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Research article

Developing a model for improving the productivity and energy production of small-scale power plants using the physical asset management model in a fuzzy environment

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Abstract: The electric power industry today is regarded as the engine of growth and development of other sectors. The technology-based nature of the electric power industry has caused its physical asset to be of particular importance. This study aims to develop a model for increasing the productivity and energy production of small-scale power plants using multi-criteria decision making in fuzzy environments. Productivity of manpower, capital, energy and quality, as the criteria affecting the purpose of the research, and ten activities of the uptime physical asset management model as a solution to meet the goal of the research have been considered.

Based on the obtained results, it can be said that teamwork-based methods are the most important strategy for improving the productivity of small-scale power plants. The importance of teamwork is to the extent that other areas of physical asset management fail to function properly without relying on teamwork-based methods. The results of the study indicate that the proposed model is suitable for real-world problems and increases the productivity and uptime at small-scale power plants.

Keywords: productivity; energy; physical asset management; Uptime Model; fuzzy TOPSIS

1. Introduction

One of the characteristics of the power supply, its continued maintenance and continuity for consumers. This feature has brought about the importance of the proper operation of equipment in this industry. Therefore, the reliability of the electricity grid for electricity companies is crucial. Therefore, proper management of physical equipment and assets of power generation companies is of particular importance, which requires the efforts of all units and organizational units. In order to increase productivity, companies should consider measures for the proper use of their network equipment.

The management of these assets and the proper maintenance of these huge assets to achieve organizational goals and increase productivity put many challenges ahead of organizations. These challenges include preventing the sudden failure of machinery and equipment [1], maintaining production consistency [2], availability of machinery, maintaining production quality, preventing delays in product delivery, and the direct or indirect loss of profitability [3].

One of the most widely used solutions in recent years is the implementation of physical asset management systems in industrial companies. These systems operate on the basis of the management of each physical asset of the company, from the smallest to the greatest assets, and get aware of their status by monitoring the assets in the planning, design, purchase, construction and commissioning, maintenance, and destruction stages, and make the right decision in each stage with complete information. This process not only reduces the time of purchase, construction and commissioning stages, but it also reduces the time of stopping the operation and consequently increases the sales volume. In addition, it reduces maintenance costs through optimal maintenance [4].

Although many still believe that physical asset management is equivalent to maintenance, this view is not correct, because physical asset management includes a wider range of activities than mere maintenance. Maintenance is mainly related to keeping equipment in operational condition, while physical asset management is a combination of technical and financial aspects along with management decisions [5,6]. The objective of physical asset management is to optimize a combination of costs, risks and performance over the lifetime of an asset to ensure that the organization gains maximum value from its physical assets. In asset-based organizations, physical assets play an important role in creating value [7], and physical asset management is considered a key criterion for organizational performance measurement [8], and supporting the decisions of physical asset management processes is critical for improving operations and increases productivity and uptime [7].

Standards such as PAS 55 [9] (by the Institute of Asset Management and Standardization of the United Kingdom) and ISO55000 [10] have been released in recent years, which can provide the basis for the creation of appropriate asset management for organizations [8,11]. Besides, many researchers in the field of industries have studied various areas for improving the productivity of corporations and asset-based organizations, some of which are mentioned below.

Chiacchionv applied the dynamic reliability approach, a well-known modeling paradigm for reliability engineering, to model and evaluate the performance of a renewable power plant. This method is generally used to evaluate the reliability properties of an engineering system in non-static work conditions [12]. Shiu and Lam studied the efficiency and productivity in China's electric power industry using the Data Envelopment Analysis (DEA) and Malmquist index [13]. Rácz & Vestergaard used the DEA[1] method to measure the productivity of the Danish electricity biogas from 2005 to 1992 [14]. Barros & Wanke's studies on the evaluation of the efficiency of Angola's thermal power plants indicated the absence of a learning curve for increasing efficiency in energy

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[1] Data envelopment analysis.

generation [15]. Lee & Leem studied changes in the concept of productivity as a longstanding and important factor in studies about manufacturing so that it can serve as a practical guideline for managers in industry, and as an academic foundation for future research into productivity [16]. On the other hand, Alsyouf showed how an effective maintenance policy could influence the productivity and profitability of a manufacturing process [17]. Nachlas showed that the use of proper maintenance planning would increase industrial productivity and production [18]. Raouf used the TPM[2] maintenance method instead of the traditional system to increase capital productivity [19].

Literature shows extensive research in the area of productivity in asset-based industries. Despite the researchers' attention to the field of physical asset management in recent years [20–23], and given its significance in improving productivity of industries, it has remained an under-researched field. The relationship between the productivity affecting criteria and physical asset management is very complex and usually affects other criteria. Evaluation and analysis of alternatives in different complicated conditions, especially in industrial areas affected by multiple criteria and alternatives, require the use of quantitative techniques and decision math models. Although different mathematical decision techniques are available to help the managers in the decision making process, these techniques are not very popular, because they are time-limited and inherently complex. Decision-making techniques related to physical asset management are mainly focused on optimizing and improving a criterion. Therefore, it is necessary to study methods in which several important contradictory criteria can be considered simultaneously in planning [24]. This is why the present study has proposed a different model to improve the productivity of small-scale power plants by using the uptime physical asset management model and the TOPSIS MCDM[3] technique in the fuzzy environment.

The present article is organized in five sections. After the introduction section, the research methodology is introduced. In the third section, a case study and the overall framework of the proposed research model are presented. In the fourth section, the findings are discussed and, finally, the conclusions and suggestions are presented in the fifth section.

2. Methodology

2.1. Fuzzy numbers and fuzzy sets

Professor Lotfizadeh put forward the theory of fuzzy sets. This theory applies in situations of ambiguity and uncertainty. This theory is able to express many of the imprecise concepts with mathematical language and provide a ground for reasoning, inference, control, and decision making in conditions of uncertainty [25]. According to this theory, $\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in X\}$ is a fuzzy set in which x represents the real values of the member of the R set and its membership function is of the form $\mu_{\tilde{A}}(x) :\to [0,1]$.

The most commonly used fuzzy numbers are triangular and trapezoidal fuzzy numbers. Triangular fuzzy numbers are more commonly used for simpler computations. Hence, we have also

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[2] Total productive maintenance.

[3] Multi-criteria decision-making.

used triangular fuzzy numbers in this study. A triangular fuzzy number A with linear membership function μ_A is defined as Eq 1, which is represented by a triangular fuzzy number (l, m, u). Figure 1 depicts this membership function [26].

$$\mu_A(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & otherwise \end{cases} \tag{1}$$

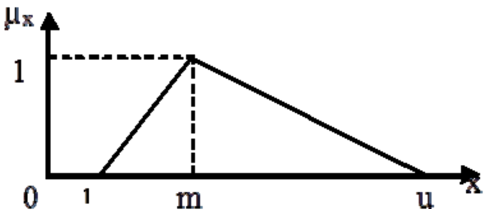

Figure 1. Triangular fuzzy number.

2.2. Fuzzy TOPSIS[4] method

The TOPSIS technique is a multi-criteria decision analysis method, which was originally developed by Hwang and Yoon in 1981 [27] with further developments by Yoon in 1987 [28], and Hwang et al. in 1993 [29].

The fuzzy TOPSIS technique was first proposed by Chen to solve multi-criteria decision-making problems under uncertainty [30]. The TOPSIS technique in fuzzy logic has been used in many studies, and the fuzzy TOPSIS decision making methods have been widely used in the electric power industry [31,32], finance [33,34] and other affairs since the 1990s. Linguistic variables were used in the fuzzy TOPSIS method to rank the alternatives and weigh the criteria, because the use of linguistic variables instead of numerical evaluation is more realistic and tangible when dealing with unclassified and vague data, especially when modeling human judgments [35]. Many methods have been proposed for evaluating the weights of the criteria and the ranking of alternatives [36–39]. The weight of each criterion can be obtained by direct allocation or by pair comparison [30,40]. The researchers have used linguistic variables in this study to evaluate the weights of the criteria and rank the alternatives based on different criteria. For ease of understanding and ease of use of the pairwise comparison matrix [38], the weights of the criteria have been evaluated and the alternatives have been ranked on the basis of pairwise comparisons. The linguistic variables and fuzzy triangular numbers corresponding to them which have been used by decision makers (D = 1, 2 ..., K) for pairwise comparisons are based on Lin fuzzy triangular numbers, as shown in Table 1 [41].

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[4] Technique for order preference by similarity to ideal solution.

Table 1. Triangular fuzzy numbers.

Linguistic variables	Triangular fuzzy numbers
Equally important	(1, 1, 1)
Intermediate	(1, 2, 3)
Weakly more important	(2, 3, 4)
Intermediate	(3, 4, 5)
Strongly more important	(4, 5, 6)
Intermediate	(5, 6, 7)
Very strongly more important	(6, 7, 8)
Intermediate	(7, 8, 9)
Absolutely more important	(9, 9, 9)

The fuzzy TOPSIS method consists of the following steps [30]:

When a decision group has an odd K, the weights of the criteria are added up and the alternatives are ranked through Eq 2 and Eq 3. $\tilde{W}_j$ represents the weight of the jth criterion.

$$\tilde{W}_j = \frac{1}{K}\left[\tilde{W}_J^1 + \tilde{W}_J^2, \ldots.., \tilde{W}_j^k\right] \tag{2}$$

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \ldots. + \tilde{x}_{ij}^k\right] \tag{3}$$

Step 1: As stated above, a fuzzy multicriteria group decision-making problem which can be concisely expressed in matrix format as (Eq 4 & 5):

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \\ \\ \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} c_1 & c_2 & & & & c_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & . & . & . & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & . & . & . & \tilde{x}_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & . & . & . & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{4}$$

$$\tilde{W} = \left[\tilde{W}_1, \tilde{W}_2, \ldots.., \tilde{W}_n\right] \tag{5}$$

In this matrix D, $\tilde{x}_{ij}$ represents the rank of the ith alternative (i = 1, 2 ..., m) on the basis of the jth criterion (j = 1, 2 ..., n), which is based on linguistic variables ($\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$).

Step 2: The fuzzy decision matrix must be converted to a comparable scale and be normalized. There are several methods for normalization, for which Chen has used the linear regression method. Therefore, we can obtain the normalized fuzzy decision matrix denoted $\widetilde{R}$ (Eq 6).

$$\widetilde{R} = \left[\widetilde{r}_{ij}\right]_{m\times n} \tag{6}$$

Where B and C are the set of benefit criteria and cost criteria (Eq 7), respectively, and

$$\tilde{r}ij = \begin{cases} \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), & j \in B, \ c_j^* = \max c_{ij} \ if \ j \in B \\ \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), & j \in C, \ a_j^- = \min a_{ij} \ if \ i \in c \end{cases} \tag{7}$$

Step 3: We obtain the fuzzy weighted normal matrix using Eq 8.

$$\widetilde{V} = \left[\widetilde{v}_{ij}\right]_{m\times n}, \quad i = 1,2,...,m, \quad j = 1,2,....,n \tag{8}$$

where $\widetilde{v}_{ij} = \widetilde{r}_{ij} . \widetilde{w}_j$.

Step 4: Then, we can define the fuzzy positive-ideal solution (FPIS, A^+) and then, we can define the fuzzy negative-ideal solution (FNIS, A^-) as (Eq 9):

$$\begin{aligned} A^* &= \left(\widetilde{v}_1^*, \widetilde{v}_2^*, ..., \widetilde{v}_n^*\right) \\ A^- &= \left(\widetilde{v}_1^-, \widetilde{v}_2^-, ..., \widetilde{v}_n^-\right) \end{aligned} \tag{9}$$

where $\widetilde{v}_j^- = (0, 0, 0)$ and $\widetilde{v}_j^* = (1, 1, 1)$.

Step 5: Distance is calculated at this stage. The distance of the i^{th} alternative or positive ideal (A^+) and the negative ideal alternative (A^-) is obtained from Eq 10 and Eq 11 and the distance between the two triangular fuzzy numbers is calculated using Eq 12.

$$d_i^* = \left\{\sum_{j=1}^{n} d \ \left(\widetilde{v}_{ij}, \widetilde{v}_j^*\right)\right\} \quad i = 1,2,...,m, j = 1,2,...,n \tag{10}$$

$$d_i^- = \left\{\sum_{j=1}^{n} d \ \left(\widetilde{v}_{ij}, \widetilde{v}_j^-\right)\right\} \quad i = 1,2,...,m, j = 1,2,...,n \tag{11}$$

$$d(\widetilde{A}, \widetilde{B}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \tag{12}$$

Step 6: Calculation of the relative closeness coefficient of the i^{th} alternative of CC_i using Eq 13.

$$CC_i = \frac{d_i^-}{\left(d_i^* + d_i^-\right)}, \quad i = 1,2,...,m \qquad i = 1,2,...,m \ 0 \le cl_{i+} < 1 \tag{13}$$

The ranking of alternatives is arranged based on the closeness coefficient of CC_i in a descending order. The best alternatives are the closest alternative to FPIS and the furthest alternative to FNIS. In other words, the greater the relative closeness, the more ideal its corresponding alternative.

3. Case study

The power industry has undergone major changes in management and ownership in recent decades as an attempt to increase the operation efficiency and encourage investors, so that different parts of the power system, including production, transmission and distribution, have become independent so that an appropriate competitive environment can be created. These developments on the one hand, and factors such as the problems of the construction of new lines on the other hand, have increased the use of small production units under the name of Distributed Generation (DG) or small-scale products (with a production capacity up to 25 MW). This industry is important due to its close relationship with the factors affecting economic growth, industrialization, and increasing productivity and efficiency are of great importance.

This research is a case study conducted on the small gas-fired power plant in Mazandaran province (Iran). As mentioned earlier, the purpose of this study is to develop a model for increasing the productivity and energy production of small-scale power plants using a multi-criteria decision-making technique. These techniques help us choose the best alternative, taking into account different quantitative or qualitative criteria. Multi-criteria decision making is a set of methods and procedures that try to make an appropriate analysis on several often incompatible indicators or criteria in order to select the best alternative. The researchers used the fuzzy TOPSIS technique in this research so as to solve the decision problem. The proposed model has three levels of goal, criteria and alternatives. The purpose of this study is to investigate the improvement of the productivity of small-scale power plants and the criteria used in the research are criteria that affect productivity. Alternatives are used as solutions which can be used to achieve the research goal and include the ten activities of the uptime physical asset management model, which we will describe them in detail.

3.1. Selection of criteria

Studies conducted in the area of productivity have identified and introduced various criteria as indicators that affect the productivity of manufacturing industries, including labor, capital, and other inputs such as energy, raw materials, etc. [42]. One of the most important studies conducted in this area is a study by Lee & Leem, which explored the productivity of manufacturing industries from 1890 to 2009. After reviewing 11237 articles in this field and identifying 95 keywords in these articles, the author classified them into 9 categories of automation, quality, process, information, innovation, cost, labor, energy, and environment [16]. Some studies have also examined the productivity indicators such as labor [43–45], energy [42,46], and capital [19,47–49] and many studies have investigated the impact of quality on productivity [50–52], which are among the most important criteria affecting productivity.

Therefore, considering the previously conducted studies and the views of the experts of the decision-making team, the researchers selected labor productivity, energy, capital and quality in the present study as the most important and effective measures of productivity, which are briefly described in Table 2.

Table 2. Definition of the productivity-affecting criteria.

Productivity-affecting criteria	Definition	Code
labor	The value-added to number of employees ratio [43]	C1
energy	The value-added to energy value ratio [42]	C2
capital	The value-added to the cost value ratio [43]	C3
quality	Management activities and techniques for improving product quality [16]	C4

3.2. Defining a set of alternative

Different models and methods such as the Terry Wireman model [53] and John Campbell model [54] are used for planning, implementation, monitoring and improvement in the area of physical asset management. These models have similar structure and tools, which differ only in details and how they are implemented. Since the John Campbell model (Uptime) has such features as comprehensiveness, integration, introduction of the process and sequence of successful implementation, and most importantly compliance with ISO 55000 standards [10] and PAS 55 [9]. The researchers have examined the Uptime Model of Excellence (Pyramid) in the present study.

The Uptime Model has been classified into ten distinct areas. In the model presented in this study, we will use these ten activities as alternatives or solutions to improve the productivity of small-scale power plants. Table 3 presents each of these areas briefly.

Table 3. Definitions of the criteria (Uptime Model) [54].

code	Description	10 activities of the Uptime Model
A1	The strategy is a road map containing alternatives and, in case of location change, the maintenance strategy is also changed.	Maintenance strategy
A2	Achieving organizational goals requires more than just physical assets. An organization needs knowledgeable, competent, and motivated personnel for the effective maintenance of the equipment.	Personne
A3	Work management means doing the right thing in the right way and at the right time, which includes planning and scheduling.	Work management
A4	Physical assets should be maintained at a required standard and basic level so that their continued operation can be ensured.	Basic care

Continued on next page

code	Description	10 activities of the Uptime Model
A5	Suitable materials and components must be available at the right time required to effectively carry out maintenance activities. The unavailability of a part often prevents doing the work.	Material and Component Management
A6	Performance parameters should develop behaviors that support the goals and strategies of the organization and should measure the progress of these efforts.	Performance management
A7	Management and support systems are tools for information storage with the ability to retrieve and use the data for analysis.	Maintenance management and support systems
A8	A thoroughly proactive approach to analyzing and making decision about the most appropriate policy for maintaining each asset.	Approaches based on equipment reliability
A9	Teamwork methods focus on further use of knowledge and different views of employees from different departments and collaboration among them to improve maintenance operations and maintain the reliability of equipment.	Teamwork methods
A10	Creating changes in the work process or eliminating these processes, or creating more coordination among them and with other processes in order to the tasks more easily.	Process optimization

Figure 2 shows the steps involved in the proposed model of the present study.

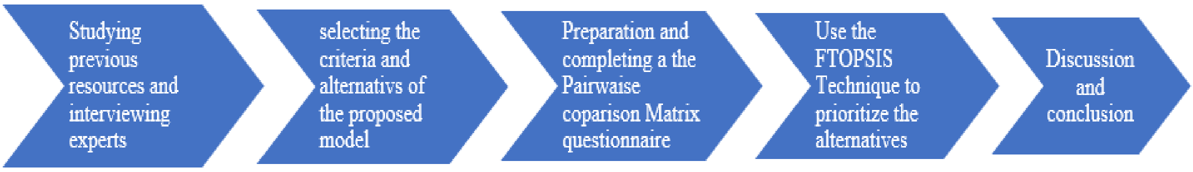

Figure 2. The stages of doing the research model.

4. Findings and discussion

We initially defined the ideal solutions (the ten tiers of the Uptime physical asset management model) in terms of the proposed criteria in order to achieve the ultimate goal of improving the productivity of small-scale power plants. Figure 3 shows the hierarchical analysis diagram of the model.

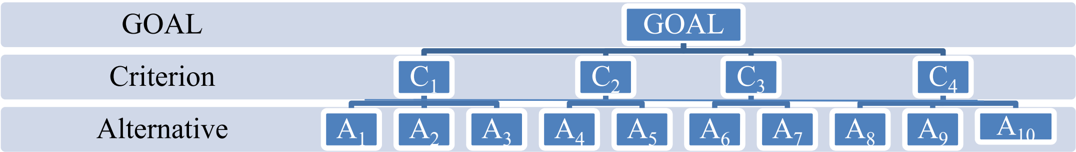

Figure 3. Hierarchical analysis diagram.

After creating the hierarchy of the proposed model, the researchers collected the views of experts including the operation manager and supervisors of the operation and maintenance teams through the Fuzzy Pairwise Comparison Matrix Questionnaire using linguistic variables and their corresponding triangular fuzzy numbers (in nine scales as presented in Table 1). First, the fuzzy pairwise comparison matrix of the alternatives was formed for each of the criteria, and the average weight the fuzzy pairwise comparison matrix of the alternatives for the variables is presented in Table 4. Then, the fuzzy pairwise comparison matrix of the alternatives in relation to the main goal of the research was determined (Table 5).

In the next step, the fuzzy pairwise comparison matrix was normalized based on Eq 6 (Table 5). After they were normalized, based on Eq 8, the weighted normal matrix, which is the result of fuzzy multiplication of the normal matrix by the weight of the criteria, is calculated (Table 6). After creating the weighted fuzzy decision matrix using Eq 10 and Eq 11, we calculated the numerical positive and negative ideal values and used Eq 12 to obtain the distance between the two fuzzy numbers (d). Finally, we determined the relative closeness of each of the alternatives to the ideal solution (Eq 13) and arranged them in a descending order (Table 7).

Table 4. The average weight of the fuzzy pairwise comparison matrix of the alternatives in relation to the criteria.

Code	C_1	C2	C_3	C_4
A_1	(2.08, 2.70, 3.37)	(0.34, 0.48, 0.67)	(0.53, 0.77, 1.06)	(0.34, 0.48, 0.67)
A_2	(4.70, 5.40, 6.10)	(0.53, 0.77, 1.06)	(0.34, 0.48, 0.67)	(0.53, 0.77, 1.06)
A_3	(2.97, 3.68, 4.45)	(0.82, 1.16, 1.54)	(0.82, 1.15, 1.53)	(1.69, 2.23, 2.81)
A_4	(0.82, 1.16, 1.54)	(4.70, 5.40, 6.10)	(2.96, 3.68, 4.45)	(3.06, 3.78, 4.55)
A_5	(1.21, 1.64, 2.13)	(2.28, 2.91, 3.58)	(2.28, 2.91, 3.58)	(2.27, 2.89, 3.53)
A_6	(1.70, 2.23, 2.81)	(0.26, 0.29, 0.38)	(0.26, 0.29, 0.38)	(0.28, 0.33, 0.46)
A_7	(0.34, 0.48, 0.67)	(1.69, 2.23, 2.81)	(1.69, 2.23, 2.81)	(0.82, 1.16, 1.54)
A_8	(0.51, 0.77, 1.06)	(3.83, 4.55, 5.30)	(4.70, 5.40, 6.10)	(4.70, 5.40, 6.10)
A_9	(3.85, 4.55, 5.30)	(2.96, 3.68, 4.45)	(3.83, 4.55, 5.30)	(3.83, 4.55, 5.30)
A_{10}	(0.26, 0.29, 0.38)	(1.21, 1.64, 2.13)	(1.21, 1.64, 2.13)	(1.43, 2.02, 2.60)
a-				
c+	(6.10, 6.10, 6.10)	(6.10, 6.10, 6.10)	(6.10, 6.10, 6.10)	(6.10, 6.10, 6.10)

Table 5. The fuzzy normalized decision matrix.

Code	C_1	C2	C_3	C_4
A_1	(0.34, 0.44, 0.55)	(0.06, 0.08, 0.11)	(0.09, 0.13, 0.17)	(0.06, 0.08, 0.11)
A_2	(0.77, 0.89, 1.00)	(0.09, 0.13, 0.17)	(0.06, 0.08, 0.11)	(0.09, 0.13, 0.17)
A_3	(0.49, 0.60, 0.73)	(0.13, 0.19, 0.25)	(0.13, 0.19, 0.25)	(0.28, 0.37, 0.46)
A_4	(0.14, 0.19, 0.25)	(0.77, 0.89, 1.00)	(0.48, 0.60, 0.73)	(0.50, 0.62, 0.75)
A_5	(0.20, 0.27, 0.35)	(0.37, 0.48, 0.59)	(0.37, 0.48, 0.59)	(0.37, 0.47, 0.58)
A_6	(0.28, 0.37, 0.46)	(0.04, 0.05, 0.06)	(0.04, 0.05, 0.06)	(0.05, 0.05, 0.08)
A_7	(0.06, 0.08, 0.11)	(0.28, 0.37, 0.46)	(0.28, 0.37, 0.46)	(0.13, 0.19, 0.25)
A_8	(0.09, 0.13, 0.17)	(0.63, 0.75, 0.87)	(0.77, 0.89, 1.00)	(0.77, 0.89, 1.00)
A_9	(0.63, 0.75, 0.87)	(0.48, 0.60, 0.73)	(0.63, 0.75, 0.87)	(0.63, 0.75, 0.87)
A_{10}	(0.04, 0.05, 0.06)	(0.20, 0.27, 0.35)	(0.20, 0.27, 0.35)	(0.24, 0.33, 0.43)
Weight of criteria	(1.08, 1.63, 2.25)	(0.45, 0.52, 0.71)	(1.75, 2.50, 3.25)	(0.65, 0.96, 1.38)

Table 6. The fuzzy weighted normalized decision matrix.

Code	C_1	C2	C_3	C_4
A_1	(0.37, 0.72, 1.24)	(0.03, 0.04, 0.08)	(0.15, 0.32, 0.56)	(0.04, 0.08, 0.15)
A_2	(0.83, 1.44, 2.25)	(0.04, 0.07, 0.12)	(0.10, 0.20, 0.36)	(0.06, 0.10, 0.24)
A_3	(0.53, 0.98, 1.64)	(0.06, 0.10, 0.18)	(0.23, 0.47, 0.81)	(0.18, 0.35, 0.63)
A_4	(0.15, 0.31, 0.57)	(0.34, 0.46, 0.71)	(0.85, 1.51, 2.37)	(0.32, 0.59, 1.03)
A_5	(0.22, 0.44, 0.79)	(0.17, 0.25, 0.42)	(0.65, 1.19, 1.19)	(0.24, 0.45, 0.80)
A_6	(0.30, 0.59, 1.04)	(0.02, 0.03, 0.04)	(0.07, 0.12, 0.20)	(0.03, 0.05, 0.10)
A_7	(0.06, 0.13, 0.25)	(0.12, 0.19, 0.33)	(0.49, 0.91, 1.50)	(0.09, 0.18, 0.35)
A_8	(0.09, 0.21, 0.39)	(0.28, 0.39, 0.62)	(1.35, 2.21, 3.25)	(0.50, 0.85, 1.35)
A_9	(0.68, 1.21, 1.95)	(0.22, 0.31, 0.52)	(1.10, 1.86, 2.82)	(0.41, 0.71, 1.19)
A_{10}	(0.05, 0.08, 0.14)	(0.09, 0.14, 0.25)	(0.35, 0.67, 1.13)	(0.16, 0.32, 0.58)
FPIS	(2.25, 2.25, 2.25)	(0.71, 0.71, 0.71)	(3.25, 3.25, 3.25)	(1.38, 1.38, 1.38)
FNIS	(0.05, 0.05, 0.05)	(0.02, 0.02, 0.02)	(0.07, 0.07, 0.07)	(0.03, 0.03, 0.03)

Table 7. The distance measurement, closeness coefficient and rank order of alternatives.

Code	d^+	d^-	CC_i	Rank
A_1	6/37537	1/24657	0/16355	9
A_2	5/84767	1/95311	0/25037	6
A_3	5/64059	2/10912	0/27215	5
A_4	4/73903	3/16295	0/40027	3
A_5	5/20054	2/66589	0/33889	4
A_6	6/74506	0/81092	0/10732	10
A_7	6/10385	1/52904	0/20032	7
A_8	4/17778	3/93397	0/48497	2
A_9	3/66056	4/49305	0/55105	1
A_{10}	6/30477	1/30347	0/17132	8

Considering the weights shown in the fuzzy weighted normalized decision matrix (Table 6), the prioritization of each of the alternatives studied (the areas of physical asset management) in relation to the criteria under study (productivity indicators) can be specified. For example, in the power plant under consideration, according to the labor productivity index, the prioritization of the physical asset management areas is such that staff is ranked the first and then, in a descending order, the teamwork-based methods, work management, maintenance strategy, performance management, material and component management, basic care, equipment reliability-based approaches, maintenance management and support systems, and ultimately, process optimization sit in the next positions. Furthermore, according to the energy Productivity criterion, the basic care alternative becomes the first priority; based on the capital productivity criterion, the teamwork-based methods alternative is the first priority; and regarding the quality criterion, the alternative involving approaches based on the equipment reliability is in the first priority.

Based on the results of the analysis of experts' views, the alternatives used to improve the productivity of small-scale power plants were prioritized in the following order: Teamwork methods (0.551) was ranked first, equipment-based approaches (0.484) was ranked second, basic care (0.400) was ranked third, and material and component management (0.338), work management (0.272), personnel (0.250), maintenance management and support systems (0.200), process optimization (0.171), maintenance strategy (0.163) and performance management (0.107) were ranked fourth to tenth respectively.

Each of these concepts can bring significant value and enhance the reliability and effectiveness of assets, thereby improving productivity. However, none of them is a complete solution for productivity and energy production enhancement, and each one may not have the desired effect if used alone. Firms often use teamwork methods to achieve the best results. The reason for that is the optimal performance of humanistic approaches. Equipment-based approaches are among teamwork approaches that focus on assets. Basic care also employs teamwork approaches, so that the operators can perform simple maintenance tasks and help the maintenance staff to work on more complex systems that have been stopped. The key to success in work management is also the timely presentation of materials and components, because operations and supply chain play an important role in this process in line with maintenance. The lack of even one part or component may change the planning and scheduling. Therefore, there is a need for good relationship and communication between the material and component management team and the work management team. The multiple skills of the maintenance staff allow them to work in smaller teams or even individually, while simultaneously cooperating well with production. Management and support systems also support the functions expected of the material and component and maintenance management, and require collaboration with other domains. The organization's employees do their work through the daily performing of processes in order to achieve the desired results. Maintenance is one of the business processes that should be optimized, integrated and collaborated with materials management, supply chain, human resources etc. for the best performance. Creation of an effective strategy and its follow-up will depend entirely on teamwork among the staff of the maintenance, operation, finance, human resource and supply chain units. Performance management also requires managing a number of measures related to work management processes, material and component management, employee training, reliability approaches, and so on. Therefore, performance management, like other domains, cannot have the desired efficiency and will not increase productivity without effective communication with other groups [54]. Therefore, it should be noted that small-scale power plants are not separated from this principles. One characteristic of electrical energy is its continuous and uninterrupted supply to consumers. The key priority of small-scale power plants is to ensure the reliable, safe, efficient, and cost-effective operation of equipment and machinery. Small-scale power plants can have a significant positive impact on distribution networks. Considering the installation of small-scale power plants at the consumption locations, the reliability of the sub-transmission and transmission networks will be improved, distribution and transmission losses will be reduced, and the quality of power provided to the final consumer will be better relative to that of large power plants. These characteristics have led to a particular importance of the proper function of equipment and assets in providing reliable and high-quality electricity in this industry. Therefore, considering the technology-oriented nature of the power industry, physical assets management plays a critical role, which itself requires the collective effort of all units and organizational units.

5. Conclusion

With regard to the asset-based nature of the power industry and the high importance of equipment and physical assets in it, the present study focused on improving the productivity and energy production of small-scale power plants, and to do so, the uptime physical asset management model was utilized. In the proposed model, fuzzy TOPSIS multi-criteria decision-making method was used. This model is capable of considering different criteria and the relationships among them at different levels and therefore can play an important role in helping small-scale power plants achieve their goal, i.e. increasing available time, thus increasing productivity. Given the space of ambiguity and uncertainty surrounding the judgment of the decision-making team, the proposed model was evaluated in a fuzzy environment.

The results of the research showed that teamwork methods are the best way to improve the productivity of small-scale power plants. Teamwork methods in physical asset management emphasize adequate communication and collaboration between teams and different groups of the organization. As a result, creating common goals among employees and integration among the operation teams, maintenance teams and other teams can help increase the reliability of equipment, improve the level of quality, reduce the waste, minimize the production costs, increase the uptime of equipment, and consequently improve the productivity of small-scale power plants.

Conflict of interest

The authors declare there are no conflicts of interest in this paper.

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