Operations Management Research
https://doi.org/10.1007/s12063-023-00348-1

Evaluating the critical success factors for maintenance management in agro-industries using multi-criteria decision-making techniques

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Received: 31 July 2022 / Revised: 10 November 2022 / Accepted: 11 January 2023

Abstract
A well-established maintenance management system is key in improving the operational performance within agricultural production systems. In this paper, we investigated the major criteria influencing effective maintenance management in agro-industries. To that end, we started by presenting a hierarchical structure of criteria and their Critical Success Factors (CSFs) after reviewing related studies and dividing the criteria into the categories of *organization management*, *human-related*, and *organizational aspects*. To assess the weight of the criteria and their cause-effect relationship, we collected the opinions of maintenance experts working in different agro-industries in Iran, using several online questionnaires which were based on Multi-criteria decision-making (MCDM) techniques such as Best-Worst Method (BWM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL). The results of the BWM revealed that *top management support*, and *fund allocation and inventory resource management* are the most important CSFs in the proposed maintenance model with the global weights of 0.108 and 0.075, respectively. According to the DEMATEL, five CSFs such as *top management support*, *training and education*, *fund allocation and inventory resource management*, *maintenance strategies and policies*, and *adequacy of the maintenance crew*, were recognized as causal variables of maintenance management within Iranian agro-industries. The proposed methodology in this paper could help agro-industries in ensuring an effective maintenance management system.

Keywords Agricultural fleet · Maintenance management · Critical success factors · Agro-industry · Multi-criteria decision-making

1 Introduction

High operational machinery reliability and availability are required to supply agricultural products in the food and agro-based industries (Zhou et al. 2017; Bottani et al. 2014; Tsolakis et al. 2014; Sørensen and Bochtis 2010; Tsarouhas 2007). Proper agricultural fleet operation with the purpose of timely agricultural activities would have a substantial influence on the overall productivity and availability (Soltanali and Rohani 2016; Najafi et al. 2015; Mousavipour et al. 2012). Whilst around 35% of primary machinery, such as tractors and harvesters, have exceeded their specified service life, mainly in developing countries, resulting in poor agricultural operatizing performance (Terentyev et al. 2020). Furthermore, high machinery availability and maintainability in agro-industries are challenging due to a lack of timely access and supply of critical spares (Afsharnia et al. 2014; Wireman 2010; Terminology 2010; Nik et al. 2009; Rohani et al. 2009).

In such circumstance, a proper maintenance management principle, which comprises a variety of policies, strategies, and advanced hardware and software, are quite effective at dealing with the above issues in agricultural production systems (Holweg et al. 2018; Soltanali et al. 2019, 2020; Parida and Chattopadhyay 2007). Maintenance management is a key process that involves decision-making at various stages of operations. Poor decision-making results in a direct loss of resources. Maintenance costs can account for up to 40% of operating costs and could increase even higher if not properly planned (Amrani et al. 2020). Maintenance management regimes are classified as operational (short-term), tactical (medium-term) and strategic (long-term) levels (Tubis and Werbińska-Wojciechowska 2015; Bochtis et al. 2014; Anthony 1965; Pintelon and Gelders 1992). Appropriate maintenance

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Published online: 18 January 2023

strategies and resource allocation are provided at the tactical level. The operational level is deals with day-to-day planning, which is achieved through the deployment of schedules to various resources (Pintelon and Gelders 1992; Pinjala et al. 2006; Hassanain 2002; Fredriksson and Larsson 2012; van Horenbeek and Pintelon 2014). Likewise, at the strategic level, defining visions, missions, and goals as well as integrating technical, organizational, and commercial challenges are all handled to achieve an effective maintenance business model (Al-Turki et al. 2014; Thomas 2005; Murthy et al. 2002).

In the literature strategic challenges related to integration of maintenance paradigms in agro-industries have received less attention than tactical and operational concerns. For example, at the operational level numerous failure analysis techniques have been developed to predict the degradation trends of agricultural fleets. Different types of advanced knowledge and data mining techniques have been utilized in this direction to address the issues of uncertainty and variability (da Silva et al. 2019; Naji et al. 2019; Kumar et al. 2019; Kurochkin et al. 2017; Hu et al. 2015; Jong et al. 2013). Moreover, performance measurement and continuous improvement (Soltanali et al. 2020; Parida and Kumar 2006; Tsarouhas 2007), reliability and availability assessment (Soltanali et al. 2022; Mishra and Satapathy 2021; Afsharnia et al. 2020), impact of information technology (Patel and Sayyed 2014; Sørensen and Bochtis 2010), maintenance cost modeling (Rohani et al. 2011; Lips and Burose 2012)., etc. have been studied in food and agriculture sectors which principally correspond to the tactical and operational supplies of the maintenance model.

In particular, the current study focuses on investigating major factors that strategically affect the maintenance activities in agro-industries. Meanwhile, understanding the underlying critical success factors in the maintenance management enables mechanisms to support tactical and operational requirements. However, the current study's key contribution was to identify the major criteria and measure their influence to provide a solution for future agro-industry maintenance projects. To that end, we proposed a framework with three key steps to identify, prioritize and comprehend interrelationship of the different criteria that influence on effective maintenance management in agro-industries. To dealing with identifying major criteria contributing to successful maintenance management in agro-industries as well as cause-effect analysis of sub-criteria or Critical Success Factors (CSFs), well-known Multi-Criteria Decision-Making (MCDM) techniques such as Best-Worst Method (BWM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) were performed (Rezaei 2015, 2016; Gabus and Fontela 1972). It is worth noting that the proposed framework could be quite useful in assisting agro-industry managers in upgrading current maintenance management models. Bearing in mind the significance of the above stated arguments and the literature, the main objectives of this study are as follows:

- Identify and categorize the influencing criteria and related CSFs contributing to effective maintenance management from the library survey and experts' opinion.
- Propose a framework of criteria categorized into *organization management*, *human-related*, and *organizational aspects*.
- Perform the BWM-DEMATEL to prioritize key criteria influencing to maintenance management and analyze the cause-effect relationship between CSFs.
- Employ the proposed framework in Iranian agro-industries to ensure an effective and robust maintenance management system.

Moreover, the main research questions are provided as follows:

- What are the major criteria and related CSFs contributing to a basic maintenance management model as well as specifically in agro-industries?
- What is the relationships between criteria and related CSFs to achieve a successful maintenance management model within agro-industries?
- What are the benefits of research outputs in upgrading the current maintenance management within agro-industries?

The remainder of the paper is laid out as follows: Section 2 reviews relevant literature and proposes a new hierarchical structure of maintenance management criteria. The proposed framework in this study is introduced in Section 3, which is supported by MCDM techniques. The major findings and discussion are provided in Section 4. Section 5 presents the main recommendations for improving the current maintenance system in agro-industries. Finally, Section 6 summarizes the findings and provides recommendations for further research.

2 Literature review

To identify the major criteria and associated Critical Success Factors (CSFs) that contribute to effective maintenance management in agro-industries, relevant strategic maintenance models and frameworks have been reviewed. It is worth noting that the literature does not only address maintenance models in agricultural systems but also all available fundamental models in other industrial and service sectors, resulting in the hierarchical structure shown in Table 1. For instance, Jonsson (2000) introduced a maintenance model in the industry based on criteria including *maintenance strategies*, *soft interaction*, and *hard interaction*. A field study was carried out in Swedish companies to evaluate the maintenance programs using such criteria. The results showed that the proactive maintenance strategies and intra-group interactions in the maintenance sector were the most important factors in competitive processes. In another research, to create a successful business model in the field of maintenance, four

Table 1 A hierarchical structure of the main criteria and CFSs in maintenance management

Criteria	Critical success factors (CSFs)	Reference
	Strategies and policies	(Jonsson 2000; Meixner et al. 2001; Tsang 2002; Adebiyi et al. 2004; Garg and Deshmukh 2006; Bengtsson and Salonen 2009; Salonen 2008, 2009; Sharma 2013; Karia et al. 2014; Arslankaya and Atay 2015; Campbell et al. 2015; Gomes et al. 2020; Gandhare and Akarte 2020; Gandhi et al. 2021)
	Top management support	(Meixner et al. 2001; Salonen 2008, 2009; Campbell et al. 2015)
Organization management	Workflow management and standardization	(Meixner et al. 2001; Garg and Deshmukh 2006; Sørensen and Bochtis 2010; Karia et al. 2014; Arslankaya and Atay 2015; Gomes et al. 2020)
	Fund allocation and inventory resource management	(Meixner et al. 2001; Salonen 2008, 2009; Sørensen and Bochtis 2010; Barberá et al. 2012; Karia et al. 2014; Milana et al. 2017; Campbell et al. 2015; Gomes et al. 2020; Gandhare and Akarte 2020; Gandhi et al. 2021)
	Awareness of maintenance and safety activities	(Campbell et al. 2015; Bokrantz et al. 2020; Gomes et al. 2020)
	Performance measurement and monitoring	(Marquez and Gupta 2004; Sørensen and Bochtis 2010; Karia et al. 2014; Arslankaya and Atay 2015; Arslankaya and Atay 2015; Branská et al. 2016; Bokrantz et al. 2020; Campbell et al. 2015; Gomes et al. 2020; Gandhi et al. 2021)
	Training & education	(Salonen 2008, 2009; Barberá et al. 2012; Sharma 2013; Karia et al. 2014; Milana et al. 2017; Campbell et al. 2015; Bokrantz et al. 2020; Gandhi et al. 2021)
	Participation and commitment	(Barberá et al. 2012; Sharma 2013; Karia et al. 2014; Milana et al. 2017; Campbell et al. 2015; Bokrantz et al. 2020; Gomes et al. 2020)
Human-related	Adequacy of the maintenance crew	(Meixner et al. 2001; Marquez and Gupta 2004; Salonen 2008, 2009; Bengtsson and Salonen 2009; Barberá et al. 2012; Sharma 2013; Karia et al. 2014; Milana et al. 2017; Campbell et al. 2015; Gomes et al. 2020)
	Employee awareness of maintenance goals and strategies	(Barberá et al. 2012; Sharma 2013; Karia et al. 2014; Milana et al. 2017; Bokrantz et al. 2020; Gomes et al. 2020; Gandhare and Akarte 2020)
	Documentation of maintenance works	(Sørensen and Bochtis 2010; Milana et al. 2017; Campbell et al. 2015; Arslankaya and Atay 2015; Branská et al. 2016; Bokrantz et al. 2020; Gomes et al. 2020)
Organizational aspects	Well-established organizational structure	(Tsang 2002; Horyovy 2007; Barberá et al. 2012; Sharma 2013; Campbell et al. 2015; Branská et al. 2016; Bokrantz et al. 2020; Bekar et al. 2020; Gandhare and Akarte 2020; Gandhi et al. 2021)
	Adequacy of IT infrastructures and facilities for operations	(Tsang 2002; Marquez and Gupta 2004; Garg and Deshmukh 2006; Horyovy 2007; Pintelon and Parodi-Herz 2008; Bengtsson and Salonen 2009; Sørensen and Bochtis 2010; Barberá et al. 2012; Salonen 2008, 2009; Sharma 2013; Karia et al. 2014; Branská et al. 2016; Bokrantz et al. 2020; Campbell et al. 2015; Bekar et al. 2020)
	Contracting out maintenance	(Tsang 2002; Horyovy 2007; Salonen 2008, 2009; Branská et al. 2016; Söderberg et al. 2017; Bokrantz et al.2020)

strategic criteria were provided: *service delivery alternatives (outsourcing of maintenance activities)*, *organizational design*, *maintenance techniques and policies*, and *support systems*. This research also looked at conceptual rules for implementing the strategic criteria and the core success factors for establishing the change processes (Tsang 2002). A management framework was developed based on criteria such as *IT system*, *maintenance performance measurement*, *technical skills*, and *production management system*. The proposed model could integrate the maintenance department with other divisions to increase the competitiveness of smart firms (Marquez and Gupta 2004).

Garg and Deshmukh (2006) conducted review research on the major issues in maintenance models utilizing the criteria such as *maintenance strategies*, *planning and scheduling processes*, and *information systems*. The findings of this study were provided to academic and industrial researchers to gain a comprehensive understanding of the gaps and challenges in this field. In another study, the evaluation of maintenance activities was carried out in the manufacturing industry based on the criteria such as *organization management*, *contracting out maintenance*, *IT infrastructures*, *strategies and policies*, *multiple skills*, *spare parts management*, and *training and education* (Salonen 2008, 2009). Followed by, Bengtsson and Salonen (2009) designed a general model for maintenance management to reduce the gap between academic theories and the real industry environment. The most important criteria in the proposed model included the *improvement of strategies*, *skills*, *maintenance organization*, and *technology*. Following the previous research, Barberá et al. (2012) developed an advanced model for maintenance management that could interact with business model objectives. The proposed model's most significant criteria comprised *human resource management*, *inventory management*, *structure management*, and *information management*. In another research, a new framework was offered to optimize the maintenance operations in industrial organizations. The primary criteria covered in the proposed framework were *strategies and goals*, *human factors management*, *support mechanisms*, *maintenance policies*, *tools and techniques*, and *organizational structure* (Sharma 2013).

Karia et al. (2014) investigated the current maintenance management model in educational organizations. *Human resources*, *continuous improvement*, *financial issues*, *strategy and objectives*, *organization management*, *policies*, *tools and techniques*, *support mechanism*, *planning and scheduling,* and *staff commitment* were significant factors for assessing the exiting maintenance management system. The developed model's most essential outcome was to provide constructive recommendations for physical asset managers to support business processes. Campbell et al. (2015) suggested a new model aiming at achieving excellence in maintenance management consisting of leadership, essentials, and choosing excellence factors. In this model, the major criteria included *strategy*, *people and teams*, *work management*, *basic care*, *material management*, *performance management*, *information systems,* and *continuous improvement*. Another study proposed a knowledge-based model to improve the integration between operations and maintenance activities in manufacturing processes. The most important measures were *workflow structure* and *resource management*. The findings verified that the proposed model is capable of improving strategic plans to achieve an appropriate maintenance system (Milana et al. 2017).

Bokrantz et al. (2020) developed a new model aimed at achieving smart maintenance based on four main criteria: *human resources*, *internal integration*, *external integration*, and *data mining based-decision making*. This study proposed a maintenance structure by establishing a logical and correct relationship between such criteria. On the agenda of another research, the most important criteria of maintenance performance from the perspective of industrial managers were investigated. *Reliability and proactive plans*, *service response system*, *effectiveness and quality*, *failure and safety*, *energy and environmental issues*, *team efficiency*, *activity planning*, *budget management*, and *human resources* were all crucial criteria in the proposed model (Gomes et al. 2020). A review study was conducted to conceptualize smart maintenance. Furthermore, additional research have identified the critical aspects influencing maintenance management (Vasudevan and Duan 2021; Bekar et al. 2020; Zhang et al. 2019; Wen et al. 2019; Kumar et al. 2018; Gopalakrishnan 2018).

In particular, several empirical studies on Critical Success Factors (CSFs) affecting maintenance management in food and agro-industries have been undertaken. For instance, Meixner et al. (2001) investigated the effectiveness of maintenance programs in Austrian food industries. *Management and leadership*, *strategy and policy*, *process and resource management*, and *job competence* were identified as the most important criteria. The results indicated that the proposed model could be used to evaluate maintenance quality and increase competitiveness in the food industry. In another research, to evaluate the maintenance activities in Nigeria's agricultural industry, asset maintenance formulations were surveyed based on several strategies. The results revealed that the overhaul strategy had the highest share of maintenance activities (Adebiyi et al. 2004). The main problems and challenges in the production and maintenance units on Ukrainian agricultural units were investigated. This study's most important criteria included *logistics structure*, *advanced cooperation between maintenance units and workshops*, and *information support* (Horyovy 2007). Another study presented a new conceptual maintenance model for agricultural fleet to address the most pressing concerns of farmers and machinery contractors. The proposed model's most notable criteria were *online monitoring of tools and equipment*, *resource allocation*, *operational planning*, *documentation*, and *hardware and software support*s (Sørensen and Bochtis 2010). Arslankaya and Atay (2015) investigated the maintenance management system and the potential for lean production in dairy farms. *Prioritizing maintenance activities*, *preparing and monitoring maintenance programs*, *maintenance strategies*, and *lean manufacturing techniques* were among the most important planned activities. Likewise, improving maintenance management system in the Czech food and chemical industries was on the agenda. *Maintenance performance activities*, *preventive planning systems*, *information* *systems*, *strategic goals*, *organizational aspects*, and *activity outsourcing* were identified as the most important criteria in maintenance management system (Branská et al. 2016).

Liu et al. (2018) developed a new framework of smart maintenance service system to support agricultural machinery operations within agro-industries. The main key factors in the proposed framework were *service capability and efficiency*, *service recourse allocation and scheduling*, *knowledge management* and *failure prediction process* in the field of maintenance service. The findings of this study were quite useful in promoting the smartness and remote service level of domestic agricultural machinery, which could indicate a more real-time, more accurate, and more efficient maintenance service scheduling decision for service providers. Another study looked at the maintenance activities focusing on *performance assessment and modeling* within agro-based sugarcane industries. The main performance metrics were defined as availability, reliability, time between failures (TBFs), and time to repairs (TTRs). The outcomes could extremely be useful in identifying agro-based sugarcane industry authorities as well as important process bottlenecks in determining proper maintenance priorities and so enhancing overall equipment performance (Sharma and Tewari 2019). Hu et al. (2020) developed a dynamic *planning and scheduling* technique to help agricultural machinery maintenance services with demand uncertainty. Likewise, a real-life case study was used to demonstrate the applicability of the proposed model as well as the effectiveness of the designed approach. The findings of the proposed approach could meet the needs of service providers seeking the best balance of high maintenance service quality and economical costs. Reis and Alves (2020) studied *human resource management* solutions for optimizing work intensity in Brazilian sugarcane agro-industries. They addressed about developing alternative strategies to boost *operators' commitment* to machine maintenance tasks, which need more physical and mental energy to be spent in the work process. Additionality, the level of complexity and comprehensiveness of maintenance trainings for machine operators, as well as leadership training tactics, were investigated. Meanwhile, Mishra and Satapathy (2021) carried out a questionnaire study in Odisha (India) to investigate *human-related aspects* based-maintenance management, concentrating on *farmers' awareness of maintenance operations* in agro-industries. Through the designed questionnaire, the knowledge of farmers' operating regarding maintenance activities such as several types of inspections and checks for agricultural machineries was obtained. Then, the MCDM techniques was unitized to identify and prioritize the machinery maintenance plans. The findings of this study could assist the decision-makers, operators, and the agricultural farmers to upkeep the farm operated machinery in better working conditions. In another study, Gandhare and Akarte (2020) surveyed maintenance performance in agro-industries. The most important criteria were considered, including *planning and* scheduling, *strategy and policy*, *spare parts management*, *organization*, *financial management*, and *human resource management*. The results revealed that it is possible to identify the major production bottlenecks, weaknesses, and opportunities for improvement in agro-industries. Another study looked at CSFs for managing maintenance at food snack centers in Indonesia. The proposed model's most important criteria were *policy implementation and organizational affairs*, *planning and control*, *maintenance costs*, *continuous improvement*, and *human resource management* (Gandhi et al. 2021).

2.1 The research gaps

Table 1 categories the influencing criteria identified as having an impact on effective maintenance management. The number of references for each criterion were used as a proxy for the importance of criteria and related sub-criteria (CSFs). We identified the major criteria in the maintenance models which were classified as *organization management*, *human-related*, and *organizational aspects*. From the literature review, we found some research gaps such as the fact that most studies have focused on the managerial aspects with less attention to human and organizational factors, while establishing strategic maintenance models in agro-industries. Meanwhile in contrast to previous models, the suggested maintenance model in Table 1 leverages relevant factors related to management, organizational, and human activities through classified criteria and associated CSFs. Our refresh also contributed the problem of weighting criteria and their interrelationships to successful maintenance management in agro-industries. For this purpose, the combined MCDM approaches such as BWM-DEMATEL were utilized to support the suggested framework, since not only to determine the relevance of the CSFs (which was found by BWM), but also to see the relationship between the CSFs (which were identified by DEMATEL). BWM has been widely used in several contexts, including education (Salimi and Rezaei 2016), location (Kheybari et al. 2019a), technology (Kheybari et al. 2019b), circular economy practices (Moktadir et al. 2020), supply chain management (Ahmad et al. 2017), water resource management (Chitsaz and Azarnivand 2017), information systems management (Kheybari et al. 2020). The main reason for using the BWM method in this study to prioritize the CSFs affecting the efficient maintenance management over other MCDM methods were the advantages of a) having a very strong paired comparison structure; b) higher data efficiency (e.g., uses less comparable data); C) reducing possible biases by respondents during the weighing process; and d) producing more trustworthy responses (Rezaei 2015, 2016). Besides, DEMATEL has been extensively employed in a variety of industrial settings (Tsai 2018; Singh and Bhanot 2020; Wu and Tsai 2012; Shen et al. 2012). We also used DEMATEL to identify the cause–effect relationship among the criteria. This relationship would help decision makers to formulate strategies towards well-established maintenance model. Additionally, to validate the proposed framework, this study focused on agro-industries in Iran, a developing country. It is expected that the findings would be useful in supporting agro-industry managers in upgrading maintenance management structures.

3 The research methodology

The major steps of the current study, based on conceptual and empirical investigations, are depicted in Fig. 1. The first step includes the definition of the most important criteria and their CSFs in the maintenance management model. Previous research as well as an open questionnaire were served as the foundation of this investigation. The second step is to apply the Best-Worst Method (BWM) to prioritize the CSFs, and Decision-Making Trial and Evaluation Laboratory (DEMATEL) to identify the cause–effect relationship the Finally, the last step deals with the practical recommendations for improving maintenance management structure in Iranian agro-industries (Section 4).

3.1 First step: review and define the criteria

An initial and open questionnaire was designed to validate, eliminate, or add effective criteria and their CSFs following the initial literature review to uncover the major criteria affecting efficient maintenance management, as indicated in Table 1. For this purpose, the opinion of 15 experts with professional expertise in maintenance consulting and management and at least 10 years of experience in various industries such as automotive, oil and gas, food and beverage, textiles, and defense were used. According to experts' responses, the CSFs such as *change management and alignment of all stakeholders* and *incentives and rules related to maintenance* were suggested to strengthen the criterion of organizational management. Likewise, in the criterion of organizational aspects, the CSFs such as *organizational culture* and *environmental and operatorial conditions* were also suggested, which the complementary structure of the maintenance model is shown in Fig. 2.

3.2 Second step: prioritize CSFs and their relations

In this step, several online questionnaires based on BWM and DEMATEL were designed to acquire the experts' judgment about the effect of the main criteria and their CSFs within Iranian agro-industry maintenance systems. The questionnaires were distributed to 30 agricultural experts with management backgrounds and working in the

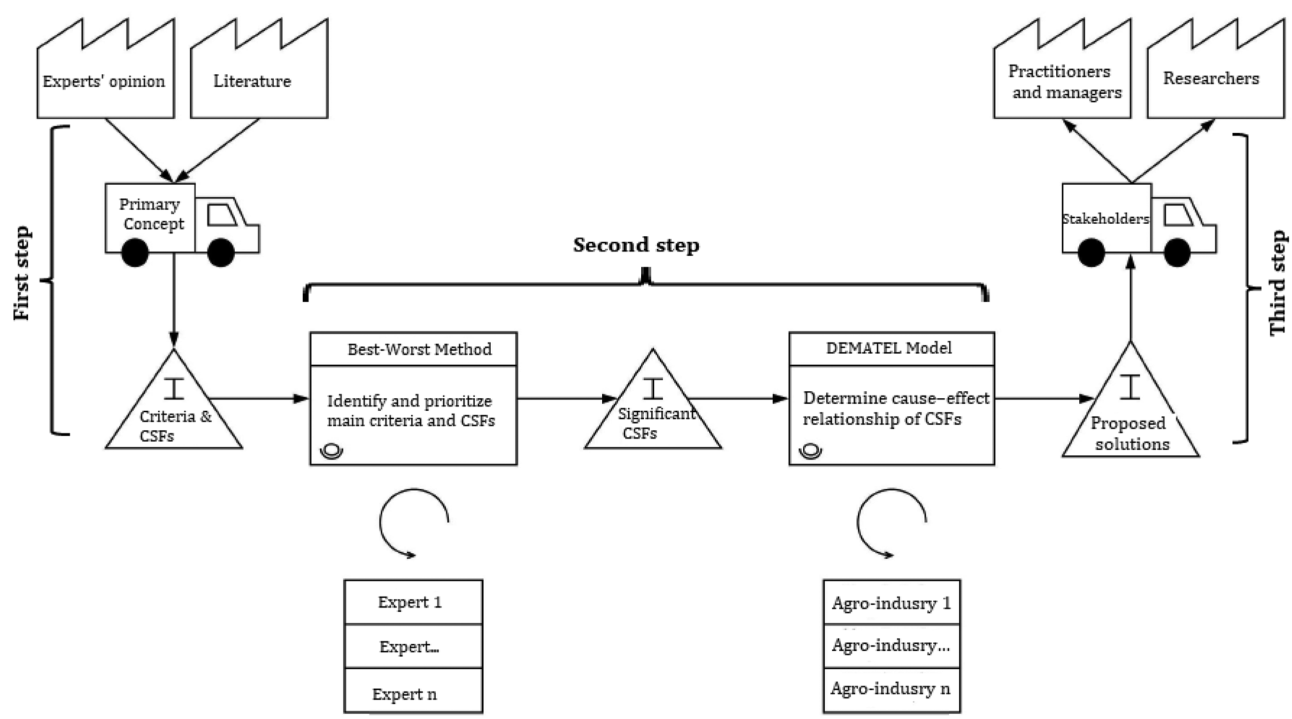


Fig. 1 The proposed structure of the current study

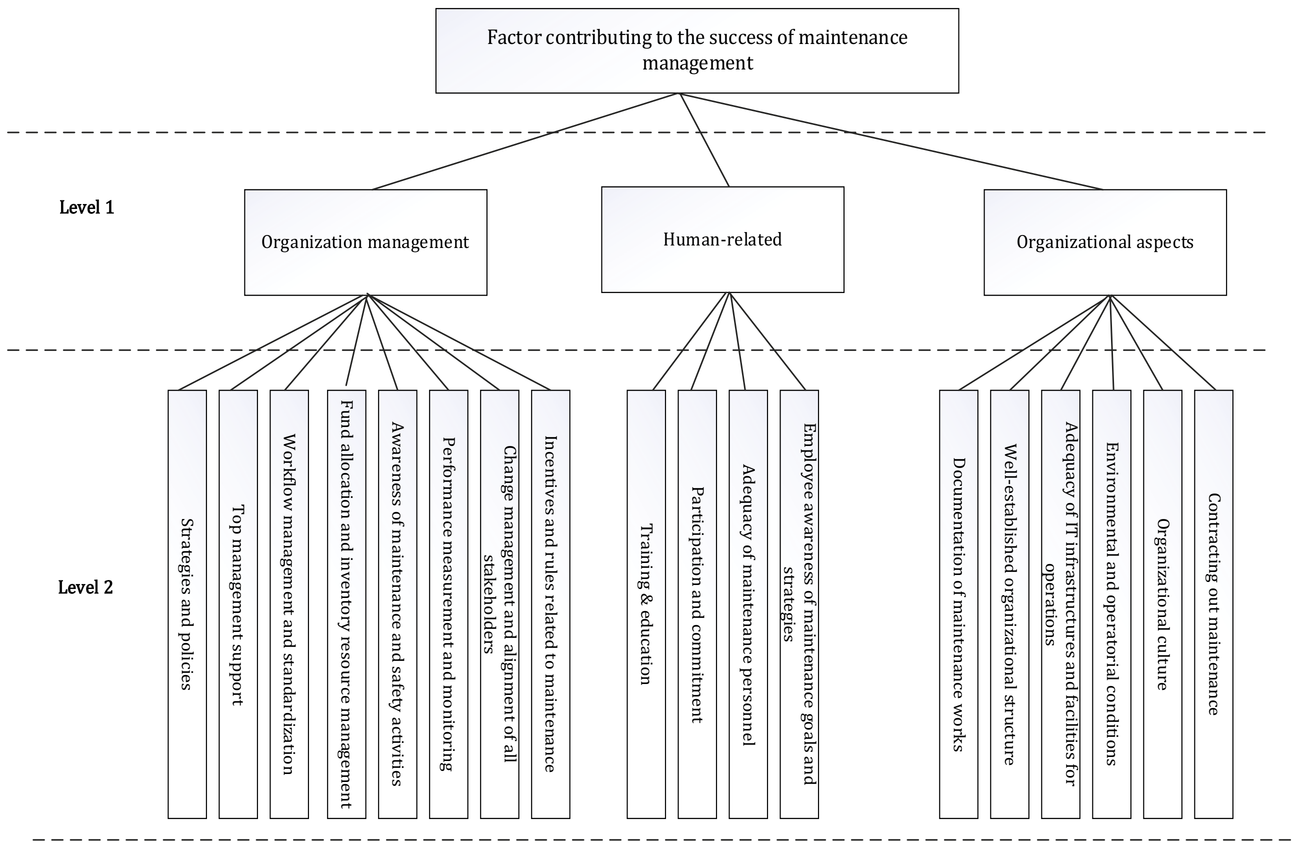


Fig. 2 The hierarchical tree for the main criteria and CSFs in maintenance management

agro-industrial sector. The experts were provided by connecting with Ministry of Agriculture Jihad in Iran. However, finally the opinions of 23 experts were utilized to examine the data based on received partial or missing information. A descriptive chart of the experts including years of experience, education levels, expert numbers, and their related department can be found in Fig. 3.

3.2.1 Best-Worst Method

The BWM was first introduced by Rezaei (2015) in 2015. In this method, the best (most desirable and most important) criteria and the worst (most undesirable and least important) criteria are identified by decision makers, and then pairwise comparisons are made between these two criteria, the best and worst and their CSFs. Then, to identify the weight of the effective criteria and CSFs, a minimum-maximum optimization problem is formulated and solved. The process of weighting by BWM is summarized in five steps, as follows (Rezaei 2015, 2016):

Step 1: Determine a set of evaluation criteria $\{c_1, c_2, \dots, c_n\}$ by the experts/decision-makers.
Step 2: Identify the most important (Best, B) and least important (Worst, W) criteria by experts/decision-makers, each of whom may have their own Best and Worst criteria.
Step 3: Determine the preference of the Best over all the other criteria with a number from 1 to 9 (where 1 represents equally important and 9 represents extremely more important). The result of Best -other comparisons is the vector $A_B = (a_{B1}, a_{B2}, \dots, a_{Bj}, \dots, a_{Bn})$, where a_{Bj} shows the preference of B over j .
Step 4: Determine the preference of all the decision criteria over the Worst. The result of others-to- Worst comparisons is the vector $A_w = (a_{1W}, a_{2W}, \dots, a_{jW}, \dots, a_{nW})$, where a_{jW} denotes the preference of the indicator j over W.
Step 5: Compute the optimal weights $\left(w_{1,}^* w_2^*, \dots, w_n^*\right)$. The optimal weights are calculated by minimizing the maximum absolute difference of $\left\{\left|w_B - a_{Bj}w_j\right|, \left|w_j - a_{jW}w_W\right|\right\}$ for all j which is translated into the following optimization problem:

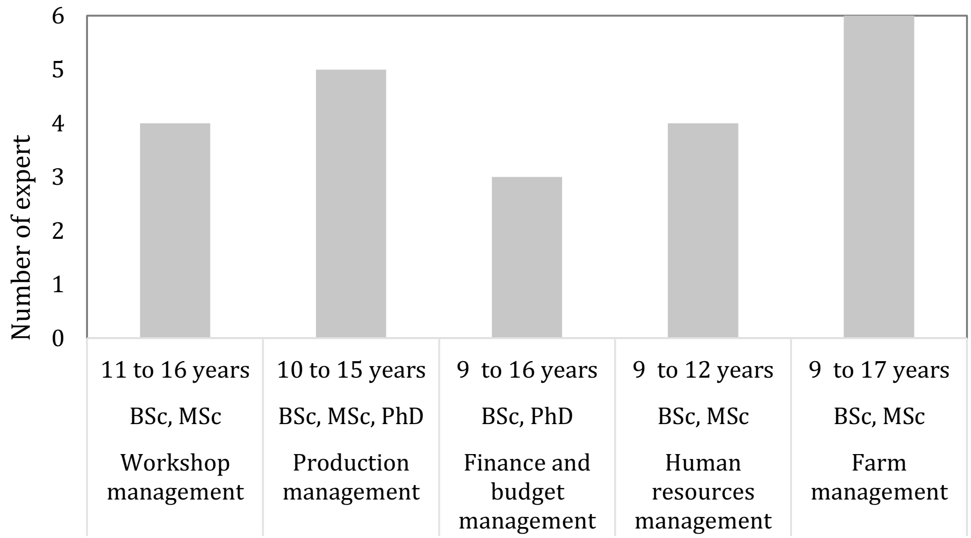


Fig. 3 A descriptive chart of the experts in Iranian agro-industries

$$\begin{aligned} & \min \max_j \left\{ \left| w_B - a_{Bj} w_j \right|, \left| w_j - a_{jW} w_W \right| \right\} \\ & \text{s.t.} \\ & \sum_{j=1}^{n} w_j = 1 \\ & w_j \geq 0, \text{ for all } j \end{aligned} \tag{1}$$

Equation of (1) is converted into:

$$\begin{aligned} & \min \xi \\ & \text{such that} \\ & \left| w_B - a_{Bj} w_j \right| \leq \xi, \text{ for all } j \\ & \left| w_j - a_{jW} w_W \right| \leq \xi, \text{ for all } j \\ & \sum_{j=1}^{n} w_j = 1 \\ & w_j \geq 0, \text{for all } j \end{aligned} \tag{2}$$

The results of Equation of (2), ξ^* and $w^* = \left(w_1^*, w_2^*, \ldots, w_n^*\right)$, represents the consistency and optimal weight of the criteria at each level respectively. If ξ^* becomes close to zero, it means that the respondent's pairwise comparison has a high level of consistency. When the criteria include more than one level in the hierarchical tree, the w* determined for each level is referred to as local weight. Consequently, the global weight of the sub-criteria (CSFs) is computed at the final level by multiplying the local weights of criteria referring to one branch by each other.

3.2.2 DEMATEL method

DEMATEL is an effective decision-making tool used in MCDM practical issues (Gabus and Fontela 1972). It has the unique ability to capture the interaction between criteria and display this relationship in a digraph (Kumar et al. 2018). This method helps decision-makers with the cognitive burden of examining and interpreting complex situations. It is one of the most well-known examples of semi-quantitative problem structuring and modeling (SPSM) (Settanni et al. 2022). The following steps could be performed to apply the DEMATEL technique (Moktadir et al. 2020):

Step 1: Construct the initial relation matrices between identified CSFs of maintenance management, using a linguistic rating scale. The linguistic rating scale in Table 2 was assigned to experts to construct the initial relation matrices. If the number of identified CSFs is n and the number of respondents is H, $k = 1, \ldots, H$, it means that each expert builds a $(n \times n)$ matrix in form of $X^k = [X_{ij}^k]$, where X_{ij}^k shows the major value of factor i affects factor j *based* on k $^{\text{th}}$ expert.
The initial relation matrices for the H number of experts were constructed as follows:

Table 2 The linguistic rating scale for DEMATEL analysis

Linguistic scale	Linguistic attributes
0	No influence
2	Very low influence
4	Low influence
6	Medium influence
8	High influence
10	Extremely highly influence

Intermediate scores 1, 3, 5, 7, and 9 can be used if necessary

$$X^1 = \left[X_{ij}^1\right], X^2 = \left[X_{ij}^2\right], \ldots, X^H = \left[X_{ij}^H\right] \tag{3}$$

As a result, by averaging initial relation matrices received from H experts, the average initial relation matrix $M = [\widetilde{X_{ij}}]$ is generated. Equation (4) is used to create the average relation matrix:

$$\widetilde{X_{ij}} = \frac{1}{H} \sum_{k=1}^{H} \left[X_{ij}^k\right] \tag{4}$$

Step 2: Construct the normalized direct-relation matrix P. Equation (5) is used to formulate this matrix from the average relation matrix M:

$$P = M \times S \tag{5}$$

where S is calculated by Eq. (6):

$$S = \min\left[\frac{1}{\sum_{i=1}^{n} |\widetilde{X}_{ij}|}, \frac{1}{\sum_{i=1}^{n} |\widetilde{X}_{ij}|}\right] \tag{6}$$

Step 3: Construct a total relation matrix T. For this, Eq. (7) is used as follows:

$$T = P[1 - P]^{-1} \tag{7}$$

where the notation I *indicates* the identity matrix.

Step 4: Develop the cause-effect variables by summing rows and columns. Through the total relation matrix, $T = T = [t_{ij}]_{n \times n}$, the r_i and c_j values are estimated. r_i signifies the sum of the i^{th} row in matrix T, and c_j denotes the sum of j^{th} column in matrix T. Therefore, r_i and c_j can be calculated by Eqs. (8) and (9).

$$r_i = \sum_{j=1}^{n} t_{ij}, \forall i \tag{8}$$

$$c_j = \sum_{i=1}^{n} t_{ij}, \forall \mathrm{j} \tag{9}$$

The total effect received by CSFs is explained by the sum of $(r_i + c_j)$. It also shows which CSFs are in the "prominence" group. It also represents the degree of importance for i^{th} CSF in the whole system. Consequently, the value of $(r_i - c_j)$ indicates the "net effect" that i^{th} CSF contributes to the whole system. If the value of $(r_i - c_j)$ is positive, the i^{th} CSF is the net cause group. If the value of $(r_i - c_j)$ is negative, the i^{th} CSF indicates the net effect.

Step 5: Compute the threshold value by the total relation matrix. This value is calculated by summing the mean and standard deviation of CSFs throughout the whole relation matrix T. As a result, the causal links may be shown in a digraph using the dataset of $((r_i + c_j), ((r_i - c_j)), \forall i = j$.

4 Results and discussion

This section deals with the results of BWM and DEMATEL to prioritize the influencing CSFs and their cause-effect relationship in the effective maintenance management of Iranian agro-industries.

4.1 The results of BWM

According to BWM and given the first level of the hierarchical structure of Fig. 2 and experts' feedback in Fig. 4a, the criteria such as *organization management*, *human-related*, and *organizational aspects* are prioritized in Fig. 4b with the average weights of 0.461, 0.192, and 0.325, respectively. The average BWM's consistency rate (ξ^*) for such criteria was obtained as 0.13, which denotes high response quality (Liang et al. 2019). According to experts, the role of *organization management* is key to defining proper strategies and policies to attain excellence in the maintenance of agro-industries. Nevertheless, there was a lack of attention to *organization management*, resulting in a lack of long-term and consistent strategies in the Iranian agro-industrial sector. Several studies have been conducted to assess the importance of *organization management* in physical asset maintenance. Thomas (2005), for example, studied *organization management* and the role of leaders in making fundamental changes in organizations to promote a maintenance culture based on the reliability idea. He highlighted the significance of leaders in developing roadmaps and visions, orienting toward policies and strategies, and focusing on change management in light of current developments. Furthermore, they are connected with organizational perspectives, ensuring organizational balance, and holding employees accountable for deviations from objectives. in a study conducted in the sugar processing sector, the most important functions of *organization management* were extended to the adoption of appropriate maintenance policies, budget allocation and inventory management, and continuous monitoring of maintenance activities (Gandhare et al. 2018). According to the findings of a research on measuring the agro-industry maintenance performance in western India, *organization management* criterion is key in defining appropriate maintenance strategies, as well as planning and scheduling activities (Gandhare and Akarte 2020). Subsequently, the criterion of *organizational aspects* was recognized as the second priority driving efficient maintenance management in Iranian agro-industries. To define individual responsibilities, agro-industries require a proper organizational culture coupled with maintenance goals and strategies, as well as an appropriate hierarchical structure. Furthermore, experts believed that the criterion of *human-related* has a lower weight and priority, owing to the seasonal nature of most maintenance tasks and the

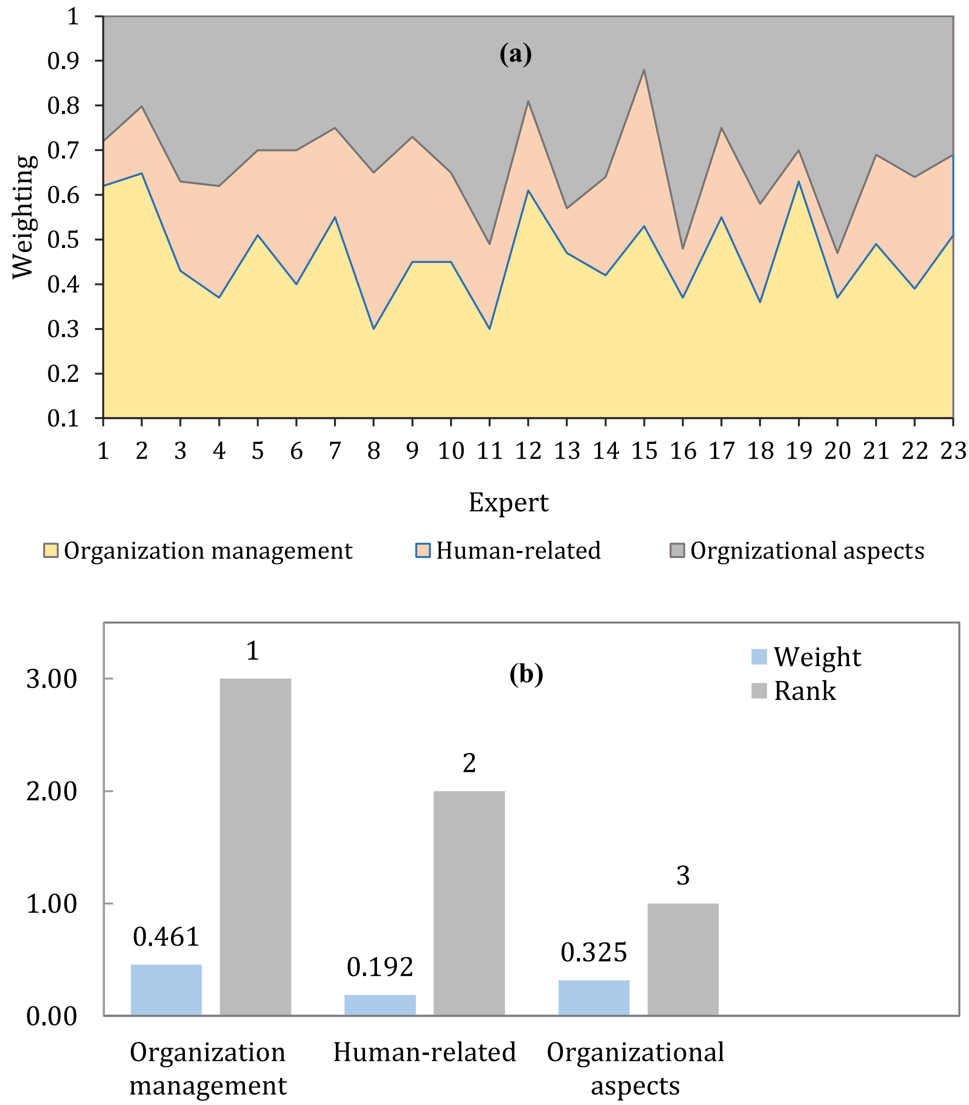


Fig. 4 The weight and rank of the criteria at the first level using BWM

limited availability of maintenance crew throughout the year in agro-industries. Nevertheless, to achieve the aims of *organization management*, it is critical to expand the annual training programs to reinforce the personnel's awareness about maintenance strategies.

The CSFs connected to each of the three criteria in the maintenance management model in agro-industries are detailed in the second level of the hierarchical diagram in Fig. 2. According to the results of the BWM in Table 3, CSFs such as *top management support*, *fund allocation and inventory resource management,* and *maintenance strategies and policies* had the highest priority in the *organization management*, with the weights of 0.246, 0.160, and 0.142, respectively. *Top management* as a motivator in agro-industries can have a direct effect on budgeting and inventory management, as well as promotion of the organization's goals and strategies, all of which can improve the effectiveness of maintenance projects. Given the importance of leaders and senior managers in maintenance management, special consideration should be given to appointing mid-level managers who ought to be knowledgeable about agro-industrial unit maintenance mechanisms. In this regard, the results of a survey on maintenance management in the Czech Republic's food and chemical industries revealed that top managers play a critical role in implementing new maintenance methods and strategies, organizing central affairs, outsourcing activities, work cycle management, and activity standardization (Branská et al. 2016). The managers' authority in agricultural farm maintenance in China was also highlighted, including supervising operational processes and mechanisms, managing support systems, and managing off-farm agents. The findings revealed that it is possible to meet the sustainable

Table 3 The weight and rank of CSFs at the second level using BWM

Criteria	Code	Critical success factors (CSFs)	Weight	Rank
	CSF1	Strategies and policies	0.142	3
	CSF2	Top management support	0.246	1
	CSF3	Workflow management and standardization	0.071	5
Organization management	CSF4	Fund allocation and inventory resource management	0.160	2
	CSF5	Awareness of maintenance and safety activities	0.116	4
	CSF6	Performance measurement and monitoring	0.047	8
	CSF7	Change management and alignment of all stakeholders	0.091	7
	CSF8	Incentives and rules related to maintenance	0.055	6
	CSF9	Training & education	0.318	2
Human-related	CSF10	Participation and commitment	0.156	3
	CSF11	Adequacy of maintenance crew	0.352	1
	CSF12	Employee awareness of maintenance goals and strategies	0.110	4
	CSF13	Documentation of maintenance works	0.163	2
	CSF14	Well-established organizational structure	0.121	4
Organizational aspects	CSF15	Adequacy of IT infrastructures and facilities for operations	0.154	3
	CSF16	Environmental and operatorial conditions	0.112	5
	CSF17	Organizational culture	0.090	6
	CSF18	Contracting out maintenance	0.191	1

development standards by regularly monitoring maintenance audit indicators following the prescribed framework (Kim et al. 2014). According to experts, CSFs like *fund allocation and inventory resource management* were regarded as the second priority to ensure the success of maintenance management in Iranian agro-industries. According to the findings, the maintenance sector's budget contribution compared to the overall organization budget in Iranian agro-industries is already negligible. In that trend, providing sufficient funds to develop maintenance techniques, particularly preventive ones, would have a substantial impact on reducing the cost of machines' failures while also increasing the efficiency of agricultural operations. Other research has emphasized the need for proper budgeting to cover a variety of maintenance expenses. In these studies, increased stress has been placed on allocating funds for preventive maintenance to mitigate the failures of agricultural machinery (Johannes et al. 2021; Gandhare and Akarte 2020; Oliveira and Lopes 2019).

Meanwhile, experts identified *maintenance strategies and policies* as the third CSF in achieving efficient maintenance in Iranian agro-industries. It was found that the current strategy is reactive maintenance (repairing/replacing machines after breakdown) which has increased unexpected breakdowns in agricultural operations, especially during peak times or seasons. Managers may consider using preventive techniques and roadmaps based on International Organization for Standardization (ISO) standards, British Standards Institution (BSI), Society of Automobile Engineers (SAE), and other European standards to cope with such issues. Other research also has addressed the impact of *strategies and policies* in maintenance management model within diverse manufacturing and agricultural sectors. In the Turkish agricultural industry, for example, reliability-based preventive technique has been preferred beyond reaction strategies to optimize maintenance programs (Yavuz et al. 2019). According to Arslankaya and Atay (2015), the use of appropriate maintenance strategies, as well as factors such as lean production methods, maintenance planning, prioritization, and monitoring can enable dairy farms to reduce machine failures, improve productivity, and increase labor force efficiency. Experts proposed the CSFs such as *awareness of maintenance and safety activities* as the next priority in the criterion of *organization management* in agro-industries, which is undeniably one of the most important tasks of managers. According to assessments, most agro-industries in Iran have paid less attention to the implementation of adequate mechanisms to increase awareness of updated maintenance and safety improvements. The evidence for this issue is reasonable given the sector's reactive strategies, which stem from a lack of awareness about the benefits of new maintenance procedures aimed at increasing the effectiveness of equipment and, ultimately, agricultural production productivity. It's also worth mentioning that CSFs like i*ncentives and rules related to maintenance* and *change management and alignment of all stakeholders* and *performance measurement and monitoring* were assigned as the lowest priority by experts, with the weighted values of 0.091, 0.055, and 0.047, respectively.

According to the BWM results in Table 3, in the criterion of *human-related*, the CSFs such as *adequacy of* *maintenance crew and training and education* were identified as the highest priority in agro-industrial unit maintenance, with the weights of 0.352 and 0.318, respectively. Continuous training programs and seasonal workshops are required to develop staff communication and technical capabilities to establish a proper maintenance program in Iranian agro-industries. Managers should also consider hiring people with multi-skill capabilities, such as software skills, emergency management skills, interaction, and communication skills, as well as hardware and technical skills. In this direction, other studies have looked into these CSFs in maintenance management models. It was considered allocating special funds, for example, to hold workshops teaching Total Productive Maintenance (TPM) to operators, strengthening maintenance personnel's communication and problem-solving abilities, as well as familiarizing personnel with computer systems to speed up workflow and eliminate manual processes. Furthermore, a special emphasis has been placed in these studies on the use of multi-skilled labor, the relevance of specialties to defined duties, periodic staff performance measurement, and personnel encouragement to obtain the necessary qualifications based on the needs of production systems (Priyantha 2021; Sarbini et al. 2021; Jandali and Sweis 2018; Tan et al. 2014; Macchi and Fumagalli 2013; Ab Wahid and Corner 2009). In continuing the analysis on the *human-related* criterion, CSFs such as *participation and commitment* and em*ployee awareness of maintenance goals and strategies* had the lowest importance in Iranian agro-industries maintenance management.

In the hierarchical classifications in Fig. 2 at the level of the *organizational aspects*, the CSFs such as *contracting out maintenance* and *documentation of maintenance works* had the highest priority with the weights of 0.191 and 0.163, respectively (Table 4). A portion of agro-industry maintenance is outsourced, particularly annual overhaul repairs. However, no relevant system exists to analyze the current policy's efficiency in this sector. As a result, agro-industry managers will need to analyze the costs incurred by external contractors as well as their track record of enhancing equipment performance in the face of failures. At the level of *organizational aspects*, the CSF such as *documentation of maintenance works* was identified as the second priority by experts, which can include breakdown times, repair and preventive times, maintenance and repair costs, personnel information, technical specifications, equipment, and spares coding, etc. In agro-industries, proper documentation might be important while deploying an integrated maintenance system. Furthermore, ensuring IT infrastructure compliance with standards like ISO 14224 can help automate and speed up the process of documenting maintenance actions. In this context, the CSFs such as *adequacy of IT infrastructures and facilities for operations* and *well-established organizational structure* were found as the next priorities in the *organizational aspect's* criterion, with the weights of 0.154 and 0.121. Non-automation mechanisms are used to carry out maintenance workflows in Iran's agro-industries. However, by providing adequate IT infrastructure and integrated software, a significant number of operations, including documenting events, managing maintenance procedures, managing users, monitoring asset performance, and cost management can be mechanized. Likewise, based on the BWM results, CSFs such as *organizational culture* and

Table 4 The global weight of the CSFs for maintenance management in agro-industries

Code	Critical success factors (CSFs)	Weight	Rank
CSF2	Top management support	0.108	1
CSF4	Fund allocation and inventory resource management	0.075	2
CSF1	Maintenance strategies and policies	0.067	3
CSF11	Adequacy of maintenance crew	0.066	4
CSF18	Contracting out maintenance	0.061	5
CSF9	Training & education	0.059	6
CSF5	Awareness of maintenance and safety activities	0.053	7
CSF13	Documentation of maintenance works	0.052	8
CSF15	Adequacy of IT infrastructures and facilities for operations	0.049	9
CSF7	Change management and alignment of all stakeholders	0.039	10
CSF14	Well-established organizational structure	0.038	11
CSF16	Environmental and operatorial conditions	0.035	12
CSF3	Workflow management and standardization	0.034	13
CSF17	Organizational culture	0.029	14
CSF10	Participation and commitment	0.028	15
CSF8	Incentives and rules related to maintenance	0.024	16
CSF12	Employee awareness of maintenance goals and strategies	0.021	17
CSF6	Performance measurement and monitoring	0.017	18

environmental and operatorial conditions were given the least significant elements in *organizational aspects*.

Several studies have looked at the CSFs' role in the formation of *organizational aspects*. The relevance of the organizational structure of agro-Industries in Western India has been acknowledged, with a special emphasis on CSFs such as integrated information management, appropriate IT infrastructure, as well as outsourcing of maintenance activities (Gandhare and Akarte 2020). According to Fountas et al. (2015) and Li et al. (2019), IT infrastructure capable of adapting to Internet platforms is quite useful for managing agricultural operations, performance measurement, workflow management, and diagnosis of agricultural equipment defects. Horyovy (2007) identified the IT supports, renting system for machinery, and the outsourcing of maintenance tasks were the most critical issues on Ukrainian farms. In another study, farmers and machine contractors were more concerned with documenting and reinforcing maintenance activities using hardware and software (Sørensen and Bochtis 2010). In Chinese agricultural farms, operation process management, support system management, in-farm, and out-of-farm factor management, and outsourcing interactions were the most essential keys to strengthening the *organizational aspects* criterion (Kim et al. 2014). In addition, as indicated in Table 4, the BWM is leveraged to estimate the global weights of the CSFs. Four CSFs such as *top management support*, *fund allocation and inventory resource management*, *maintenance strategies and policies*, and *adequacy of maintenance crew* had the greatest impact on maintenance management in agro-industries, with weights of 0.108, 0.075, 0.067, and 0.066.

4.2 Validation of the results provided by BWM

In order to validate the BWM results, we interviewed with 12 experts who involved in the BWM-based weighting process to acquire their opinion on the factors that affect maintenance management in the agro-industries. All of the experts had experience with maintenance management concerns from their work in Iranian agro-industries. Each interview lasted approximately 20 min. We asked the experts to explain why they agree/disagree with the result provided by BWM and to give us their opinions regarding the rank of (i) the criteria in Level 1 and, (ii) the sub-criteria in Level 2 categorized into the three dimensions. The results of the interviews are provided in Table 5. As seen, with regard to the experts' opinion, *organization management*, *top management support* and *contracting out maintenance,* with 12, 10 and 9 (out of 12) votes, respectively, recognized the highest priorities in the maintenance management of agro-industries. The only CSF on which the experts disagree more than they agree is *adequacy of maintenance crew*. Hence, as indicated in the column of negative reasons, the respondents appeared to be

Table 5 Results of interviews

Criteria	CSFs	No. of agree	No. of disagree	Positive reasons	Negative reasons
Organization management	Main Factor	12	0	• The success of each maintenance project in agro-industries is directly related to the organization management. • Decisions and policy of an organization are made by the organization management.	-
Organization management	Top management support	10	2	• Full support of top management is essential to have an efficient maintenance program within agro-industries.	• The main cause of the lack of support from top management is unclear goals. • A proper mechanism is not defined to clarify the duties and authorities of top managers in maintenance of agro-industries.
Human-related	Adequacy of maintenance crew	5	7	• Adequacy of maintenance crew with multi-skill abilities e.g., technical and communication skills are key to reach a suitable maintenance program.	• Lack of mechanism to hire people with multiple skills. • Lack of people with communication and technical skills in agro-industries.
Organizational aspects	Contracting out maintenance	9	3	• Major part of overhauls in agro- industries are cost-effective to be outsourced and therefore it requires contracts with external contractors.	• With an effective maintenance program, the majority of costs and routines related to overhauls that are contracted out can be managed.

Table 6 Average matrix based on experts' opinion

CSFs	CSF2	CSF4	CSF1	CSF11	CSF18	CSF9	CSF5	CSF13	CSF15
CSF2	0.000	8.613	8.361	5.875	7.150	7.660	8.192	5.429	6.330
CSF4	4.718	0.000	6.094	5.053	8.201	9.025	2.974	3.027	9.526
CSF1	3.043	5.173	0.000	9.025	9.138	7.980	5.028	8.423	9.619
CSF11	2.914	1.824	4.336	0.000	8.851	3.862	8.385	9.592	9.713
CSF18	1.176	8.224	2.766	1.334	0.000	5.005	0.828	2.850	5.875
CSF9	8.741	4.011	9.808	9.619	5.036	0.000	9.343	8.826	9.903
CSF5	0.727	5.932	9.025	8.113	8.035	2.078	0.000	1.762	7.844
CSF13	0.968	1.417	0.711	2.558	5.538	2.385	7.913	0.000	6.469
CSF15	3.758	3.043	7.917	2.800	4.399	4.729	9.435	9.408	0.000

unable to reach a consensus on such given criterion. In summary, when compared to the other criteria, the BWM-ranked criterion has received the most approval from the experts.

4.3 The results of DEMATEL

Following the results of the BWM method for CSFs prioritization, the DEMATEL method was used to determine the cause-effect relationship between CSFs in maintenance management in Iranian agro-industries. The results of the BWM's global weight of CSFs (Table 4) were used as a foundation for DEMATEL analysis. In other words, CSFs from orders 1 to 9, which had the highest priority and the highest share (60 percent) of whole CSFs, were considered. The research team then contacted the experts via an online questionnaire to acquire their responses on the interactions between the finalized CSFs. In this step, 15 experts out of 23, responded and provided information on the interactions between the CSFs. The comparison relationship matrices were constructed based on experts' feedback using the linguistic rating scale shown in Table 2. The initial relationship matrices for the CSFs are given in Tables A1–A3 (Appendix). Equation (4) was used to create the average relationship matrix, which is shown in Table 6. The normalized direct relation matrix (P) is constructed from the average matrix using Eq. (5). The final normalized CSF relation matrix is given in Table 7. Further, total relation matrix is built using Eq. (6) which is shown in Table 8.

Equations (8) and (9) are used to calculate the values of ri and cj from the total relation matrix. The sum of $(r_i + c_j)$ and $(r_i - c_j)$ was also computed. The sum of CSFs cause-effect is represented by (ri + cj). Based on (ri + cj) values, the importance of the nine CSFs can be prioritized as CSF15 > CSF9 > CSF1 > CSF5 > CSF11 > CSF4 > CSF18 > CSF2 > CSF13. Dependence of *adequacy of IT infrastructures and facilities for operations (CSF15)* is the most important effect factor, whereas *documentation of maintenance works (CSF13)* is the least important factor among these effect barriers. The value of $(r_i - c_j)$ indicates the impact of each CSF. If the value of $(r_i - c_j)$ is positive, the CSFs are considered causal. If the value of $(r_i - c_j)$ is negative, the CSF is in the effect group. The causal impact of CSFs is displayed in Table 9. Those values greater than the threshold (> 0.267) are underlined in the total relation matrix (Table 7) and their interactions with other CSFs are depicted in Figs. 5 and 6.

As seen in Table 9 and Fig. 5, the CSFs such as *top management support (CSF2), training and education (CSF9)*, *fund allocation and inventory resource management (CSF4)*, *maintenance strategies and policies (CSF1)*, and *adequacy of maintenance crew (CSF11)* are recognized as impactful causal variables with the positive $(r_i - c_j)$ values of +1.626, +1.159, +0.599, +0.368 and +0.144, respectively. According to the experts' feedback, it can be found that *top management support (CSF2)* has the greatest impact on the *adequacy of IT infrastructures and facilities for operations (CSF15) and contracting out*

Table 7 Normalized direct relation matrix (P)

CSFs	CSF2	CSF4	CSF1	CSF11	CSF18	CSF9	CSF5	CSF13	CSF15
CSF2	0.000	0.132	0.128	0.090	0.110	0.117	0.125	0.083	0.097
CSF4	0.072	0.000	0.093	0.077	0.126	0.138	0.046	0.046	0.146
CSF1	0.047	0.079	0.000	0.138	0.140	0.122	0.077	0.129	0.147
CSF11	0.045	0.028	0.066	0.000	0.136	0.059	0.128	0.147	0.149
CSF18	0.018	0.126	0.042	0.020	0.000	0.077	0.013	0.044	0.090
CSF9	0.134	0.061	0.150	0.147	0.077	0.000	0.143	0.135	0.152
CSF5	0.011	0.091	0.138	0.124	0.123	0.032	0.000	0.027	0.120
CSF13	0.015	0.022	0.011	0.039	0.085	0.037	0.121	0.000	0.099
CSF15	0.058	0.047	0.121	0.043	0.067	0.072	0.145	0.144	0.000

Table 8 Total relation matrix (T)

CSFs	CSF2	CSF4	CSF1	CSF11	CSF18	CSF9	CSF5	CSF13	CSF15
CSF2	0.138	0.318	0.368	0.312	0.387	0.325	0.378	0.334	0.420
CSF4	0.190	0.171	0.305	0.266	0.356	0.313	0.277	0.274	0.414
CSF1	0.175	0.259	0.237	0.336	0.397	0.314	0.331	0.369	0.447
CSF11	0.145	0.185	0.259	0.174	0.347	0.222	0.331	0.337	0.392
CSF18	0.094	0.215	0.171	0.136	0.145	0.187	0.151	0.176	0.253
CSF9	0.269	0.276	0.413	0.384	0.391	0.238	0.432	0.413	0.500
CSF5	0.113	0.231	0.309	0.279	0.328	0.197	0.196	0.226	0.357
CSF13	0.075	0.116	0.133	0.141	0.211	0.131	0.235	0.118	0.243
CSF15	0.155	0.197	0.302	0.219	0.285	0.231	0.337	0.327	0.254

maintenance (CSF18) activities with the weight values of 0.420 and 0.387. These cause-group barriers ought to be considered immediately in the Iranian agro-industry maintenance system. Besides, the CSFs such as *contracting out maintenance (CSF18), documentation of maintenance works (CSF13), adequacy of IT infrastructures and facilities for operations (CSF15), and Awareness of maintenance and safety activities (CSF5)* with the negative $(r_i - c_j)$, values are affected by other CSFs, respectively. In other words, *contracting out maintenance (CSF18)* with the value of -1.319 is the greatest effect factor, while *Awareness of maintenance and safety activities (CSF5) with* the value of -0.434 is the least effect factor.

According to Fig. 6, CSFs like *top management support (CSF2)* and *training and education (CSF9)* are classified as high impactful elements, while *fund allocation and inventory resource management (CSF4), maintenance strategies and policies (CSF1),* and the CSFs like *adequacy of maintenance crew (CSF11)* are classified as medium impactful elements, and finally, the CSFs such as contracting out maintenance (CSF18), documentation of maintenance works (CSF13), *adequacy of IT infrastructures and facilities for operations (CSF15)* and *awareness of maintenance and safety activities (CSF5)* are classified as low impactful elements on maintenance management in Iranian agro-industries.

5 Managerial implications

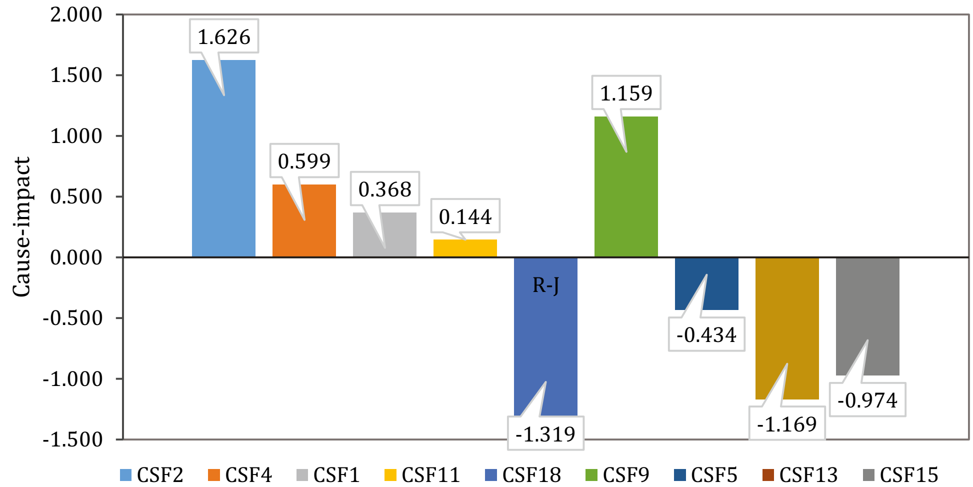
The focus of this study was on how CSFs serve a fundamental role in effective maintenance management in Iranian agro-industries. CSF prioritization and cause-effect analysis using BWM and DEMATEL tools can assist agro-industry managers in better understanding the factors required to effectively adopt a proper maintenance management system. Meanwhile, it may contribute to the improvement of agricultural fleet performance and the establishment of a sustainable food supply. This study has a number of implications, which are described below:

- According to the study's findings, *top management support* is both the highest-ranked success factor and a causal factor in the proposed maintenance model. This means that substantial commitment from management will be required for the successful adoption of maintenance procedures in agro-industries. This will necessitate ongoing leadership to support maintenance initiatives and motivate maintenance staff to accomplish the ultimate goals. Top management also can have a direct impact on agro-industry budgeting and inventory management, as well as the promotion of the organization's goals and strategy, all of which can influence the effectiveness of maintenance projects.
- *Budget allocation and inventory resource management* were found to be the second highest-ranked success element in BWM and the third causative factor in DEMATL to ensure the success of maintenance management in Iranian agro-industries. Because the current maintenance budget in agro-industries is so limited, providing financial support is beneficial in holding workshops to raise awareness about the importance of maintenance and safety culture, particularly preventive ones, purchasing high-quality spare parts to avoid unexpected failures, replacing aged assets, funding awards to increase participation in problem-solving and commitment in Iranian agro-industries.

Table 9 Causal impact of CSFs

Name of CSFs	CSF2	CSF4	CSF1	CSF11	CSF18	CSF9	CSF5	CSF13	CSF15
R	2.980	2.566	2.865	2.392	1.528	3.317	2.235	1.403	2.306
J	1.355	1.967	2.497	2.248	2.847	2.158	2.669	2.572	3.280
R + J	4.335	4.534	5.361	4.641	4.375	5.475	4.904	3.975	5.586
R-J	1.626	0.599	0.368	0.144	-1.319	1.159	-0.434	-1.169	-0.974
Impact	Cause	Cause	Cause	Cause	Effect	Cause	Effect	Effect	Effect

Fig. 5 The causal impact of CSFs



- The third CSF in achieving effective maintenance management in agro-industries was highlighted as *maintenance strategies and policies*. Because the current maintenance strategy in this sector is reactive, modern techniques and roadmaps based on International Organization for Standardization (ISO) standards, the British Standards Institution (BSI), the Society of Automobile Engineers (SAE), and other European standards can be recommended. Among these international maintenance standards, systematic approaches such as Reliability Centered Maintenance (RCM), Risk-Based Maintenance (RBM), Predictive Maintenance (Pd.M.), and Total Productive Maintenance (TPM) have proven to be effective in improving operational performance of machine failures in agricultural fleet.
- Given the importance of adequate maintenance personnel expertise from the perspective of experts, appropriate mecha-

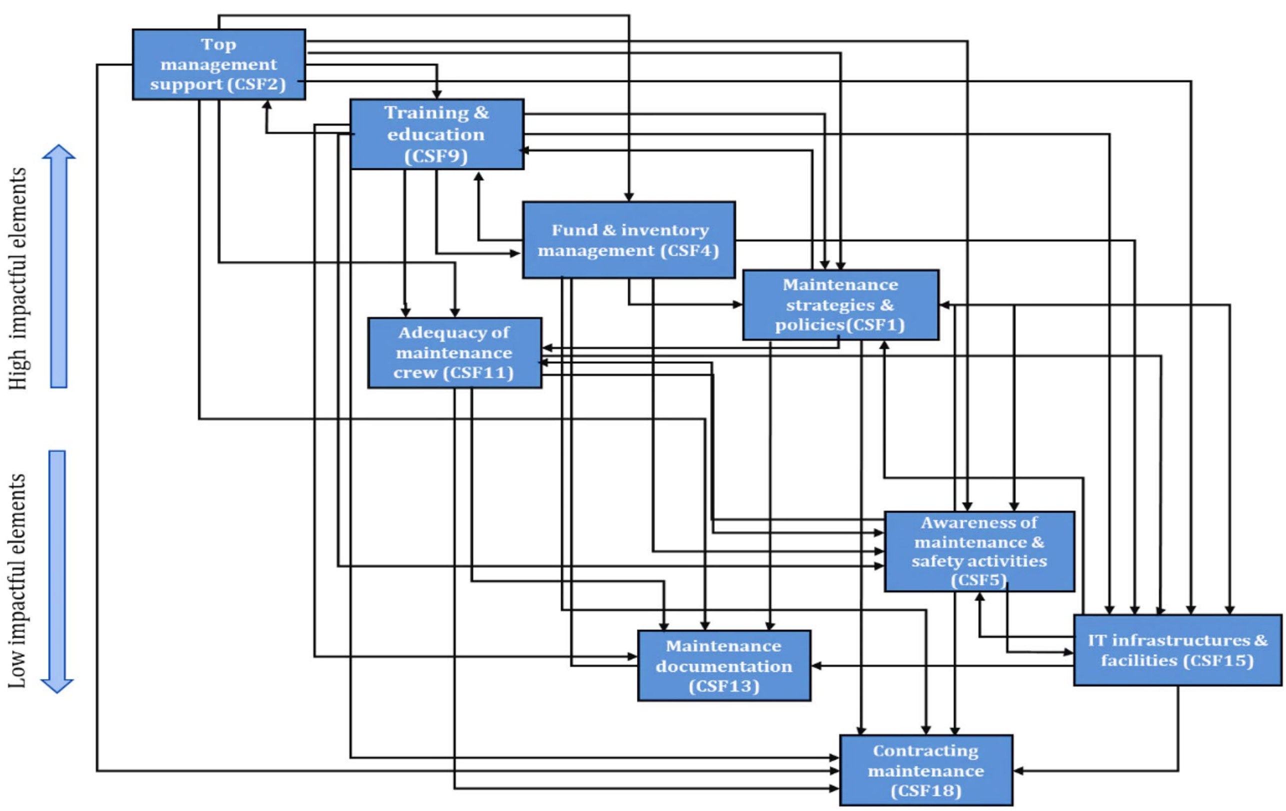


Fig. 6 The cause-effect relationships between CSFs

nisms could be used for recruiting the required personnel, such as considering multi-skills such as software and hardware knowledge, emergency management skills, and interaction and communication skills. Furthermore, since *top management support* has the greatest impact on the adequacy of IT infrastructures in maintenance management (DEMATEL results), and because most Iranian agro-industries are currently non-automated in terms of maintenance and repair workflows, an appropriate IT infrastructure and software system for the integrated management of diverse maintenance operations can be recommended.

6 Conclusion and future work

Maintenance management is one of the pillars of achieving sustainable production and service in today's competitive business network. Hence, all types of businesses are in charge of optimizing management maintenance structures to boost their competitiveness in global markets. Likewise, proper maintenance management in agro-industries is crucial for increasing agricultural supply chain productivity and availability. This research intends to enable agro-industries in identifying how to achieve successful maintenance management in their operations. From a conceptual point of view, the research defined and identified the major criteria and sub-criteria (CSFs) in the maintenance management model. This was accomplished by a literature review and the solicitation of expert opinions. To achieve the intended objectives, an integrated framework incorporating both BWM and DEMATEL was used. BWM was performed to prioritize the CSFs, and DEMATEL was used to discover interrelationships between CSFs for effective agro-industry maintenance management. Following an extensive literature review and feedback from experts in Iranian agro-industries, three main criteria were validated: *organization management*, *human-related*, and *organizational aspects*, as well as eighteen sub-criteria (CSFs). According to the BWM analysis, the highest priority factors were CSFs such as *top management support*, *fund allocation and inventory resource management*, *maintenance strategies and policies, and adequacy of the maintenance crew*. Meanwhile, DEMATEL analysis showed that the CSFs such as *top management support*, *training and education*, *fund allocation and inventory resource management*, *maintenance strategies and policies*, and *adequacy of maintenance crew* were causal factors. The findings of this study could potentially assist agro-industry managers and practitioners in deciding where to focus their efforts to achieve a robust and efficient maintenance management structure. This study has some limitations: (i) It principally focused on strategic challenges of maintenance management in agro-industries with less emphasis on the tactical and operational requirements; (ii) a limited number of experts from agro-industries were involved during the data collection process; and (iii) some of the CSFs have been merged due to restrictions in designing questionnaires and facilitating expert responses. (iv) we used less than nine CSFs for pairwise comparisons under a single criterion to reduce the complexity of calculations and improve the reliability of MCDM models. (v) we tried to cover all relevant criteria; however, since there is no literature review on maintenance management in agro-industries, we may have missed some.

Given the findings presented in this paper, decision makers can prioritize the actions that have to be taken in designing an appropriate maintenance management system to meet the needs of tactical and operational duties in agro-industries. On the other hand, the research results may enable policy makers to concentrate on increasing the productivity of agricultural products in agro-industries through the implementation of a successful maintenance service system. Likewise, this research aids in identifying and focusing on the crucial elements, which can enhance the overall readiness of agricultural operations. The methodology outlined in this paper is also a good way to address the multicriteria problem in the evaluation process with the lowest level of risk as well as to identify the relationships between major elements in the maintenance service systems in the agro-industries. In addition to helping managers and practitioners in the agro-industries decide where to concentrate their efforts to create an effective maintenance program, the proposed framework also has the potential to be applied to various food enterprises to successfully adapt maintenance management systems. Further, future research can concentrate on the tactical and operational levels of maintenance model in the form of medium or short-term plans, considering factors such as type of cultivation, type of season, and type of machinery in agro-industries. Additionally, the current research findings can be applied to various food businesses to successfully adapt maintenance management systems.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12063-023-00348-1.

Funding Authors acknowledge the funding support from Iran National Science Foundation (No. 99024775) and Ferdowsi University of Mashhad, which has been a joint Postdoctoral research project.

Declarations

Conflict of interest The authors have declared no conflicts of interest for this article.

References

Ab Wahid R, Corner J (2009) Critical success factors and problems in ISO 9000 maintenance. Int J Qual Reliab Manag 26(9):881–893

Adebiyi KA, Ojediran JO, Oyenuga OA (2004) An appraisal of maintenance practice in food industries in Nigeria. J Food Eng 62(2):131–133

Afsharnia F, Asoodar M, Abdeshahi A (2014) Regression Analysis and Modeling of Failure Rate and its Effective Factors on Tractors in Some Cities of Khuzestan Province. J Agric Eng 36(2):49–58
Afsharnia F, Marzban A, Asoodar MA, Abdeshahi A (2020) Availability Modeling of Sugarcane Harvesting System by Using Markov Chain. J Biosyst Eng 45(3):145–154
Ahmad WNKW, Rezaei J, Sadaghiani S, Tavasszy LA (2017) Evaluation of the external forces affecting the sustainability of oil and gas supply chain using Best Worst Method. J Clean Prod 153:242–252
Al-Turki UM, Ayar T, Yilbas BS, Sahin AZ (2014) Integrated maintenance planning. Integrated Maintenance Planning in Manufacturing Systems. Springer, Cham, pp 25–57
Amrani MA, Alhomdi M, Ghaleb AM, Al-Qubati M, Shameeri M (2020) Implementing an integrated maintenance management system for monitoring production lines: a case study for biscuit industry. J Qual Maint Eng 28(1):180–196
Anthony RN (1965) Planning and control systems: a framework for analysis. Division of Research, Graduate School of Business Administration, Harvard University
Arslankaya S, Atay H (2015) Maintenance management and lean manufacturing practices in a firm which produces dairy products. Procedia Soc Behav Sci 207:214–224
Barberá L, Crespo A, Viveros P, Stegmaier R (2012) Advanced model for maintenance management in a continuous improvement cycle: integration into the business strategy. Int J Syst Assur Eng Manag 3(1):47–63
Bekar ET, Nyqvist P, Skoogh A (2020) An intelligent approach for data pre-processing and analysis in predictive maintenance with an industrial case study. Adv Mech Eng 12(5):1687814020919207
Bengtsson M, Salonen A (2009) On the need for research on holistic maintenance. Proceedings of the 22nd international congress on Condition Monitoring and Diagnostic Engineering Management (COMADEM), pp 9–11
Bochtis DD, Sørensen CG, Busato P (2014) Advances in agricultural machinery management: A review. Biosys Eng 126:69–81
Bokrantz J, Skoogh A, Berlin C, Wuest T, Stahre J (2020) Smart maintenance: an empirically grounded conceptualization. Int J Prod Econ 223:107534
Bottani E, Ferretti G, Montanari R, Vignali G (2014) An empirical study on the relationships between maintenance policies and approaches among Italian companies. J Qual Maint Eng 20(2):135–162
Branská L, Pecinová Z, Paták M, Stankova M, Kholová P (2016) Maintenance management systems in the Czech enterprises of chemical and food industries. Trends Econ Manag 10:20–29
Campbell JD, Reyes-Picknell JV, Kim HS (2015) Uptime: Strategies for excellence in maintenance management. CRC Press
Chitsaz N, Azarnivand A (2017) Water scarcity management in arid regions based on an extended multiple criteria technique. Water Resour Manag 31(1):233–250
da Silva CAG, Rodrigues de Sá JL, Menegatti R (2019) Diagnostic of failure in transmission system of agriculture tractors using predictive maintenance-based software. AgriEngineering 1(1):132–144
Fountas S, Sorensen CG, Tsiropoulos Z, Cavalaris C, Liakos V, Gemtos T (2015) Farm machinery management information system. Comput Electron Agric 110:131–138
Fredriksson G, Larsson H (2012) An analysis of maintenance strategies and development of a model for strategy formulation. Master of science thesis in production engineering. Department of product and production development, Chalmers University of Technology, Göteborg, Sweden
Gabus A, Fontela E (1972) World problems, an invitation to further thought within the framework of DEMATEL. Battelle Geneva Research Center, Geneva, Switzerland, pp 1–8
Gandhare BS, Akarte MM (2020) Benchmarking maintenance performance in select agro-based industry. J Qual Maint Eng 28(2):296–326
Gandhare BS, Akarte MM, Patil PP (2018) Maintenance performance measurement–a case of the sugar industry. J Qual Maint Eng 24(1):79–100
Gandhi A, Purwani DR, Susanti YD, Prasetya Y (2021) The Status of Maintenance Management in Indonesia: Result from a Pilot Survey Food Snack MSMEs. Proceedings of the 11th Annual International Conference on Industrial Engineering and Operations Management, Singapore
Garg A, Deshmukh SG (2006) Maintenance management: literature review and directions. J Qual Maint Eng 12(3):205–238
Gomes CF, Yasin MM, Simões JM (2020) The emerging organizational role of the maintenance function: a strategic perspective. J Qual Maint Eng
Gopalakrishnan M (2018) Data-driven Decision Support for Maintenance Prioritisation: Connecting Maintenance to Productivity. Chalmers Tekniska Hogskola, Sweden
Hassanain MA (2002) Integrated systems for maintenance management. University of British Columbia. http://hdl.handle.net/2429/13109 (Doctoral dissertation). Accessed 23 Sept 2009
Holweg M, Davies J, De Meyer A, Lawson B, Schmenner RW (2018) Process theory: The principles of operations management. Oxford University Press
Horyovy VP (2007) Developing the production and maintenance support of enterprises of the AIC [agro-industrial complex of Ukraine]. Visnyk Ahrarnoyi Nauky, Ukraine
Hu Y, Guo Z, Wen J, Han J (2015) Research on knowledge mining for agricultural machinery maintenance based on association rules. 2015 IEEE 10th Conference on Industrial Electronics and Applications (ICIEA). IEEE, pp 885–890
Hu Y, Liu Y, Wang Z, Wen J, Li J, Lu J (2020) A two-stage dynamic capacity planning approach for agricultural machinery maintenance service with demand uncertainty. Biosys Eng 190:201–217
Jandali D, Sweis R (2018) Factors affecting maintenance management in hospital buildings: Perceptions from the public and private sector. Int J Build Pathol Adapt
Johannes K, Theodorus Voordijk J, Marias Adriaanse A, Aranda-Mena G (2021) Identifying Maturity Dimensions for Smart Maintenance Management of Constructed Assets: A Multiple Case Study. J Constr Eng Manag 147(9):05021007
Jong CH, Tay KM, Lim CP (2013) Application of the fuzzy failure mode and effect analysis methodology to edible bird nest processing. Comput Electron Agric 96:90–108
Jonsson P (2000) Towards a holistic understanding of disruptions in Operations Management. J Oper Manag 18(6):701–718
Karia N, Asaari MHAH, Saleh H (2014) Exploring Maintenance Management in Service Sector: A Case Study. Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management, Bali, Indonesia
Kheybari S, Kazemi M, Rezaei J (2019a) Bioethanol facility location selection using best-worst method. Appl Energy 242:612–623
Kheybari S, Rezaie FM, Rezaei J (2019b) Measuring the importance of decision-making criteria in biofuel production technology selection. IEEE Trans Eng Manag 68(2):483–497
Kheybari S, Rezaie FM, Naji SA, Javdanmehr M, Rezaei J (2020) Evaluation of factors contributing to the failure of information systems in public universities: The case of Iran. Inf Syst 92:101534
Kim EJ, Jeong WI, Lee YK, Lim CS (2014) Development of evaluation indicators for maintenance and preservation of agriculture and rural heritage. J Agric Ext Commun Dev 21(4):1191–1226
Kumar A, Shankar R, Thakur LS (2018) A big data driven sustainable manufacturing framework for condition-based maintenance prediction. J Comput Sci 27:428–439
Kumar A, Mangla SK, Luthra S, Ishizaka A (2019) Evaluating the human resource related soft dimensions in green supply chain management implementation. Prod Plan Control 30(9):699–715

Kurochkin VN, Seryogin AA, Valuev NV, Zabrodin VP, Gazalov VS, Nikitchenko SL (2017) Mathematical modeling of agricultural machinery technical maintenance. J Fundam Appl Sci 9(7S):742–751

Li D, Zheng Y, Zhao W (2019) Fault analysis system for agricultural machinery based on big data. IEEE Access 7:99136–99151

Liang F, Brunelli M, Rezaei J (2019) Consistency issues in the best worst method: Measurements and thresholds. Omega 96:102175

Lips M, Burose F (2012) Repair and maintenance costs for agricultural machines. Int J Agric Manag 1(1029-2016–82247):40–46

Liu Y, Hu Y, Wen J, Tang Y (2018) An overview on smart maintenance service scheduling system and theoretical basis for agricultural machinery. 2018 IEEE International Conference on Internet of Things (I Things) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData). IEEE, pp 766–771

Macchi M, Fumagalli L (2013) A maintenance maturity assessment method for the manufacturing industry. J Qual Maint Eng 19(3):295–315

Marquez AC, Gupta JN (2004) Modern maintenance management for enhancing organizational efficiency. Intelligent Enterprises of the 21st Century. IGI Global, SU, pp 321–332

Meixner O, Pöchtrager S, Haas R (2001) Determining the success factors for the introduction and maintenance of quality management in the Austrian food industry using the Analytic Hierarchy Process. Proceedings of the 6th International Symposium on the Analytic Hierarchic Process. ISAHP, pp 2–4

Milana M, Khan MK, Munive-Hernandez JE (2017) Design and development of knowledge-based system for integrated maintenance strategy and operations. Concurr Eng 25(1):5–18

Mishra D, Satapathy S (2021) Reliability and maintenance of agricultural machinery by MCDM approach. Int J Syst Assur Eng Manag. https://doi.org/10.1007/s13198-021-01256-y

Moktadir MA, Kumar A, Ali SM, Paul SK, Sultana R, Rezaei J (2020) Critical success factors for a circular economy: Implications for business strategy and the environment. Bus Strateg Environ 29(8):3611–3635

Mousavipour A, Sheikh Davoodi MJ, Ghanian M, Saeedi SN (2012) Economic comparison of two common emergency methods and oil status monitoring maintenance and repair of sugarcane harvesting machines. J Agric Eng 36(2)

Murthy DNP, Atrens A, Eccleston JA (2002) Strategic maintenance management. J Qual Maint Eng 8:287–305

Najafi P, Asoodar MA, Marzban A, Hormozi MA (2015) Reliability evaluation and analysis of sugarcane 7000 series harvesters in sugarcane harvesting. J Agric Mach 5(2):446–455

Naji A, Oumami ME, Bouksour O, Beidouri Z (2019) Mixed methods research toward a framework of a maintenance management model: A survey in Moroccan industries. J Qual Maint Eng 26(2):260–289

Nik ME, Khademolhosseini N, Abbaspour-Fard MH, Mahdinia A, Alami-Saied K (2009) Optimum utilisation of low-capacity combine harvesters in high-yielding wheat farms using multi-criteria decision making. Biosys Eng 103(3):382–388

Oliveira MA, Lopes I (2019) Evaluation and improvement of maintenance management performance using a maturity model. Int J Product Perform Manag 69(3):559–658

Parida A, Chattopadhyay G (2007) Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM). J Qual Maint Eng 13(3):241–258

Parida A, Kumar U (2006) Maintenance performance measurement (MPM): issues and challenges. J Qual Maint Eng 12(3):239–251

Patel S, Sayyed IU (2014) Impact of information technology in agriculture sector. Int J Food Agric Vet Sci 4(2):17–22

Pinjala SK, Pintelon L, Vereecke A (2006) An empirical investigation on the relationship between business and maintenance strategies. Int J Prod Econ 104(1):214–229

Pintelon LM, Gelders LF (1992) Maintenance management decision making. Eur J Oper Res 58(3):301–317

Pintelon L, Parodi-Herz A (2008) Maintenance: an evolutionary perspective. Complex system maintenance handbook. Springer, London, pp 21–48

Priyantha J (2021) Literature Review: The Role of organizational factors in maintenance organizations affecting their manufacturing performance, from Sri Lankan cultural perspective. Int J Res Innov Soc Sci 4(5)

Reis LF, Alves FJDC (2020) Brazilian sugarcane agro-industry human resources' management: strategies to increase work intensity. Gestão Produção 27(2):e5147. https://doi.org/10.1590/0104-530X5147-20

Rezaei J (2015) Best-worst multi-criteria decision-making method. Omega 53:49–57

Rezaei J (2016) Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega 64:126–130

Rohani A, Ranjbar I, Ajabshir Y, Abbaspour-Fard MH, Valizadeh M (2009) Prediction of two-wheel drive tractor repair and maintenance costs using artificial neural network in comparing with regression. J Agric Eng Res 16(1):225–235

Rohani A, Abbaspour-Fard MH, Abdolahpour S (2011) Prediction of tractor repair and maintenance costs using Artificial Neural Network. Expert Syst Appl 38(7):8999–9007

Salimi N, Rezaei J (2016) Measuring efficiency of university-industry Ph. D. projects using best worst method. Scientometrics 109(3): 1911–1938

Salonen A (2008) Strategic Factors for Maintenance in Manufacturing Industry. The proceedings of 21st International Congress and Exhibition COMADEM – 2008, Prague, The Czech Republic

Salonen A (2009) Formulation of maintenance strategies. Ma¨lardalen University, Va¨stera°s (Doctoral dissertation)

Sarbini NN, Ibrahim IS, Abidin NI, Yahaya FM, Azizan NZN (2021) Review on maintenance issues toward building maintenance management best practices. J Build Eng 44:102985

Settanni E, Heijungs R, Srai JS (2022) Where have all the equations gone? A unified view on semi-quantitative problem structuring and modelling. J Oper Res Soc 1–20

Sharma SK (2013) Maintenance reengineering framework: a case study. J Qual Maint Eng 19(2):96–113

Sharma G, Tewari PC (2019) Performance modeling and assessment of maintenance priorities for steam generation unit of a sugar plant. Int J Qual Reliab Manag 36(2):286–296

Shen JL, Liu YM, Tzeng YL (2012) The cluster-weighted DEMATEL with ANP method for supplier selection in food industry. J Adv Comput Intell Intell Inform 16(5):567–575

Singh R, Bhanot N (2020) An integrated DEMATEL-MMDE-ISM based approach for analyzing the barriers of IoT implementation in the manufacturing industry. Int J Prod Res 58(8):2454–2476

Söderberg L, Bengtsson L, Kaulio M (2017) A model for outsourcing and governing of maintenance within the process industry. Oper Manag Res 10(1):20–32

Soltanali H, Rohani A (2016) Evaluation of reliability of production systems in food industry. 10th National Congress of Agricultural Machinery Engineering (Biosystems) and Mechanization of Iran. Ferdowsi University of Mashhad, Mashhad, Iran

Soltanali H, Garmabaki AHS, Thaduri A, Parida A, Kumar U, Rohani A (2019) Sustainable production process: An application of reliability, availability, and maintainability methodologies in automotive manufacturing. Proc Inst Mech Eng O J Risk Reliab 233(4):682–697

Soltanali H, Khojastehpour M, Farinha JT (2020) Measuring the production performance indicators for food processing industry. Measurement 173:108394

Soltanali H, Khojastehpour M, Pais JEDAE, Farinha JT (2022) Sustainable Food Production: An Intelligent Fault Diagnosis Framework for Analyzing the Risk of Critical Processes. Sustainability 14(3):1083

Sørensen CG, Bochtis DD (2010) Conceptual model of fleet management in agriculture. Biosys Eng 105(1):41–50

Tan Y, Shen L, Langston C, Lu W, Yam MC (2014) Critical success factors for building maintenance business: a Hong Kong case study. Facilities 32(5/6):208–225

Terentyev SE, Gnezdova JV, Semchenkova SV (2020) Features of Machine-Technological Stations Organization in the System of Agro-Industrial Production. IOP Conf Ser Earth Environ Sci 459(6):062060

Terminology M (2010) CEN (European Committee for Standardization). European Standard EN, 13306, 2010

Thomas SJ (2005) Improving maintenance and reliability through cultural change. Industrial Press

Tsai SB (2018) Using the DEMATEL model to explore the job satisfaction of research and development professionals in china's photovoltaic cell industry. Renew Sustain Energy Rev 81:62–68

Tsang AH (2002) Strategic dimensions of maintenance management. J Qual Maint Eng

Tsarouhas P (2007) Implementation of total productive maintenance in food industry: a case study. J Qual Maint Eng 13(1):5–18

Tsolakis NK, Keramydas CA, Toka AK, Aidonis DA, Iakovou ET (2014) Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy. Biosys Eng 120:47–64

Tubis A, Werbińska-Wojciechowska S (2015) Concept of controlling for maintenance management performance: a case study of passenger transportation company. Safety and reliability of complex engineered systems proceedings of the 25th European Safety and Reliability Conference. ESREL, pp 1055–1063

Van Horenbeek A, Pintelon L (2014) Development of a maintenance performance measurement framework–using the analytic network process (ANP) for maintenance performance indicator selection. Omega 42(1):33–46

Vasudevan A, Duan X (2021) A systematic data science approach towards predictive maintenance application in manufacturing industry. Examensarbete för masterexamen. https://hdl.handle.net/20.500.12380/302632 (Master Thesis). Accessed 18 June 2021

Wen Q, Zhang JP, Hu ZZ, Xiang XS, Shi T (2019) A data-driven approach to improve the operation and maintenance management of large public buildings. IEEE Access 7:176127–176140

Wireman T (2010) Benchmarking Best Practices in Maintenance Management, 2nd edn. Industrial Press Inc., New York (Electronic)

Wu HH, Tsai YN (2012) An integrated approach of AHP and DEMATEL methods in evaluating the criteria of auto spare parts industry. Int J Syst Sci 43(11):2114–2124

Yavuz O, Doğan E, Carus E, Görgülü A (2019) Reliability Centered Maintenance Practices in Food Industry. Procedia Comput Sci 158:227–234

Zhang W, Yang D, Wang H (2019) Data-driven methods for predictive maintenance of industrial equipment: A survey. IEEE Syst J 13(3):2213–2227

Zhou Q, Jiang J, Zhao Z, Zhong J, Pan B, Jin X, Sun Y (2017) Research on the Internet of Things Platform Design for Agricultural Machinery Operation and Operation Management. International Conference on Computer and Computing Technologies in Agriculture. Springer, Cham, pp 400–410