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Framework for sustainable maintenance system: ISM–fuzzy MICMAC and TOPSIS approach

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Abstract

Due to the increasing complexity of manufacturing processes and automation, maintenance of all machines and equipments has become challenging task for production managers today. Due to lack of sensitivity for maintenance, share of maintenance cost in total product cost is also increasing along with decreased productivity. Organizations are either quite slow or getting failed in updating their maintenance systems with time. Keeping in view the importance of maintenance in today's context, this study has tried to develop a framework for a sustainable maintenance system for manufacturing organizations. Usually organizations are not able to identify critical factors for effective maintenance. Therefore, in this context, the study has identified fourteen factors for the effective maintenance management from the literature review. Some of these factors are process oriented and some are result oriented. Interpretive structural modeling approach is applied for the development of structural relationship among the factors from a strategic perspective. Fuzzy MICMAC analysis is then carried out to categorize these factors based on their driving and dependence value. Further to prioritise major driving factors, Technique for order preferences by similarity of an ideal solution approach has been also applied. It is observed that top management support and commitment, strategic planning and implementation, continuous upgradation of maintenance system to reduce manufacturing lead time and cost are major factors to ensure the sustainable competitive advantage.

Keywords Maintenance management · Sustainability · Productivity · Manufacturing strategy · Fuzzy methods

1 Introduction

Manufacturing organisations are the core of the economy for most of the developing countries like India. They contribute around 15% in the countries GDP (Word Development Indicators 2013). However, it has been noted that, this share has been decreasing

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continuously. Economic recessions and the dynamic environment are the main challenges today for sustainable growth of businesses. Thus to stay competitive in such a competitive environment, manufacturing organizations need to be sustainable by reducing product cost, manufacturing lead time, product rejections, break downs etc. According to Komonen (2002), maintenance cost estimates around 25% of the overall operating cost in manufacturing organizations. Poor maintenance does not only increase the product cost, but it also reduces overall productivity.

Various strategies like integrated production systems, integrated supply chain, automation, etc. have already been utilized for increasing the productivity and profits. Maintenance management provides the next big opportunity, which the organisations can en-cash for increasing the productivity and profitability. It thus helps in increasing the competence of the firm on the basis of cost, delivery performance and quality. Maintenance is the combination of the actions during the lifecycle of an item, namely all technical, administrative and management actions (Narayan 2012). Maintenance is more than just to bring the equipment back to its working conditions. It helps the firm to achieve their overall goals and helps in increasing their competitiveness through improved reliability, quality and ability to meet demand (Singh and Sharma 2015). Productivity has been improved dramatically with the improved equipment efficiency. However, equipments are getting more complex and expensive. They get degraded with the period of time and ultimately become non operational, thus incur heavy losses to the industry. But the rate of degradation depends on the effectiveness of maintenance management program. Thus narrowly defined operational perspective is shifting, to an organizational strategic perspective. But with increasing automation, complexity in equipment and shift from man to machine, the maintenance cost is rising. Even in some industries like petrochemical, mining industries, the maintenance cost may surpass the operational cost (Parida et al. 2015). Therefore, in many leading firms, it was once regarded as the necessary evil. But the accelerating developments in the field of maintenance have changed the concept and application of maintenance policies (Bottani et al. 2014). The concept of corrective maintenance is being taken over by the systematic preventive approach (Wu et al. 2013). Thus the maintenance activities, which earlier used to be reactive and expensive, are now moving toward proactive and cost effective maintenance practices like preventive maintenance, condition based maintenance. Therefore the business leaders are using it to optimize their productivity and maximize the overall equipment effectiveness (OEE). Singh et al. (2013a) have found in their study that the systematic application of maintenance system helped Munjal Showa Limited (MSL), a shock absorber manufacturer in India to achieved 68% reduction in space, 93% reduction in breakdowns, 48% reduction in cycle time and massive increase in productivity by 52%.

Availability and reliability of equipments are improved by an effective maintenance program. Therefore, waste reduction and an increase in profit can only be achieved if the maintenance program is employed effectively. The best way to generate profit is by managing equipment maintenance (Bartz et al. 2014). It is observed that in developing countries, organizations ignore preventive maintenance programs and mainly are working on breakdown maintenance approach. Appropriate frameworks for successful implementation of maintenance systems are also not easily available. Most of the organizations are not aware of role of maintenance systems in developing sustainable manufacturing process. Therefore, objectives of this study are as follows:

- To identify the factors for effective maintenance from the literature review.
- To develop the structural relationship framework among these factors by fuzzy Interpretive structural modelling (ISM) approach.

- Categorization of these factors by Fuzzy-MICMAC analysis on the basis of driving and dependence values of these factors.
- To rank these factors based on their importance by technique for order preferences by similarity of an ideal solution (TOPSIS) approach for strategy perspective.

The rest of the paper is organized as follows: Section 2 deals with literature review for identifying the factors for sustainable performance improvement. Section 3 deals with the research methodology used to analyze the factors, section 4 deals with the results and analysis and finally section 5 is the concluding remark.

2 Literature review

Even after development of different maintenance models, organizations are not able to realize the full potential of maintenance program. This can be attributed to the lack of integration between short term and long term strategic goals of the organisation. Thus, there is an impending need to integrate the technical and commercial aspects with long-term perspective. Therefore, the major initial step for successful implementation of maintenance program is to find the critical success factors of maintenance management. Korpela and Tuominen (1996) have defined critical success factors as the variables that when properly managed, maintained or sustained can help the organization to achieve its objectives. These factors are combination of process and result parameters (Pettit and Beresford 2009).

The major critical factors were identified through literature review, brainstorming with maintenance management experts, nominal group technique and idea engineering. These factors are the combination of corporate objectives, business practices, and key functional areas. Four to five factors have been taken from each level. While selecting the critical factors, many personal and group interactions with experts were carried out. Fourteen identified critical factors for effective maintenance are described in the following section.

2.1 Top management support and commitment

Top executives should be active participants in the maintenance department. Their involvement serves as a symbol of commitment to the other employees. Many a times, the employees show resistance to change, at that point top management plays a crucial role of acting as a torchbearer. Like at MSL, India top management support helped in successful implementation of TPM (Singh et al. 2013a). Therefor top management must show up the full commitment towards maintenance and reliability issues to ensure the successful accomplishment of the programs and achieve goals (Lorén and Maré 2015; Everett 2002). Management commitment means committing own time and resources (Singh et al. 2016) for the improvement of quality. It fosters the environment to achieve quality, excellence, competitiveness and continuous improvement (Graham et al. 2014). Highly motivated management helps in creation of motivated employees, which in turn helps in achieving the organizational goals. Harrington (1987) also noted that the improvement in processes is directly proportionate to the rate of commitment demonstrated by the top management.

2.2 Participatory and innovative work culture

Culture is the prerequisite to sustain the maintenance program in the organization. An organization's expectations, philosophy, experiences and values build up the work culture of the organization. It holds them together, and is expressed in their self-image, the outside world interactions and inner workings (Block et al. 2014). It helps in cultivating the innovation and quality with clarity in the minds. Participation of entire team helps to promote value and norms which can help the organization to reach its strategic objectives. A supportive organization results in highest creativity by the satisfied employees. It enables the development of innovation management, employee involvement, knowledge sharing and thus having a potentially significant impact on operational performance of the company (Yunis et al. 2013).

2.3 Strategic planning and implementation

Strategies help the firm, to integrate their quality requirement with business activities (Yunis et al. 2013), by providing directions to operations strategy for sustainable competitiveness. It is needed to integrate the company's mission, vision and strategic priorities. This integration will help in identifying the obstacles and driving forces for achieving the desired goals (Abreu et al. 2013). Hassini et al. (2015) have observed that scheduling of production and maintenance operations should be properly integrated. Selection of effective and efficient strategy is most crucial to enhance the operational capabilities continually, which helps in reducing the maintenance cost and increasing the competitiveness of the firm (Kumar et al. 2013).

2.4 Development of skilled and empowered workforce

Skillful and knowledgeable employees are the prerequisite for the effective working of the maintenance department (Mosadeghrad 2014). Knowledge and belief system of employees is one of the deciding factors in successful implementation of maintenance program. Skilled manpower can be developed by proper training schedules in the organization. It will also help in increasing the commitment level of employees and tobring positive behavioral changes. The mindset of the employees' needs to be changed from the traditional maintenance approach to the new and modern prevention based approach. It will help in building a matured and empowered staff for competitive advantage by adopting the processes as per market requirements. Hassini et al. (2015) have also observed that human resource should be properly utilized for effective maintenance management.

2.5 Continuous progress assessment of processes

Continuous progress assessment of process is required for analysing and reporting the overall improvement (Haavisto and Goentzel 2015). It will help to achieve the higher maintenance standard regularly by continuous improvements by measuring one's performance against the best in the industry (Shaaban and Awni 2014). Continuous improvements are carried so that the desired results of quality and customer satisfaction are attained (Singh 2011). It is proved to be a useful tool in ensuring the maintainability and reliability of the equipment. It bridges the gap between the prevailing equipment conditions and desired manufacturing excellence. The problem like unplanned downtime, defects in equipment or degradation in the speed of manufacturing are main points of concern for the continuous progress. Thus it helps in increasing the overall reliability and maintainability of the equipment.

2.6 Continuous up gradation of maintenance system

Mangano and Marco (2014) have observed that the upgradation of maintenance system can give high returns in terms of improved safety, quality and lead times. In developing countries, usually organizations ignore investment in maintenance systems. Organizations are more focused on short term goals by ignoring sustainability dimensions. According to Lotfi et al. (2013), organizations should allocate fixed resources for maintenance systems and set the targets accordingly. Strategic investment in human resources may help in increasing the product quality, utilization of hardware and in a reduction of labor cost. Singh et al. (2013a) have observed that in MS Ltd, India, reconditioning of machines according to TPM concepts has helped to convert very large machine into small, simple and lean machine.

2.7 Effective and efficient maintenance system

Effective maintenance helps organizations by improving productivity of all the processes (Block et al. 2014). It helps in extending the life of the equipment, improving the equipment availability and in retaining the equipment in proper condition. The effective maintenance policy has great impact on the productivity and profitability of a manufacturing process (Simões et al. 2016). Effective maintenance may enhance the profit of the company by improving the efficiency, effectiveness and productivity of the manufacturing processes. It has been observed that an effective maintenance system can contribute significantly to increase the plant availability, reliability, and profitability, thus leading to the efficient and sustainable improvement in its performance (Bottani et al. 2014).

2.8 Sustainable performance improvement

Top management is being triggered by the intense competitive pressure to look at the performance of each and every function in the business, whether it is production or maintenance, or any other business function to achieve the competitive advantage (Maletič et al. 2012). One of the main objectives of business is the profitability, not only in the near future, but in the entire life span of the business without having adverse impact on society. This demands that the company should stand on the changing requirements of the customer. It demands the safe and profitable operations throughout the life of the asset and that demands the sustainable and effective performance. The main factors for the improvement of performance are reliability, productivity and sustainability (Narayan 2012). This can be achieved by effective maintenance systems.

2.9 Increasing awareness about safety and health

Narayan (2012) has observed that for sustainable growth of any organization, safety of people, environment and resource management are very important aspect. It protects the firm from the financial losses that are possible due to any type of hazards in absence of proper safety programs (Shaaban and Awni 2014). Maintenance work is usually critical to operator's health; therefore the maintenance department should work toward the creation of safe workplace (Noroozi et al. 2013). Initially, the purpose of periodic maintenance was to increase the overall safety rather than for the improvement in the availability or reduction of costs, or to increase the performance. Safety includes personal as well as process safety. Narayan (2012) has also observed that process safety is more important as it can avoid major disasters, potentially with multiple fatalities.

2.10 Quality management system

The expected characteristic of a saleable product is its quality; it is the major criteria used by the customers to select any product or service (Graham et al. 2014). Thus the quality policy of a firm determines its growth prospects. Quality policy shows the intentions of the management to achieve the high standards of quality. In other words quality policies are the organization's mission statement. The quality management system aligns the members, division and elements of the organization towards the long term goals. Bouslah et al. (2016) have observed that production systems, quality management system and maintenance system should be integrated to reduce product rejection rate.

2.11 Reduction in machine breakdown

Machine breakdown is the biggest challenge to the manufacturing plant as it disturbs the whole production planning abruptly (Sharma and Trikha 2011). Breakdown losses can be categorized into two types, namely: equipment failure leading to time losses when productivity is reduced and defective products leading to quantity losses. Poduval et al. (2015) has observed that to overcome a breakdown situation, organizations need to maintain higher inventories thus adding up the cost. Machine breakdown is one of the reasons for the interruption in production process and thus affecting the effectiveness of the plant (Parida et al. 2015). Readiness to deal with such events is influenced by the decisions of top management (Parida et al. 2015). Top management should identify the management policies on the basis of a breakdown impact. Certain filter system should be installed to get the signal when there is a breakdown (Bottani et al. 2014) so that proactive measures can be taken to avoid the losses.

2.12 Reduction in manufacturing lead time

Process lead time can be reduced by practicing the effective maintenance management (Gosavi et al. 2011). Reduction in lead time has been proved to be one of the motivating factors for investing in maintenance initiatives. Thus reducing the lead time should be one of the targets of the maintenance system (Kumar et al. 2014). Effective maintenance helps in reducing the idling and minor stops. For lead time reduction, process needs to control breakdowns by effective maintenance of machines. To reduce lead time, machine failures have to be minimized.

2.13 Reduction in defective products

Defective products are the outputs that are not according to the quality standards, specifications, and other technical norms (El-Akruti et al. 2016). There are two types of rejections: reparable and irreparable production rejection. Reparable rejections are the rejects whose repairs are technically possible and economically advisable. Irreparable rejections are technically impossible or economically disadvantageous to repair (Gustafson et al. 2013). Such articles are waste for the firm. Defective products are produced due to incorrect adjustment of a machine tool, and equipment malfunction, errors in technical specifications, disrupted discipline production, or the lower level skill of workers (Kumar et al. 2013). Defects in production should be discovered by the workers, the foremen, and the departmental employees of the technical control team. Product rejections are reduced by organizational and technical measures, including the process mechanization and automation, proper equipment maintenance, and by introducing the advanced forms and methods of technical control. The major factors of great significance for preventing rejections in production are: manufacturing with zero defects, strictly observing the work area of production discipline, correct labor organization (Maletic et al. 2012).

2.14 Overall cost reduction

The world market is facing intense competition in terms of quality improvement, lesser cost and superior performance in the diverse range of products. The main aim of maintenance management is to increase the quality standards and to reduce the occurrence of unlikely and unexpected machine breakdowns that disrupt production, resulting in many losses and ultimately causing millions of bucks annually, thus increasing the overall cost of the product (Kumar et al. 2014). Thus, Effective maintenance of production systems helps in reducing manufacturing cost.

Based on literature review and discussion with experts, total fourteen factors have been finalized as summarized in Table 1.

3 Research methodology

After exhaustive literature review for identification of maintenance factors, this study is carried out in two parts. The Research methodology framework is given in Fig. 1. First part consists of development of a framework for sustainable performance improvement. Second part consists of ranking of the major factors for prioritizing the actions. Therefore, research methodology follows hybrid approach, i.e. ISM–MICMAC and TOPSIS. A structural relationship framework is developed using ISM (Interpretive structural modeling) and fuzzy MICMAC (Matriced' Impacts Croisés Appliquée á un Classement). A ranking of the major driving factors is done by TOPSIS approach.

To decide weights and relationships of different factors during analysis, a team of five experts was made. Three of the experts are maintenance management heads in their respective manufacturing organisation situated in NCR Delhi, India. These organisations

Table 1 Factors for effective maintenance management

Code	Maintenance factors	References
F1	Top management support and commitment	Graham et al. (2014) and Kumar et al. (2015)
F2	Strategic planning and implementation	Mosadeghrad (2014), Hassini et al. (2015) and Singh et al. (2016)
F3	Continuous upgradation of maintenance system	Lotfi et al. (2013) and Mangano and Marco (2014)
F4	Development of skilled and empowered workforce	Lin et al. (2015), Hassini et al. (2015) and Singh et al. (2016)
F5	Participatory and innovative work culture	Yunis et al. (2013), Block et al. (2014) and Singh et al. (2016)
F6	Increasing awareness about safety and health	Mangano and Marco (2014) and Rafiq (2015)
F7	Quality management system	Macchi and Fumagalli (2013), Graham et al. (2014) and Bouslah et al. (2016)
F8	Continuous progress assessment of processes	Shaaban and Awni (2014) and Singh et al. (2016)
F9	Effective and efficient maintenance system	Van Horenbeek et al. (2010) and Block et al. (2014)
F10	Reduction in defective products	Bartz et al. (2014), Kumar et al. (2013) and Bouslah et al. (2016)
F11	Reduction in machine breakdown	Parida et al. (2015) and Yan (2015)
F12	Reduction in manufacturing lead time	Uzun and Ozdogan (2012), Kumar et al. (2014), Lu et al. (2015) and Tyagi et al. (2015)
F13	Sustainable performance improvement	Narayan (2012), Maletic et al. (2012) and Singh and Sharma (2014)
F14	Overall cost reduction	Kumar et al. (2014) and Singh et al. (2016)

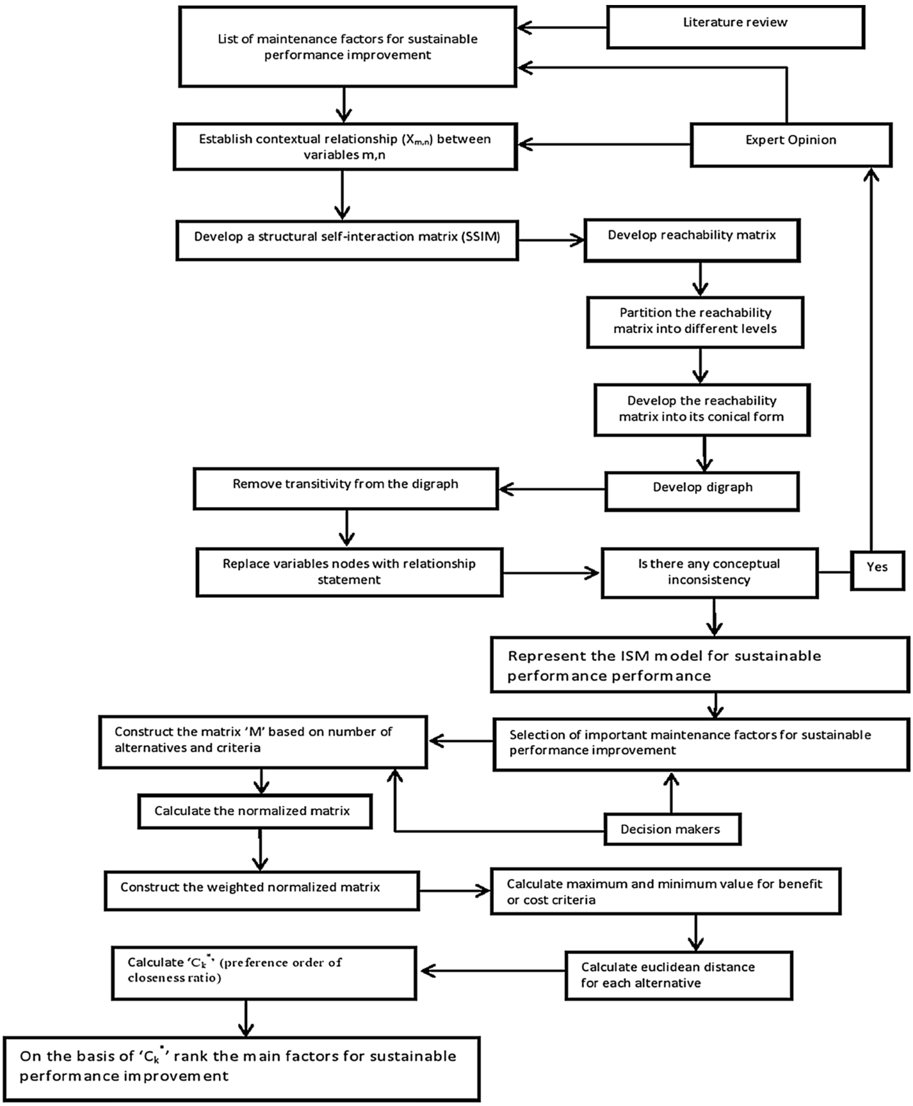

Fig. 1 Research methodology framework

are mainly from the automotive sector. Experts have experience of more than 10 years of successfully implementing maintenance policies in their respective organisations. Other two experts are academicians having researched significantly in the area of maintenance systems.

Interpretive structural modeling (ISM) is one of the most used techniques as it is interactive in nature. This technique is used to analyse the factor by developing a framework. The process is very systematic and efficient. Thus it helps in mapping of the complex relations between the factors in a complex system. It uses transitive inference for reducing the number of required relational queries by 50–80%. The main idea is to decompose the complex system into smaller elements, by using the experts' experience and knowledge.

By using fuzzy MICMAC, factors are then categorized on the basis of their driving and dependence power. Therefore, insights into the collective understanding of the relationships between the factors can be understood through ISM and fuzzy MICMAC. The major highlight of the ISM–MICMAC approach is that, it helps to analyse the problem situation through graphical representation and structured model (Singh 2015).

Due to the effectiveness and application potential of this technique, many researchers have used it for the analysis. Singh (2015) used ISM for Modeling of critical factors for responsiveness in the supply chain. Singh et al. (2018) used ISM and fuzzy MICMAC for analyzing the interaction of factors for the resilient humanitarian supply chain. Vinodh et al. (2016) have used ISM for analyzing the factors for lean sustainable systems.

Stepwise description of interpretive structural modeling (ISM) is as follows:

1. Relevant Problem or issue is identified with the help of literature review
2. The pair of elements will be examined on the basis of contextual relationship established between the elements.
3. To indicate the pairwise relationship among the factors. SSIM (system structural self-interaction matrix) is developed.
4. Reachability matrix which has been developed from the SSIM is checked for transitivity. Transitivity is one of the important assumptions in ISM. According to the transitivity rule, if an element "X" is related to the element "Y", which is further related to "Z", then, "X" should also be related to "Z".
5. Reachability matrix is partitioned into different levels.
6. According to the relations given above in the reachability matrix, directed graph (DIGRAPH) is drawn. After drawing the DIGRAPH, transitivity links are removed.
7. ISM is formed by the replacement of the element nodes with statements.
8. Necessary modifications are made after checking the ISM model for any conceptual inconsistency.

Based on the above mentioned steps, ISM based framework would be developed in the following section. As ISM framework does not provide ranking of factors, therefore, TOPSIS approach will be used. Integrating TOPSIS methodology with fuzzy ISM–MICMAC, promises to give a better understanding of the strategic factors.

Hwang and Yoon (1981) proposed the TOPSIS methodology. TOPSIS gives very reliable solution because in this technique, performance in one criterionalone does not determine the overall ranking. Therefore, many researchers have used this technique. Singh et al. (2016) used TOPSIS for ranking of barriers in effective maintenance. Singh et al. (2017) used fuzzy TOPSIS for the selection of an appropriate 3PL in order to outsource logistics activities of perishable products. This methodology is simpler and faster than the other MCDM techniques like FDAHP, SAW and AHP.

Steps in TOPSIS approach are as follows:

1. On the basis of a number of alternatives (m) and criteria (n), a matrix with elements x_{kj} is made. Where the rating of kth decision making unit (DMU) with respect to jth criteria is denoted by each element

This matrix is denoted by ‘M’:

2. Normalised matrix is calculated as per following formula.

$$\mathrm{M} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix}$$

$$\mathrm{r_{kj}(x)} = \frac{X_{kj}}{\sqrt{\sum_{k=1}^{n} X_{kj}^{2}}}, \mathrm{k} = 1, \ldots, \mathrm{n}; \mathrm{j} = 1, \ldots, \mathrm{m}$$

n = number of criteria, m = number of alternatives.

Normalised matrix is denoted by R.

$$\mathrm{R} = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ r_{m1} & r_{m2} & \ldots & r_{mn} \end{bmatrix}$$

3. Weighted normalized matrix with elements $\mathrm{v_{kj}} = \mathrm{w_j r_{kj}}$ is constructed, where $\mathrm{w_j}$ = weights of different decision makers. This matrix is denoted by V.

$$\mathrm{V} = \begin{bmatrix} v_{11} & v_{12} & \ldots & v_{1n} \\ v_{21} & v_{22} & \ldots & v_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ v_{m1} & v_{m2} & \ldots & v_{mn} \end{bmatrix}$$

4. The negative ideal solutions $\mathrm{v_j^-}$ and positive ideal solution $\mathrm{v_j^+}$ are found. These are the minimum and maximum values of weighted normalized elements of each column.
5. Euclidean distance for each alternative is calculated.

   $\mathrm{D_k^*}$ represents the Euclidean distance from positive ideal solution

$$\mathrm{D_k^*} = \sqrt{\sum_{j=1}^{m} \left[v_{kj}(x) - v_j^{+}(x)\right]^2}$$

where k = 1, 2,…, m; j = 1, 2,…, n.

   $\mathrm{D_k^-}$ represents the Euclidean distance from negative ideal solution.

$$\mathrm{D_k^-} = \sqrt{\sum_{j=1}^{m} \left[v_{kj}(x) - v_j^{-}(x)\right]^2}$$

where k = 1, 2,…, m; j = 1, 2,…, n.

6. $\mathrm{C_k^*}$represents the relative closeness to the ideal solution. It’s closeness to ‘1’, depicts the best solution.

$$\mathrm{C_k^*} = \left(\mathrm{D_k^-}\right) / \left(\mathrm{D_k^*} + \mathrm{D_k^-}\right)$$

where $0 < C_k^* < 1$, D_k^* = distance from positive ideal solution D_k^- = distance from negative ideal solution.
7. On the basis of preference order of closeness ratio C_k^* factors are ranked. Shorter the distance from the ideal solution better the alternative.

Halcomb and Andrews (2005) have observed that use of different methods like case studies and interaction with experts helps in making findings more comprehensive. It helps in making data more richer, authentic and helps in its validation (Casey and Murphy 2009; Foss and Ellefsen 2002). Therefore to validate the findings of this study, apart from the various maintenance related cases dealt by experts in their respective companies, many other case studies mainly situated outside India from different sectors were also discussed. These case studies widened the perspective of the overall research and helped in validating the findings.

4 Results and analysis

Results have been analyzed in two parts. In the first part, ISM has been applied for developing a structural relationship framework. Then fuzzy MICMAC has been applied to categorize the factors as drivers, dependents, linkages and autonomous. In the second part, ranking of these factors derived by TOPSIS approach will be analyzed.

4.1 Analysis based on ISM and fuzzy MICMAC

ISM based analysis and development of a framework for maintenance has been done as per following steps.

4.1.1 Structural self-interaction matrix (SSIM)

SSIM is developed based on inputs from a team of experts. Contextual relationship among the variables is developed through brainstorming, nominal group technique and other management techniques. Five experts took part in this activity. As already mentioned, among these experts, three belonged to the industry and two were from the academia. Direction of the relationship between the factors m and n ($m < n$) is denoted by following symbols:

- Symbol 'V' is used when 'm' leads to 'n'.
- Symbol 'A' is used when 'n' leads to 'm'.
- Symbol 'X' is used when 'm' and 'n' leads to each other.
- Symbol 'O' is used when 'm' and 'n' are not related to each other.

SSIM is developed on the basis of the contextual relationships as shown in Table 2.

4.1.2 Reachability matrix

From the SSIM, a binary matrix is formed known as a reachability matrix by the substitution of the various symbols, i.e. V, A, X and O with 1 and 0 as per the case. The rules followed for the substitution of 1 s and 0 s are given below.

Table 2 Structural Self-Interaction Matrix (SSIM)

Factor code	Maintenance factors	F14	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2	F1
F1	Top management support and commitment	V	V	V	V	V	V	V	V	V	V	V	V	V	
F2	Strategic planning and implementation	V	V	V	V	V	V	V	V	V	V	V	O		
F3	Continuous upgradation of maintenance system	V	V	V	V	V	V	V	V	V	V	V			
F4	Development of skilled and empowered workforce	V	V	V	V	V	V	V	V	V	V				
F5	Participatory and innovative work culture	V	V	V	V	V	V	V	V	V					
F6	Increasing awareness about safety and health	V	V	V	V	V	V	X	X						
F7	Quality management system	V	V	V	V	V	V	X							
F8	Continuous progress assessment of processes	V	V	V	V	V	V								
F9	Effective and efficient maintenance system	V	V	V	V	V									
F10	Reduction in defective products	V	V	O	O										
F11	Reduction in machine breakdown	V	V	O											
F12	Reduction in manufacturing lead time	V	V												
F13	Sustainable performance improvement	A													
F14	Overall cost reduction														

Table 3 Final reachability matrix

Factor code	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	D.P
F1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
F2	0	1	0	1	1	1	1	1	1	1	1	1	1	1	12
F3	0	0	1	1	1	1	1	1	1	1	1	1	1	1	12
F4	0	0	0	1	1	1	1	1	1	1	1	1	1	1	11
F5	0	0	0	0	1	1	1	1	1	1	1	1	1	1	10
F6	0	0	0	0	0	1	1	1	1	1	1	1	1	1	9
F7	0	0	0	0	0	1	1	1	1	1	1	1	1	1	9
F8	0	0	0	0	0	1	1	1	1	1	1	1	1	1	9
F9	0	0	0	0	0	0	0	0	1	1	1	1	1	1	6
F10	0	0	0	0	0	0	0	0	0	1	0	0	1	1	3
F11	0	0	0	0	0	0	0	0	0	0	1	0	1	1	3
F12	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
F13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
F14	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Dependence	1	2	2	4	5	8	8	8	9	10	10	10	14	13	104

D.P = driving power

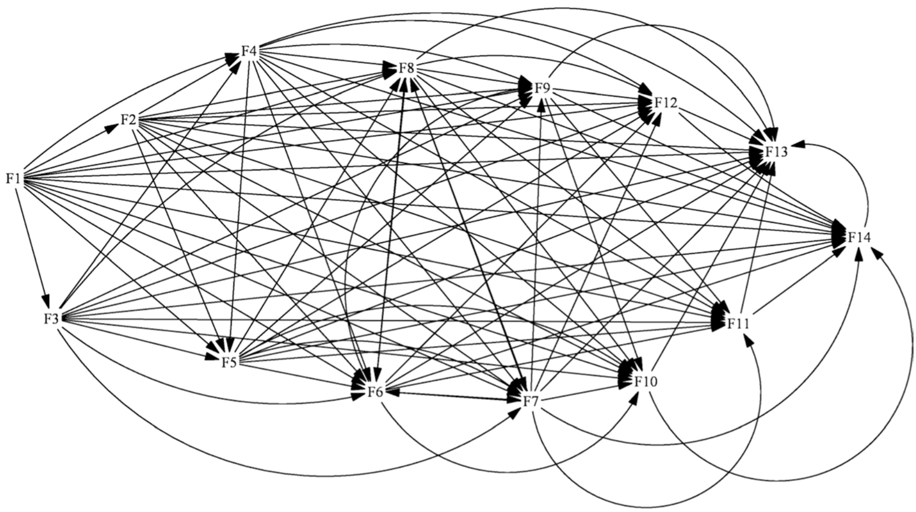

Fig. 2 Diagraph depicting relationship among maintenance factors for sustainable performance improvement

The entry (m, n) in SSIM can have four symbols. The various substitutions made, if the entry (m, n) is:

- V—Entry (n, m) is substituted by 0 and entry (m, n) is substituted by 1.
- A—Entry (n, m) is substituted by 1 and the entry (m, n) is substituted by 0.

- X—Entry (n, m) is substituted by 1 and the entry (m, n) is also substituted by 1.
- O—Entry (n, m) is substituted by 0 and entry (m, n) is also substituted by 0.

Final reachability matrix (Table 3) is formed, by using the above rules. The relationships between the factors have also been shown using the diagraph in Fig. 2. In the diagraph following symbols are used:

- A → B represents, A leads to B.
- A ↔ B represents, A and B both leads to each other.

Then, the transitivity rule is applied (step 4). For each factor, the dependence and driving power are also shown. Dependence shows the total number of variables, which help in achieving that variable. Whereas driving power shows the total number of variables, which a variable helps to achieve.

4.1.3 Level partitions

Find reachability and antecedent set for each factor from the final reachability matrix. The set of the elements (including itself) which help to achieve it are grouped as antecedent set. On the other hand the set of the elements (including itself), which it helps to achieve are grouped as reachability set. The intersection elements of these two sets are grouped as intersection set. The element having the same intersection and reachability set forms the top-level of the ISM hierarchy. In this study, factor F13 is assigned level 1 as shown in Table 4. After the identification of top-level element, it is segregated from the other elements. Similarly, the next levels for other elements are found by multiple iterations. Iteration process is carried out until the level of all the factors is obtained. Table 5 shows the summary of obtained levels of all factors. With the help of these identified levels, the digraph and final model are built.

4.1.4 Development of ISM based framework

The structural model is generated from the final reachability matrix (Table 3), by using lines of edges and vertices. The relation between the factors is drawn by arrows. This kind of graph is called a digraph or directed graph. Once the final modifications are made and the transitivities are removed, which leads to the ISM model as shown in Fig. 3.

4.1.5 Findings from ISM based framework

According to the ISM framework (Fig. 3), top management support and commitment is at the ninth level i.e. at the bottom. Top management is mainly responsible for the investment in the various maintenance initiatives and to develop the maintenance strategy. Strategic planning and implementation and Continuous upgradation of maintenance system constitutes the eighth level of the model. Level seven of the model consists of development of skilled and empowered workforce. It is another major driver for implementing maintenance systems. For development of skilled and empowered workforce, management should focus on training of employees and also support in terms of investment. Training and empowerment of employees lead to the positive changes in the work culture of the organization, which makes the level six of the model. Better

Table 4 Iteration 1

Factor code	Reachability set	Antecedent set	Intersection set	Level
F1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1	1	
F2	2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2	2	
F3	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3	3	
F4	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4	4	
F5	5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5	5	
F6	6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5, 6	6	
F7	6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5, 6, 7	7	
F8	6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5, 6, 7, 8	8	
F9	9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5, 6, 7, 8, 9	9	
F10	10, 13, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	10	
F11	11, 13, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 11	11	
F12	12, 13, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 12	12	
F13	13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	13	I
F14	13, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14	14	

Table 5 Levels of maintenance factors based on multiple iterations

Factor code	Reachability set	Antecedent set	Intersection set	Level
F1	1	1	1	IX
F2	2	1, 2	2	VIII
F3	3	1, 3	3	VIII
F4	4	1, 2, 3, 4	4	VII
F5	5	1, 2, 3, 4, 5	5	VI
F6	6	1, 2, 3, 4, 5, 6	6	V
F7	7	1, 2, 3, 4, 5, 6, 7	7	V
F8	8	1, 2, 3, 4, 5, 6, 7, 8	8	V
F9	9	1, 2, 3, 4, 5, 6, 7, 8, 9	9	IV
F10	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	10	III
F11	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 11	11	III
F12	12	1, 2, 3, 4, 5, 6, 7, 8, 9, 12	12	III
F13	13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	13	I
F14	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14	14	II

organization culture promotes the innovation and participation of employees, steers the path of the quality management system. It also helps in increasing awareness about health and safety; and promotes the continuous progress assessment of the process (level five). All the three factors at level five, help in building an effective and efficient maintenance system (level four). The effective maintenance system means a reduction in manufacturing lead time, reduction in machine breakdown and reduction in defective products. All these three factors are at level three of the framework. If all the above levels are achieved by the firm, then it leads to the overall cost reduction (level two), and thus finally leading to the sustainable improvement in the performance of the firm (level one).

Mwanza and Mbohwa (2015) have conducted a case study of a chemical manufacturing plant in Zambia. It was observed by them that top management support plays a crucial role in implementation of maintenance management. Training and empowerment of employees, cooperative work culture, and healthy and safe work environment were also found important factors for effective maintenance system. Adoption of maintenance policies also helps in achieving reduction of rework, losses and in increasing profitability and competitiveness of the firms. In addition to this, Wakjira and Singh (2012) have found similar results in a case study of Asella Malt Industry, Asella, Ethiopia, Africa.

In the present context of globalised markets, organizations need to work for sustainable performance improvement rather than for short term goals of profit. It can be only achieved by reducing wastage, energy consumption and breakdowns. Organizations need to develop a long term strategy for continuous improvement of processes and for creating the appropriate culture for overcoming different barriers in implementing maintenance systems (Singh et al. 2016). There may be many factors responsible for implementation of maintenance systems. For this purpose, the study needs to identify

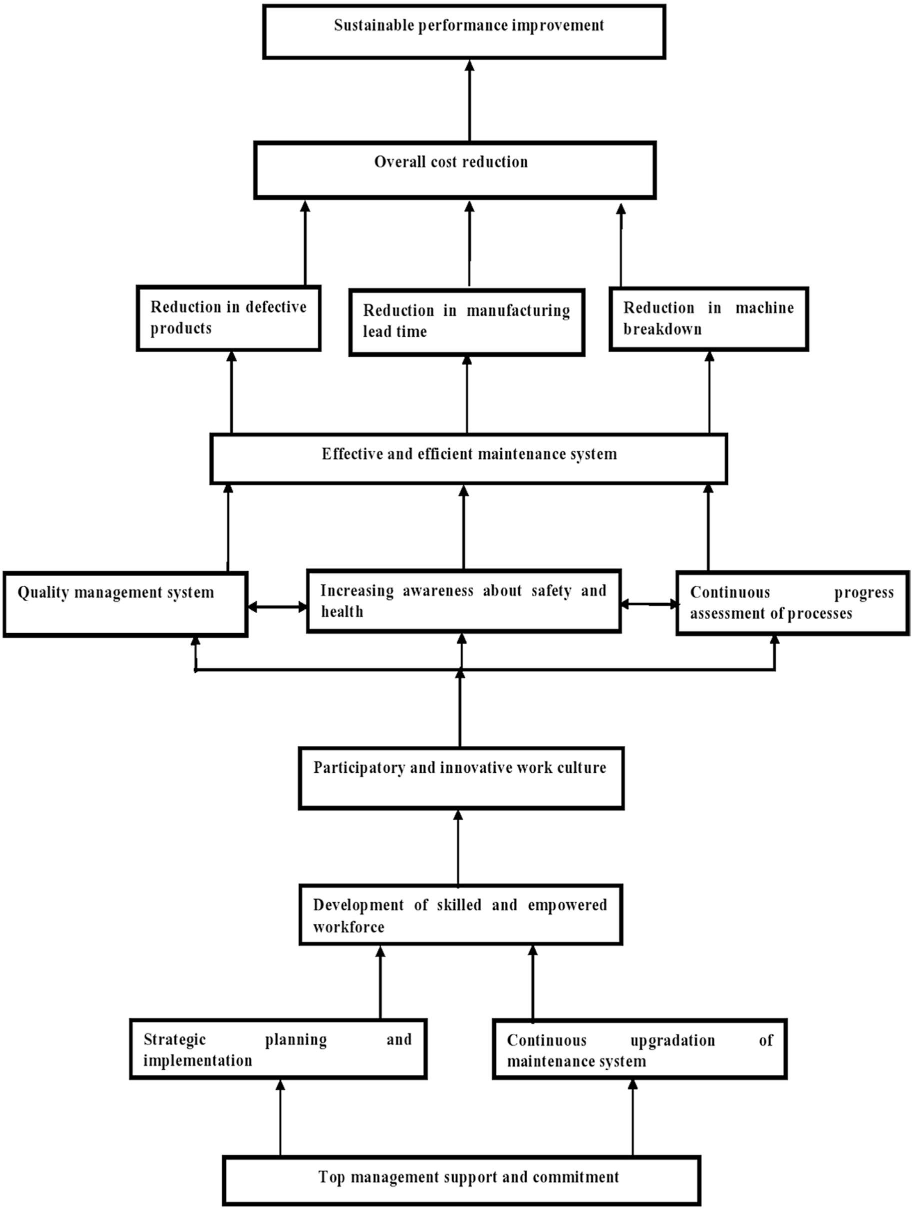

Fig. 3 ISM based model for maintenance management for sustainable performance improvement

the driving power and dependence power of different factors in the realistic framework. For this purpose, fuzzy MICMAC analysis has been done in the next section. This fuzzy MICMAC analysis will take care of vagueness in decision making.

4.1.6 Fuzzy MICMAC analysis

In the development of the ISM framework, only 0 and 1 is used to denote the relation between the two variables. But the relations may have various degrees of levels like strong, or even better. Fuzzy theory is used to deal with vagueness and uncertainty in human language and thoughts in decision making. Various ideas, experiences, opinions and motivations of each expert can be integrated by translating the linguistic judgments into fuzzy numbers (Zadeh 1965; Khatwani et al. 2015).

Theorems used in this paper are as follows:

Theorem 1 Addition of two triangular fuzzy numbers $\dot{B}_1 = (l_1, m_1, u_1)$ and $\dot{B}_2 = (l_2, m_2, u_2)$, results into another triangular fuzzy number, which is represented by:

$$\dot{B}_1 + \dot{B}_2 = \left(l_1 + l_2, m_1 + m_2, u_1 + u_2\right) \tag{1}$$

Theorem 2 Defuzzification method used in this study is called CFCS (Converting Fuzzy data into Crisp Scores) (Khatwani et al. 2015). In this study a positive fuzzy number is denoted by $\dot{B}_k = (l_k, m_k, u_k)$ where, $k = 1, 2, \ldots, n$ and the crisp value is denoted by $\dot{B}_k^{crisp}$.

Following steps are used to find the crisp value of p-th criteria:

Step 1: For each alternative using Eq. (1), compute $R = \max(u_k)$; $L = \min(l_k)$; $k = 1, 2\ldots, n$ and $\Delta = R - L$

$$X_{lk} = \left(l_k - L\right)/\Delta, x_{mk} = \left(m_k - L\right)/\Delta, x_{uk} = \left(u_k - L\right)/\Delta \tag{2}$$

Step 2: Using Eq. (3), compute right score (rs) and left score (ls) normalized values

$$x_k^{ls} = x_{mk}/\left(1 + x_{mk} - x_{lk}\right) \text{ and } x_k^{rs} = x_{uk}/\left(1 + x_{uk} - x_{mk}\right) \tag{3}$$

Step 3: Using Eq. (4), compute total normalized crisp value

$$x_k^{crisp} = \left[x_k^{ls} * \left(1 - x_k^{ls}\right) + x_k^{rs} * x_k^{rs}\right]/\left[1 - x_k^{ls} + x_k^{rs}\right] \tag{4}$$

Step 4: With the help of Eq. (5), compute crisp value for $\dot{B}_k$

$$\dot{B}_k^{crisp} = L + x_k^{crisp} * \Delta \tag{5}$$

Table 6 Linguistic scales for the influence (Khatwani et al. 2015)

Terms	Value
Very high influence (VH)	(0.75, 1.0, 1.0)
High influence (H)	(0.5, 0.75, 1.0)
Low influence (L)	(0.25, 0.5, 0.75)
Very low influence (VL)	(0, 0.25, 0.5)
No influence (No)	(0, 0, 0.25)

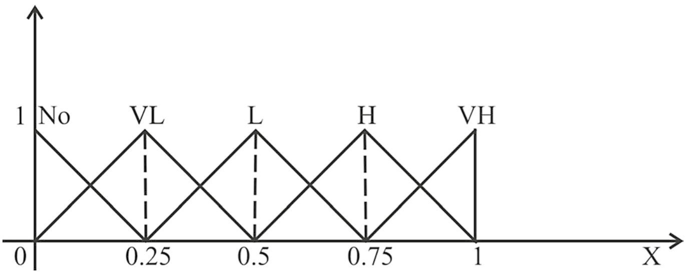

Fig. 4 Triangular fuzzy numbers for linguistic variables (Khatwani et al. 2015)

4.1.7 Steps of fuzzy MICMAC analysis

The detailed procedure of fuzzy MICMAC is as follows. The linguistic terms with its values are tabulated in Table 6. The triangular fuzzy numbers for linguistic variables (Fig. 4) is the basis of these linguistic values.

Step 1: Beginning of decision making process.

Firstly the decision goals are defined. After the significant information is gathered, the possible alternatives are identified. The possible alternatives are then evaluated and monitored.

Step 2: Select the criteria.

A set of criteria is established in this step. The criteria have relationship through which either they are impacted/influenced by the other criteria or they influences/impacts the other criteria or both. The linguistic uncertainty in judgments of experts can be dealt by using the crisp method of decision making and by incorporating fuzzy linguistic scale for decision making as shown in Table 6.

Step 3: Gather the responses and create SSIM Matrix for fuzzy MICMAC.

With the help of group of experts the relationship between the criteria $C = \{Cp|p = 1, 2, \ldots, n\}$ are found, which is then filled in SSIM matrix. A combination of symbols ‘A’, ‘X’, ‘V’ and ‘O’; and linguistic terms (mentioned in Table 6) are used by the respondents. There was following four options with the respondent.

- Symbol ‘V’ is used when element ‘p’ leads to ‘q’. ‘V’ is followed by [Very high (VH), High (H), Low (L), Very low (VL)].
- Symbol ‘A’ is used when element ‘q’ leads ‘p’. ‘A’ is followed by [Very high (VH), High (H), Low (L), Very low(VL)].
- Symbol ‘X’ is used when element ‘p’ leads to ‘q’ and ‘q’ to ‘p’. ‘X’ is followed by [Very high (VH), High (H), Low (L), Very low(VL)].
- Symbol ‘O’ is used when there is no relationship between the two elements. ‘O’ is followed by [No influence (No)].

Table 7 Aggregated SSIM matrix for fuzzy MICMAC analysis

Factor code	F14	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2	F1
F1	V(H)	V(VH)	V(H)	V(H)	V(H)	V(H)	V(VH)	V(VH)	V(VH)	V(VH)	V(VH)	V(VH)	V(VH)	
F2	V(H)	V(H)	V(H)	V(VH)	V(VH)	V(VH)	V(H)	V(VH)	V(VH)	V(VH)	V(VH)	O(NO)		
F3	V(H)	V(VH)	V(H)	V(VH)	V(VH)	V(H)	V(H)	V(VH)	V(VH)	V(H)	V(VH)			
F4	V(H)	V(H)	V(H)	V(H)	V(H)	V(VH)	V(L)	V(H)	V(L)	V(L)				
F5	V(VH)	V(VH)	V(L)	V(L)	V(L)	V(VH)	V(H)	V(H)	V(H)					
F6	V(VH)	V(L)	V(L)	V(L)	V(L)	V(VH)	X(H)	X(L)						
F7	V(H)	V(VH)	V(H)	V(L)	V(VH)	V(H)	X(H)							
F8	V(H)	V(H)	V(VH)	V(VH)	V(VH)	V(H)								
F9	V(VH)	V(VH)	V(VH)	V(VH)	V(VH)									
F10	V(VH)	V(L)	O(N0)	O(NO)										
F11	V(H)	V(H)	O(NO)											
F12	V(VH)	V(H)												
F13	A(H)													
F14														

Step 4: Calculate SSIM and final fuzzy reachability matrix.

The responses received from the individual experts are used to aggregate the responses shown in Table 7. The aggregated SSIM matrix is transformed into the fuzzy reachability matrix by replacing the linguistic terms by its corresponding fuzzy triangular linguistic values. During the creation of final fuzzy reachability matrix, entry (p, q) can have the following situations. The various substitutions made, if entry (p, q) is:

- V(VH)—Entry (p, q) is represented by (0.75,1.0,1.0) and entry (q, p) will be 0{No} which is represented by (0,0,0.25).
- V(H)—Entry (p, q) is represented by (0.5,0.75,1.0) and entry (q, p) will be 0{No} which is represented by (0,0,025).
- V(L)—Entry (p, q) is represented by (0.25,0.5,0.75) and entry (q, p) will be 0{No} which is represented by (0,0,0.25).
- V(VL)—Entry (p, q) is represented by (0,0.25,0.5) and entry (q, p) will be 0{No} which is represented by (0,0,0.25).
- A(VH)—Entry (p, q) will be 0{No} which is represented by (0,0,0.25) and entry (q, p) is represented by (0.75, 1.0, 1.0).
- A(H)—Entry (p, q) will be 0{No} which is represented by (0,0,0.25) and entry (q, p) is represented by (0.5, 0.75, 1.0).
- A(L)—Entry (p, q) will be 0{No} which is represented by (0,0,0.25) and entry (q, p) is represented by (0.25, 0.5, 0.75).
- A(VL)—Entry (p, q) will be 0{No} which is represented by (0, 0, 0.25) and entry (q, p) is represented by (0, 0.25, 0.5).
- X(VH)—Entry (p, q) is represented by (0.75, 1.0, 1.0) and entry (q, p) is represented by (0.75, 1.0, 1.0).
- X(H)—Entry (p, q) is represented by (0.5,0.75,1.0) and entry (q, p) is represented by (0.5, 0.75, 1.0).
- X(L)—Entry (p, q) is represented by (0.25,0.5,0.75) and entry (q, p) is represented by (0.25, 0.5, 0.75).
- X(VL)—Entry (p, q) is represented by (0, 0.25, 0.5) and entry (q, p) is represented by (0, 0.25, 0.5).
- X(VH,H)—Entry (p, q) is represented by (0.75, 1, 1) and entry (q, p) is represented by (0.5, 0.75, 1). Other possible scenario are X(VL, L), X(VL, VH), X(VL, H), X(L, H), X(L, VL), X(L, VH), X(H, VL), X(H, L), X(H, VH), X (VH, VL), X (VH, L).
- O—Entry (p, q) and entry (q, p) will be 0{NO} which is represented by (0, 0, 0.25).

Ž denote the final fuzzy reachability matrix.

$$\tilde{Z} = \begin{bmatrix} \tilde{z}_{11} & \tilde{z}_{12} & \cdots & \tilde{z}_{ln} \\ \tilde{z}_{21} & \tilde{z}_{22} & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \tilde{z}_{nn} \end{bmatrix}$$

where $\check{Z}_{p,q} = (l_{p,q}, m_{p,q}, u_{p,q})$.

Step 5: Calculate dependence and driving power for MICMAC analysis

Table 8 Fuzzy reachability matrixes

Factor code	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1		VH	VH	VH	VH	VH	VH	VH	H	H	H	H	VH	H
F2	NO		NO	VH	VH	VH	VH	VH	H	VH	VH	H	H	H
F3	NO	NO		VH	H	VH	VH	H	H	VH	VH	H	VH	H
F4	NO	NO	NO		L	L	H	L	VH	H	H	H	H	H
F5	NO	NO	NO	NO		H	H	H	VH	L	L	L	VH	VH
F6	NO	NO	NO	NO	NO		L	H	VH	L	L	L	L	VH
F7	NO	NO	NO	NO	NO	L		H	H	VH	L	H	VH	H
F8	NO	NO	NO	NO	NO	H	H		H	VH	VH	VH	H	H
F9	NO	NO	NO	NO	NO	NO	NO	NO		VH	VH	VH	VH	VH
F10	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	NO	L	VH
F11	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	H	H
F12	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		H	VH
F13	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO
F14	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	H	

By summation of columns and rows of a fuzzy reachability matrix (Table 8) the dependence and driving power is calculated (Eq. 1). For defuzzification, Eq. (5) is used and MICMAC analysis is carried out based on fuzzy reachability matrix. Table 9 represents the final fuzzy values of dependence and the driving power.

Step 6: Creation of driving power and dependence matrix (MICMAC analysis)

On the basis of crisp values, the driving power and dependence matrix (MICMAC analysis) is shown in Fig. 5.

4.1.8 Findings from fuzzy MICMAC analysis

Fuzzy MICMAC is carried out for the analysis of driving and the dependence power of the factors for the successful implementation of the maintenance management. In fuzzy MICMAC analysis, factors are classified into four clusters, namely: Cluster 1 is of the autonomous factors, Cluster 2 is of the dependent factors, Cluster 3 is linkage factors and Cluster 4 is independent factors.

4.1.9 Autonomous factors

Autonomous factors generally contain those factors which are disconnected from the system. These factors have weak driving power and dependence. Hence, they do not influence the system much. In this study, there is no autonomous factor, as could be seen from the driving power-dependence matrix. It implies that all the fourteen factors are relevant and important for the system, thus top management should not neglect any factor while formulating maintenance strategy.

Table 9 Final fuzzy matrixes with fuzzy and crisp values of driving power and dependence of criteria

F.C	F1	F2	F3	F4	F5	F6	F7	F8
F1	(1, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)
F2	(0, 0, 0.25)	(1, 1, 1)	(0, 0, 0.25)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)
F3	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)
F4	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)
F5	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)
F6	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)
F7	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(1, 1, 1)	(0.5, 0.75, 1)
F8	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(1, 1, 1)
F9	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)
F10	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)
F11	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)
F12	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)
F13	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)
F14	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)
*	(1, 1, 4.25)	(1.75, 2, 5)	(1.75, 2, 5)	(3.25, 4, 6.5)	(3.25, 4.25, 7)	(4.75, 6.5, 9)	(5, 6.75, 9.25)	(4.75, 6.5, 9.25)
#	1.441207	2.471614	2.471614	4.3939412	4.660765841	6.680830517	6.922302648	6.73215031

F.C	F9	F10	F11	F12	F13	F14	**	#
F1	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(9.5, 12.75, 14)	12.28
F2	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(8.25, 11, 12.5)	10.66
F3	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(8, 10.75, 12.5)	10.45
F4	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(5.5, 8, 11)	8.071
F5	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.75, 1, 1)	(5.5, 7.75, 10.25)	7.790
F6	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(4.25, 6.25, 9)	6.450
F7	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(5, 7, 9.75)	7.172

Table 9 (continued)

F.C	F9	F10	F11	F12	F13	F14	**	#
F8	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(5.75, 7.75, 10.25)	7.842
F9	(1, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(4.75, 6, 8)	6.190
F10	(0, 0, 0.25)	(1, 1, 1)	(0, 0, 0.25)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(2, 2.5, 5.5)	2.976
F11	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0, 0, 0.25)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(2, 2.5, 5.75)	3.027
F12	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)	(2.25, 2.75, 5.75)	3.238
F13	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(1, 1, 1)	(0, 0, 0.25)	(1, 1, 4.25)	1.433
F14	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.5, 0.75, 1)	(1, 1, 1)	(1.5, 1.75, 5)	2.245
*	(5.75, 7.75, 10.25)	(6.25, 8.5, 10.5)	(5.75, 8, 10.25)	(5.5, 7.75, 10.5)	(8.25, 11.5, 13.5)	(8.25, 11.25, 13.25)		
#	7.83109315	8.403640383	7.969715852	7.825059231	11.09477233	10.9037764		

*Dependence; **driving power; #Crisp value, F.C = factor code

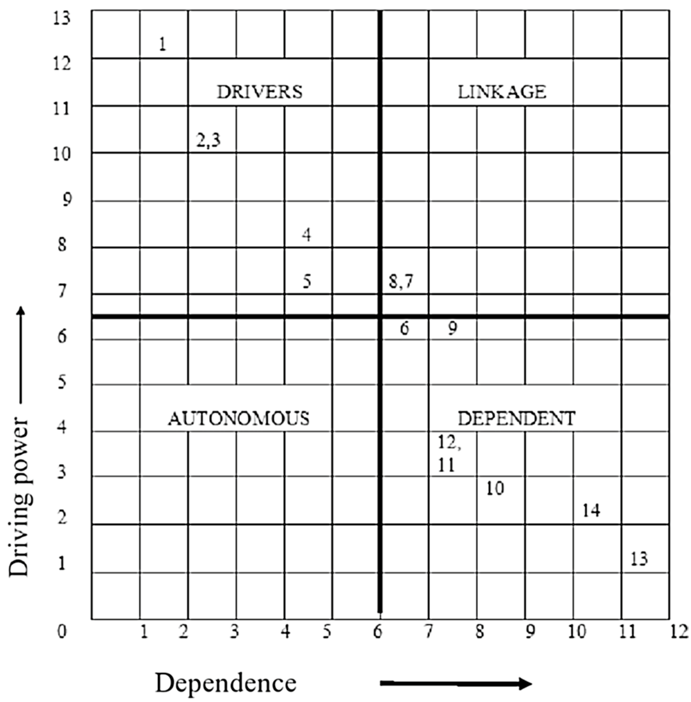

Fig. 5 Driving power and dependence matrix based on fuzzy MICMAC analysis

4.1.10 Dependent factors

Factors which have weak driving power, but high dependence are generally categorized as dependent factors. These factors are at the top of the ISM model. Increasing awareness about safety and health, effective and efficient maintenance system, reduction in defective products, reduction in machine breakdown, reduction in manufacturing lead time, sustainable performance improvement and overall cost reduction are weak drivers but are strongly dependent on the other factors. They represent the desired goals of the organization. It implies that, these goals should be kept in mind while formulating the maintenance strategies.

4.1.11 Linkage factors

These factors are highly unstable and are characterized by the high driving power and dependence. Any action on them produces the effects on the other factors as well as has a feedback on them. Quality management system and continuous progress assessment of processes are the linkage variables. These factors can disturb the model at any time, therefore management should be very careful while dealing with these linkage factors.

4.1.12 Independent factors

These factors are characterized by high driving power and weak dependence. Top management support and commitment, strategic planning and implementation, continuous upgradation the maintenance system, development of skilled and empowered workforce; and participatory and innovative work culture are the drivers. Management should address these factors more cautiously. These factors help to achieve system goals or the dependent factors appearing at the top of the ISM hierarchy framework. As they are the drivers of the other dependent factors, they should be handled on a priority basis.

4.2 Analysis based on TOPSIS approach

For sustainable improvement in performance through maintenance system, management should prioritize the critical maintenance factors based upon their relative importance. ISM based structural framework has been developed in the previous section, but it does not rank the major factors based on their relative importance. Therefore, in this section, the major factors are ranked by using MCDM tool to formulate effective strategy. There are many 'MCDM' techniques, but the TOPSIS approach has been widely preferred.

TOPSIS selects the alternative that is farthest from negative ideal alternative and closest to the ideal solution. Thus, it provides a more realistic form of modeling since it uses both positive and negative criteria simultaneously. Moreover, it is faster and simpler than other methods such as FDAHP, SAW and AHP (Singh et al. 2016). Further analysis will be done on the basis of different steps of TOPSIS approach given in Sect. 3.

For doing ranking of factors, initially eight important factors, mainly with high driving power were shortlisted by the team consisting of five decision makers. These decision makers gave the score to these factors in a scale of 1–10 (1—Very low, 10—Very high). On the basis of experience and profile of the team members, DM1 (Decision maker 1) is given a weightage of '0.3', DM2 (Decision maker 2) a weightage of '0.3', DM3 (Decision maker 3) a weightage of '0.2', DM4 (Decision maker 4) a weightage of '0.1' and DM5 (Decision maker 5) a weightage of '0.1'.

By using step 2 and 3 of TOPSIS methodology, the weighted, normalized decision matrix is made as given in Table 10. Positive and negative ideal solutions are found using the step 4, these are the maximum and minimum elements of each column. Positive and negative ideal solutions are given in Table 11. From positive and negative ideal solution, Euclidean distance of each factor is determined by using step 5 as shown in Tables 12 and 13. Euclidean distance is nothing but the absolute value of separation of each element from negative and positive ideal solution. Now, the closeness ratio of each factor is determined by using step 6. Closeness ratio helps to determine the relative closeness of factor from the ideal solution. Based on closeness ratio, i.e. step 7, relative ranking of these factors is given in Table 14. Further the rankings are plotted on a bar graph for better readability in Fig. 6.

It is observed that Top management support and commitment has a highest closeness ratio; therefore it is the highest ranked factor. Based on ISM approach also, it has emerged as a major driver for implementing maintenance system. For effective maintenance systems, all initiatives have to be taken by top management. Willingness of top management support can be considered as the prerequisite for bringing the cultural and functional changes in the company. The next important factor identified is strategic

Table 10 Weighted normalized matrix

Factors code	Decision makers Factors	D.M 1 (0.3)	D.M 2 (0.3)	D.M 3 (0.2)	D.M 4 (0.1)	D.M 5 (0.1)
F2	Strategic planning and implementation	0.12534	0.11011	0.06556	0.03960	0.04200
F5	Participatory and innovative work culture	0.09749	0.11011	0.06556	0.03960	0.03734
F4	Development of skilled and empowered workforce	0.11141	0.11011	0.08429	0.02970	0.04200
F8	Continuous progress assessment of processes	0.11141	0.09635	0.05619	0.03960	0.02800
F7	Quality management system	0.08356	0.08258	0.06556	0.02475	0.02800
F6	Increasing awareness about safety and health	0.06963	0.08258	0.07492	0.02475	0.01867
F1	Top management support and commitment	0.12534	0.12388	0.07492	0.04455	0.04200
F3	Continuous upgradationof maintenance system	0.11141	0.12388	0.07492	0.03465	0.03734

Table 11 Summary of +ve ideal solution and −ve ideal solution

Decision makers	D.M 1	D.M 2	D.M 3	D.M 4	D.M 5
Negative ideal solution	0.06963	0.08258	0.05619	0.02475	0.01867
Positive ideal solution	0.12534	0.12388	0.08429	0.04455	0.04200

Table 12 Distance from positive ideal solution (D_k^*)

Decision makers	D.M 1	D.M 2	D.M 3	D.M 4	D.M 5	Average
Factors code						
F2	0	0.01376	0.01873	0.00495	0	0.00748
F5	0.02785	0.01376	0.01873	0.00495	0.00466	0.01399
F4	0.01392	0.01376	0	0.01485	0	0.00850
F8	0.01392	0.02752	0.02809	0.00495	0.01400	0.01770
F7	0.04178	0.04129	0.01873	0.01980	0.01400	0.02712
F6	0.05570	0.04129	0.00936	0.01980	0.02333	0.02990
F1	0	0	0.00936	0	0	0.00187
F3	0.01392	0	0.00936	0.00990	0.00466	0.00757

Table 13 Distance from negative ideal solution (D_k^-)

Decision makers	D.M 1	D.M 2	D.M 3	D.M 4	D.M 5	Average
Factors code						
F2	0.05570	0.02752	0.00936	0.01485	0.02333	0.02615
F5	0.02785	0.02752	0.00936	0.01485	0.01867	0.01965
F4	0.04178	0.02752	0.02809	0.00495	0.02333	0.02513
F8	0.04178	0.01376	0	0.01485	0.00933	0.01594
F7	0.01392	0	0.00936	0	0.00933	0.00652
F6	0	0	0.01873	0	0	0.00374
F1	0.05570	0.04129	0.01873	0.01980	0.02333	0.03177
F3	0.04178	0.04129	0.01873	0.00990	0.01867	0.02607

Table 14 Closeness ratio (C_k^*) and ranking of maintenance factors

Factor code	Factors	Closeness ratio	Ranking
F2	Strategic planning and implementation	0.77741	2
F5	Participatory and innovative work culture	0.58411	5
F4	Development of skilled and empowered workforce	0.74712	4
F8	Continuous progress assessment of processes	0.47392	6
F7	Quality management system	0.19393	7
F6	Increasing awareness about safety and health	0.11133	8
F1	Top management support and commitment	0.94433	1
F3	Continuous upgradationof maintenance system	0.77495	3

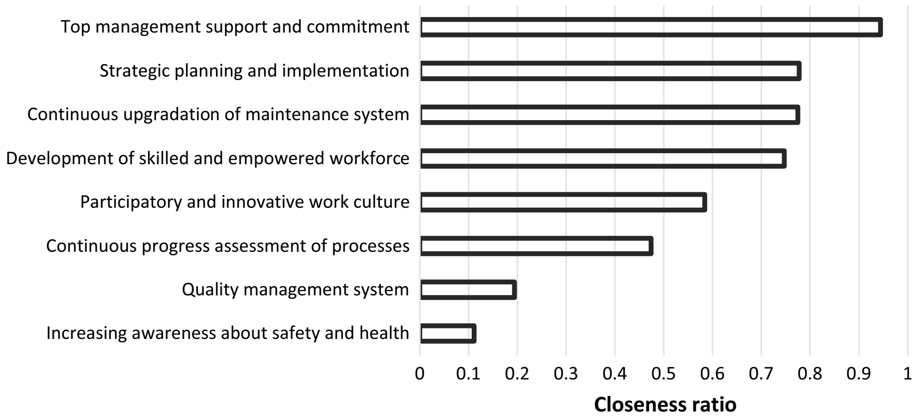

Fig. 6 Closeness ratio versus factor

planning and implementation. It helps to set the targets and lays the road map to achieve those targets. The maintenance management exclusive policy helps to boost the moral of the entire organisation (Singh et al. 2016). Continuous upgradation of maintenance system is ranked third. Lotfi et al. (2013) have also observed that proper allocation of resources improves effectiveness and efficiency of the maintenance system. Development of skilled and empowered workforce is ranked fourth. Usually it is observed that organizations do not upgrade the knowledge of their workforce with time, therefore it becomes a deterrent in implementing maintenance system. Training and empowerment of the employees, helps in increasing the skill set, morale, commitment towards maintenance activities and job satisfaction. This further helps to create a sense of ownership among the employees. Participatory and innovative work culture have been ranked fifth. A conducive and open culture in the company promotes the teamwork and increases the communication among the different level. When the whole company is working towards the common goal, then the chances of the success increase exponentially. Continuous progress assessment of processes has been ranked sixth. It helps to identify the areas where the improvement is needed, thus provides the important motivation to become the 'best in class'. The quality management system is ranked seventh. The major aim of any organization is to increase profits and market share. Quality is essential for any company, if it intends to capture the market and increase the profits. Therefor focus on quality should always be maintained. Increasing awareness about safety and health is ranked eighth. It implies that management should not ignore health and safety of workers for implementing maintenance system. Shaaban and Awni (2014) have also observed that improved health system protects the firm from the financial losses as well as reduces the hazards to the operators. Singh et al. (2013b) have observed the importance of top management support, training of employees, work culture, quality, kaizens, development of safe and healthy work conditions in context to a case study of RBD Engineers Ltd. (India). Similarly Kigsirisin et al. (2016) also observed the importance of various critical factors in the case study of Metropolitan Waterworks Authority (MWA), Thailand. Therefore, it is implied that the importance of factors for effective maintenance in this study is quite similar across other sectors also. This analysis further validates the significance of results observed in this study.

5 Conclusion

It has been widely researched that manufacturing processes should be continuously improved for making them sustainable in a globally competitive environment. In developing countries, the majority of manufacturing organizations are not able to perform with reference to global benchmark standards in terms of process capability, product rejections, energy consumption, pollution control, etc. Capacity utilization is also not up to the global standards due to the increasing number of breakdowns in machines. Therefore, all manufacturing organizations are trying to invest in maintenance management as part of the long term operations strategy. In spite of huge investment, the success rate of maintenance initiatives is not very encouraging.

This is the first kind of study, which has integrated the use of ISM–Fuzzy MICAMC and TOPSIS for analysing the interaction of maintenance management factors. This would help to guide the maintenance managers to prioritise strategic factors identified in the study. In this study, fourteen factors for successful implementation of maintenance systems have been identified from the literature review. As it is evident that no single factor can work in isolation to increase the performance of manufacturing systems. Therefore, it is needed to develop a structural relationship among different factors. For prioritisation of actions, factors need to be ranked also. To develop a structural relationship framework, ISM approach is used. The fuzzy MICMAC approach has been applied for categorizing the factors as Drivers, Dependents, Linkages and Autonomous. Practitioners should concentrate more on the factors having higher driving power. These are the enablers for the other factors having the higher dependence power. Major driving factors have been ranked by TOPSIS approach. Findings of TOPSIS in terms of the relative ranking of factors validate the ISM based hierarchy framework.

The findings imply that top management should be actively involved in the development of maintenance strategies, upgradation of the maintenance system, promoting participatory and innovative work culture and upgradation of the maintenance system. Maintenance managers should handle the major driving factors identified through fuzzy MICMAC and TOPSIS on priority basis. The findings will also be useful for professionals from industry in the implementation of sustainable maintenance system. As this framework is mainly based on inputs derived from experts, this framework can be further validated by structural equation modeling for a bigger sample size. However, before generalizing these findings, some empirical and case studies may be carried out as the future scope of study to strengthen these findings.

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