better quality of maintenance work (Duffuaa and Raouf, 2015).

CM: request for repair works, which are commonly sent by the production personnel to the maintenance unit, is categorized as corrective or routine maintenance, although it may not have the same special priority and conditions as emergency maintenance (Haj Shirmohammadi, 1998).

PM is the best and usually, the most economical form of maintenance, which is defined, designed and implemented in a programmed manner based on the objectives and functional or calendar courses (Separi *et al.*, 2012).

PDM and CBM: CBM is one type of PM where the equipment's condition is monitored (Tsang, 2002). An ideal scenario in maintenance is that it is possible to predict a fault before it occurs, which helps managers to take the necessary measures and change the faulty part before a failure occurs and stops production or operation (Haj Shirmohammadi, 1998). PDM involves the use of modern measurement and signal processing methods to accurately predict and diagnose equipment condition during operation (Murthy *et al.*, 2002).

RCM: This process determines the needs for equipment and machinery maintenance under working conditions, to ensure that each equipment can perform its main tasks effectively. The lack of RCM reduces maintenance reliability and efficiency (Noori, 2004).

TPM is a unique intellectual framework, based on which a comprehensive maintenance system can be developed in an organization. On the other hand, TPM is considered as one of the main methods in the area of maintenance, which considers the division of operational works among various departments and prevents the concentration of operations at one department (Gandhare and Akarte, 2012).

TPM is defined as a management approach to maintenance that imports total quality management (TQM) philosophy and techniques to maintenance. TPM focuses on involving all employees in the organization in equipment improvement. TPM started in Japan and has spread to the Far East, Europe, South America and the United States. It became a recognized methodology for improving equipment reliability and plant productivity. TPM eliminates losses resulting from unplanned down time, reduced speed and quality. TPM brought to industry overall equipment effectiveness (OEE) as a measure that combines losses from unplanned down time, reduced speed and quality (Duffuaa and Raouf, 2015).

The initiative-based activities in TPM are a new partnership between manufacturing, maintenance, engineering and service workforce, to improve the overall performance of the equipment. Nowadays, TPM is adopted by many companies across the world, including the automotive, steel, chemical and household appliances industries (Gandhare and Akarte, 2012). Further, changes in the direction and procedures of maintenance can be observed in different fields and the PDM or CBM has replaced PM. The following section reviews previous studies carried out in this field to define the gap of research.

Shagluf *et al.* (2018) conducted a study on adaptive decision support systems (ADSSs) to present a strategy for machinery maintenance from reactive to preventive systems. Using a case study, they designed a program consisting of PM to decrease the need for the reoccurrence of failures in reactive maintenance based on precision information measuring instruments. Based on their results, a 28% reduction in anticipated costs was related to precision, indicating a saving of 14 kg per device over five years.

Furthermore, Rana and Emosi (2018) measured the effectiveness of maintenance activities, aiming to present a framework for measuring the undesirable and subjective "practical" impacts of major maintenance activity. Such measurement not only leads to the adaptability of the effectiveness of maintenance by the workforce without any intervention by a specialist but also helps to measure the slow performance deterioration of the existing system within the main one. In this regard, the main maintenance operation was studied on the diesel engines of a power plant company and expert opinions were used to select key parameters and produce the outcome (measuring effectiveness). The results of an adaptive neuro-fuzzy inference system (ANFIS) were significantly consistent with the opinions of several experts.

In another study, Can Özcan *et al.* (2017) considered maintenance strategy selection and revealed that it is possible to employ fuzzy goal programming to select an optimal maintenance strategy for key equipment in the pulp and paper industry. Based on this, in Kasra paper producing company, optimal repair and maintenance policy-making has been done for 13 machines existing in the company. In the paper producing industries, various machines such as printing machine, writing paper machine, tissue machine, rewinding machine, tissue machine (for box facial tissue making), packing paper machine and specialty paper machine exist. The machinery of this company some of which are similar includes water pumps, oil and paper pulp. For any pump failure mode, given the criteria of failure mode and effects analysis (FMEA), which consisted of probability (P), severity (S) and detection (D), a network structure was formed using the analytic hierarchy process (AHP) and multiple-criteria decision-making (MCDM). Next, after determining the weights of the criteria, an optimal strategy was defined for each failure by solving the goal programming model. The results indicate the superiority of predictive and PM strategies compared to the CM strategy at resource usage and failure reduction. Therefore, these strategies provide maintenance managers with useful information to limit the negative aspects of failure. Alayi and Davoodi (2016) carried out a study on maintenance. Using the dynamical systems theory (DST) and regarding the conditions of the company, they investigated and modeled variables affecting the maintenance system and evaluated the effect of the model on the supply chain management. Then, key factors contributing to the stable success of the company were identified and finally, different scenarios were presented based on the proposed model. The results indicated that training the human workforce and proper programming of the maintenance plan increase the success rate of the company by 46%.

Xie *et al.* (2013) performed a systematic review using the fuzzy AHP based on goal programming, to select maintenance strategies for transformers. Horizons Ierace and Cavalieri (2013) proposed a model based on an AHP that enabled maintenance managers to prioritize relevant choices using appropriate tools. This model was tested at two industrial units.

Jain *et al.* (2013) attempted to select the optimal maintenance and reconstruction strategy for multilane highways, by comparing different maintenance and reconstruction alternatives and using highway management and development tools at multilane highways located in northern India. Bashiri *et al.* (2011) proposed a new strategy for optimal maintenance strategy selection, using qualitative and quantitative data obtained from interacting with maintenance experts.

Moreover, Separi *et al.* (2012) used AHP to prioritize equipment for RCM. This process was implemented on a sample network of the distribution network located in Neka county, Mazandaran, Iran. Ebrahimi *et al.* (2010) evaluated and compared the maintenance strategies under uncertainty, using hierarchical cluster analysis (HCA). This research was performed at the Kara Novin Nikoo company. The results suggested the high capability of multi-attribute decision-making (MADM) models and particularly, AHP determining the maintenance strategy. The analytic network process (ANP) considers complicated internal connections between decision levels and relations concerning the AHP, although this method has been rarely used in research. Meanwhile, goal programming is one of the oldest and most frequently used perspectives in multiple-criteria decision-making models, which attempts to integrate the logic of optimization into mathematical programming at the request of the decision-maker to achieve multiple objectives. To the best of our knowledge, no study has been conducted on maintenance strategy selection, using goal programming, BWM and TOPSIS. Hence, after investigating the scientific foundations of various maintenance strategies, this study aims to employ goal programming and TOPSIS to prioritize and select the best strategy for the studied company.

To present a model for selecting the best maintenance strategy using a goal programming approach, BWM and TOPSIS technique, we first specify the type of the maintenance strategy and then, determine the criteria for selecting the maintenance strategy, according to the characteristics of Amad Behine Saz Eng Co., which is a spare parts manufacturing company. After that, using BWM, the weights of the criteria are determined and prioritized according to the actual conditions of the company, which is a new initiative in the company. Compared to the identified criteria, the weights of each of the maintenance strategy items are determined using the TOPSIS method. It is worth noting that this stage has never implemented at the company and the basis for decision-making and prioritizing in the maintenance strategy was exclusively empirical and non-analytical. Finally, according to each of the objectives of the company and the constraints of the devices in the maintenance plan, maintenance strategy selection is performed through goal programming. This stage is also considered an innovation both for the company and in terms of how to apply various decision-making techniques together. By reviewing the literature and using the opinions of maintenance experts, four factors were selected as the main selection criteria for maintenance strategy selection. These criteria include the following: cost (C), added value (A), safety (S), feasibility (E). Table 1 presents the identified criteria and sub-criteria.

Using AHP and ANP algorithms, Zaeim *et al.* (2012) conducted a study on the maintenance strategy selection in a case study at a local newspaper-printing center, aiming to illustrate the

Cost (C)	Added value (A)	Safety (S)	Feasibility (E)
(1) Equipment depreciation (2) Energy consumption (3) Research and development (4) Hardware (5) Staff salary (6) Software (7) Production loss (8) Training (9) Equipment installation time (10) Spare parts (11) Waste disposal (12) Raw materials	(1) Quality of products (2) Equipment and personnel performance (3) Customer satisfaction (4) Creativity (5) Increased competitiveness (6) Time productivity (7) Return on capital (8) Profitability (9) Developing the experiences of managers and engineers	(1) Equipment safety (2) Environmental impacts (3) Personnel safety (4) Environmental standards (5) Governing laws (6) Release of toxins into the air, soil and water	(1) Management approval (2) Existence of spare parts (3) Employee approval (4) Shareholder approval (5) Workforce capabilities (6) Necessary software features (7) Necessary hardware features (8) Technological complexity (9) Technical feasibility
Authors	**Authors**	**Authors**	**Authors**
Horizons Ierace and Cavalieri (2013), Jain *et al.* (2013), Can Özcan *et al.* (2017)	Horizons Ierace and Cavalieri (2013), Sajjadi and Farhang Moghaddam (2013)	Ahren (2005), Cheng and Tsao (2010), Raufi (2009)	Horizons Ierace and Cavalieri (2013), Ahren (2005), Raufi (2009)

Table 1.
The identified criteria of maintenance strategy selection

most appropriate maintenance strategy by using two decision-making methods for organizations having important production requirements. In this research, they considered three corrective, periodic (time-based) and predictive (condition-based) maintenance policies and then, determined the weights of all three different maintenance policies. The results indicated that the two methods were effective for selecting the maintenance strategy and had almost identical results, and PDM was the most appropriate maintenance strategy in both AHP and ANP analysis.

Hong Ding *et al.* (2012) carried out a research on maintenance strategy selection in a case study at a palm oil production company, using a multi-criteria decision-making technique called TOPSIS. The purpose of this article was to discuss the difficulties and complexity of the selection process, due to the combination of conflicting constraints on maintenance, such as available spare parts, workforce size and maintenance skills. Ultimately, PM was selected as the optimal maintenance strategy to reduce system failure. The results highlighted that the developed model could present accurate results in the short term, which is suitable for industries that need to make effective decisions in the short term.

Chemweno *et al.* (2016) carried out a data exploration method for analyzing the underlying cause for choosing a thermal power plant maintenance strategy. Their methodology consists of standardization of data and heuristic framework that helps decision-makers to exploit the failure of meaningful communication embedded in retention data for maintenance strategy selection. In this resext, Another work was also was conducted by Ighravwe and Ayoola Oke (2017) that presented the ranking of maintenance strategies for sustainable maintenance planning in structural systems using FAD and fuzzy-TOPSIS techniques. They concluded that using fuzzy-TOPSIS leads to have an optimum maintenance strategy.

In 2018, Tuyet and Chou carried out a research on the maintenance strategy for the cost-effective improvement of offshore wind systems to provide optimal maintenance plans. They suggested that group maintenance is more appropriate than individual maintenance because it requires less maintenance activities.

One of the recent works was implemented in the cement industry in India by Kurian *et al.* (2019) using an analytical network process. The results reflect that considering the dependency between strategic factors, the ANP method can be employed as an effective tool for evaluating possible options in maintenance strategy decision-making issues.

At the end, one of the most recent works is done by Jin *et al.* (2020). They carried out a research on an optimal and efficient maintenance strategy to maximize the net income of each unit for multi-state deterioration systems using simulation technique. The numerical results demonstrate the high efficiency of the optimal strategy, especially for large-scale systems.

In another study, Hemmati *et al.* (2018) evaluated selecting a maintenance strategy for seven devices in a case study at a sulfuric acid manufacturing company, aiming to develop a fuzzy ANP model to select the best maintenance strategy. For this purpose, they investigated four CM, TBM, CBM and shutdown maintenance (SM). Based on the results, the CBM policy is suitable for high-risk equipment (cooling tower) and high value-added equipment (absorption tower). Also, TBM is selected for boilers and converters while SM is used for molten sulfur pools. Finally, the CM policy was utilized for low cost, low risk and low-value equipment (sulfur fuel furnace and heat exchanger), due to its suitability in the process.

Considering research conducted on selecting a maintenance strategy, this study attempts to select the best maintenance strategy for the 13 devices in a case study at a paper production company. The purpose of this study is to provide a model for selecting the appropriate maintenance strategy by integrating BWM and TOPSIS, to prioritize criteria, as well as goal programming. This research is considered an innovation for both the company and the procedure of applying different types of decision-making techniques together. Given the complexity of the problem of selecting the best maintenance strategy for the company, this problem cannot be solved by general mathematical programming methods. To better explain the problem, it is possible to use goal programming techniques, which show the way to move toward multiple goals simultaneously. Several goals can be satisfied simultaneously in goal programming. This technique seeks an answer that minimizes the total (weight) deviation of each goal from the ideal setting for the same goal and allows reaching all goals as far as possible.

3. Methodology design

The methodology of this research was of a descriptive-analysis type. In addition to studying and describing the facts and features of various maintenance strategies in the company, the researcher intended to use a systemic analysis of factors affecting the selection of the best strategy and utilize its results in suggesting useful recommendations. By applying a field survey and an internal analysis, factors affecting the selection of the best strategy were identified and then, reviewed by addressing the available literature, resources and the theoretical framework. The priority of the maintenance strategy was determined at various departments of the company according to expert opinions. Figure 1 illustrates the research framework.

In this research, the reliability was determined using SPSS 20.0 software. At this stage, the results obtained from completing questionnaires were evaluated by software and then, the Cronbach's alpha coefficient was calculated. This coefficient was obtained 84% for all questionnaire questions, indicating a desirable level of reliability.

Analyzing research reliability using Cronbach's alpha and SPSS software: Tables 2 and 3

List wise deletion based on all variables in the procedure.

T-test analysis to test the criteria for selecting the appropriate maintenance strategy: Table 4

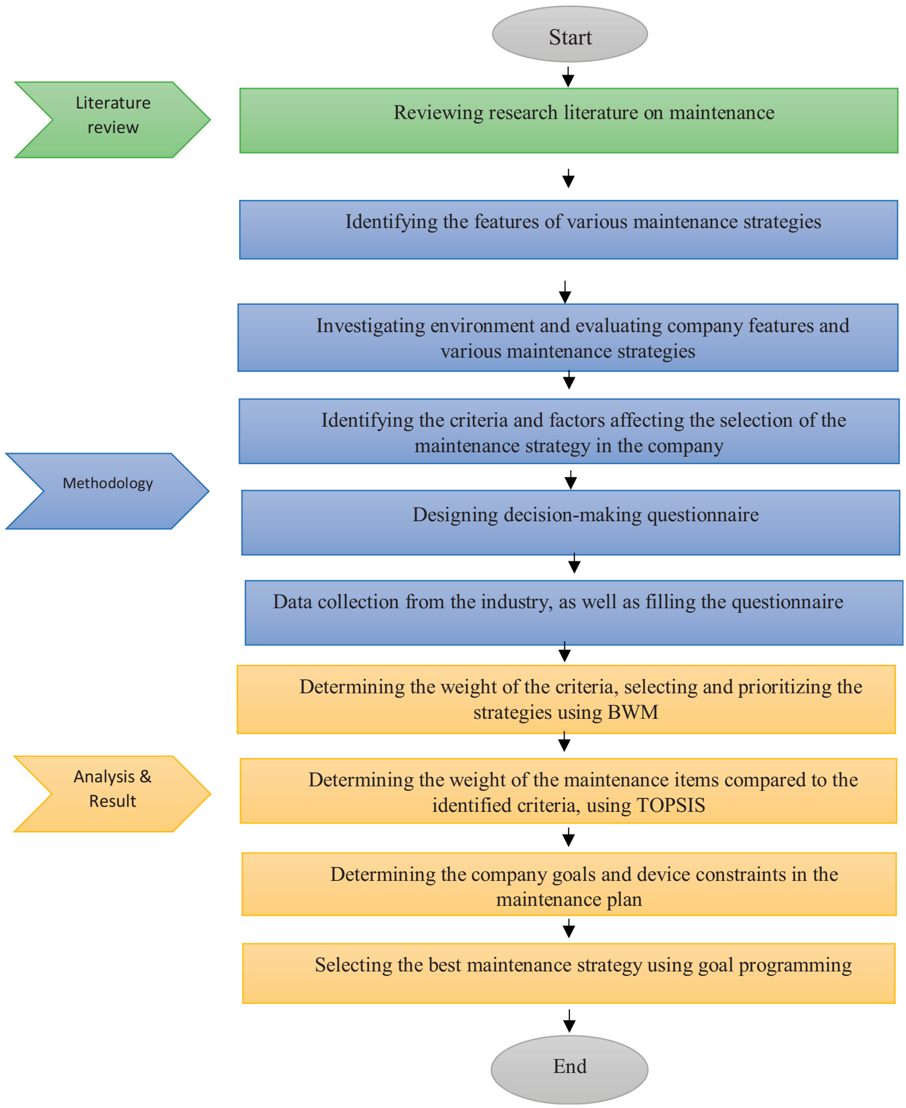

Figure 1.
Research framework

		N	%
Cases	Valid	54	100.0
	Excluded	0	0.0
	Total	54	100.0

Table 2.
Case processing summary

In the next stage, the weights of the criteria were determined through BWM and then, the maintenance strategy items were completed by the experts with respect to the criteria using the TOPSIS technique. Finally, corresponding to each goal of the company and the constraints of the devices in the maintenance plan, maintenance strategy selection was carried out using goal programming.

Table 3.
Reliability statistics

Cronbach's alpha	No of items
0.841	36

Table 4.
One–sample test

	Test value = 3					
					95% confidence interval of the difference	
	t	df	Sig. (2-Tailed)	Mean difference	Lower	Upper
VAR00001	7.159	53	0.000	2.074	0.760	2.820
VAR00002	2.857	53	0.002	2.250	1.070	2.630
VAR00003	1.113	53	0.278	1.389	−0.56	1.630
VAR00004	0.676	53	0.412	1.009	−1.61	1.480
VAR00005	3.012	53	0.001	2.241	−0.24	1.860
VAR00006	1.04	53	0.273	1.028	−0.874	1.580
VAR00007	7.807	53	0.000	2.278	1.760	3.030
VAR00008	5.759	53	0.000	2.370	1.220	2.600
VAR00009	4.162	53	0.000	1.898	0.630	1.890
VAR00010	7.113	53	0.000	1.889	1.420	2.580
VAR00011	0.636	53	0.531	1.370	−0.79	1.480
VAR00012	2.481	53	0.012	1.843	0.740	2.250
VAR00013	0.161	53	0.539	1.083	−0.81	1.570
VAR00014	2.504	53	0.030	1.880	0.250	2.620
VAR00015	0.091	53	0.928	1.074	−1.03	0.950
VAR00016	0.297	53	0.769	1.028	−1.13	1.040
VAR00017	1.349	53	0.217	1.861	0.870	2.130
VAR00018	0.628	53	0.091	1.509	0.024	1.820
VAR00019	1.892	53	0.074	2.352	1.650	2.790
VAR00020	1.101	53	0.063	1.056	1.030	1.770
VAR00021	0.449	53	0.658	1.093	−1.46	0.940
VAR00022	1.24	53	0.085	1.111	1.250	2.760
VAR00023	1.85	53	0.072	1.102	1.190	2.770
VAR00024	7.116	53	0.000	2.287	1.670	2.940
VAR00025	1.832	53	0.812	1.843	−0.15	2.320
VAR00026	0.87	53	0.518	1.824	−0.24	1.620
VAR00027	0.387	53	0.237	1.056	0.490	1.840
VAR00028	3.649	53	0.001	2.278	1.270	2.910
VAR00029	0.276	53	0.785	1.481	−1.11	0.850
VAR00030	0.151	53	0.881	1.083	−1.26	1.170
VAR00031	1.125	53	0.467	1.509	0.340	1.790
VAR00032	2.746	53	0.004	1.880	0.610	2.830
VAR00033	1.74	53	0.074	1.870	1.040	2.340
VAR00034	0.636	53	0.531	1.509	−0.79	1.480
VAR00035	2.808	53	0.014	1.917	0.760	2.430
VAR00036	5.71	53	0.002	2.176	0.920	2.450

The statistical population of this research consisted of managers, senior experts and employees working in the maintenance field. The reason for selecting these individuals for data collection was their proficiency and experience in maintenance activities and features, as well as their familiarity with the topics discussed in this study. The required data for this study were collected from all the statistical population because the statistical population size was clear and small. Thus, the statistical population of the research was 54 individuals from the company. This study was conducted at Kaghaz Kar Kasra Co.

3.1 Goal programming

To formulate and solve linear programming problems, the modeling process focuses on maximizing profits or minimizing costs. However, limiting organizational goals to one goal is not considered feasible and appropriate in many real-life decision-making situations because most organizations consider several other goals such as consolidating personnel, maximizing market share and controlling prices, in addition to maximizing profits or minimizing costs. To formulate and solve problems requiring several goals and objectives, a reliable method has been created to complete the technique of linear programming, which is called goal programming. While being as flexible as linear programming, goal programming includes conflicting goals and presents the optimal solution by considering the priorities of goals from the perspective of decision-makers. The distinguishing aspect of this method is in those goals, which are prioritized based on the degree of priority or the rate of importance from the perspective of decision-makers and obtained in a sequential row through a goal programming approach. It is not always possible to accomplish every single goal. Hence, in the goal programming method, a decision-maker is required to focus his efforts on several goals at a satisfactory level, instead of realizing an optimal result for one goal. Modeling multiple goals in goal programming includes an objective function, linear or nonlinear constraints and continuous or discrete variables. It should be noted that the concept of goal programming was first proposed by "Charnes" and "Cooper" in 1967 to handle infeasibility caused by conflicting goals for linear programming. This method was later developed by "Lee", who presented lexicographic goal programming.

Furthermore, "Ignizio" played a major role in developing this method by precisely developing and using goal programming with integers and working on nonlinear goal programming. For every goal in goal programming, a numeric goal is first determined and then, a solution should be found that minimizes the weighted sum of goal deviation from relevant goals (Movahedi and Moetamedi, 2010).

The variables are mathematically defined as follows:

X_j = Problem decision variables

C_{jk} = Coefficient X_j for the k th goal in the objective function

G_k = Goal K th

Thus, we have:

$$\text{(First goal)}: \quad \sum_{j=1}^{n} C_{j1}X_J = g_1$$

$$\text{(Second goal)}: \quad \sum_{j=1}^{n} C_{j2}X_J = g_2$$

$$. \qquad\qquad .$$

$$(K\text{ th goal}): \quad \sum_{j=1}^{n} C_{jk}X_J = g_k$$

Since it is not possible to simultaneously achieve all goals, an integrated objective function is specified for the goal programming model. Assuming that positive and negative deviations from goals are equally important, the integrated objective function for the goal programming model will be as follows:

$$\operatorname{Min} Z = \sum_{k=1}^{n} \sum_{j=1}^{n} C_{jk} X_j - g_k \tag{1}$$

If we define the term inside the absolute value as d_k, the following relation is obtained:

$$\operatorname{Min}\ Z = \sum_{k=1}^{n} d_k \tag{2}$$

Since d_k can be a positive or negative value, it can be replaced with the distance between the two new non-negative variables of d_k^+ and d_k^-. Consequently, we have:

$$\begin{aligned} d_k &= d_k^+ - d_k^- \quad d_k^+ + \geq 0,\ d_k^- \geq 0 \\ d_k &= d_k^+ - d_k^- = d_k^+ - d_k^- \quad k = 1, 2, \ldots, k \end{aligned} \tag{3}$$

The presented goal programming model can be solved using the simplex method. The solution acquired for all the variables, including (X_j) the values of d_k^+ and d_k^-, is utilized to determine the values of $d_k = d_k^+ - d_k^-$ and then, neglected.

In most cases, an objective limit includes a minimal success deviation variable (d_k^-) and a maximal deviation variable (d_k^+), although it is possible that neither of these variables appeared in the objective limit under some circumstances.

If d_k^+ does not appear in the objective limit, it will reveal that the success higher than this level of goal is not possible. This is an example of an upper bound goal and is similar to the inequality of ≥ in the linear programming model. In this state, the objective limit will be as follow:

$$\sum_{j=1}^{n} C_{jk} X_J + d_k^- = g_k \Rightarrow \sum_{j=1}^{n} C_{jk} X_J \leq g_k \tag{4}$$

On the other hand, if d_k^- does not appear in the objective limit, the success lower than this level of goal is not possible. This is an example of a lower bound goal and is similar to the inequality of ≥ in the linear programming model. The following is the objective limit in this case:

$$\sum_{j=1}^{n} C_{jk} X_J - d_k^- = g_k \Rightarrow \sum_{j=1}^{n} C_{jk} X_J \geq g_k \tag{5}$$

Besides, it is possible that the deviation from some of the goals may be more important than that of other goals and or a deviation in a direction that may have higher importance compared to the opposite direction for a certain goal.

$$\begin{aligned} &\operatorname{Min} Z = \sum_{k=1}^{n} \left(w_k^+ w_k^+ + w_k^- d_k^- \right) \\ &s.t. \sum_{j=1}^{n} C_{jk} X_J - (d_k^+ - d_k^-) = g_k \Rightarrow k = 1, 2, \ldots, k \\ &d_k^+ + \geq 0, d_k^- + \geq 0, x \geq 0, \quad j = 1, 2, \ldots, n \end{aligned} \tag{6}$$

3.2 TOPSIS

TOPSIS algorithm is a highly technical and powerful decision-making method for prioritizing items through making similar to an ideal solution. In this method, the selected item should have the least distance from the ideal solution and the highest distance from the most inefficient solution. Other advantages of this method include integrating and combining qualitative and quantitative indicators for decision-making and distinguishing and emphasizing all indicators based on the cost and profit indicators (Ertuğrul and Karakaşoğlu, 2006).

This section briefly evaluates the m^*n decision matrix with m items and n criteria and measurement in TOPSIS technique. In this algorithm, it is assumed that each indicator and criterion in the decision matrix has a uniform increasing or decreasing desirability. In other words, if the higher values obtained by the criteria in this matrix are profits, they have higher desirability and if they are costs, then they have lower desirability (Mehrgan, 2007). In this model, all the values attributed to the criteria must be quantitative for mathematical calculations; if an attributed value is qualitative, then it must be converted to a quantitative value, as presented in Table 5.

3.2.1 TOPSIS steps.

(1) Preparing a normalized matrix (R matrix):

Since there is a strong possibility that the quantitative values attributed to the criteria and indicators have no single units, the dimension of their units should be eliminated and these quantitative values should be converted to dimensionless numbers. For this purpose, all the values given to the elements of a decision matrix should be converted to dimensionless values based on the formula below.

$$R_{ij} = \frac{X_{ij}}{\left(\sum_{i=j}^{m} (X_{ij})^2\right)^{\frac{1}{2}}}$$
$$I = \{1,, \ldots, m\}$$
$$J = \{1,, \ldots, n\} \tag{7}$$

The normalized matrix resulting from this process is represented by R.

(2) Preparing a normalized and weighted matrix (V matrix):

To equalize the values of the elements of the R matrix, all the weights in the set of the W_j parameters are multiplied the columns of this matrix peer to peer. The matrix obtained from this process is a weighted and normalized matrix and is shown by V.

The set of the weights of the W_j parameters has the following conditions:

$$\sum W_j = 1$$
$$W = (W_1,\ W_2,\ \ldots, W_n) =>$$
$$V_{11} = W_1 R_{11},\ \ldots, V_{mn} = W_n R_{mn} \tag{8}$$

(3) Selecting the best solutions (the most profitable and costly ones):

In this stage, the two parameters of A_- and A^* are used to identify the best solutions and the lowest priority solutions, respectively. The method for acquiring these parameters is as follows:

Table 5. Conversion of qualitative criteria to quantitative parameters

Qualitative criterion	Very low	Low	Average	High	Very high
Quantitative criterion	1	3	5	7	9

$$J = \{1, 2, 3, \ldots, n\}$$

(J) belongs to a set whose criteria are profits.

$$J_{-} = \{1, 2, 3, \ldots, n\}$$

(J_{-}) belongs to a set whose criteria are costs.

$$\begin{aligned} A^{*} &= \{(\text{Max } V_{ij}; j \text{ å } J); (\text{Min } V_{ij} - ; j - \text{å } J -); i = \{1, 2, 3, \ldots, m\})\} \\ A_{-} &= \{(\text{Min } V_{ij}; j \text{ å } J); (\text{Max } V_{ij} - ; j - \text{å } J -); i = \{1, 2, 3, \ldots, m\})\} \end{aligned} \tag{9}$$

(4) Calculating the distance of criteria:

In this stage, regarding the type (profit and or cost) of the item, the distance between each item and the best solution (the ideal and or the worst) is calculated using the Euclidean distance method (n-dimensional) as follows:

$$S_i \text{ Max} = (\text{Ó}(V_{ij} - V_j\text{Max})2)1/2; \; I = \{1, \ldots, m\} \tag{10}$$

S_i Max is the distance between the (i) item and the ideal solution.

$$S_i \text{ Min} = \left(\sum (V_{ij} - V_{ij}\text{Min})2\right)1\big/2; \; I = \{1, \ldots, m\} \tag{11}$$

S_i Min is the distance between the (i) item and the worst solution.

(5) Calculating the relative proximity to the ideal solution:

In this step, the relative proximity of the items to the ideal solution is calculated using the C^{*} parameter:

$$\begin{aligned} &C^{*}i = S_i \text{Min}/(S_i \text{ Max} + S_i \text{Min}) \\ &I = \{1, \ldots, m\} \end{aligned} \tag{12}$$

(6) Adjusting the items based on the magnitude of the $C^{*}i$ value:

To adjust and prioritize the items, we will adjust the values obtained for $C^{*}i$ based on the magnitude of the numbers. Therefore, the importance and priority of the items depend on the magnitude of their number and the bigger the values, the higher the priority and importance for selection will be (Kabak *et al.*, 2012).

3.3 Best Worst Method (BWM)

This section discusses a new method called BWM for multiple-criteria decision-making problems that evaluate several alternatives based on a group of criteria to select the best alternative. Using the BWM, the best (or in other words, ideal, most important) and the worst (or most undesirable, the least important) criteria are identified by a decision-maker and paired comparisons are performed between each of the two criteria (best and worst) and other criteria. Next, the MAX MIN problem is formulated and solved to identify the weight of different criteria. The weight of the alternatives is obtained in the same way based on different criteria. The final scores are calculated by summing the different weights of the criteria and the alternatives, which are used to select the best alternative. A consistency ratio is also included in the BWM to validate comparisons. Further, AHP, which is based on paired comparisons, is used for comparing criteria. The statistical results indicate that the BWM is significantly more efficient inconsistency ratio and other performance criteria, including minimum error, total deviation and consistency, compared to the AHP (Rezaei, 2016). Some of the significant features of the proposed method compared to existing MCDM methods are as follows:

(1) Requiring fewer comparative data

(2) Providing more consistent and stable comparisons; that is, more reliable solutions.

3.3.1 BWM stages. Stage 1: specify the set of decision-making indicators. In this stage, the set of indicators is defined as $(C_1, C_2, C_3, \ldots, C_n)$, which is required for making a decision.

Stage 2: determine the best (most important, most desirable) and worst (least important and least desirable) indicators. In this stage, the decision-maker defines the best and worst indicators in general without any comparison.

Stage 3: characterize the preference of the best indicator compared to other indicators with numbers 1 to 9. The preference vector of the best indicator compared to the other indicators is shown as $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$, where a_{Bj} represents the preference of the best indicator B to the indicator j. It is clear that $a_{\mathrm{BB}=}1$.

Stage 4: specify the preference of all indicators concerning the worst indicator from 1 to 9. The preference vector of the other indicators compared to the worst indicator is as follows:

$$A_w = (a_{1w}, a_{2w}, \ldots, a_{nw})^T$$

where a_{jw} denotes the preference of the indicator j compared to the worst indicator (W). It is clear that $a_{ww} = 0$.

Stage 5: find the optimal values of the weights $(w_1^*, w_2^*, \ldots, w_n^*)$. The relations $\frac{w_j}{w_w} = a_{iw}$ and $\frac{w_B}{w_i} = a_{Bw}$ should be hold to determine the optimal weight of each pair of indicators. To meet these conditions in all js, a solution should be found that maximizes $\frac{w_j}{w_w} - a_{iw}$ and $\frac{w_B}{w_i} = a_{Bj}$ for all minimized js. Given the fact that the weights and their sum are non-negative, the model can be formulated as follows:

$$\begin{aligned} & \min\max\left\{\left|\frac{W_B}{W_j} - a_{Bj}\right|\left|\frac{W_j}{W_w} - a_{jw}\right|\right\} \\ & \sum_j^{s.t.} w_j = 1 \\ & w_j \geq 0, \quad \text{for all } j \end{aligned} \tag{13}$$

Moreover, the above model can be converted to the following one:

$$\begin{aligned} & \min \xi \\ & s.t. \\ & \left|\frac{W_B}{W_j} - a_{Bj}\right| \leq \xi, \quad \text{for all } j \\ & \left|\frac{W_j}{W_w} - a_{jw}\right| \leq \xi, \quad \text{for all } j \\ & \sum_j^{w} W_j = 1 \\ & w_j \geq 0, \quad \text{for all } j \end{aligned} \tag{14}$$

The linear model of the above function is presented below (Rezayi, 2016) and the weight of the indicators is calculated from this model in this research.

$$\begin{aligned} &\min \xi \\ &s.t. \\ &|W_B - a_{Bj} w_j| \le \xi, \text{ for all } j \\ &|W_j - a_{jw} w_w| \le \xi, \text{ for all } j \\ &\sum_j W_j = 1 \\ &w_j \ge 0\ , \quad \text{for all } j \end{aligned} \tag{15}$$

Solving the above model gives optimal values for $(w_1^*,\ w_2^*,\ \ldots,\ w_n^*)$ and ξ^*.

3.3.2 Calculating BWM consistency. In this research, the consistency rate was calculated using ξ^*. The larger the amount of ξ^*, the greater the rate of consistency will be. Since $a_{Bj} \times a_{jw} = a_{BW}$ and $a_{BW} \in \{1,\ 2,\ \ldots,\ 9\}$, it is possible to obtain the maximum value of ξ^*. The consistency rate can be calculated using the consistency indicators reported in Table 6 and Relation (16).

$$\text{Consistency rate} = \frac{\xi^*}{\text{Consistency indicator}} \tag{16}$$

4. Case study

Paper Mill is a complete set of manufacturing and trading facilities in the paper industry of Iran. The company was founded in Yazd Industrial Park in 2000 in the city of Yazd, aiming to produce all kinds of recycled paper and waste paper.

4.1 Identifying and prioritizing the criteria of maintenance strategy selection

By analyzing and testing the hypothesis, 14 factors were identified as the most important ones for selecting and ranking maintenance strategy. BWM is used to determine the weight of the factors. Table 7 and Figure 2 indicate the final weight of the maintenance strategy selection criteria, as well as the priority of each factor and their dimensions, respectively.

After solving the linear programming model of the BWM, it is observed that the cost (C) dimension has been identified as the most important dimension among the maintenance strategy selection dimensions, followed by the dimensions of added value (A), feasibility (e) and safety (E). Among the criteria of the feasibility (E) dimension, the criteria of technical feasibility, human workforce capabilities, management approval and technological complexity have the highest importance, respectively. Considering the criteria of the cost dimension, the criteria of the equipment depreciation, equipment installation time and energy cost gained the highest scores, respectively. Based on the Table, the consistency ratio of the comparisons at the level of the dimensions and criteria are acceptable and calculated to be 0.0318, 0.0164, 0 and 0, respectively.

Table 6.
Consistency indicators using BWM

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency indicator	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Main dimensions	Weight of dimensions	Strategy selection criteria	Consistency ratio	The final weight of the criterion	Final rank
Feasibility (e)	0.153	Management approval	0.0318	0.0240	12
		Human workforce capabilities		0.0268	11
		Technical feasibility		0.0940	4
		Technological complexity		0.0081	14
Cost (C)	0.578	Cost of production loss	0.01648	0.0520	7
		Energy cost		0.0553	6
		Staff salary		0.0349	10
		Cost of raw material consumption		0.0190	13
		Cost of spare parts		0.0435	9
		Cost of training		0.0510	8
		Equipment installation time		0.1154	3
		Equipment depreciation		0.2164	1
Safety (E)	0.0619	Personnel safety	0	0.0619	5
Added value (A)	0.197	Equipment and personnel performance	0	0.1971	2

Table 7.
The final weights of the maintenance strategy selection criteria

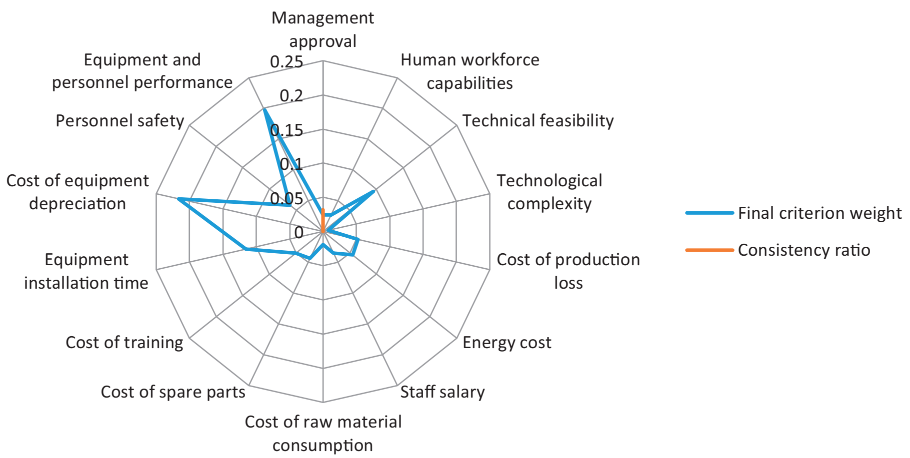

Figure 2.
The weights of maintenance strategy selection criteria

Rank	Normalized weight	Maintenance strategy
1	0.280	Preventive maintenance strategy
2	0.243	Predictive maintenance strategy
3	0.218	Corrective maintenance strategy
4	0.208	Condition-based maintenance strategy
5	0.051	Recurring maintenance strategy

Table 8.
The results of ranking the maintenance strategies in the company

4.2 Weighting maintenance strategy using TOPSIS

After determining the criteria for maintenance strategy selection using a quadruple approach, as well as specifying five items from the selected maintenance strategy, the prioritization stages were implemented based on TOPSIS. The results of ranking the maintenance strategies in the company are presented in Table 8 and Figure 3.

Based on the results, "preventive maintenance strategy", "predictive maintenance strategy", "corrective maintenance strategy", "condition-based maintenance strategy" and "recurring maintenance strategy" were identified as the best strategies, respectively.

Hence, to simplify calculations and consider the company conditions and expert opinions, the first three strategies with the highest priorities and scores were selected and used for modeling with goal programming.

The objective function of goal programming is as follows:

$$\mathrm{Min}\, Z = P_1\left(d_c^+\right) + P_2\left(d_{MT}^+\right) + P_3\left(d_{\mathrm{score}}^-\right) + P_4\left(w_0 d_0^- + w_s d_s^- + w_D d_D^-\right) \tag{17}$$

where P_1, P_2, P_3, and P_4 represent first, second, third and fourth priority, respectively. The objective function in goal programming requires allocating the appropriate priority level to the selected goal.

The following fuzzy constraints are defined concerning the four goals considered in the study. It is worth noting that two or more options can be used in this maintenance program.

(1) Minimizing maintenance costs

$$\left(C_{\mathrm{CORR}} X_{i,\mathrm{CORR}} + C_{\mathrm{PRED}} X_{i,\mathrm{PRED}} + C_{\mathrm{PREV}} X_{i,\mathrm{PREV}}\right) - d_c^+ + d_c^- = T_C \tag{18}$$

(2) Minimizing the hours allocated to maintenance activities.

$$\left(MT_{\mathrm{CORR}} X_{i,\mathrm{CORR}} + MT_{\mathrm{PRED}} X_{i,\mathrm{PRED}} + MT_{\mathrm{PREV}} X_{i,\mathrm{PREV}}\right) - d_{MT}^+ + d_{MT}^- = T_{MT} \tag{19}$$

(3) Maximizing final points of maintenance strategies

$$\begin{aligned}&\left(\mathrm{SCORE}_{\mathrm{CORR}} X_{i,\mathrm{CORR}} + \mathrm{SCORE}_{\mathrm{PRED}} X_{i,\mathrm{PRED}} + \mathrm{SCORE}_{\mathrm{PREV}} X_{i,\mathrm{PREV}}\right)\\ &\quad - d_{\mathrm{SCORE}}^+ + d_{\mathrm{SCORE}}^- = 1\end{aligned} \tag{20}$$

(4) Maximizing second-level scores, maintenance strategies based on occurrence, intensity and detection criteria

$$\begin{aligned}&\left(\mathrm{SCORE}_{O,\mathrm{CORR}} X_{i,\mathrm{CORR}} + \mathrm{SCORE}_{O,\mathrm{PRED}} X_{i,\mathrm{PRED}} + \mathrm{SCORE}_{O,\mathrm{PREV}} X_{i-\mathrm{PREV}}\right)\\ &\quad - d_O^+ + d_O^- = T_{O,\mathrm{SCORE}}\end{aligned} \tag{21}$$

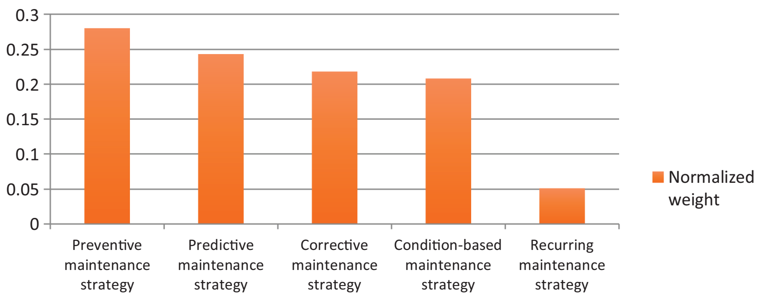

Figure 3.
Ranking strategies

$$(\mathrm{SCORE}_{S,\mathrm{CORR}}X_{i,\mathrm{CORR}} + \mathrm{SCORE}_{S,\mathrm{PRED}}X_{i,\mathrm{PRED}} + \mathrm{SCORE}_{S,\mathrm{PREV}}X_{i,\mathrm{PREV}}) - d_S^+ + d_S^- = T_{S,\mathrm{SCORE}} \quad (22)$$

$$(\mathrm{SCORE}_{D,\mathrm{CORR}}X_{i-\mathrm{CORR}} + \mathrm{SCORE}_{D,\mathrm{PRED}}X_{i-\mathrm{PRED}} + \mathrm{SCORE}_{D,\mathrm{PREV}}X_{i-\mathrm{PREV}}) - d_D^+ + d_D^- = T_{D,\mathrm{SCORE}} \quad (23)$$

Defining variables and parameters

Parameters representing the hierarchy of goals:

W: Weights of the k th criterion

CCORR, CPRED and CPREV: Costs consumed in maintenance system to implement corrective/preventive/predictive strategy

T_{MT} and T_C: Total budget/time available for maintenance

MT_{PREV}, MT_{PRED} and MT_{CCORR}: The time consumed in the maintenance system to implement corrective/preventive/predictive strategies

$\mathrm{SCORE}_{k,\,i}$: Score obtained from i th maintenance strategy concerning k th criterion

$T_{k,\,\mathrm{SCORE}}$: Threshold defined for equality of constraints related to maximizing the k th criterion score

X_i: i th strategy

d_c^+ and d_c^-: Positive and negative deviation from the optimal threshold in cost constraint

d_{MT}^+ and d_{MT}^-: Positive and negative deviation from the optimal threshold in a time constraint

d_O^+ and d_O^-: Positive and negative deviation from the optimal threshold in weights constraint of detection criterion

d_S^+ and d_S^-: Positive and negative deviation from the optimal threshold in weights constraint of intensity criterion

d_D^+ and d_D^-: Positive and negative deviation from the optimal threshold in weights constraint of occurrence criterion

d_{SCORE}^+ and d_{SCORE}^-: Positive and negative deviation from the optimal threshold in weights constraint of maintenance strategy options

4.3 Selecting the optimal maintenance strategy for the equipment

The data were collected by considering the characteristics of the studied company and expert opinions. Then, the data were used in the modeling with goal programming. Table 9 reports

Equipment No.	Corrective strategy	Preventive strategy	Predictive strategy	Selected strategy
1	0	1	0	Preventive
2	0	1	0	Preventive
3	0	0	1	Predictive
4	0	1	1	Preventive/predictive
5	0	1	0	Preventive
6	0	1	1	Preventive/predictive
7	0	1	0	Preventive
8	0	1	1	Preventive/predictive
9	0	1	0	Preventive
10	0	1	0	Preventive
11	0	0	1	Predictive
12	0	0	1	Predictive
13	0	1	1	Preventive/predictive

Table 9. The results of solving the goal programming model of the maintenance strategy

the results of solving the goal programming model of the maintenance strategy. According to Table 9, based on the results, preventive and PDM strategies were selected for devices (1, 2, 5, 7, 9 and 10) and (3, 11 and 12), respectively, while both strategies were applied for devices (4, 6, 8 and 13) simultaneously. Finally, predictive and PM strategies present a better performance in using resources and reducing the failure rate, compared to corrective strategies. Therefore, these strategies provide useful information to maintenance managers to limit the negative aspects of failure.

5. Conclusion

In this research, maintenance strategies were prioritized by combining two-goal programming and TOPSIS techniques. First, we identified all factors affecting the maintenance and then, a questionnaire containing discussed factors was distributed between experts, considering the four dimensions elaborated in this study. The first questionnaire was designed using a 5-point Likert scale, which ultimately included 12 criteria in the cost dimension, 9 criteria in the value-added dimension, 6 in the safety dimension and 9 criteria in the applicability dimension. These criteria were identified using the opinions of experts in the company and professionals in the field of maintenance, and then, 14 factors were considered as the most important ones in the maintenance strategy selection and ranking, by analyzing the results and using the hypothesis test. The validity and reliability analysis was performed using SPSS software and the Cronbach's alpha was obtained 84%, indicating a desirable level of criteria. The second questionnaire used BWM to determine the importance of each of the criteria, among which the criteria of equipment depreciation cost, the efficiency of equipment and personnel, the time of installation and setting up of equipment and technical feasibility had gained the highest scores, respectively. The prioritization steps were performed based on TOPSIS technique after determining the criteria for selecting a maintenance strategy with the quadruple approach and specifying five options of the selected maintenance strategy. According to the findings obtained from the third questionnaire completed by 11 experts of the company and considering the steps of the TOPSIS technique, we ranked each maintenance strategy based on its features and per the criteria and then, analyzed the stages of ranking. Based on the results, "PM strategy", "PDM strategy", "CM strategy", "CBM strategy" and "re-maintenance strategy" were identified as superior strategies, respectively. To facilitate the calculations and according to the company conditions, as well as the opinions of the experts, the first three strategies with the highest priority and scores were selected as the optimal maintenance strategy for the 13 devices in the company. Accordingly, all the technical specifications, as well as the cost and time of each device were extracted separately and modeled using the goal programming technique. The proposed model was solved using Lingo software and the best option for each device was specified after modeling and determining the weight of the three different policies of "PM strategy", "PDM strategy" and "CM strategy". Given the CM strategy, significant damage caused by equipment failure causes an unacceptable increase in production loss costs. "Breakdown (failure rate) is one of the important and huge loses in different industries" (Fekri Sari and Avakh Darestani, 2019). In the paper producing industries, various machines such as printing machine, writing paper machine, tissue machine, rewinding machine, tissue machine (for box facial tissue making), packing paper machine and specialty paper machine exist. The machinery of this company some of which are similar includes water pumps, oil and paper pulp. According to the results and expert's opinions, the CM strategy (ranked by TOPSIS as the third strategy) was not recommended for any machines. The results obtained from solving the goal programming model of maintenance strategy represent that both preventive and PDM strategies are effective for selecting the maintenance strategy and are the most appropriate maintenance policy in the Kaghaz Kar Kasra Co. To analyze the goal programming technique. As mentioned before, the CM strategy comparing with preventive and predictive strategies results in lower productivity and higher failure rates. Hence, both preventive and PDM strategies are offered to managers for the paper industry.

5.1 Practical suggestions

Based on the results, several suggestions are provided to the related company:

The criteria were prioritized by taking into account the prioritization performed on the maintenance strategy criteria compared to each of the dimensions. The priorities should be highly considered to ensure the stable success and development of the company. For example, the criteria of equipment depreciation, equipment and personnel performance, equipment installation time and technical feasibility obtained the highest scores, respectively. Thus, these criteria must be specifically considered in major decisions and maintenance activities. Besides, maintenance plays an important role in every aspect of the companies, regarding the research foundations and the position of the maintenance strategy in manufacturing companies, which is regarded as one of the infrastructural factors for realizing long-term goals and accomplishing the company vision (stable growth and development).

Given the prioritization obtained from comparing the main dimensions affecting maintenance strategy selection, the dimensions of cost (C), added value (A), feasibility (E) and personnel and equipment safety (S) received the highest scores, respectively. The criteria with the highest priority in the two dimensions of cost (C) and added value (A) should be addressed to implement maintenance strategies. To utilize and apply this model, it is suggested to localize it in all departments of the factory according to the environmental conditions.

According to the results of the optimal maintenance strategy, it is necessary to prepare the infrastructure of the strategies with the highest priority. Regarding the research findings, the operational infrastructure of preventive and PDM strategies, which are identified as the ideal options, include training human workforce and preparing equipment, and the company should present a precise plan for this purpose. The results of the analysis section on three criteria of probability (P), severity (S) and detection (D) recommended that devices with a high-risk priority number (RPN) should be at the highest priority in maintenance decisions. According to the information derived from the goal programming stage, a precise plan should be designed based on research findings, to implement the optimal strategy selected for each equipment.

6. Suggestions for future research

(1) The prioritization of equipment in special fields can be a good topic for future studies.

(2) The processes of ranking and evaluating maintenance strategy are a good opportunity to identify the strengths and weaknesses of a company and can be used as the main input for company strategy programming in future studies.

(3) To develop the proposed model, it is possible to use the AHP or fuzzy ANP in the best and worst stage, add items to the decision network and enter the effect of the main dimensions on each other, as the effect of the criteria on each other, into the model.

(4) Utilizing and analyzing the sub-networks of benefit, opportunity, cost and risk (BOCR) can be addressed in the decision network of TOPSIS.

References

Aalaei, A. and Davoudi, H. (2016), “Revised multi-choice goal programming for incorporated dynamic virtual cellular manufacturing into supply chain management: a case study”, *Engineering Applications of Artificial Intelligence*, Vol. 47, pp. 3-15.

Ahren, T. (2005), “Study of maintenance performance indicators for the Swedish railroad system”, Lulea University of Technology, Division of Operating and Main Truancy Engineering.

Al-Turki, U. (2011), “Methodology and theory a framework for strategic planning in maintenance”, *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 2, pp. 150-162.

Bashiri, M., Badri, H. and Hejazi, T. (2011), “Selecting optimum maintenance strategy by fuzzy interactive linear assignment method”, *Applied Mathematical Modelling*, Vol. 35, pp. 152-164.

Can Özcan, E., Ünlüsoy, S. and Tamer, E. (2017), “A combined goal programming – AHP approach supported with TOPSIS for maintenance strategy selection in hydroelectric power plants”, *Renewable and Sustainable Energy Reviews*, Vol. 78, pp. 1410-1423.

Chemweno, P., Morag, I., Sheikhalishahi, M., Pintelon, L., Muchiri, P. and Wakiru, J. (2016), “Development of a novel methodology for root cause analysis and selection of maintenance strategy for a thermal power plant: a data exploration approach”, *Engineering Failure Analysis*, Vol. 66, pp. 19-34, doi: 10.1016/j.engfailanal.2016.04.001.

Cheng, Y.H. and Tsao, H.L. (2010), “Rolling stock maintenance strategy selection, spares parts’ estimation, and replacements’ interval calculation”, *International Journal of Production Economics*, Vol. 128, pp. 404-412.

Ding, S.H. and Kamaruddin, S. (2015), “Maintenance policy optimization—literature review and directions”, *International Journal of Advanced Manufacturing Technology*, Vol. 76, pp. 1263-1283.

Duffuaa, S. and Raouf, A. (2015), *Planning and Control of Maintenance Systems: Modelling and Analysis*, Springer International Publishing. doi: 10.1007/978-3-319-19803-3-12.

Ebrahimi, S.K., Hemmati, M. and Rostamian, M. (2010), “Maintenance strategy selection using the fuzzy group MADM approach”, *Sixth Iranian Conference on Maintenance*.

Ertuğrul, Í. and Karakaşoğlu, N. (2006), “The fuzzy analytic hierarchy process for supplier selection and an application in a textile company”, in *Proceedings of 5th International Symposium on Intelligent Manufacturing Systems, May 29-31*, pp. 195-207.

Fekri Sari, M. and Avakh Darestani, S. (2019), “Fuzzy overall equipment effectiveness and line performance measurement using artificial neural network”, *Journal of Quality in Maintenance Engineering*, Vol. 25 No. 2, pp. 340-354, doi: 10.1108/JQME-12-2017-0085.

Gandhare, B.S. and Akarte, M. (2012), “Maintenance strategy selection”, *Ninth AIMS International Conference on Management Proceedings*, pp. 1330-1336.

Gonçalves, C.D.F., Dias, J.A.M. and Machado, V.A.C. (2015), “Multi-criteria decision methodology for selecting maintenance key performance indicators”, *International Journal of Management Science and Engineering Management*, Vol. 10 No. 3, pp. 215-23.

Haj Shirmohammadi, A. (1998), *Total Productive Maintenance (TPM)*, 1st ed., Arkan Publications, Esfahan.

Hemmati, N., Rahiminezhad Galankashi, M., Imani, D. and Farughi, H. (2018), “Maintenance policy selection: a Fuzzy-ANP spproach”, *Journal of Quality in Maintenance Engineering*, Vol. 29 No. 7, pp. 1253-1268.

Hong Ding, S., Kamaruddin, S. and Abdul Azid, I. (2012), “Maintenance policy selection model – a case study in the palm oil industry”, *Journal of Quality in Maintenance Engineering*, Vol. 25 No. 3, pp. 415-435.

Horizons Ierace, S. and Cavalieri, S. (2013), “An analytic hierarchy process-based model for the selection of decision categories in maintenance systems”, *Management and Production Engineering Review*, Vol. 4 No. 2, pp. 37-49.

Ighravwe, D. and Ayoola Oke, S. (2017), "Ranking maintenance strategies for sustainable maintenance plan in manufacturing systems using fuzzy axiomatic design principle and fuzzy-TOPSIS", *Journal of Manufacturing Technology Management*, Vol. 28 No. 7, pp. 961-992, doi: 10.1108/JMTM-01-2017-0007.

Jain, K., Singh Jain, S. and Singh Chauhan, M. (2013), "Selection of optimum maintenance and rehabilitation strategy for multiline highways", *International Journal of Traffic and Transportation Engineering*, Vol. 3 No. 3, pp. 269-278.

Jin, H., Han, F. and Sang, Y. (2020), "An optimal maintenance strategy for multi-state deterioration systems based on a semi-Markov decision process coupled with simulation technique", May 2020, *Mechanical Systems and Signal Processing*, Vol. 139, 106570, doi: 10.1016/j.ymssp.2019.106570.

Kabak, M., Burmaoğlu, S. and Kazançoğlu, Y. (2012), "A fuzzy hybrid MCDM approach for professional selection", *Expert Systems with Applications*, Vol. 39 No. 3, pp. 3516-3525.

Kurian, M.C., Shalij, P.R. and Pramod, V.R. (2019), "Maintenance strategy selection in a cement industry using analytic network process", *Journal of Quality in Maintenance Engineering*, Vol. 26 No. 4, pp. 509-525, doi: 10.1108/JQME-07-2017-0048.

Mehrgan, M.R. (2007), "Advanced operations research", 3rd audition, University Book Publications, Tehran (In Persian).

Movahedi, M.M. Moetamedi, M. (2010), "Familiarity with decision analysis theories", 1st ed., Technical and Engineering Book, Tehran (In Persian).

Murthy, D.N.P., Atrens, A. and Eccleston, J.A. (2002), "Strategic maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 4, pp. 287-305.

Noori, A. (2004), "Reliability-centered maintenance", *07th Railway Transportation Conference, Sharif University of Technology, Civil Engineering*, Tehran, available at: http://www.civilica.com/Paper-RTC07-RTC07_167.html.

Rana, A. and Emosi, V.M.K. (2018), "Measuring maintenance activity effectiveness", *Journal of Quality in Maintenance Engineering*, Vol. 24 No. 4, pp. 437-448, doi: 10.1108/JQME-11-2016-0061.

Raufi, M. (2009), "Professional interactions, duties, and activities of maintenance engineering", *The First National Conference on Engineering and Management of Infrastructures*.

Rezaei, J. (2016), "Best-worst multi-criteria decision-making method: some properties and a linear model", *Omega*, Vol. 64, pp. 126-130.

Safari, S., Siyahzadeh, S. and Sadeghi, R. (2010), "Maintenance policy selecting using the AHP and goal programming", *Sixth Iranian Conference on Maintenance*.

Sajjadi, S.J. and Farhang Moghaddam, B. (2013), "Investigating maintenance costs in industries", available at: http://www.irma.ir/files/site1/pages/2013.pdf.

Separi, F. and Asadi Kiapey, M.B. (2012), "Reliability-centered maintenance strategy based on the AHP in distribution networks", *25th International Power System Conference*.

Seyed Hosseini, S.M. (2005), *Systemic Planning of Maintenance Systems in the Industrial and Services Sector of Tehran*, Industrial Management Institute.

Shagluf, A., Parkinson, S., Longstaff, A.P. and Fletcher, S. (2018), "Adaptive decision support for suggesting a machine tool maintenance strategy from reactive to preventative", *Journal of Quality in Maintenance Engineering*, Vol. 24 No. 3, pp. 376-399, doi: 10.1108/JQME-02-2017-0008.

Tsang, A.H.C. (2002), "Strategic dimensions of maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 1, pp. 7-39.

Tuyet, N.T.A. and Chou, S.Y. (2018), "Maintenance strategy selection for improving cost-effectiveness of offshore wind systems", 1 February 2018, *Energy Conversion and Management*, Vol. 157, pp. 86-95.

Xie, H., Shi, L. and Xu, H. (2013), "Transformer maintenance policies selection based on an improved fuzzy analytic hierarchy process", *Journal of Computers*, Vol. 8 No. 5, pp. 1343-1350.

Zaim, S., Turkyılmaz, A., Acar, M.F., Al-Turki, U. and Demirel, O.F. (2012), "Maintenance strategy selection using AHP and ANP algorithms: a case study", *Journal of Quality in Maintenance Engineering*, Vol. 18 No. 1, pp. 16-29.

Corresponding author
Soroush Avakh Darestani can be contacted at: ad5710@coventry.ac.uk

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**