



A critical success factors model for total productive maintenance in manufacturing industry

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Abstract

Background: Total productive maintenance (TPM) recently attracted the manufacturers and researchers of developing countries like Bangladesh because of its usefulness in waste minimization and production improvement. However, successful implementation of TPM in manufacturing industry depends on many critical factors. It is very important to know the significance level of these factors due to effective management. *Purpose:* This study aims to develop a critical success factors model for TPM implementation in manufacturing industries.

Methodology: This research used a Delphi based analytic hierarchy process (AHP) to develop the critical success factors model for TPM implementation. Data were obtained from eight manufacturing organizations of Bangladesh.

Results: The research found that the lack of managerial expertise and staff motivation are the most critical factors for TPM implementation in developing countries like Bangladesh. This research can assist the manager to understand the nature of each critical factors. Finally, a sensitivity analysis was performed to justify the robustness of the rankings of the factors.

Keywords: analytic hierarchy process (AHP), critical success factors model, Delphi; manufacturing industry, total productive maintenance (TPM)

1. Introduction

In today's industrial scenario, almost all the manufacturing processes are carried out by using sophisticated machines and equipment. Manufacturers are now concerned about the effectiveness and efficiency of these machinery and equipment (Brodny *et al.*, 2017) ^[9]. Meanwhile, manufacturing companies are facing a lot of problems to maintain the steady state performance of machine and equipment. In addition, manufacturing firms are more focused on improving production performance in terms of productivity output in order to survive in a competitive environment since high productivity performance is directly related to equipment efficiency and process control (Azizi, 2015) ^[6]. Besides, minimization of wastage in terms of materials, times and investments is the major focus of attention. These wastages are occurred due to idle manpower, breakdown of machines, problems with tooling and part unavailability in time, etc (da Silva *et al.*, 2017) ^[12]. Lack of adopting proper maintenance policy and inadequate attention on maintenance management is one of the major reasons for these wastages. Therefore, total productive maintenance (TPM) contributes to manufacturing industries in formulating a proper maintenance strategy and increasing efficiency of machines and equipment (Velmurugan & Dhingra, 2015 ^[41]; Joshi & Bhatt, 2018) ^[20]. Total productive maintenance is completely new philosophy and Seiichi Nakajima developed TPM based on the experience of the realistic use of best maintenance in Japan (Nakajima, 1988) ^[28]. Maintenance has generally been regarded as a support function and nonproductive. Maintenance investment is now one of a company's core functions because it gives better quality, safety, and dependability, flexibility and lead times. (Teresko, 1992 ^[40]; Busse *et al.*, 2018) ^[10]. Thriving in this competitive manufacturing world

requires minimization of wastage and improving productivity through adopting proper maintenance policy and involving everyone in the organization in maintenance activity to some extent. Total productive maintenance involves the top management and every employee in maintenance activity and focuses on efficient production not merely efficient maintenance (Singh *et al.*, 2018) ^[36]. Total Productive Maintenance (TPM) philosophy optimizes equipment performance, removes faults and encourages self-sufficient maintaining among operators through daily activities involving all force work (Nakajima, 1988) ^[28]. TPM focuses on increasing the efficiency and productivity of existing equipment through maintenance of equipment at optimal levels to reduce the cost of its life cycle (Modgil & Sharma, 2016) ^[27]. In an effort to increase the efficiency and productivity of the manufacturing system, companies are making investments for adopting this TPM philosophy. However, in most of cases they face a lot of challenges to implement TPM in the manufacturing industries. Successful implementation of TPM philosophy depends on the many factors. Lack of understanding of these critical success factors and focusing on action according to these factors by the managers are the main reasons for the failure of TPM implementation in manufacturing industries. Investigating the critical success factors for TPM implementation is vital in today's manufacturing scenario. Proper investigation on success factors can help the manufacturing organizations to formulate more effective strategies. There are few studies on success factors for TPM implementation in manufacturing industries. Shen (2015) ^[35] presented a qualitative assessment of key success factors in enterprises. Seng *et al.* (2017) ^[32] investigated the factors of successful TPM implementation for Malaysian manufacturing organizations. However, there is a lack of comprehensive investigation on

success factors to implement TPM for manufacturing industries in the context of Bangladesh. Bangladesh is a developing country. Rapid development of its manufacturing sector demands a comprehensive quantitative investigation of critical success factors to implement the TPM effectively in the manufacturing industries. A quantitative analysis of success factors of TPM may help manufacturing firms and industrial engineers to formulate effective strategy for TPM implementation. Bangladeshi manufacturing organizations are facing a lot of problems regarding the efficiency of machines and equipment. However, implementing TPM in manufacturing industries has also become challenging due to improper strategy based on critical success factors. Therefore, it is imperative to quantitatively assess the critical success factors for implementing TPM in the context of Bangladesh. It will help industrial managers and maintenance managers to formulate effective strategy for successful TPM implementation. The goal of this study is to identify key success factors and establish a model for evaluating the implementation and quantitative evaluation of TPM within the manufacturing sector in Bangladesh. Finally, other operational consequences for the successful implementation of TPM in manufacturing industries were proposed. To achieve the aims, a Delphi-based analytic hierarchical process (AHP) approach was applied for identifying and quantifying the critical success factors. Delphi method was used to extract data from systematic and structured questionnaires given to experts. AHP method was used to analysis the critical factors and rank them according to their intensity. This paper is organized into 7 sections. Section 1 reviews the background of this study. Section 2 reviews the related literature on TPM implementation. Delphi-based AHP approach is presented in section 3. An application of the proposed approach is described in section 4. Section 5 presents and discusses the results. A sensitivity analysis is performed in section 6. Section 7 concludes the paper.

2. Literature review

2.1 Total Productive Maintenance (TPM)

Total productive maintenance (TPM) is productive maintenance carried out by all managers and workers through small group activities (Seiichi Nakajima, 1988). Although, TPM is one of the popular maintenance strategies, it has close relationship with the quality of products (Cua *et al.*, 2001^[11]; Kedar *et al.*, 2016^[21]; Díaz-Reza *et al.*, 2019)^[13]. TPM has been widely used to meet the lack of synergy between maintenance management and quality improvement strategies in the organization. With increased global competition, manufacturing organizations have shifted their attention to meet market conditions in terms of performance and quality (Yamashina, 1995^[44]; Liu *et al.*, 2019)^[23]. In order to improve profitability, manufacturing companies must introduce quality and performance changes in all dimensions of their operations (Ben-Daya and Duffuaa, 1995)^[7]. Maintenance activities and management play an important role here. Manufacturing organizations must consider maintenance as an important budget item and integrate the maintenance strategy with the organization's core strategy (Seng *et al.*, 2017)^[33]. TPM is a strategic approach that improves the maintenance activities in the organization and brings maintenance into focus. TPM has been recognized as a strategic weapon of increasing production effectiveness and

improving manufacturing performances (Dwyer, 1999; Dossenbach, 2006^[15]; Hooi *et al.*, 2017)^[17]. Over the last three decades, TPM has been widely used internationally to achieve the organizational objectives (Ahuja *et al.*, 2004)^[3]. TPM maximizes equipment effectiveness and lifetime through proper maintenance activities. The three ultimate goals of TPM are 'zero defects', 'zero accident', and 'zero breakdowns' (Nakajima, 1988; Willmott, 1994)^[42]. TPM ensures the efficient management of plant assets and optimizes equipment reliability (Maggard and Rhyne, 1992)^[24]. Therefore, by everyday activities, TPM prevents breakdowns and encourages autonomous management by its operators (Bhadury, 2000^[8]; Adesta *et al.*, 2018)^[1]. TPM aims ultimately to optimize delivery time, service standard and productivity in order to meet customer requirements and demands (Singh and Ahuja, 2015)^[37]. This creates a culture of cooperation and mutual understanding between managers, maintenance workers and engineers (Witt, 2006)^[43].

2.2 TPM implementation: Critical success factors

Successful implementation of TPM in manufacturing industry depends on many critical factors. Although TPM is all about maximum asset utilization and increasing the capacity of plant with little investment (Nallusamy *et al.*, 2017)^[29], it is not possible to implement TPM in a manufacturing plant without the commitment from the top management. Swanson (2001)^[39] describes the four key elements of TPM: worker training, operator involvement, teams and preventive maintenance. Hooi and Leong (2017)^[18] emphasize on the top management role and commitment for TPM implementation at the early stage. Focused improvement team and their training are also required for successful implementation of TPM (McKone *et al.*, 2001)^[26]. In measuring the success of TPM implementation, proper documentation and extent of operator involvement play significant role (Maier *et al.*, 1998)^[25]. Before the involvement of operators in TPM project, they must be educated about the philosophy of TPM and proper training must be facilitated (Seth and Tripathi, 2005^[34]; Siong and Ahmed, 2007)^[38]. These can only be done if top management ensures enough support and makes contribution (Ahuja and Khamba, 2008). It is necessary to assess the significance of these factors for successful TPM implementation.

2.3 AHP

The AHP method is used to rank some selected alternatives with respect to some criteria. AHP was developed by Thomas L. Saaty (1980)^[31]. AHP simplifies the evaluation process of alternatives through a systematic pairwise comparison. This pairwise comparison between the criteria and alternatives uses the fundamental scale of absolute numbers. Al Khalil (2002)^[4] used AHP for the key project success variable to choose the most suitable project delivery method. Amponash (2011) determined the critical success factors for procurement of capital projects using AHP. Ilbahar, Karaşan, Cebi, and Kahraman (2018)^[19] used Pythagorean fuzzy AHP & fuzzy inference system to evaluate risk for occupational health and safety. AHP provides easy quantification of different factors by converting the subjective judgment into numeric. Lalib *et al.* (1998) proposed a model to select the appropriate maintenance system using AHP and fuzzy integrated

approach. This research uses AHP for the assessment of critical success factors of TPM implementation. This research aims at developing the critical success factors model of successful TPM implementation in manufacturing industry and assessing their intensity. To achieve these goals, 8 leading manufacturing organizations have been studied and series of discussions have been done with the industry experts.

3. Solution Methodology

3.1 Delphi method

Delphi method is one of the popular and widely used method in which a group of experts fill a series of questionnaires designed to extract the data. In this research, this method is used for exploring the critical success factors which are associated with successful TPM implementation. For obtaining the proper data, this research considered several technical and operational experts from different manufacturing industries in Bangladesh. In Delphi method, there is no hard and fast rule for selecting the number of experts for data collection. In general, 10 to 15 experts are enough to get suitable and reliable results. Okoli and Pawlowski (2004) [30] suggested to select 10-18 experts for obtaining proper and reliable data. In this research, 14 experts have been selected from 8 different manufacturing industries in Bangladesh. Several meetings have been done for proper and reliable data extraction. The proposed framework is shown in Figure 1.

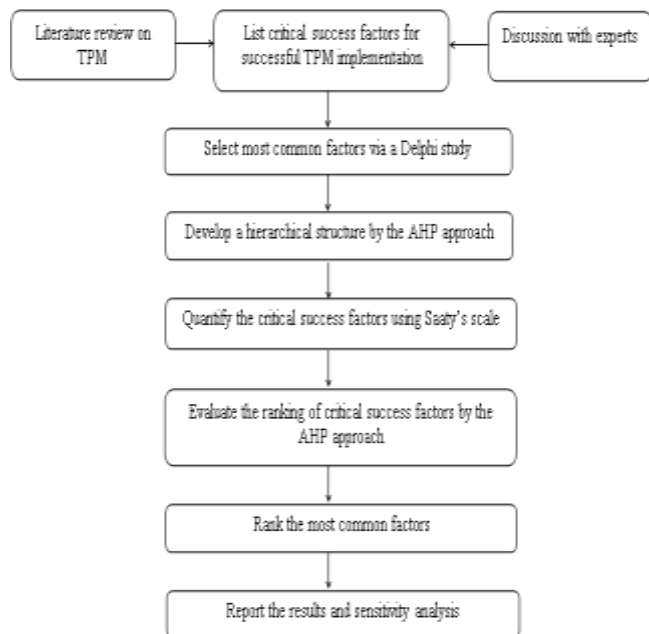


Fig 1: Proposed framework of the current research

3.2 AHP Methodology

Analytical hierarchy process (AHP) is a weight determination process through developing a hierarchy of goals, their affiliated criteria and alternatives. This research attempts to assess the critical success factors of TPM implementation in manufacturing industry applying AHP. The steps for AHP are presented below:

Step 1: Define the objective: The objective of this research is defined as the assessment of the critical success factors in case of TPM implementation in manufacturing industries.

Step 2: Select the alternatives and criteria: AHP performs the assessment process of alternatives with respect to some

criteria. In this research, the critical factors for TPM implementation success, selected by the experts and from different literatures are considered as alternatives. The criteria are also selected by consulting with the experts so that they ensure the relevance.

Step 3: Build pairwise comparison matrix: In this step, a pairwise comparison relation matrix (A) of selected criteria and identified alternatives (critical success factors) are developed using the fundamental scale of AHP as given in table 1. In the matrix A , each element a_{ij} means the relative importance of i^{th} factor with respect to j^{th} factor. If the identified factor is m , the pairwise comparison matrix will be as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1m} \\ a_{21} & 1 & \dots & a_{2m} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & 1 \end{bmatrix} \tag{1}$$

The relative importance of j^{th} factor with respect to i^{th} factor will be as follows:

$$a_{ji} = 1/a_{ij}; a_{ij} > 0 \text{ for } i, j = 1, 2, 3, \dots, m$$

There is no negative entry in matrix A .

Table 1: Relative importance of factors

Relative importance (a_{ij})	Description
1	Equal importance of i and j
3	Moderate importance of i over j
5	Strong importance of i over j
7	Very strong importance of i over j
9	Absolute importance of i over j
2,4,6,8	Intermediate values

Step 4: Calculate the priority weights: Eigenvalues and eigenvectors are calculated using the pairwise comparisons matrices of factors. Weights of the factors are calculated using the following equation:

$$\begin{bmatrix} 1 & a_{12} & \dots & a_{1m} \\ a_{21} & 1 & \dots & a_{2m} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_m \end{bmatrix} = \lambda_{max} \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_m \end{bmatrix} \tag{2}$$

Where λ_{max} denotes the maximum eigenvalue of matrix A which can be calculated from eigenvector W_{max} .

$$W_{max} = [w_1, w_2, \dots, w_m] \tag{3}$$

The normalized value of factors can be calculated by a normalization process for the eigenvector, as shown below:

$$W = \left[\frac{w_1}{\sum_{i=1}^m w_i}, \frac{w_2}{\sum_{i=1}^m w_i}, \dots, \frac{w_m}{\sum_{i=1}^m w_i} \right]^T \tag{4}$$

Where w denotes the weight coefficient vector and w_i denotes the weights of factors i . Here, m represents the number of factors.

Step 5: Investigation of the consistency ratio: Consistency ratio can be calculated using the following equation:

$$CR = CI/RI \tag{5}$$

Where, CR denotes the consistency ratio, CI denotes the consistency index, and RI denotes the random consistency index. Value of RI is shown in table 2. CI values can be computed using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

For a better consistency level, the value of CR should be less than 0.10.

Table 2: Random consistency index values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. An illustrative example

Table 3: Critical success factors for implementing TPM in manufacturing industry

Critical success factors	Source
(1) Proper strategic planning (CSF ₁)	Expert opinion
(2) Data management system (CSF ₂)	Expert opinion
(3) Staff motivation (CSF ₃)	Expert opinion
(4) Managerial expertise (CSF ₄)	Expert opinion
(5) Training and education (CSF ₅)	Seth and Tripathi (2005) [34], Siong and Ahmed(2007) [38]
(6) Top management’s contribution and support (CSF ₆)	Ahuja and Khamba (2008)
(7) Organizational structure (CSF ₇)	Expert opinion
(8) Monitoring and evaluation (CSF ₈)	Hansson et. al. (2003)

The assessment criteria for the AHP method were also selected by the industry experts. These are: (i) difficulty of implementation (C_1), (ii) implementation time (C_2), (iii) investment (C_3) and (iv.) management complexity (C_4)

4.2 Critical success factors model for TPM

4.2.1 Phase 1: pairwise comparison of criteria using Saaty’s scale

The main goal was to develop the critical success factors model of TPM implementation in manufacturing industries. A hierarchical model, shown in Figure 2, was developed for better understanding of the methodology.

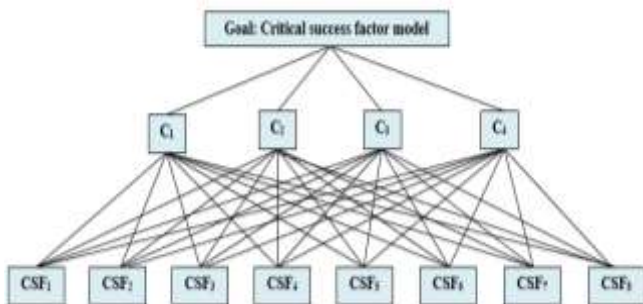


Fig 2: Hierarchical model of critical success factors for TPM.

In this hierarchical model, first level indicates the objective

In this section, to illustrate the concepts and computations of the proposed framework for assessing the critical success factors for successful TPM implementation in manufacturing industry, a case study of manufacturing industries of Bangladesh is presented. 8 manufacturing farms have been selected for the study. The main objectives are: (i) to develop critical success factors model for TPM implementation for manufacturing industry and (ii) to assess the intensity of these factors.

4.1 Data collection via Delphi method

Recently many manufacturing companies in Bangladesh are trying to implement total productive maintenance (TPM) in their farms. A preliminary list of critical success factors for successful TPM was prepared from reviewing the existing literature. Then a series of discussion were held with 14 managers and industry experts from 8 manufacturing farms in Bangladesh. Using the Delphi method, finally 8 critical success factors were selected for further study in which 4 were selected from expert opinions and the rest 4 were selected from existing literature. Table 3 shows the selected critical success factors which will be assessed using AHP method.

of this study and the next two levels indicate the assessment criteria and critical factors respectively. Assessment of each factor

Considered the impact of all the assessment criteria. At first, a pairwise comparison matrix among the assessment criteria was developed using Saaty’s scale. Table 4 shows the pairwise comparison matrix and relative weights of criteria C_1 (difficulty of implementation), C_2 (implementation time), C_3 (investment) and C_4 (management complexity).

Table 4: Pairwise comparison matrix of criteria

Criteria	C_1	C_2	C_3	C_4	Relative weight
C_1	1	1/3	1/5	1/3	0.079
C_2	3	1	1/3	1/4	0.151
C_3	5	3	1	2	0.457
C_4	3	4	1/2	1	0.314

$$\lambda_{max} = 4.254636; CI = 0.084879; CR = 0.09 < 0.10$$

Here, C_3 and C_4 have got relatively more weights than the other two.

4.2.2 Phase 2: pairwise comparison of all factors against each criterion

In this phase, all the selected critical success factors were assessed against each criterion.

4.2.2.1 Assessment of factors against difficulty of implementation

A pairwise comparison matrix was developed for all the

factors considering the level of difficulty of implementation. Table 5 shows the pairwise comparison matrix and relative weights of all factors against the criterion C₁.

Table 5: Pair-wise comparison for difficulty of implementation

	CSF ₁	CSF ₂	CSF ₃	CSF ₄	CSF ₅	CSF ₆	CSF ₇	CSF ₈	Relative Weight	Rank
CSF ₁	1	1/2	3	3	4	3	4	4	0.2461	1
CSF ₂	2	1	2	3	3	2	2	2	0.2172	2
CSF ₃	1/3	1/2	1	2	3	2	1/2	2	0.1166	4
CSF ₄	1/3	1/3	1/2	1	1/2	2	1/2	2	0.0760	6
CSF ₅	1/4	1/3	1/3	2	1	2	1/3	3	0.0894	5
CSF ₆	1/3	1/2	1/2	1/2	1/2	1	1/2	2	0.0679	7
CSF ₇	1/4	1/2	2	2	3	2	1	2	0.1338	3
CSF ₈	1/4	1/2	1/2	1/2	1/3	1/2	1/2	1	0.0531	8

$\lambda_{max} = 8.842881$; $CI = 0.120411$; $CR = 0.08 < 0.10$

Here, CSF₁ (proper strategic planning) and CSF₂ (data management system) have got relatively more weights than others. Most of the time, the manufacturing industries lack proper strategic planning for TPM implementation. As a result, after deciding to adopt the TPM philosophy in the farm, it loses the direction for having no proper strategic planning. In developing country like Bangladesh, most of the manufacturing farms face difficulties to establish proper

data management system.

4.2.2.2 Assessment of factors against implementation time

Considering the duration to implement, a pairwise comparison matrix was developed among the critical success factors of TPM implementation. Table 6 shows the relative weights of the success factors.

Table 6: Pair-wise comparison for implementation time

	CSF ₁	CSF ₂	CSF ₃	CSF ₄	CSF ₅	CSF ₆	CSF ₇	CSF ₈	Relative Weight	Rank
CSF ₁	1	2	1/3	1/3	1/3	1/2	1/2	1/3	0.0579	8
CSF ₂	1/2	1	1/2	1/3	1/4	1/3	1/2	1/4	0.0438	7
CSF ₃	3	2	1	1/2	1/2	1/3	2	1/3	0.0969	5
CSF ₄	3	3	2	1	2	3	3	1/2	0.1942	2
CSF ₅	3	4	2	1/2	1	2	2	1/3	0.1462	3
CSF ₆	2	3	3	1/3	1/2	1	2	1/3	0.1199	4
CSF ₇	2	2	1/2	1/3	1/2	1/2	1	1/3	0.0738	6
CSF ₈	3	4	3	2	3	3	3	1	0.2674	1

$\lambda_{max} = 8.570221$; $CI = 0.081460$; $CR = 0.06 < 0.10$

Here, organizational structure (CSF₈) and managerial expertise (CSF₈) have got relatively more weights than others while considering the implementation time. Modifying the organizational structure in a manufacturing farm requires a lot of time. Developing the managerial expertise of the key persons also require much time. Managerial expertise can be developed through proper training and development.

4.2.2.3 Assessment of factors against investment

Factors were assessed against the amount of investment required for implementation. Table 7 shows the pairwise comparison matrix among the critical factors with respect to required investment for implementation. CSF₃ (staff motivation) and CSF₅ (training and development) have got the higher weights than the others. Both of the factors require a large amount of investment for implementing TPM throughout the organization.

Table 7: Pair-wise comparison for investment

	CSF ₁	CSF ₂	CSF ₃	CSF ₄	CSF ₅	CSF ₆	CSF ₇	CSF ₈	Relative Weight	Rank
CSF ₁	1	1/2	1/4	1/4	1/4	1/3	1/2	1/2	0.0417	7
CSF ₂	2	1	1/4	1/2	1/3	1/2	1/2	1/2	0.0596	8
CSF ₃	4	4	1	2	2	3	2	2	0.2440	1
CSF ₄	4	2	1/2	1	1/2	2	2	3	0.1541	3
CSF ₅	4	3	1/2	2	1	3	3	4	0.2226	2
CSF ₆	3	2	1/3	1/2	1/3	1	2	2	0.1102	4
CSF ₇	2	2	1/2	1/2	1/3	1/2	1	2	0.0933	5
CSF ₈	2	2	1/2	1/3	1/4	1/2	1/2	1	0.0745	6

$\lambda_{max} = 8.425444$; $CI = 0.060777$; $CR = 0.04 < 0.10$

As TPM involves the operators in an organization, they need to be motivated for implementing and adopting TPM. Most of the times, they treat the initiative of TPM implementation as extra work or burden. So, reward should be declared by the manufacturing farm for employees and

operations for implementing TPM. Investments are required for this.

4.2.2.4 Assessment of factors against managerial complexity

TPM success factors were assessed with respect to

managerial complexity of implementing this factors. Table 8 shows the pairwise comparison matrix of the success factors

considering managerial complexity.

Table 8: Pair-wise comparison for management complexity

	CSF ₁	CSF ₂	CSF ₃	CSF ₄	CSF ₅	CSF ₆	CSF ₇	CSF ₈	Relative Weight	Rank
CSF ₁	1	2	4	3	4	3	3	3	0.2813	1
CSF ₂	2	1	1/2	1/3	2	1/2	1/2	1/3	0.0662	6
CSF ₃	4	4	1	1/3	2	1/2	1/2	1/3	0.0688	7
CSF ₄	4	2	1/2	1	3	3	3	2	0.1938	2
CSF ₅	4	3	1/2	2	1	1/2	1/2	1/3	0.0463	8
CSF ₆	3	2	1/3	1/2	1/3	1	3	1/2	0.1113	4
CSF ₇	2	2	1/2	1/2	1/3	1/2	1	1/2	0.0851	5
CSF ₈	2	2	1/2	1/3	1/4	1/2	1/2	1	0.1472	3

$\lambda_{max} = 8.671789$; CI = 0.095969; CR = 0.07 < 0.10

Here, CSF₁ (proper strategic planning) and CSF₄ (managerial expertise) have got relatively higher weights. Without proper strategic planning, TPM implementation will become difficult. Formulation of proper strategic planning has a lot of managerial challenges.

4.2.2.5 Phase 2: Development of ranking of critical Success Factors

Finally, an overall ranking of the critical success factors was developed considering all the criteria. Table 9 shows the global rank of the success factors. Here, CSF₄ (managerial expertise) got the highest global weight and CSF₂ (data management system) got the lowest global weight.

Table 9: Overall rank of the success factors

	C ₁ (0.079)	C ₂ (0.151)	C ₃ (0.457)	C ₄ (0.314)	Global Weight	Global Rank
CSF ₁	0.2461	0.0579	0.0417	0.2813	0.1356	4
CSF ₂	0.2172	0.0438	0.0596	0.0662	0.0718	8
CSF ₃	0.1166	0.0969	0.2440	0.0688	0.1569	2
CSF ₄	0.0760	0.1942	0.1541	0.1938	0.1666	1
CSF ₅	0.0894	0.1462	0.2226	0.0463	0.1454	3
CSF ₆	0.0679	0.1199	0.1102	0.1113	0.1088	6
CSF ₇	0.1338	0.0738	0.0933	0.0851	0.0911	7
CSF ₈	0.0531	0.2674	0.0745	0.1472	0.1248	5

For developing country like Bangladesh, managerial expertise plays a major role for successful TPM implementation in manufacturing firm. Staff motivation is

also very crucial for successful TPM implementation as CSF₃ (staff motivation) got the second highest global weight.

5. Discussion

In this section, we discuss the details of our research findings. This findings may help to understand the critical success factors of TPM implementation in manufacturing industry. The findings reveals that the critical success factors can be summarized as follows:

CSF₄ > CSF₃ > CSF₅ > CSF₁ > CSF₈ > CSF₆ > CSF₇ > CSF₂

Here, managerial expertise (CSF₄) was ranked highest and data management system (CSF₂) was ranked lowest. These indicate that for a manufacturing organization managerial expertise plays the most crucial role in TPM implementation. Managers are the key role players in TPM implementation. They involve the operators and other staffs in TPM implementation in an organization. So, the success is largely dependent on their expertise. Successful implementation of TPM requires the full involvement of the operators and staffs. For this reason, staff motivation (CSF₃) plays a vital role and proper policy should be formulated for motivating operators and staffs through rewards. TPM follows some systematic steps and methods. Without proper training and education of the managers and operators, implementation of TPM will become very difficult. Proper training and education (CSF₅) was ranked third in this research. Proper strategic planning (CSF₁) was ranked next.

Successful implementation of TPM requires proper strategic planning. Monitoring and evaluation (CSF₈) of this strategic plan is also required. Sometimes, the structure of the organization is required to be changed for TPM implementation purpose. But, changing the organizational structure is very time consuming and sometimes very difficult. Organizational structure (CSF₇) got low global weight.

6. Sensitivity analysis

In multi-criteria decision analysis, sometimes results may be affected by the vagueness of the judgment by the experts. Therefore, robustness of ranking should be investigated by performing sensitivity analysis. Ranking of the factors are dependent on the weights of the criteria. In this research, the weights of the criteria were obtained by pair-wise comparison matrix which was developed using the subjective data from the experts. Because of the vagueness of this subjective data, a sensitivity analysis was performed for ranking the success factors of TPM implementation. Table 10 shows the varying weights of different criteria used for sensitivity analysis. In this research, C₃ (investment) got the highest weight.

Table 10: Sensitivity analysis

Criteria	Weights of criteria									
	0.079	0.113	0.105	0.098	0.073	0.063	0.052	0.042	0.034	0.020
C ₁	0.151	0.341	0.291	0.186	0.093	0.081	0.077	0.062	0.053	0.031
C ₂	0.457	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
C ₃	0.314	0.446	0.404	0.416	0.434	0.356	0.272	0.196	0.113	0.049
Total	1	1	1	1	1	1	1	1	1	1

For sensitivity analysis, the weight of this criteria was varied from 0.1 to 0.9 in increments of 0.1. Simultaneously, the weights of other criteria were changed accordingly. Weights of criteria C₁, C₂ and C₃ were varied from 0.020 to

0.113, 0.031 to 0.341 and 0.049 to 0.446 respectively. From Table 11, it should be noted that the rankings of the critical success factors have changed as the weight of the major criteria is varied.

Table 11: Ranking according to sensitivity analysis

Critical Success Factors	Normal (0.457)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
CSF ₁	4	1	2	2	2	4	4	6	7	4
CSF ₂	8	8	8	8	8	8	8	8	8	8
CSF ₃	2	6	4	4	3	2	1	1	1	2
CSF ₄	1	2	1	1	1	1	2	3	3	1
CSF ₅	3	5	5	5	4	3	3	2	2	3
CSF ₆	6	4	6	6	6	6	6	4	4	6
CSF ₇	7	7	7	7	7	7	7	7	5	7
CSF ₈	5	3	3	3	5	5	5	5	6	5

CSF₁ (proper strategic planning) ranks first when the weight of the criteria C₃ (investment) is 0.1. CSF₄ (managerial expertise) ranks first when criteria C₃ weights from 0.2 to 0.5 and 0.9. Finally, CSF₃ (staff motivation) ranks first when the weight of criteria C₃ varies from 0.6 to 0.8. The weight of criteria C₃ (investment) and rankings of the critical factors during sensitivity analysis are presented in Figure 3.

AHP method. Three criteria and eight critical success factors were analyzed. Among them managerial expertise and staff motivation got the most significance. After the assessment of the critical success factors, sensitivity analysis was done to confirm the stability of the ranking. Beside AHP technique, this research direction may be explore further by utilizing extension of AHP technique like, fuzzy-AHP, Pythagorean fuzzy AHP & fuzzy inference system, interval rough AHP. This research may help manufacturing companies to develop business policies related to critical success factors in TPM implementation.

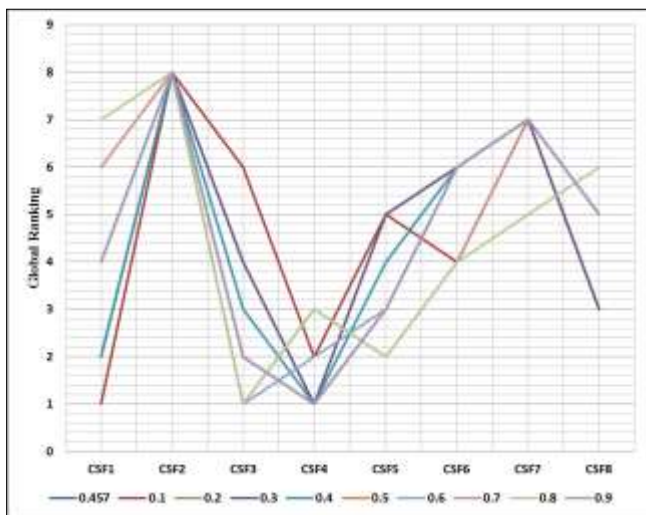


Fig 3: Sensitivity analysis of critical success factors of TPM implementation in manufacturing industry (by rank)

7. Conclusions

In this modern manufacturing era, many manufacturing organizations are starting to adopt TPM (total productive maintenance) to improve the business. The adoption of TPM is still in the early stage in Bangladesh. Manufacturing organizations are facing challenges in adopting TPM in their farms. Therefore, this research contributes to the TPM literature by assessing the significance of each critical success factor in TPM implementation using a Delphi based

8. References

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