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Implementation model for cellular manufacturing system using AHP and ANP approach

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Abstract

Purpose – The purpose of this paper is to visualize the prioritization among essential factors of cellular manufacturing system (CMS) implementation using the analytic hierarchy process (AHP) and analytic network process (ANP) methods.

Design/methodology/approach – Based on literature review, 4 enabler dimensions and 17 CM factors were identified which were validated by experts from academia and industry. Then, AHP and ANP models are proposed in evaluating CMS implementation dimensions and factors. The results are validated using sensitivity analysis.

Findings – These models give firms a straightforward and simple to utilize way to deal with CMS efficiently. The two strategies were appeared to be powerful in choosing a strategy for CMS implementation. The two strategies brought about nearly similar outcomes. Both methods consider the particular necessities of the organization through its own accessible ability.

Practical implications – The techniques exhibited in this paper can be utilized by a wide range of organizations for adopting CMS that have a higher impact on performance and thus overall productivity. The two techniques are explained in a step-by-step approach for easier adoption by practitioners.

Originality/value – The strength of the present study is that it is one of the first few to be conducted in perspective for CM implementation factors analysis.

Keywords Analytical hierarchy process, Analytic network process, Cellular manufacturing system, Implementation

Paper type Research paper

1. Introduction

Cellular manufacturing (CM) is an approach for enhancing operations of job shop and batch shop production. CM is used to achieve the advantages of a product-oriented production system for medium volume, medium variety condition by preparing a group of parts on a group (cell) of machines. CM, which clusters machines, is dedicated to the part family of similar components (Dekkers, 2018). Although CM does not have the flexibility of job shops in making an extensive variety of items yet, it has a high production rate and efficient flow (Liu *et al.*, 2018). In the present batch production situation, demand for the product is considered by endless varieties concerning volumes, product mix and new product development. CM increases productivity, delivery performance by reducing work-in-progress inventory and lead times, hence helping manufacturing industries to be

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more competitive. There are significant benefits that can be accomplished as a result of implementing a cellular manufacturing system (CMS). These include reduced handling of materials, reduced tooling and equipment, reduced setup time, reduced work-in-process inventory, reduced part makespan and enhanced operator capability (Sakhaii *et al.*, 2013). Changing over the process, from batch production to CM system, is crucial to address the challenges of a worldwide economic crisis (Garbie, 2011). CMS shows the enhanced performance than the continuous shop and job shop manufacturing system, in fulfilling the demand for mid-variety and mid-volume of products.

The primary objective of the design of CMS is to group part families, the formation and arrangement of machine cells and assignment of part families to machine cells with the end goal that the movement of parts between cells is reduced (Wu *et al.*, 2016). GT and CM are suitable for the manufacturing plants which currently have a process-type layout and follow batch production.

The implementation of CM in a job shop or batch production comprises the transformation of all or a portion of an organization's manufacturing system into cells. While actualizing CM, it is essential to include every one of the levels of divisions and to have concurrence with workforce so that a better understanding of the CMS can be made. Many companies lean toward CMS, but this transformation is not natural as it depends on various critical factors (Bhangale and Mahalle, 2013). A mutual match amongst technical and social factors is needed to guarantee enhancement of CMS. Therefore, there is a need to study factors that influence CM implementation at the company.

Extant literature on CMS focuses on the design of cell, while none analyzes critical factors for CMS implementation. In this research, analytic hierarchy process (AHP) and analytic network process (ANP) are used to prioritize CM implementation factors, by assigning weights, to assist managers to comprehend the effects of critical factors.

The twofold objectives of this study are to:

(1) investigate the essential factors to implement CM; and

(2) develop AHP and ANP models for decision making, thus prioritizing factors critical to CM implementation.

The rest of the paper is organized as follows. Section 2 presents the review of the literature. Section 3 covers the research framework and methodology. Model development is explained in Section 4. Sensitivity analysis is provided in Section 5. Section 6 covers the results and discussions. Implications of the research, concluding remarks with limitations and future scope are discussed in Section 7.

2. Literature review

The idea of CM was first proposed by Burbidge (1979). A manufacturing cell can be well defined as a group of functionally different machines, placed together on the floor, devoted to the manufacture of a family of similar parts (Ham *et al.*, 1985). CM has been seen as a standout amongst the most inventive approaches to enhance flexibility and productivity for today's manufacturer, for diverse product range and low volume production, since it can reasonably change batch-type production into line-type production. Evidence shows that firms on their journey to transform to CM often struggle with implementation (Wemmerlöv and Johnson, 2000; Yauch and Steudel, 2002). Few researchers have proposed models for the implementation of CM that emphasis on a particular area of the implementation process (Hyer, 1982; Sambasivarao and Deshmukh, 1995; Badham and Couchman, 1996; Olorunniwo, 1997). Well-designed cells can yield productivity (Irani, 1999). Afzulpurkar *et al.* (1993) emphasized on technical issues that could critically impact the successful implementation of CM. In an investigation of performance obstacles in CM implementation in a manufacturing plant, Park and Han (2002) found that critical factors were employee training, teamwork, supervision and scheduling. Fraser *et al.* (2007) suggested a sequential model of six-phase CM implementation.

While there is sufficient evidence on expanding acceptance of CM (Johnson and Wemmerlöv, 2004), there is additional evidence that CM has not been productive in few organizations. Organizations acclimating to CM often fight with implementation issues and achieve results that are not as much as predicted (Wemmerlöv and Johnson, 1997). It is recommended that CM implementation benefits not be accomplished because of the circumstance where the research works on CM over the last 20 years have focused on the techniques to tackle the cell formation problem (Wemmerlöv and Johnson, 2000; Norman *et al.*, 2002; Chakravorty and Hales, 2004). Accentuation on technical issues has additionally been seen by firms implementing CM (Suresh and Kay, 1998; Fraser *et al.*, 2007).

Wemmerlöv and Johnson (1997) inferred that significant benefits can be accomplished with CM. However, its implementation is not just a change of the factory layout. Rather, it is a convoluted re-organization that contains hierarchical and human-related aspects of the manufacturing organizations. Most of the problems experienced by organizations implementing CM are related to people, not technical issues. Gunasekaran *et al.* (2001) stated: "Various techniques discussed in the literature offer no clear framework for the design and implementation of manufacturing cells." Park and Han (2002) contended that CM implementation is a dynamic and full research area and one in which interdisciplinary contribution appears to be productive. Table I offers a listing of case research describing the CM implementation and tool used in different industry types.

From the review of the literature, it is seen that there is not any study on prioritization and interrelationships among factors of CMS implementation; however, such studies have been led in different fields, for example, total quality management and lean manufacturing. What is absent from the perspective of professionals and managers of the organizations is an investigation of factors for fruitful implementation of CM. There is a need to recognize and prioritize the factors in CM implementation that would encourage business people and managers to get the advantages of customer satisfaction and economy.

Essential factors for CM implementation were obtained using literature review and discussed with five experts from academics and industry. Based on their responses, 17 factors have been categorized into 4 dimensions for further analysis. These factors are given in Table II and discussed subsequently.

2.1 Structural factor plays significant role in CM design and implementation

It tends to customize products while effectively keeping up the process adaptability (Xiong *et al.*, 2017; Khanna *et al.*, 2014).

2.1.1 Group technology. Group technology is necessary to CM (Dekkers, 2018). Mitrofanov and Burbidge proposed the concept of GT. Mitrofanov (1966) defined GT as "a method of manufacturing piece parts by the classification of these parts into groups and subsequently applying to each group similar technological operations." GT gives the establishment of a developmental way to deal with complete automation (Burbidge, 1991). GT is the backbone of every CM system existing in any organization (Khanna *et al.*, 2014).

2.1.2 Integrated product and process design. Mahadevan and Shah (2000) performed an investigation on "product–part–machine" dimension, in a CMS issue, and experimentally established that high product ownership could ensure high component ownership. Lennartson *et al.* (2010) presented a framework from product design to planning, to final production of a car manufacturing cell. Akturk and Yayla (2005) proposed a CM system design for product variety by incorporating technology in designing cell.

S. no.	Researchers	Technique used	Implications	Industry category
1	Wemmerlöv and Johnson (1997)	Survey	Report the findings of a survey study of 46 user plants involved with cellular manufacturing	Manufacturing
2	Wemmerlöv and Hyer (1989)	Survey	Report the findings of a survey study of 32 US firms involved with cellular manufacturing	Manufacturing
3	Javadian *et al.* (2011)	A non-dominated sorting genetic algorithm (NSGAII)	Present a multi-objective dynamic cell formation problem	Manufacturing
4	Varanujit and Peerapattana (2013)	Rank order clustering (ROC)	Adapted ROC and ROC2 for cell formation	Hard disk drive industry
5	Sakhaii *et al.* (2013)	Integer linear programming	Proposed a new integrated mixed-integer linear programming (MILP) model to solve a dynamic cellular manufacturing system (DCMS) with unreliable machines and a production planning problem simultaneously	Manufacturing
6	Sharma *et al.* (2015)	Lean	CMS implementation improves system flexibility	Textile
7	Jadhav *et al.* (2015)	Interpretive structural modeling	Comparative study of UNIDO–ACMA model and ISM model of lean implementation	Automotive
8	Renna and Ambrico (2015)	LINGO	Propose a cellular manufacturing system (CMS) with reconfigurable machines to handle the turbulent market conditions	Manufacturing
9	Imran *et al.* (2016)	Simulation integrated hybrid genetic algorithm	Suggest a method for cell formation in a cellular manufacturing system	Automobile
10	Wu *et al.* (2016)	Function block	Propose configuration and operation architecture for dynamic cellular manufacturing product–service system	SMEs
11	Rabbani *et al.* (2017)	Simulation	Study manpower allocation and cell loading problem, where demand is stochastic	Lamp manufacturing
12	Kumar *et al.* (2017)		Cellular manufacturing system (CMS) proves to be advancement in other manufacturing systems like flexible manufacturing system (FMS) and traditional manufacturing system (TMS)	Manufacturing
13	Soolaki and Arkat (2018)	Linear integer programming	A three-echelon supply chain that has several markets, production sites and suppliers is designed as a cellular manufacturing system (CMS)	Supply chain
14	Liu *et al.* (2018)	Integrated bacteria foraging algorithm	The cellular manufacturing system is integrated with the supply chain. Late delivery and production in advance result in backorder and holding costs	Supply chain

Table I.
Summary of industries in which CM implementation has been studied

2.2 Operational factors are helpful in the design for production planning and production control of CM

These are most technically focused factors of CM implementation (Bhangale and Mahalle, 2012).

2.2.1 Level scheduling. Scheduling of parts in CM is an essential issue. CM achievement is enhanced if jobs are scheduled and tracked inside the cells. Venkataramanaiah (2008) asserts that the operational performance of CM relies upon the level of missing tasks and scheduling approach utilized.

Dimension	Sub-factor	Author(s)
Structural F1	Group technology F1(1)	Kusiak (1987), Gunasekaran *et al.* (1994), Khanna *et al.* (2014), Dekkers (2018)
	Integrated product and process design F1(2)	Mahadevan and Shah (2000), Suresh and Kay (1998), Akinnuli (2016)
Operational F2	Level scheduling F2(1)	Mosier and Taube (1985), Vakharia and Wemmerlöv (1990), Wemmerlöv and Vakharia (1991), Chan *et al.* (1999), Park and Han (2002), Tesic *et al.* (2016)
	Total productive maintenance F2(2)	Chand and Shirvani (2000), Das *et al.* (2007), Valles and Sanchez (2011)
	Quality improvement/Six Sigma F2 (3)	Sakran *et al.* (2016)
	Setup time reduction/elimination plans F2(4)	Wemmerlöv and Hyer (1989), Wemmerlöv and Johnson (1997), Sakran *et al.* (2016)
	Line balancing F2(5)	Özgürler and Güneri (2010), Mahmad *et al.* (2017)
	Workplace organization plans F2(6)	Afzulpurkar *et al.* (1993), Nomden and Slomp (2006), Seifermann *et al.* (2014), Sakran *et al.* (2016)
	Robotics F2(7)	Tan *et al.* (2009) Zhang and Fang (2017)
Human related F3	Multi-skill employee F3(1)	Olorunniwo and Udo (2002), Park and Han (2002), Bidanda *et al.* (2005), Kaku *et al.* (2008), Sakran *et al.* (2016)
	Employee training F3(2)	Park and Han (2002), Bidanda *et al.* (2005), Olorunniwo and Udo (2002), Böllhoff *et al.* (2016)
Process improvement F4	Lean manufacturing F4(1)	Pattanaik and Sharma (2009), Metternich *et al.* (2013), Shah and Patel (2018)
	Computer-integrated manufacturing F4(2)	Nagalingam and Lin (2008)
	Value-added analysis F4(3)	Singh and Singh (2014)
	Flexible manufacturing systems F4 (4)	Chan and Abhary (1996), Suresh and Kay (1998), Mukattash *et al.* (2017)
	Agile manufacturing F4(5)	Garbie *et al.* (2008), Hallgren and Olhager (2009), Sabu and Krishnankutty (2014)
	Concurrent engineering F4(6)	Fruchter *et al.* (1998), Pullan *et al.* (2010), Aleisa *et al.* (2011)

Table II.
CM factors

2.2.2 Total productive maintenance. The efficient maintenance of the production and plant machinery is necessary for defining the total viability of the manufacturing process (McLaughlin and Durazo-Cardenas, 2013). Chand and Shirvani (2000) investigated the overall equipment effectiveness of a semi-automated assembly cell. Researchers proposed conducting a pilot project to implement a TPM program for the cell and then grow it further to the further cells in the plant. Das *et al.* (2007) proposed a preventive maintenance model for performance improvement of CM concerning machine reliability and resource utilization. It was confirmed that planning maintenance might accomplish much falls in maintenance-related costs and integrate it into the CMS design process. Maintenance is essential for the flexibility of CM (Qiu *et al.*, 2014).

2.2.3 Quality improvement/Six Sigma. Because of a higher natural ability of the processes, simplicity of material flow and diminished amounts of scrap and rework, CM systems give a high-class quality manufacturing process. Shirazi *et al.* (2010) utilized a Six Sigma way to achieve a balanced flow with the minimum fluctuations of inter and intra-loop flowed of material in CM and abridged that proposed method could be implemented in any physical setting where there is a liberal monetary thought for manage way plan.

2.2.4 Setup time elimination plans. Reduction in the setup time on each machine inside the cell to enhance throughput is a typical desire. Wemmerlöv and Johnson (1997) reported investigation of plants having CMS and how they accrue the advantages from CMS in the areas of move-distances, throughput times, customer response times, WIP inventory and setup times. Applying the concept of CM has several benefits which incorporate eliminating setup time (Sakran *et al.*, 2016).

2.2.5 Line balancing. Özgürler and Güneri (2010) discussed designing of U-shaped production lines and U-shaped cells at sheet metal workshop of a tractor factory and found that U-shaped cell line balancing increases production efficiency and effectiveness. Pujo *et al.* (2015) led distinctive experiment to focus on the performance gap between a U-cell and straight cell design.

2.2.6 Workplace organization plans. Work cell entails careful design. It is one of the technically engaged phases of CM implementation (Sakran *et al.*, 2016). It comprises update on current layout, determination of machine footprints, complete inventory of objects in cell, part routing, machine sequencing and part quantities resulting in cell traffic, tracking of a sample of commonly run parts, from–to chart analysis, generation of alternative layouts, generation of layouts for conventional sub-cells and estimation of machine loads in sub-cells (Irani, 1999).

2.2.7 Robotics. Utilizing robot, processing of parts or assemblies, ready for use by a downstream operation or cell or for shipment to a customer can be scheduled and managed rapidly. Robotic CM utilizes at least one mechanical robot to perform complex assembly operations. Robotic CM system provides significant production advantages as compared to manual assembly systems. Tan *et al.* (2009) considered the design and development of human and robot collaboration in CM and found significant improvement in system performance. Zhang and Fang (2017) talked about the difficulties and basic advances in the robotic cell layout optimal design.

2.3 Human-related factor

For successful implementation of CM, it is essential to focus on human-related factors (Hao *et al.*, 2013).

2.3.1 Multi-skill employee. Multi-skill employee can comprehend and deal with the system as a whole in less time. CM implementation is fruitful if employees are cross-trained to run different machines. Kaku *et al.* (2008) performed simulation experiments to examine the human-task-related performance in CM that incorporates the additional operational tasks, the skill level and the cross-training of workers. It was inferred that the most significant contribution in CM implementation is not just the motivation yet additionally the level of skill of workers (Rabbani *et al.*, 2017). Coordination and high skill of workers are necessary for CM as workers have to work inside and outside the cell (Park and Han, 2002).

2.3.2 Employee training. Employees play a standout amongst the essential parts in implementing CM. The characteristics and complexity of a CM dictate the skills required to perform a job. In CM, workers from each cell have to work both inside and outside the cell. In a situation where one worker operates several machines, and work-pieces are fixed several times, the elimination of human error is crucial for product quality. Böllhoff *et al.* (2016) conducted an experiment to demonstrate that in machining, there is a huge impact of human workers on the quality of manufactured parts, at least for less trained workers. Park and Han (2002) expressed that training and worker development is important for managing human resources in CM implementation.

2.4 Process improvement factors are constant improvement factors that endeavor to enhance all aspects of CM
An advance clarification of these factors is imperative to justify how the CM improvement will progress (Hunter and Black, 2007).

2.4.1 Lean manufacturing. Lean manufacturing centers around identification and elimination of waste and delivering high-quality products at the most reduced cost (Sharma *et al.*, 2016) and furthermore gives a monetary premise to managers for investment planning decision. The primary characteristics are that production and distribution are demand driven, the minimum stock is maintained and a quick response is made to specific orders. Pattanaik and Sharma (2009) proposed a methodology for CM considering lean concept through manufacturing-based case study and analyzed original cell to minimize several wastages in the form of non-value-added activities.

2.4.2 Computer-integrated manufacturing. Completely functional CIM system in an enterprise will give the flexibilities and benefits of CM efficiently and economically. Ordinarily, CIM systems link management functions with engineering, manufacturing and support operations. It pools separate applications, such as computer-aided design, computer-aided engineering, computer-aided manufacturing, robotics and manufacturing resource planning (Groover, 2011). Scheer considers that the eventual aim of CIM is to streamline the manufacturing operations and to consolidate them with different business functions (such as financing, marketing and dispersing).

2.4.3 Value-added analysis. It tends to eliminate non-value-adding activities in CM. Singh and Singh (2014) demonstrate reducing non-value-adding activities present in the manufacturing process by using CM.

2.4.4 Flexible manufacturing systems. The flexibility of a CM is its adaptability to an extensive variety of conceivable changing environments that it may encounter. Chan and Abhary (1996) study the design of an integrated system, with both part family and machine groups simultaneously, in the design process of the CM and FMS. CM can be a lean and flexible alternative to the done-in-one concept with sophisticated, highly automated machine tools (Metternich *et al.*, 2013).

2.4.5 Agile manufacturing. It refers to quick response to customer demand with high quality, low cost and less time.

2.4.6 Concurrent engineering. It aims to improve the product design process to improve organizational performance. It is a product and process design method that incorporates simultaneous cooperation by customers, suppliers, planning, engineering, operations, accounting and other functions so that the input of every single concerned party is perceived at product's conception and design stages.

3. Methodology

The research methodology includes two stages. The first stage involves the selection of success factors by literature survey and discussion with experts. The second stage involves assigning weights and ranking factors using the AHP and ANP methods. The framework for this research work is illustrated in Figure 1.

In the first stage, all possible factors were identified from the literature and discussed with experts from academics and industry. In the present study, 20 factors critical for implementing CM were identified through the extant literature review. These factors were then put up for discussions with experts to seek their opinion to finalize factors to be considered for this study. Experts were selected very carefully to ensure valid results for the research. All experts have at least five years of experience. Five experts were from academia with PhD as a professional qualification, and five experts were from organizations working as managers in different prestigious

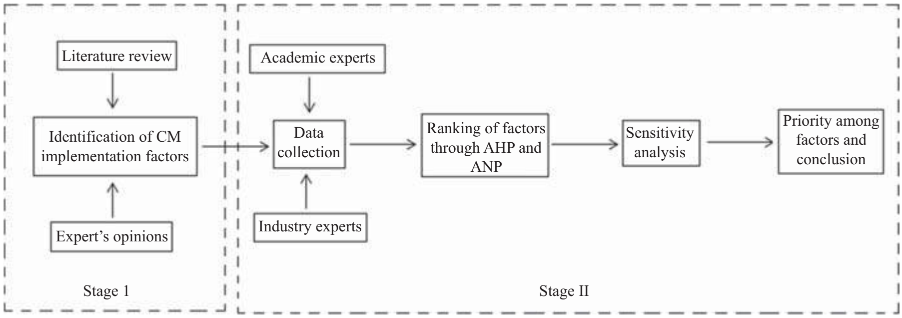

Figure 1.
Research framework

Indian manufacturing firms. After three rounds of discussions with experts, 17 factors have been categorized in 4 dimensions (discussed in Section 2). Questionnaires were used to collect the data.

The questionnaire comprises the following features:

(1) introduction to group technology and CM;

(2) description of the factors;

(3) steps of how to fill in the questionnaire table; and

(4) pairwise comparison matrix of the factors.

Now, all the experts were requested to complete the questionnaire. Furthermore, AHP and ANP methodologies were used for ranking of essential factors of CM.

3.1 Analytic hierarchy process (AHP)

AHP has been adopted as it is easy to use, flexible, check the consistency of the comparison matrix and is a formal method of handling criteria and sub-criteria (Emrouznejad and Marra, 2017). AHP is one of the most widely used multi criteria decision-making methods that were initially created by Prof Thomas L. Saaty (1980). It is a technique to get proportion scales from paired comparisons. It is helpful in decision-making model including both quantitative and qualitative components. AHP is a viable decision-making method and suitable to the problem where the choice factors can be organized hierarchically into sub-factors (Tuzmen and Sipahi, 2011).

The methodology steps of AHP are as follows:

(1) Define the goal.

(2) Construct structure which is hierarchical with decision factors.

(3) Establish pairwise comparison matrices which illustrate importance of one factor over other. It is constructed by Saaty's nine-point scale in which 1 represents equal importance and 9 represents extreme importance.

(4) Calculate consistency ratio using the following formula. The acceptable limit of CR is 0.1:

$$CI = \frac{\lambda_{\max - n}}{n-1} \quad CR = \frac{CI}{RI},$$

where $\lambda_{\max}$ is the largest eigenvalue, n is the rank of the matrix, CI is the consistency index and RI is the random index.

(5) Calculate local and global weight. The estimation of a local weight was given by Super Decision software. The estimation of global weight can be obtained using the following formula:

$$\text{Global weight} = \sum \text{Local weight of factor } i \times \text{local weight of sub} \\ -\text{factor } j \text{ with respect to factor } i.$$

The method has found application in several areas as presented in Table III.

3.2 Analytic network process (ANP)

ANP is the generic form of AHP.

Decision-making problems in ANP are modeled as a network (Saaty and Vargas, 2013). ANP allows individuals or groups to deal with the interconnections between factors in decision-making process (Saaty, 2004). ANP incorporates the associations and dependencies among the factors through all levels of the model which are assumed to be independent in an AHP.

Research has demonstrated that the ANP goes beyond linear relationship and permits interrelationships among factors. As ANP replaces single-direction relationship, it is more powerful then AHP in a decision environment with uncertainty (Saaty, 2004; Tran *et al.*, 2004).

The ANP methodology is enumerated as follows:

(1) Define the goal and construct the model and structure the problem like a network.

(2) Establish pairwise comparison matrices which illustrate importance of one factor over other. It is constructed by Saaty's nine-point scale in which 1 represents equal importance and 9 represents extreme importance.

(3) Calculate consistency ratio using the following formula. The acceptable limit of CR is 0.1:

$$CI = \frac{\lambda_{\max - n}}{n-1} \quad CR = \frac{CI}{RI},$$

where, $\lambda_{\max}$ is the largest eigenvalue, n is the rank of the matrix, CI is the consistency index and RI is the random index.

(4) Develop supermatrix. An element of the matrix represents the association and weight from one node (factor) to another node (factor). The matrix obtained from the pairwise comparison is un-weighted supermatrix. The values of un-weighted supermatrix are multiplied by the weight of each cluster to obtain weighted supermatrix. The limiting supermatrix is then obtained by raising the weighted supermatrix to a significantly massive power to have the stable values.

The method has been applied in varied areas of research as presented in Table IV.

Field	Authors
Technology transfer	Kumar *et al.* (2015), Lee *et al.* (2018)
Sustainable manufacturing system	Shankar *et al.* (2016)
Six Sigma implementation	Rimantho *et al.* (2017), Pandey *et al.* (2018)
Supplier selection	Xu *et al.* (2013), Moktadir *et al.* (2017)
Supply chain	Singh and Sharma (2014), Mathiyazhagan *et al.* (2018)
FMS implementation	Bayazit (2005), Sundarani and Qureshi (2017)
Manufacturing company	Görener (2012), Bhandari *et al.* (2018)
Lean implementation	Vinodh *et al.* (2011), Pereira and Tortorella (2018)
ERP implementation	Armand and Roger (2017), Tasnawijitwong (2018)

Table III. Use of AHP by various researchers across sectors

4. Model development

The entire problem of modeling the factors into hierarchy and network, pairwise comparison, inconsistency check and ranking of factors were carried out using the "Super Decision" software developed by Creative Decisions Foundation.

4.1 Development of AHP model

4.1.1 Step 1: defining the goal. This study aims to rank and prioritize critical factors influencing CM implementation.

4.1.2 Step 2: construction of hierarchal structure. Based on literature review and opinion from experts, a hierarchal structure has been formed. The goal of the problem is placed at the top of the model. Four factors (F1, F2, F3 and F4) and 17 sub-factors are placed at next levels. Figure 2 illustrates a hierarchy model in Super Decision software.

4.1.3 Step 3: pairwise comparison. Opinion of industry and academic experts were taken to create pairwise comparison of factors and sub-factors of CM. Experts were asked to compare 4 factors and 17 sub-factors by Saaty's nine-point scale in which 1 represents equal importance and 9 represents extreme importance. Next, geometric mean of expert's opinion was computed

Table IV. Use of ANP by various researchers across sectors

Field	Authors
Supplier selection	Xuguang *et al.* (2007), Kasirian *et al.* (2010), Bottani *et al.* (2018)
Lean implementation	Anand and Kodali (2009), Aminuddin *et al.* (2014), Luis *et al.* (2018)
Flexible manufacturing systems	Kodali and Anand (2010)
Supply chain	Hosseini *et al.* (2013), Chen *et al.* (2009)
Six Sigma	Vinodh and Swarnakar (2015)
TQM	Bayazit and Karpak (2007), Alidrisi and Mohamed (2012)

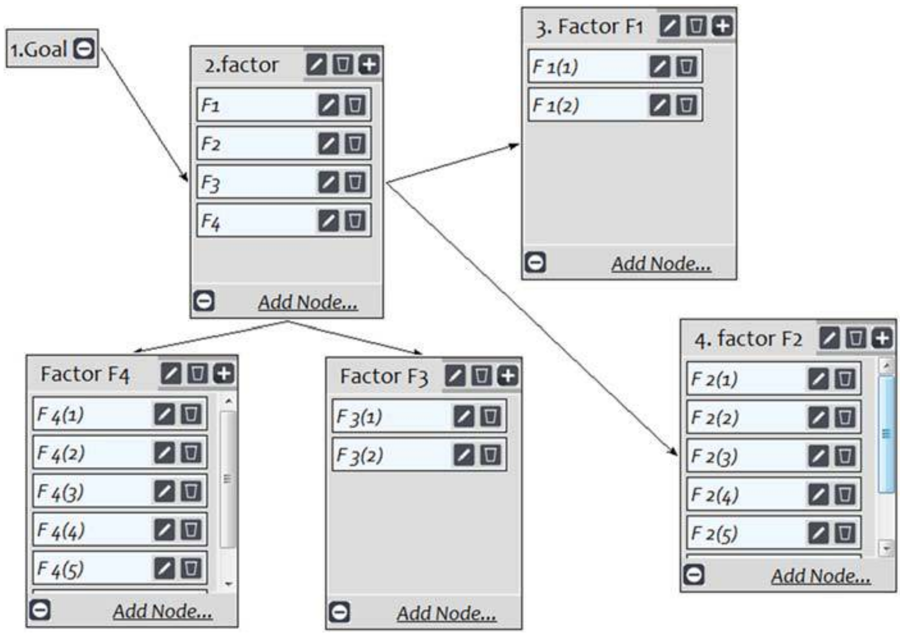

Figure 2. AHP model in Super Decision software

to average out their answers. Figure 3 illustrate one pairwise comparison from Super Decision software.

Pairwise comparison matrix of the four dimensions is presented in Table V. Pairwise comparison matrix of the sub-factors is presented in Table VI.

4.1.4 Step 4: consistency ratio. Evaluation of consistency is viewed as the most vital part of AHP technique. Inconsistency may prompt obscure and inaccurate results. CR is utilized as a measure to assess consistency in the judgment of experts. According to Satty, values going from 0.0 to 0.1 are considered to be inside acceptable limits; if its value is more than

Figure 3. Questionnaire-based pairwise comparison

	F1	F2	F3	F4	CR = 0.055 Priority weights
F1	1	0.5	0.142857	1	0.0868
F2	2	1	0.25	5	0.2221
F3	7.000007	4	1	6	0.6167
F4	1	0.2	0.166667	1	0.0743

Table V. Pairwise comparison of four dimensions

								CR = 0
	F 1(1)	F 1(2)						Priority weights
F 1(1)	1	3						0.75
F 1(2)	0.3333	1						0.25
								CR = 0.055
	F 2(1)	F 2(2)	F 2(3)	F 2(4)	F 2(5)	F 2(6)	F 2(7)	Priority weights
F 2(1)	1	1	1	6	2	1	0.25	0.1337
F 2(2)	1	1	3	6	1	1	0.25	0.1337
F 2(3)	1	0.33333	1	1	0.25	0.5	0.1666	0.0572
F 2(4)	0.1666	0.1666	1	1	0.3333	0.3333	0.1666	0.0380
F 2(5)	0.5	1	4	3.0003	1	1	0.2	0.1143
F 2(6)	1	1	2	3.0003	1	1	0.25	0.1107
F 2(7)	4	4	5.9999	5.9999	5	4	1	0.4121
								CR = 0
	F 3(1)	F 3(2)						Priority weights
F 3(1)	1	1						0.5
F 3(2)	1	1						0.5
								CR = 0.044
	F 4(1)	F 4(2)	F 4(3)	F 4(4)	F 4(5)	F 4(6)		Priority weights
F 4(1)	1	1	1	1	6	0.2		0.1408
F 4(2)	1	1	1	1	8	0.5		0.1634
F 4(3)	1	1	1	1	7	1		0.1835
F 4(4)	1	1	1	1	7	1		0.1835
F 4(5)	0.1666	0.125	0.1428	0.1428	1	0.125		0.0254
F 4(6)	5	2	1	1	8	1		0.3032

Table VI. Pairwise comparison of sub-factors with their respective dimensions

0.1, at that point the experts may need to re-examine the pairwise comparison. As illustrates in Tables V and VI, CR estimations of all factors and sub-factors fell inside acceptable limits.

4.1.5 Step 5: local and global weight. Local weight and global weight of factors and sub-factors are shown in Table VII.

The AHP process makes it possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria. The method utilizes pairwise comparisons of main criteria as well as pairwise comparisons of the multiple sub-criteria for each main criterion. After making the pairwise comparison of main criteria and sub-criteria, the global weight of the sub-criteria is identified by multiplying the local weight of sub-criteria by the weight of its main criteria. From this global weight, a conclusion can be made about the rank of the importance of sub-criteria according to the opinions of decision makers.

4.2 Development of ANP model

4.2.1 Step 1: defining the goal. The aim is to rank and prioritize critical factors influencing CM implementation.

4.2.2 Step 2: construction of network model structure. Based on the literature review and opinion from experts, a network model has been formed. Figure 4 illustrates a network model in Super Decision software. The ANP structure is completed by building up the networks among cluster and nodes. These connections decide how the pairwise comparison is to be made in the network.

4.2.3 Step 3: pairwise comparison. Opinions of industry and academic experts were taken to create pairwise comparison of factors and sub-factors of CM. Experts were asked to compare 4 factors and 17 sub-factors by Saaty's nine-point scales where 1 represents equal importance and 9 represents extreme importance. Next, geometric mean of expert's opinion was computed to average out their answers. For the proposed model a series of pairwise comparison matrix is developed. There were 73 pairwise comparison matrixes, because of space constraint they are not shown here.

4.2.4 Step 4: consistency ratio. This step is the same as discussed in AHP.

				AHP				ANP			
Dimension	Dimension weight	Rank	Sub-factors	Local weight	Relative rank	Global weight	Global rank	Local weight	Relative rank	Global weight	Global rank
F1	0.0868	3	F1 (1)	0.75	1	0.0651	3	0.163	1	0.0141	3
			F1 (2)	0.25	2	0.0217	8	0.088	2	0.0076	5
F2	0.2221	2	F2 (1)	0.1337	2	0.0296	4	0.035	2	0.0077	4
			F2 (2)	0.1337	2	0.0296	4	0.035	2	0.0077	4
			F2 (3)	0.0572	5	0.0127	10	0.015	5	0.0033	10
			F2 (4)	0.0380	6	0.0084	13	0.010	6	0.0022	13
			F2 (5)	0.1143	3	0.0253	5	0.030	3	0.0066	6
			F2 (6)	0.1107	4	0.0245	6	0.029	4	0.0064	7
			F2 (7)	0.4121	1	0.0915	2	0.095	1	0.0210	2
F3	0.6167	1	F3 (1)	0.5	1	0.3083	1	0.125	1	0.0770	1
			F3 (2)	0.5	1	0.3083	1	0.125	1	0.0770	1
F4	0.0743	4	F4 (1)	0.1408	4	0.0104	12	0.036	4	0.0026	12
			F4 (2)	0.1634	3	0.0121	11	0.042	3	0.0031	11
			F4 (3)	0.1835	2	0.0136	9	0.046	2	0.0034	9
			F4 (4)	0.1835	2	0.0136	9	0.046	2	0.0034	9
			F4 (5)	0.0254	5	0.0018	14	0.007	5	0.0005	14
			F4 (6)	0.3032	1	0.0225	7	0.073	1	0.0054	8

Table VII. Weight and ranks for dimensions and sub-factors

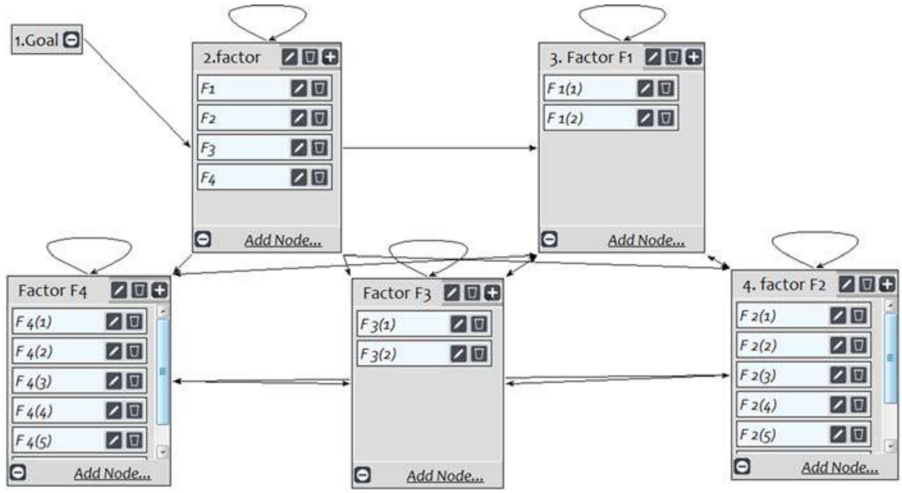

Figure 4.
ANP model in Super Decision software

4.2.5 Step 5: forming the supermatrix. The network of ANP is represented as a matrix by listing all nodes horizontally and vertically. An element of the matrix represents the association and weight from one node (factor) to another node (factor). The matrix obtained from the values of Step 3 is the un-weighted super-matrix (Table IX). The values of un-weighted supermatrix are multiplied by the weight of each cluster to obtain stochastic supermatrix which is known as weighted supermatrix (Table X). The column sum of any column in weighted supermatrix is equal to 1. The limiting supermatrix (Table XI) was then obtained by raising the weighted supermatrix to a significantly massive power to have the stable values. The values of the limit matrix are the desired priorities of the factors concerning the goal.

ANP utilizes supermatrix to manage the relationship and association among the factor. In the event that no associated relationship exists among the factor, the pairwise comparison was maintained 0. If an associated and input relationship exists among the factors, at that point, such value would never be 0 and an un-weighted supermatrix will be developed.

5. Sensitivity analysis

Sensitivity analysis was used to explore how sensitive the rankings of the criteria and their related sub-criteria are to change, if the weights of the criteria and its related sub-criteria are subjected to change. Toward this end, the percentage of each criterion was increased by 10 percent and after that, for the sub-criteria, it was disseminated equally so that the total sum is kept balanced, and then figuring out the changes in ranking (Abd El-Naby, 2015). It may be noted that, in the sensitivity analysis, one factor is modified at a time, while other factors are maintained unaltered to perceive what the effects or enhancements happen to the modified factor and its related sub-factors.

Table VIII illustrates the changes in weights and rank for the factor and sub-factor when increasing the weight for each factor by 10 percent while other criteria stay unaltered. Subsequently, the weights were disseminated equally to the related sub-factors.

6. Results and discussions

The study attempts to identify critical factors to implement CM successfully and analyze the importance of factors by applying AHP and ANP techniques. The study is based on interaction with five experts from academia and industry. Essential factors have been

Dimension	Old weight	Old rank	New weight	New rank	Sub-factors	Old global weight (AHP)	Weight increased	New global weight	Old rank	New rank
F1	0.0868	3	0.1868	3	F1 (1)	0.0651	0.05	0.1151	3	2
					F1 (2)	0.0217	0.05	0.0717	8	4
F2	0.2221	2	0.3221	2	F2 (1)	0.0296	0.0142	0.0438	4	5
					F2 (2)	0.0296	0.0142	0.0438	4	5
					F2 (3)	0.0127	0.0142	0.0269	10	12
					F2 (4)	0.0084	0.0142	0.0226	13	13
					F2 (5)	0.0253	0.0142	0.0395	5	6
					F2 (6)	0.0245	0.0142	0.0387	6	8
					F2 (7)	0.0915	0.0142	0.1057	2	3
F3	0.6167	1	0.7167	1	F3 (1)	0.3083	0.05	0.3583	1	1
					F3 (2)	0.3083	0.05	0.3583	1	1
F4	0.0743	4	0.1743	4	F4 (1)	0.0104	0.0166	0.027	12	11
					F4 (2)	0.0121	0.0166	0.0287	11	10
					F4 (3)	0.0136	0.0166	0.0302	9	9
					F4 (4)	0.0136	0.0166	0.0302	9	9
					F4 (5)	0.0018	0.0166	0.0184	14	14
					F4 (6)	0.0225	0.0166	0.0391	7	7

Table VIII.
Sensitivity analysis summary

identified from the literature and validated by experts. A total of 17 factors of CM implementation have been categorized in 4 dimensions.

The AHP hierarchical model, shown in Figure 2, is divided into the goal (objective of the problem), factors (the dimensions of CM) and sub-factors (essential factors of CM). AHP started with a pairwise comparison of different factors and sub-factors. Local and global weights of all the factors were determined. From Table V it can be inferred that human-related factors (0.6167) are a vital influencer in an implementation of CM. The finding bolsters previous research by Park and Han (2002) and Wemmerlöv and Johnson (1997) who had, through the survey, affirmed that human-related factors are at the center of CM implementation. The management of the organization should immensely focus on the human-related factors. Operational factors (0.2221) stand at the second rank as it significantly emphasizes on CM implementation. It is followed by a structural factor (0.0868) and process improvement factor (0.0743).

Furthermore, under each of the four dimensions, sub-factors have been analyzed as illustrated in Table VI. In structural dimension, "group technology" has been found as the most important factors followed by "integrated product and process design" factor. Similarly, "robotics" has been shown as most important sub-factor in operational dimension. "Multi-skill employee" and "employee training" are equally important sub-factors under human-related dimension. Furthermore, in "process improvement" dimension of CM, "concurrent engineering" has been reported as the most important factor.

The study further proposes to calculate a global weight of each factor by considering the local weight of factors and multiplying it by weight of respective dimensions. As shown in Table VII, "multi-skill employee" and "employee training" have been rated as most important factors based upon global weight values of factors. This finding is in line with the results of Park and Han (2002) and Wemmerlöv and Johnson (1997). Training gives essential knowledge and skills to employees for enhancing performance and emphasizes on means to increase employees' brainpower and mental capabilities. (Wemmerlöv and Johnson, 2000) contended that the absence of achievement is not only due to the absence of an implementation model but can also be due to the absence of understanding of the human issues linked to implementation. McLaughlin and Durazo-Cardenas (2013) affirmed that employee training, reward, job analysis and planning may impact the achievement of the CM system.

"Robotics" stands at the second position in the AHP model. Robots in CM help to produce a wide range of products and also allow the production in small lots as per customer requirements due to the ability to quickly reconfigure machines (Caggiano and Teti, 2018). "Group technology" is ranked third. This is in line with the findings from a survey conducted by Urban Wemmerlöv and Johnson (2000) that gives high priority to group technology. Dekkers (2018) claims that group technology increases firms' customer orientation and product customization.

The ANP network model is illustrated in Figure 4. The outputs obtained from the Super Decision software are un-weighted, weighted and limit matrix, as illustrated in Tables IX–XI. The result obtained with ANP is marginally different from AHP. It may be because the ANP model takes into consideration the influence of other factors. As shown in Table VII top four sub-factors obtained from ANP are similar to AHP. The ranking of other sub-factors obtained from ANP is illustrated in Table VII. The ranking of sub-factors like "integrated product and process design," "line balancing," "workplace organization plans" and "concurrent engineering" obtained in AHP and ANP are quite similar. The output of ANP supports the finding of AHP since the top four factors in the hierarchy are the same.

The results of this study are consistent as inconsistency ratio of all pairwise comparison is under 0.1. Furthermore, in a sensitivity analysis, changing 10 percent of the weights may be an exceedingly likely possibility because of change in pairwise comparison; these slight changes influence the positions of the factors. "Integrated product and process design" jumps from 8 to 4 ranks by only increasing weight 0.05. Table VII summarizes changes in weight and ranks of all sub-factors.

7. Conclusions and implications of the research

CM is presently getting significant practical consideration. The organizations need to pay careful attention to choose CM implementation factors, as implementing all of them simultaneously can become a massive task. This study utilized AHP and ANP methodologies to prioritize essential CM factors which are further validated through sensitivity analysis. Initially, all possible factors were identified from the literature and discussed with five experts from academics and industry.

There emerges a fundamental issue concerning dividing the set of CM factors into some noteworthy segments to speed up its implementation. By focusing on relevant factors, the managers can implement CM in the organization successfully (Sharma *et al.*, 2016). The main contribution of this study is to identify and prioritize the factors that managers often face in CM implementation.

The factors identified in this study can help as a checklist that carefully covers possible success factors related to CM implementation, setting the stage for some additional directions for CM implementation. It can also raise the cognizance regarding critical factors for those involved in implementing CM. Proper planning and solutions should then be carried out to accomplish a higher degree of success in CM implementation. Based on AHP and ANP ranking, the significance level can be judged for every factor.

The research shows an entire framework of critical factors along with their global weight and rank. The managers of the organization can be able to recognize the required abilities with a specific end goal to achieve and maintain their upper hand. Ordinarily because of the absence of adequate assets, it is not feasible for the managers to manage all success factors at the similar time. In this way, with the prioritization of success factors, the professionals can have the capacity to understand that on which factors they need to work on the need premise.

The analysis brings forth that "multi-skill employee," "employee training," "robotics" and "group technology" are the top ranking factors on which the

Table IX. Un-weighted super matrix

	Goal	F1	F2	F3	F4	F 1(1)	F 1(2)	F 2(1)	F 2(2)	F 2(3)	F 2(4)
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.087	0.000	0.115	0.225	0.125	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.222	0.287	0.000	0.610	0.150	0.000	0.000	0.000	0.000	0.000	0.000
F3	0.617	0.635	0.764	0.000	0.725	0.000	0.000	0.000	0.000	0.000	0.000
F4	0.074	0.078	0.121	0.166	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F 1(1)	0.000	0.750	0.000	0.000	0.000	0.000	1.000	0.750	0.750	0.750	0.750
F 1(2)	0.000	0.250	0.000	0.000	0.000	1.000	0.000	0.250	0.250	0.250	0.250
F 2(1)	0.000	0.000	0.134	0.000	0.000	0.134	0.134	0.000	0.159	0.153	0.123
F 2(2)	0.000	0.000	0.134	0.000	0.000	0.134	0.134	0.159	0.000	0.136	0.124
F 2(3)	0.000	0.000	0.057	0.000	0.000	0.057	0.057	0.053	0.070	0.000	0.062
F 2(4)	0.000	0.000	0.038	0.000	0.000	0.038	0.038	0.047	0.048	0.038	0.000
F 2(5)	0.000	0.000	0.114	0.000	0.000	0.114	0.114	0.141	0.133	0.102	0.120
F 2(6)	0.000	0.000	0.111	0.000	0.000	0.111	0.111	0.128	0.127	0.118	0.114
F 2(7)	0.000	0.000	0.412	0.000	0.000	0.412	0.412	0.471	0.463	0.453	0.456
F 3(1)	0.000	0.000	0.000	0.500	0.000	0.500	0.500	0.500	0.500	0.500	0.500
F 3(2)	0.000	0.000	0.000	0.500	0.000	0.500	0.500	0.500	0.500	0.500	0.500
F 4(1)	0.000	0.000	0.000	0.000	0.141	0.141	0.141	0.141	0.141	0.141	0.141
F 4(2)	0.000	0.000	0.000	0.000	0.163	0.163	0.163	0.163	0.163	0.163	0.163
F 4(3)	0.000	0.000	0.000	0.000	0.184	0.184	0.184	0.184	0.184	0.184	0.184
F 4(4)	0.000	0.000	0.000	0.000	0.184	0.184	0.184	0.184	0.184	0.184	0.184
F 4(5)	0.000	0.000	0.000	0.000	0.025	0.025	0.025	0.025	0.025	0.025	0.025
F 4(6)	0.000	0.000	0.000	0.000	0.303	0.303	0.303	0.303	0.303	0.303	0.303

	F 2(5)	F 2(6)	F 2(7)	F 3(1)	F 3(2)	F 4(1)	F 4(2)	F 4(3)	F 4(4)	F 4(5)	F 4(6)
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F 1(1)	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
F 1(2)	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
F 2(1)	0.140	0.151	0.231	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134
F 2(2)	0.162	0.151	0.230	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134
F 2(3)	0.071	0.064	0.094	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
F 2(4)	0.045	0.042	0.056	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
F 2(5)	0.000	0.124	0.200	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114
F 2(6)	0.130	0.000	0.189	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
F 2(7)	0.453	0.468	0.000	0.412	0.412	0.412	0.412	0.412	0.412	0.412	0.412
F 3(1)	0.500	0.500	0.500	0.000	1.000	0.500	0.500	0.500	0.500	0.500	0.500
F 3(2)	0.500	0.500	0.500	1.000	0.000	0.500	0.500	0.500	0.500	0.500	0.500
F 4(1)	0.141	0.141	0.141	0.141	0.141	0.000	0.165	0.160	0.160	0.140	0.234
F 4(2)	0.163	0.163	0.163	0.163	0.163	0.214	0.000	0.194	0.194	0.158	0.248
F 4(3)	0.184	0.184	0.184	0.184	0.184	0.235	0.224	0.000	0.225	0.189	0.241
F 4(4)	0.184	0.184	0.184	0.184	0.184	0.235	0.224	0.225	0.000	0.189	0.241
F 4(5)	0.025	0.025	0.025	0.025	0.025	0.032	0.032	0.031	0.031	0.000	0.035
F 4(6)	0.303	0.303	0.303	0.303	0.303	0.284	0.355	0.390	0.390	0.324	0.000

management must pay the first focused attention. Managers should stress on employee training since it is the most critical factor that would yield a maximum positive impact on other factors.

The primary reason of the proposed methodology is that it has been applied and demonstrated in different complex applications, it deteriorates the complex problems into a simple hierarchical structure which exposes the transparency in the choices of the decision makers and it can be easily understood at the operational level.

The strength of the present study is that it is one of the first few to be conducted to study critical factors for CM implementation. The proposed study also has certain

	Goal	F1	F2	F3	F4	F 1(1)	F 1(2)	F 2(1)	F 2(2)	F 2(3)	F 2(4)
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.087	0.000	0.057	0.112	0.062	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.222	0.144	0.000	0.305	0.075	0.000	0.000	0.000	0.000	0.000	0.000
F3	0.617	0.317	0.382	0.000	0.362	0.000	0.000	0.000	0.000	0.000	0.000
F4	0.074	0.039	0.060	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F 1(1)	0.000	0.375	0.000	0.000	0.000	0.000	0.250	0.188	0.188	0.188	0.188
F 1(2)	0.000	0.125	0.000	0.000	0.000	0.250	0.000	0.063	0.063	0.063	0.063
F 2(1)	0.000	0.000	0.067	0.000	0.000	0.033	0.033	0.000	0.040	0.038	0.031
F 2(2)	0.000	0.000	0.067	0.000	0.000	0.033	0.033	0.040	0.000	0.034	0.031
F 2(3)	0.000	0.000	0.029	0.000	0.000	0.014	0.014	0.013	0.018	0.000	0.015
F 2(4)	0.000	0.000	0.019	0.000	0.000	0.010	0.010	0.012	0.012	0.009	0.000
F 2(5)	0.000	0.000	0.057	0.000	0.000	0.029	0.029	0.035	0.033	0.026	0.030
F 2(6)	0.000	0.000	0.055	0.000	0.000	0.028	0.028	0.032	0.032	0.030	0.029
F 2(7)	0.000	0.000	0.206	0.000	0.000	0.103	0.103	0.118	0.116	0.113	0.114
F 3(1)	0.000	0.000	0.000	0.250	0.000	0.125	0.125	0.125	0.125	0.125	0.125
F 3(2)	0.000	0.000	0.000	0.250	0.000	0.125	0.125	0.125	0.125	0.125	0.125
F 4(1)	0.000	0.000	0.000	0.000	0.070	0.035	0.035	0.035	0.035	0.035	0.035
F 4(2)	0.000	0.000	0.000	0.000	0.082	0.041	0.041	0.041	0.041	0.041	0.041
F 4(3)	0.000	0.000	0.000	0.000	0.092	0.046	0.046	0.046	0.046	0.046	0.046
F 4(4)	0.000	0.000	0.000	0.000	0.092	0.046	0.046	0.046	0.046	0.046	0.046
F 4(5)	0.000	0.000	0.000	0.000	0.013	0.006	0.006	0.006	0.006	0.006	0.006
F 4(6)	0.000	0.000	0.000	0.000	0.152	0.076	0.076	0.076	0.076	0.076	0.076

	F 2(5)	F 2(6)	F 2(7)	F 3(1)	F 3(2)	F 4(1)	F 4(2)	F 4(3)	F 4(4)	F 4(5)	F 4(6)
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F 1(1)	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188
F 1(2)	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
F 2(1)	0.035	0.038	0.058	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
F 2(2)	0.040	0.038	0.057	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
F 2(3)	0.018	0.016	0.024	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
F 2(4)	0.011	0.011	0.014	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
F 2(5)	0.000	0.031	0.050	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
F 2(6)	0.032	0.000	0.047	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
F 2(7)	0.113	0.117	0.000	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103
F 3(1)	0.125	0.125	0.125	0.000	0.250	0.125	0.125	0.125	0.125	0.125	0.125
F 3(2)	0.125	0.125	0.125	0.250	0.000	0.125	0.125	0.125	0.125	0.125	0.125
F 4(1)	0.035	0.035	0.035	0.035	0.035	0.000	0.041	0.040	0.040	0.035	0.059
F 4(2)	0.041	0.041	0.041	0.041	0.041	0.053	0.000	0.049	0.049	0.040	0.062
F 4(3)	0.046	0.046	0.046	0.046	0.046	0.059	0.056	0.000	0.056	0.047	0.060
F 4(4)	0.046	0.046	0.046	0.046	0.046	0.059	0.056	0.056	0.000	0.047	0.060
F 4(5)	0.006	0.006	0.006	0.006	0.006	0.008	0.008	0.008	0.008	0.000	0.009
F 4(6)	0.076	0.076	0.076	0.076	0.076	0.071	0.089	0.097	0.097	0.081	0.000

Table X. Weighted super matrix

limitations, which suggest the path for future research. First, the analysis is based on the opinion of five experts, which can be increased. Second, the data can be collected from many industries from the different geographical regions for better generalization of results. Third, the results can be compared to other methods such as interpretive structural modeling, DEMATEL and TOPSIS. Fuzzification of data can give some new insights. Furthermore, proper contextual case studies might be appropriately dissected by following deliberate action plan, and comparing the results to approve the findings and usability of suggestions.

	Goal	F1	F2	F3	F4	F 1(1)	F 1(2)	F 2(1)	F 2(2)	F 2(3)	F 2(4)
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F 1(1)	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163
F 1(2)	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
F 2(1)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
F 2(2)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
F 2(3)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
F 2(4)	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
F 2(5)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
F 2(6)	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
F 2(7)	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
F 3(1)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
F 3(2)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
F 4(1)	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
F 4(2)	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
F 4(3)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
F 4(4)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
F 4(5)	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
F 4(6)	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073

	F 2(5)	F 2(6)	F 2(7)	F 3(1)	F 3(2)	F 4(1)	F 4(2)	F 4(3)	F 4(4)	F 4(5)	F 4(6)
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F 1(1)	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163
F 1(2)	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
F 2(1)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
F 2(2)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
F 2(3)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
F 2(4)	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
F 2(5)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
F 2(6)	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
F 2(7)	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
F 3(1)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
F 3(2)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
F 4(1)	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
F 4(2)	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
F 4(3)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
F 4(4)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
F 4(5)	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
F 4(6)	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073

Table XI.
Limit supermatrix

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Further reading

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