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Gunjan Yadav

Assistant Professor, Production Engineering Department,
Veermata Jijabai Technological Institute (VJTI), Mumbai-400019, Maharashtra, India
E-mail: gunjanyadav86@gmail.com

Sunil Luthra*

Assistant Professor, Department of Mechanical Engineering,
State Institute of Engineering & Technology, Nilokheri-132117, Haryana, India
E-mail: sunilluthra1977@gmail.com

Prof. Donald Huisingh

The Institute for a Secure and Sustainable Environment,
University of Tennessee, Knoxville- 37996, U.S.A.
Editor-in-Chief, Emeritus- Journal of Cleaner Production
E-mail: dhuisingh@utk.edu

Sachin Kumar Mangla

Lecturer in Knowledge Management and Business Decision Making
Plymouth Business School (PBS), University of Plymouth- PL4 8AA, United Kingdom
E-mail: sachin.kumar@plymouth.ac.uk; sachinmangl@gmail.com

Balkrishna Eknath Narkhede

Associate Professor, Industrial Engineering & Manufacturing System,
NITIE, Mumbai-400087, India
E-mail: benarkhede1@gmail.com

Yang Liu

Department of Management and Engineering,
Linköping University, Linköping-SE-581 83, Sweden
E-mail: yang.liu@liu.se

*Corresponding Author

Graphical Abstract

Development of a lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies

Abstract: The urgent need to reduce negative corporate environmental impacts while enhancing their financial strength and positive societal benefits is attracting company leaders to implement various quality improvement systems such as lean manufacturing, six sigma, sustainable manufacturing, and circular economy concepts, approaches and technologies. All of these approaches are valuable, with Lean Manufacturing (LM) among the leading systems, if implemented within an appropriate framework. In that context, the objective of the authors was to document the drivers for improving implementation of LM within manufacturing companies. Implementation of LM practices is already providing competitive advantages such as improvements in product quality, productivity, worker health and safety and customer satisfaction in developed countries but has not been widely implemented in companies in developing countries. To help to enhance implementation of LM in developing countries, the authors developed a framework for enhancing the adoption of lean manufacturing processes in such companies. The hybrid Fuzzy Analytical Hierarchy Process (FAHP)- Decision Making Trial and Evaluation Laboratory (DEMATEL) tools were used as the framework to identify and to quantify the interrelationships among the drivers for implementation of LM. This hybrid approach facilitated documentation of the relative importance and priority of the thirty-one lean manufacturing drivers. The results revealed that improved shop-floor management, quality management, and manufacturing strategy drivers were among the most critical drivers, which enhance LM adoption. These findings are beneficial for company leaders and researchers working to improve environmental, economic and societal health, especially within companies in developing countries.

Keywords: Lean Manufacturing (LM); DEMATEL; Drivers; Enablers; Manufacturing industries; Multi Criteria Decision Making (MCDM)

1. Introduction to Existing LM Frameworks

Although, there is an increase in the number of documented benefits to companies, which implemented Lean Manufacturing (LM) literature, there is also information from a large

number of companies, which report about LM adoption failures (Henao et al., 2019). Fewer firms were successful in adoption of LM because of non-availability of frameworks to support LM implementation processes (Jadhav et al., 2014). The LM oriented research performed in US firms, documented that only thirty percent of LM implementing organisations achieved the potential benefits defined in the early stages of project execution (Gandhi et al., 2018). In the United Kingdom, the success rate was only twenty-five percent; which reflects upon the serious challenges for LM implementing organisations (Hofer et al., 2012; Ramesh and Kodali, 2012; Bhasin, 2013). This may be due to the fact that the available adoption frameworks, were designed for large-scale organisations (Alhuraish et al., 2017).

But, the reality is that there are far more Small and Medium Enterprises (SMEs) than large scale industries. This suggests that there is an urgent need to perform research that is focussed on the development of LM implementation frameworks within SMEs. However, until now, only a minority of SME company leaders have showed interest in implementing (Helleno et al., 2017). Moyano-Fuentes and Sacristán-Díaz (2012) reported that poor consideration of LM drivers was one of the major reasons behind poor LM adoption. Adoption of LM requires a structured process and an effective roadmap (Anvari et al., 2014), and a better understanding about the intensity of LM drivers (Duarte and Cruz-Machado, 2009; Carvalho et al., 2011).

In recent years, China has emerged as the global leader as an outsourcing hub due to low manufacturing costs and low costs of labour (Ramos et al., 2018). China is especially a leader in production of electronic products. They are considered to be the masters in producing the prototypes of electronic products at the lowest possible prices (Farias et al., 2019). This has been helped by their extensive adoption of LM practices, because LM practices are especially advantageous in companies that are mass producers of products. Researchers including, (Caldera et al., 2019). Storch and Lim (1999) have documented, that even a reduction of 2-3 seconds within the production process can result in huge financial savings. Hence, the LM practices are very popular among Chinese companies. But in comparison, companies in other developing countries have seriously struggled in adopting LM.

Although the LM concept emerged in the 1960s, most companies have had difficulties in successfully implementation of LM. Researchers have documented that LM adoption rates across developed economies is much higher than the developing economies. This is due to the existence of the dominance of large-scale companies in developed economies, which are highly successful in implementing LM. But in developing economies, which have a preponderance of SME's and poor educational and supportive infrastructures, they continue

to have difficulties in successfully implementing LM. Therefore, there is an increasing need for providing a driver-based framework and training for implementing LM in SME's in developing countries. Such a framework can increase the percentage of companies, which successfully implement LM and with that, increased energy and material's efficiency and enhanced product quality and worker health and safety.

But, merely developing a helpful framework will not be beneficial until the framework has been verified through case studies or Multi Criteria Decision Making (MCDM) approaches have verified the applicability of the developed framework. Belekoukias et al. (2014) found that there are several LM frameworks available but few have been verified through appropriate statistical procedures in real world company adoptions. Although the MCDM domain offers many approaches that can be utilised by researchers working in LM and can provide flexibility in justifying the developed framework, many researchers have only developed theoretical and conceptual models for LM adoption but they lacked validation, which contributed to the low frequency of successful implementation of LM in SMEs.

Despite several successful applications of LM in large-scale industries, the SMEs continue to have difficulties in adopting LM (Panwar et al., 2015). Many case studies in the Indian context reported LM failures in SMEs and concluded that the Indian context is far from being ready for wide-spread, successful, adoption of LM (Thanki and Thakkar, 2014). Some researchers emphasised that there is an urgent need for providing leaders of SMEs with clear instructions on the key drivers that can help them to successfully implement LM and to achieve improvement in their company's performance (Hofer et al., 2012). Many researchers have developed lists of drivers for LM adoption but they did not investigate the intensity of influence of the drivers in successful LM adoption (Ramesh and Kodali, 2012). Therefore, there is need for research that documents the drivers, their intensities and their inter-relationships.

To make progress on this journey, the authors of this article began by reviewing relevant literature on LM drivers (Shamah, 2013a; Stentoft Arlbjörn and Vagn Freytag, 2013). Accordingly, the objectives of the authors were:

- To identify and assess the intensity of key lean manufacturing drivers that assist LMs adoption in manufacturing companies in developing economies;
- To develop a LM implementation framework and to analyse the inter-relationships among the drivers;.

- To validate the conceptual framework by using case methodology in a real manufacturing company.

To achieve these objectives, initially, an exhaustive literature review was performed to explore the key LM drivers reported by various researchers in the context to manufacturing companies of developing economies. Further, a case company, which manufactures pump parts, was selected for an in-depth case study. An expert panel (see section 4 for details) was formed within the organisation to finalise the LM drivers and develop a framework suitable for present research work. The expert panel was engaged to develop the inputs for the hybrid fuzzy AHP-DEMATEL approach. The fuzzy AHP was employed to identify the intensity of influence of LM drivers; while, DEMATEL was used to analyse the inter-relationship among the constructs (LM drivers) of the developed framework. The developed framework was supplied to the case company to enhance lean manufacturing adoption. Furthermore, before and after performances of the case company were documented to validate the framework developed in this study. This paper is comprised of the following seven sections:

Section 1 Contains the introduction;

Section 2 Contains the literature review of LM drivers reported by researchers. It highlights the gaps observed in existing LM frameworks;

Section 3 Outlines the research methodology used in the paper;

Section 4 Presents the details of the framework development and its testing within the selected case study company;

Section 5 Summarises the findings and the discussion of the analysis of the case study;

Section 6 Highlights implications of the findings of this paper, for company leaders and for researchers;

Section 7 Summarises the conclusions and highlights urgently needed future research.

2. Literature Review

It is important to build upon the relevant articles from the literature to effectively achieve the defined objectives. For this purpose, the systematic literature review approach adopted by (Tranfield et al., 2003; Yadav and Desai, 2016) was employed for this literature review. For conducting the comprehensive literature review, initially; the articles related to LM frameworks and drivers were searched for on Scopus and Web of Science by using the

following key words, “lean manufacturing frameworks”, “lean frameworks”, “lean drivers”, “lean enablers”, lean critical success factors”. The relevant articles published in the LM domain from 1998 to April 2019 were considered. To ensure the quality of articles, only journal articles were included while all other types of articles such as conference articles, book chapters, short surveys, editorial notes etc. were excluded. Finally, the forward snowball and backward snowball approach (Yadav et al., 2018) was used to eliminate duplicity and to include all relevant papers.

2.1 Lean Manufacturing Drivers Reported in the Selected Literature

The LM drivers were explored through the literature review and were tabulated as shown in Table 1. The drivers basically helped the researchers in diagnosing the key areas that needed to be addressed. By carefully reviewing areas and by developing the strategies to implement them, it will be easier for practitioners to implement LM in their companies. In the literature review, several sets of LM drivers were identified that were general to all sectors and which, were specific to manufacturing, service and healthcare sectors. Because the focus of this research was on manufacturing companies, the drivers reported for other sectors were excluded. A total of thirty-one LM drivers were reported by various researchers, which were selected for analysis in this research (See Table 1).

Table 1: The LM drivers identified through the literature review applicable to manufacturing companies

S. No.	Lean Manufacturing drivers	Description	Literature support
1	Production Scheduling	It includes implementation of continuous flow processes which provide support for achieving production of standardised products	(Bamber and Dale, 2000; Panizzolo et al., 2012)
2	Effective utilisation of resources	It can be achieved by effective allocation and monitoring of resources within the entire system	(Azadegan et al., 2013; Pernstål et al., 2015)
3	Effective management of inventory	It can be achieved by utilising Kanban practices and implementing ‘just-in-time’ methodologies within the company	(Bayou and Korvin, 2008; Gurumurthy and Kodali, 2008)
4	Control of product flow	It refers to adoption of forecasting approaches and monitoring of takt time (Average time taken for production of one unit)	(Hodge et al., 2011; Lyons et al., 2013)
5	Reduction of cycle time	It can be achieved by minimising non-value-added activities and avoiding bottlenecks by adopting Poka Yoke	(Vinodh et al., 2011; Julia et al., 2014)

6	Safety improvement initiatives	It includes usage of safety equipment and maintaining cleanliness on shop floor which enhances protection of employees	(Jadhav et al., 2014; Zhou, 2016)
7	Reduction of setup time	It includes the use of standardized jigs and fixtures, availability of checklists for guiding rapid and consistent setups and detailed instructions for changeovers	(Soriano□Meier et al., 2011; Jasti and Kodali, 2014)
8	Quality product design	It involves achieving zero defects by utilising the equipment that can detect defects and can provide solutions by eliminating the root cause(s)	(Huo et al., 2019; Leme et al., 2018)
9	Aligned distribution management across networks	This can be achieved by adopting shared distribution facilities and using optimisation approaches for transportation systems	(Fercoq et al., 2016; Thanki et al., 2016; Kurilova-Palisaitiene et al., 2018)
10	Effective strategies for marketing management	This includes the planning for promotion, usage of forecasting techniques and enhancing pull systems	(Gandhi et al., 2018; Huo et al., 2019)
11	Standardise product development approaches	It can be achieved by standardising the parts and by integrating design for manufacturing as integral in the early product/service system designs	(Duarte and Cruz-Machado, 2009; Gupta and Jain, 2013)
12	5S	It refers to effective housekeeping, standardising and sustaining them effectively	(Bayou and Korvin, 2008; Matt and Rauch, 2013)
13	Value stream mapping	It includes mapping of the current status of activities, diagnosing the NVA activities and by providing suggestions for developing future state activities map	(Bhaskaran, 2012; Rahman and Karim, 2014; Zhou, 2016)
14	Waste analysis	It can be achieved by identifying different types of wastes that lead to development of non-value-added activities	(Shah and Ward, 2007; Marinescu and Toma, 2008; Matt and Rauch, 2013)
15	Total quality management	It includes adoption of innovative quality practices and commitment of top management and strategic planning of all production processes	(Panizzolo, 1998; Marinescu and Toma, 2008; Ar, 2012)
16	Total productive maintenance	It includes maintenance practices that prevent or reduce frequency of system breakdowns and helps to ensure smooth execution of all production-related activities	(Seyedhosseini et al., 2013; Zhou, 2016)
17	Cellular manufacturing	It includes mapping of similar activities, for developing the product families and preparing the work cells systematically	(Detty and Yingling, 2010; Green et al., 2010)

18	Technology management	It includes adoption of advanced technologies that can help to facilitate the reduction of production lead time and to enhance product quality	(Singh et al., 2010; Soriano & Meier et al., 2011)
19	Standardisation of work	It can be achieved by aligning the process operations and by adopting standardised work procedures	(Helleno et al., 2017; Farias et al., 2019)
20	Process focus	It can be achieved by observing the fluctuating demands and by standardising the processes for product and production optimisation	(Panizzolo, 1998; Chiarini, 2011; Bhasin, 2013)
21	Continuous improvement approach	It includes adoption of Kaizen and by continuously diagnosing the activities that lead to non-value addition	(Bayou and Korvin, 2008; Matt and Rauch, 2013)
22	Visual management	It refers to visualisation of activities for identification of wastes by visual aids and by visual information systems	(Bhasin, 2011b; Ar, 2012; Bhaskaran, 2012)
23	Appropriate supplier evaluation strategies	Mapping the performance of suppliers by estimating their comparative costs and by promoting 'just-in-time,' deliveries	(Bhaskaran, 2012; Rahman and Karim, 2014; Zhou, 2016)
24	Mapping the delivery performance	By understanding the uncertainties in the demand and by initiating measures to provide the products by the customer's desired delivery time	(Marksberry, 2011; Ramesh and Kodali, 2012; Thanki and Thakkar, 2014)
25	Supplier development	Integrating suppliers with the system processes by training them and by building long-term, supportive relationships	(Detty and Yingling, 2010; Green et al., 2010)
26	Identifying the requirements of customers	Understanding the product modifications by considering the requirements of customers and working with them accordingly	(Ramos et al., 2018; Caldera et al., 2019; Henao et al., 2019)
27	Monitoring feedback from customers	Developing an effective customer feedback system by responding to their complaints and recommendations	(Alhuraish et al., 2017; Huo et al., 2019)
28	Adequate workforce evaluation strategies	Assigning the effective appraisal programs and incentives for lean project member's performance	(Azadegan et al., 2013; Pernstål et al., 2015)
29	Workforce training and education system	Providing effective training and education for better understanding and implementation of lean manufacturing activities	(Duarte and Cruz-Machado, 2009; Gupta and Jain, 2013)
30	Employee proficiency	It includes enhancement of multi-functionality of employees by changing their work programs and thereby making them adaptive for new workforce challenges	(Gurumurthy and Kodali, 2008; Vinodh et al., 2011)

31	Workforce empowerment & involvement	It refers to encouragement of employees to become actively involved in the planning and implementation of lean projects and by assigning them explicit responsibilities	(Detty and Yingling, 2010; Bortolotti and Romano, 2012; Vinodh and Joy, 2012)
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Production scheduling and effective utilisation of resources were among the key drivers that help in implementation of LM (Matt and Rauch, 2013). By production scheduling the production work can be standardised throughout the production processes (Shah and Ward, 2007). Similarly, by reviewing '*Just-In-Time*,' manufacturing systems, Kanban practices, and by effectively allocating and monitoring the resources within the system, the entire shop-floor management can be more effectively managed (Teichgräber and Bucourt, 2012). However, the control of product flow and safety improvement initiatives strengthen the involvement of employees and help to keep employees and management motivated (Panizzolo, 1998). By reducing cycle times, set-up times and by making checklists for set-ups available, improvements in shop-floor management usually results (Panwar et al., 2015). By linking these drivers together, all shop-floor activities can be synchronised effectively, which can lead to enhanced productivity of the entire production system (Thanki and Thakkar, 2014).

Quality product design and aligned distribution management across networks plays a vital role in efficient and effective production (Hofer et al., 2012). It consists of striving to achieve zero defects by utilising the proper equipment that can detect defects and by providing solutions for root causes of the problems. Thereby, more effective management can be achieved by adopting shared distribution facilities and by using optimisation techniques and enhancing the pull systems (Anvari et al., 2014). Researchers including (Shetty et al., 2010; Ramesh and Kodali, 2012; Soriano-Meier et al., 2011; Jasti and Kodali, 2014) suggested adoption of strategies for marketing management and for following standardised product development approaches as a manufacturing strategy which supports LM adoption.

By building upon the drivers listed in Table 1, LM can be smoothly adopted across the entire system.

Several researchers discussed quality management practices such as 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke), value stream mapping, waste analysis, total quality management and total productive maintenance as essential components that need to be adopted to facilitate the adoption of LM (Marksberry, 2011). Generally, 5S refers to effective housekeeping, standardising and sustaining them effectively (Jadhav et al., 2014). It consists of five elements namely; sort, set in order, shine, standardise, and sustain, which helps to ensure

effective operation of the entire system (Bhasin, 2011b). Similarly, the value stream mapping refers to mapping the current activities, to develop the current state map to identify the key areas for which improvement is needed and to explore the non-value-added activities, to eliminate those activities or processes, which do not contribute to increasing the production systems value (Mangla et al., 2019).

By incorporating the improved solutions, a new state map can be developed as proposed by Singh et al. (2010). However, total productive maintenance involves practices that help in preventing or minimising breakdowns and supports smooth implementation of activities to maintain a smooth and top quality of the production system's work flow (Singer and Becker, 2013). Standardisation of work, employing the continuous improvement approach, visual management, technology management and cellular manufacturing emerged as key drivers for effective implementation of lean manufacturing (Chiarini, 2011). The cellular manufacturing includes mapping of similar activities, developing the product families and preparing the work cell whereas, visual management refers to visualisation of activities for identification of wastes by visual aids and by visual information systems (Manzouri et al., 2013).

However, the process focus was achieved by observing the fluctuations in demands and by standardising the processes for optimised work flows (Shamah, 2013b). The technology management includes the adoption of advanced technologies, which can assist in reduction of lead-times and can reduce or eliminate non-value added activities (Arya and Jain, 2014). The continuous improvement approach includes adoption of Kaizen that focuses upon continuously diagnosing the key areas of improvement (Hasle et al., 2012). Kaizen refers to change for betterment and helps in eliminating non-value-added activities that directly support LM. Appropriate supplier evaluation strategies, mapping the delivery performance, supplier development, identifying the requirements of customers and monitoring the feedback from customers are the most important drivers reported by researchers in the evaluated literature (Setijono et al., 2010; Cudney and Elrod, 2011; Moyano-Fuentes and Sacristán-Díaz, 2012; Gupta and Jain, 2013; Stentoft Arlbjørn and Vagn Freytag, 2013).

Effective strategies for supplier evaluation should be adopted and the supplier's performance should be monitored by estimating its costs and by promoting '*Just-In-Time*,' approaches to minimise inventory storage costs (Yadav et al., 2018) which helps to reduce or eliminate storage wastes and to promote implementation of LM. Integrating suppliers within the system processes by training them and by building long-term relationships, leads to more reliable supplier development (Jasti and Kodali, 2014). In developing an effective customer feedback system, prompt, polite and helpful responses to their complaints help the company to make

needed corrections to avoid problems in the future and thereby, build loyal customers (Luthra et al., 2019). These approaches will help to improve the company's sustainable profitability (Jasti and Sharma, 2014). Working with customers to better understand their needs and by making product modifications accordingly, helps the company ensure repeat customers (Duarte and Cruz-Machado, 2009).

Adequate work force strategies, work force training and an employee educational system, monitoring employee proficiency, work force empowerment and involvement are among the approaches needed to help companies to move effectively in implementing LM (Carvalho et al., 2011). Using effective appraisal strategies and effective incentives for lean project members, helps to develop and to support a positive and productive workforce (Pavnaskar et al., 2003; Marodin and Saurin, 2013; Pakdil and Leonard, 2014). By providing effective training and education for better understanding of LM activities elevates the importance of the workforce training and educational system (Machado and Tavares, 2008; McDonald et al., 2009). Employee proficiency includes enhancement of multi-functionality of employees by rotating their work programs and thereby making them more adaptive for new workforce challenges (Machado and Leitner, 2010; Upadhye et al., 2010). Workforce empowerment and involvement can be enhanced by encouraging the employees' active participation in LM projects and by assigning important responsibilities to them (Yadav et al., 2018).

2.2 Literature Gaps

Based on the literature review conducted to explore the LM drivers, the following gaps were identified:

- Many studies on LM framework development (Johansen and Walter, 2007; Gao and Low, 2014; Yadav et al., 2017) were conceptual and were not verified, this creates uncertainty among company leaders in regard to LM's adoption. Although, several researchers (Zargun and Al-Ashaab, 2013; Alhuraish et al., 2017) identified drivers for successful LM adoption, few modelled them into a framework.
- Two research teams (Gandhi et al., 2018; Caldera et al., 2019) identified the weights of different LM drivers but did not explore the inter-relationships among them, which generated uncertainty about their behaviour during LM adoption processes.
- Two driver-oriented studies (Seth and Panigrahi, 2015; Yadav and Desai, 2017a) were focussed on managerial components but they did not focus upon the LM implementation drivers. Most of the researchers highlighted identification of non-

value adding activities for the framework development. However, limited research was done on the roles of quality practices in LM frameworks needed to ensure higher quality throughout the systems.

- The applications of the LM frameworks were documented in some healthcare (Hussain et al., 2016) and service-oriented sectors (Waterbury and Bonilla, 2008) through case studies. However, in the manufacturing sectors, few studies were found.
- The framework behaves differently when applied to companies within developed and developing economies because of differences in infrastructure development and availability of technological resources (Mathur et al., 2012). There are large differences between the two types of economies, during adoption of the LM frameworks with regard to governmental policies, implementation and enforcement of the policies, worker health and safety rules and regulations and their enforcement.
- In cases where the company only produces for local consumers, the situation may be different from global market companies with more strict expectations in products and services and in worker health and safety. Hence, it is necessary to develop country economy -specific frameworks rather than proposing generalised frameworks reported in the reviewed, LM literature.

Based on these gaps, it is clear that there is an urgent need for a framework and for a process by which company leaders can quantify the weights of LM drivers and can build upon the inter-relationships among the drivers. That framework should address aspects such as quality management practices, manufacturing processes and practices, worker health and safety, customer satisfaction, environmental impacts of all dimensions of the supply chain, of the customer usage of the products and of the ‘end-of-life’ management of the products.

Hence, this clearly supports the objective of the authors of this paper to develop a useful and effective framework for systematically and consistently implementing LM in manufacturing companies.

3. The Research Flow and Adopted Methodology

It is essential to have a structured methodology to perform effective research. Similarly, it is necessary to ensure that the research methods used in the study are justified for their applicability. The authors used a hybrid FAHP-DEMATEL approach to achieve the defined

objectives. Accordingly, this section presents research flow and discusses the adopted methodologies in subsequent sub sections.

3.1 The Research Flow Adopted for the Study

The LM drivers reported by various researchers were tabulated and were presented to a panel of experts for their evaluations and recommendations. After, their finalisation of drivers, the experts were asked to categorise them under different groups and to provide the initial inputs for the fuzzy AHP and DEMATEL approach. The fuzzy AHP approach was used to compute the LM driver weights and DEMATEL was utilised to help the researchers identify cause and effect drivers and to investigate the inter-relationships among them. Figure 1 presents the research flow adopted for the research.

[Figure 1 about here]

3.2 Fuzzy Analytical Hierarchy Process (FAHP)

Under the umbrella of multi-criteria decision-making approaches; there are several weight computation approaches that can be used, such as the simple multi-attribute rating technique, and the step-wise assessment ratio analysis, Simos etc. (Yadav et al., 2018). Although, there are several decision-making tools, the analytical hierarchy approach has emerged as the preferred choice of researchers, as observed from the literature. It was reported by Thomas Saaty (Saaty, 1981), to be a widely adopted approach. Later, the analytical hierarchy approach was integrated with fuzzy set theory to improve the precision of the solutions. The authors of this paper utilised the paired comparisons made by the experts and further checked its consistency to ensure quality inputs for computation of the weights of the drivers. The detailed procedure for these steps is explained in the following sections.

(1) Identification and finalisation of LM drivers: This step involved the identification of LM drivers. Additionally, an expert panel was formed to obtain inputs for FAHP. The experts were asked to finalise the LM drivers that influenced its adoption. Once the LM drivers were finalised for inclusion within the framework development process, the experts were requested to group the drivers into groups with similarities in function.

(2) Construct paired comparisons: This step used the input of data of paired comparisons from the decisions made by the experts. During this phase, all LM drivers of a particular group were compared together according to the scale presented in Table 2.

Figure 1: Research flow adopted for this research.

Table 2: Relative importance of the drivers in supporting implementation of LM

Intensity	Fuzzy Allocation	Corresponding Function
Equally Important	$\tilde{1}$	(1,1,3)
Weakly Important	$\tilde{3}$	(1,3,5)
Strongly Important	$\tilde{5}$	(3,5,7)
Very Strongly Important	$\tilde{7}$	(5,7,9)
Extremely Strongly Important	$\tilde{9}$	(7,9,11)

(1) The experts were asked to rate the comparisons among every two drivers, in such a way, that it critically defined how much a particular driver influences the other driver in the pair.

$$A=[a_{ij}], \text{ where } i, j=1, 2, 3, \dots, n \quad (\text{Eq.1})$$

(2) Compute the Eigen values: Each matrix was then processed by computing the Eigen values through each paired comparison matrix. It is important to highlight that for each $n \times n$ matrix, there will be n Eigen values. However, for further calculations the maximum value of those Eigen values was considered.

(3) Consistency check: Once the Eigen values for a particular matrix were obtained, they were utilised for checking the consistency of the particular matrix. Once the matrix was found to be consistent, then it was forwarded for calculation of the driver weights. The Consistency Ratio (CR) was the measure which, was used to check the consistency. It basically refers to the ratio of consistency index to the random index (see Table 3) for that particular matrix. For a matrix to be consistent its CR value should be less than 0.1.

Table 3: Random Consistency Index

Size (n)	1	2	3	4	5	6	7	8
Random Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40

(4) Compute the consistency index- The consistency ratio requires availability of a consistency index. A consistency index is the ratio of the difference between the maximum Eigen value and n , with one less value than n . The consistency index tends to be important because it assists in computing the driver's consistency.

3.3 Decision Making Trial and Evaluation Laboratory (DEMATEL)

The DEMATEL approach is one of the most commonly used research methods in the MCDM domain (Tzeng et al., 2007). This approach is a well-known problem solving technique that is

utilised for analysing complex problems (Mehregan et al., 2014; Uygun et al., 2014). This tool basically helps in analysing the factors of the problems within two different groups, namely; the cause group and the effect group (Malekzadeh et al., 2016; Su et al., 2016). The grouping of factors stated above helps the company leaders and researchers to have a better visualisation of their behaviour (Abdullah and Zulkifli, 2015; Rad et al., 2017). When compared to other modelling approaches (Analytical Network Process (ANP), Total Interpretive Structural Modelling (TISM), and Graph Theory and Matrix Approach (GTMA) etc.), this approach assists the researchers in understanding the contextual relations among the included factors within the problem structure and helps in identifying the strength of their inter-relationships (Gwo-Hshiung and Jih-Jang Huang, 2010).

(1) Develop the Initial Direct Reachability Matrix (IDRM) and the average matrix: This step helps in developing the IDRM and the average matrix. IDRM refers to initial direct reachability matrix. For the rating purpose, the experts were asked to rate the drivers based on their intensity of influence. Here the comparison was made when allotting the influence of one driver over the other. The average direct-relation matrix M was calculated by utilising (Eq.2).

$$m_{ij} = \frac{1}{H} \sum_{K=1}^H x_{ij}^k \quad (\text{Eq.2})$$

(2) Compute the normalised matrix: The average matrix developed in previous step was utilised to develop the normalised matrix by utilising (Eq.3).

$$D = M * S \quad (\text{Eq.3})$$

$$\text{Here, } S \text{ represents } = \min \left[\frac{1}{\max \sum_{j=1}^n |m_{ij}|}, \frac{1}{\max \sum_{i=1}^n |m_{ij}|} \right]$$

(3) Construct total relation matrix: Once the normalised matrix was obtained, then finally, a total relation matrix was constructed. The final relation matrix is represented by T and computed by (Eq.4)

$$T = D (I - D)^{-1} \quad (\text{Eq.4})$$

In Eq.4 the “ T ” designates the identity matrix. Once the total relation matrix is developed, all the rows and columns are added. The row sum indicates the direct and indirect influence of one LM on all the other drivers. Whereas, the column sum defines the direct and indirect

influence of one LM driver through all other remaining drivers. Then, " $r_i + c_j$ " and " $r_i - c_j$ " were calculated. Here, " $r_i + c_j$ " represents the total effects that a LM driver has on other drivers and what effects it receives from all other drivers. The formula, " $r_i - c_j$ " represents the net impacts which the LM driver puts on the entire system. All the LM drivers occurring in " $r_i + c_j$ " were considered as cause group drivers whereas, all the drivers occurring in " $r_i - c_j$ " were considered as effect group drivers.

(4) Diagnose threshold value: The threshold value was identified through the total direct relation matrix. The threshold value was calculated by taking the average of all the values of total relation matrix. The threshold value helps in diagnosing the direct and indirect effects of a particular LM driver on the entire system. All the values that were greater than the threshold value indicated the impact of LM driver on the particular driver as well as upon the entire system. All values greater than threshold indicate the relationship of criterion A with criterion B. If only i,j or j,i entry is greater than threshold then there is a unidirectional relationship among the selected factors. If both i,j and j,i entries are greater than threshold then there is a bi-directional relationship among the selected factors. The outcomes of threshold value calculations helped in developing the relationship diagram.

The combination of fuzzy AHP-DEMATEL adopted in this research, not only helped in identifying the intensity of influence of each LM driver during the adoption process but also predicted the inter-relations among them in their anticipated behaviour during the LM adoption process. As discussed earlier, there are several techniques to assess the criteria weights but FAHP has an advantage over other MCDM techniques because it compares all the criteria individually and inclusion of fuzzy set theory effectively handles the vagueness among the experts' judgements. Although, many techniques were reported in the reviewed literature to assess the interactions among drivers, DEMATEL can be used to effectively document the interactions among LM drivers spread over different groups which, are often very complex and might affect the final results.

4. Framework Development and its Testing

This section presents the framework development and its testing within the case company. Initially, the problem definition and organisation description was explained. Further, the

expert panel was formed and a framework was developed. Finally, fuzzy AHP and DEMATEL were applied to compute the weights and inter-relationships among the selected drivers. The details are presented in subsequent subsections.

4.1 Problem Definition and Organisation Description

To test the applicability of the developed framework, a pump parts manufacturing organisation was selected. It is a private firm which is classified as Indian Non-Government company that manufactures different types and different sizes of motor parts and a sub supplier of pump manufacturing company. The annual turnover of the organisation is 55 million Indian rupees (approximately US\$ 0.8 million). It has approximately 180 employees. The organisation produces Die cast Rotors, Machining Motor Shafts, Machining Die Cast Rotors, Machining Threading Shafts, Machining Motor Shafts Housing, Machining ING Motor Stator Housings, Machining end Shields, Machining Flanges, Machining Rotor with Shafts and many more. The company is equipped with machining facilities such as moulding machines, milling machines, extrusion machines, lathe machines, hydraulic machines, drilling machines, CNC machines, grinding machines etc. The company consists of seven sections namely; foundry section, stator housing section, ES and flange section, stamping section, rotor with shaft section, die casting section, and assembly section.

Before LM implementation, the case company was struggling with defects in their products and facing continuous pressure from its major customer to reduce defects. The company was working on continuous improvement activities but was constantly facing the occurrence of non-value adding activities and generated several wastes within their production processes, which stimulated them to adopt the LM framework as a solution to their inefficiency problems. However, it is important to note that the initial adoption cost of LM was high; so, they wanted to ensure its applicability in their company. Therefore, with these expectations, they agreed to test the LM framework proposed by the authors of this paper, within their company. The proposed LM framework was introduced and implemented during July 2017 and the resultant improvements were documented in July 2018.

4.2 Panel Formation and Framework Development

A decision panel, contained a group of six experts, was formed. The selected experts had more than ten years of experience and exposure to LM. Two experts were from the production and design department (senior engineers from the selected case company's major customer), two were from top management, one was from the R & D department and one was

from the warehouse and packaging. LM is considered to be a well-proven methodology for improving the organizational performance of manufacturing industries of large, medium as well as small scale organizations. Hence, any framework developed by the researchers/practitioners should hold its applicability across all types of organizations. Hence, in this study, the selection of experts for framework development process has been done keeping the above-mentioned criterion in mind.

The data collection from the experts was performed with the inputs from two brainstorming sessions. First morning session is conducted to finalise the criteria to be chosen for the framework development. The exhaustive list of LM drivers was provided to the experts to finalise the final list of drivers based on their suitability for facilitating the LM adoption across SMEs of developing economies. Later, the experts were asked to group the drivers with similar behaviour. The experts categorised the selected LM drivers into six different aspects of the company namely: the shop floor management, the manufacturing strategies, the quality management, the manufacturing processes, the supplier and customer management, and the work force management, to develop a LM framework to enhance its adoption as shown in Figure 2.

[Figure 2 about here]

This session helped in obtaining the four levels of the LM framework. The Level 1, Level 2, and Level 3 are the three levels of the framework where Level 1 represents the objective of the framework; Level 2 represents major group of drivers; Level 3 represents the sub group drivers of each major group of drivers. The second session was conducted to obtain the inputs for hybrid fuzzy AHP-DEMATEL approach. In fuzzy AHP, the pairwise comparison of drivers of each group were recorded for computing the driver weights; whereas, the comparisons made for DEMATEL approach were utilised to compute the inter-relationships among the drivers included for the LM framework development process. To test this framework, the expert's decisions were utilised for paired comparisons of LM drivers to compute their weights through the fuzzy AHP approach and later to identify the inter-relationships among them through the DEMATEL approach.

Figure 2: Framework developed for lean manufacturing adoption

4.3 Application of Fuzzy AHP

For computing the weights of LM drivers scrutinised for present research work, fuzzy AHP approach was utilised in this section. As discussed in previous the section, the pairwise comparisons were taken from the experts for the group being developed as shown in Table 1. Based on the feedback from the experts, comparisons of the main criteria drivers and sub-criteria drivers were developed. Sub-criteria drivers included shop floor management, manufacturing strategy, quality management, manufacturing process, supplier and customer management and work force management drivers. The detailed comparisons made by the experts for the main criteria were included in Table 4.

Table 4: Paired comparison of main criteria drivers

Main drivers	SFM	MS	QM	MP	SCM	WM	Weights
Shop Floor Management (SFM)	1	3	1	3	5	3	0.2969
Manufacturing Strategy (MS)	1/3	1	1	3	5	3	0.2097
Quality Management (QM)	1	1	1	3	5	3	0.2409
Manufacturing Process (MP)	1/3	1/3	1/3	1	5	3	0.1344
Supplier & Customer Management (SCM)	1/5	1/5	1/5	1/5	1	1	0.0478
Workforce Management (WM)	1/3	1/3	1/3	1/3	1	1	0.0704

$$\lambda_{\max} = 6.5505, CR = 0.088$$

After obtaining decisions from the experts, the standard procedure discussed in the previous section (research methodology) was followed. Each matrix comparison made by the experts was checked for consistency. Initially, the $\lambda_{\max}$ and consistency index was calculated and later its consistency index CI was checked. Only those matrices with a CI value that were less than 0.1 were included for weight calculation purposes. If any matrix was found to be inconsistent then it was again taken to the experts for their opinion (Yadav et al., 2018b; Yadav and Desai, 2017b).

In the present case, all the matrix comparisons made by the experts were found to be consistent. Once the weights of the main and sub-criteria were achieved their global weights were calculated as shown in Table 5.

Table 5: Weights of lean management drivers

Main Criteria drivers	Main Criteria Weight	Sub-driver code	Consistency ratio	Local weight	Global Weight	Rank
Shop floor management (SFM)	0.296	SFM1	0.067	0.1468	0.0436	9
		SFM2		0.0397	0.0118	25

		SFM3		0.2775	0.0824	1
		SFM4		0.0496	0.0147	22
		SFM5		0.2389	0.0709	4
		SFM6		0.1587	0.0471	8
		SFM7		0.0887	0.0263	16
Manufacturing strategy (MS)	0.209	MS1	0.086	0.3004	0.0630	5
		MS2		0.3837	0.0805	2
		MS3		0.1348	0.0283	15
		MS4		0.1811	0.0380	11
Quality management (QM)	0.240	QM1	0.087	0.2539	0.0612	6
		QM2		0.0910	0.0219	17
		QM3		0.3255	0.0784	3
		QM4		0.2446	0.0589	7
		QM5		0.0850	0.0205	18
Manufacturing process (MP)	0.134	MP1	0.095	0.3070	0.0413	10
		MP2		0.2166	0.0291	14
		MP3		0.2495	0.0335	12
		MP4		0.1245	0.0167	20
		MP5		0.0599	0.0081	28
		MP6		0.0425	0.0057	29
Supplier and customer management (SCM)	0.047	SCM1	0.073	0.2699	0.0129	23
		SCM2		0.0962	0.0046	31
		SCM3		0.3327	0.0159	21
		SCM4		0.1855	0.0089	26
		SCM5		0.1158	0.0055	30
Workforce management (WM)	0.070	WM1	0.092	0.2875	0.0202	19
		WM2		0.4208	0.0296	13
		WM3		0.1146	0.0081	27
		WM4		0.1770	0.0125	24

4.4 Application of DEMATEL

After calculating the weights of all included drivers, the next stage was to compute their relationships and their cause and effect intensities. For this purpose, the standard DEMATEL approach was utilised as discussed in the previous section. As done in computing the driver weights, the experts were again asked to make the relationship comparisons of the drivers. Each expert was asked to make separate comparisons and later an average direct relationship matrix (Table 6) was developed by taking mean of all the judgements made by the experts for all the comparisons separately.

Table 6: Average direct relation matrix of main criteria drivers

Drivers	SFM	MS	QM	MP	SCM	WM
SFM	0	2.8	3.4	2.8	2.6	3.4
MS	1.8	0	3	3.4	2.4	1.8
QM	3.2	2.8	0	2.4	2.8	3.2
MP	2.2	2.2	3	0	2.4	1.8
SCM	2.8	2.2	1.8	1.6	0	1.6
WM	2.6	1.6	2	1.6	1.6	0

Further, with the help of the average direct relation matrix, a normalised direct relation matrix (Table 7) was developed for the drivers across all categories.

Table 7: Normalised direct relation matrix of main criteria drivers

Drivers	SFM	MS	QM	MP	SCM	WM
SFM	0	0.186	0.226	0.186	0.173	0.226
MS	0.12	0	0.2	0.226	0.16	0.12
QM	0.213	0.186	0	0.16	0.186	0.213
MP	0.146	0.146	0.2	0	0.16	0.12
SCM	0.186	0.146	0.12	0.106	0	0.106
WM	0.173	0.106	0.133	0.106	0.106	0

Consequently, by following the standard procedure described in the previous section, the total relations and direct-indirect relationships (Table 8) that were the r_i and c_j values for all the comparisons was used.

Table 8: Total relation and direct-indirect relation matrix of main criteria drivers

Drivers	SFM	MS	QM	MP	SCM	WM	r_i	$r_i + c_j$	$r_i - c_j$
SFM	<i>0.748</i>	<i>0.852</i>	<i>0.960</i>	<i>0.860</i>	<i>0.852</i>	<i>0.897</i>	5.170	9.640	0.699
MS	<i>0.745</i>	0.594	<i>0.829</i>	<i>0.788</i>	<i>0.741</i>	0.710	4.406	8.569	0.242
QM	<i>0.898</i>	<i>0.829</i>	<i>0.748</i>	<i>0.817</i>	<i>0.837</i>	<i>0.863</i>	4.992	9.633	0.351
MP	<i>0.734</i>	0.693	<i>0.796</i>	0.570	0.711	0.684	4.188	8.398	-0.023
SCM	0.691	0.627	0.664	0.603	0.505	0.607	3.697	7.917	-0.524
WM	0.654	0.569	0.644	0.574	0.575	0.484	3.499	7.744	-0.746
Sum c_j	4.471	4.163	4.641	4.210	4.220	4.245	<i>Threshold value = 0.721</i>		

Note: The italic values in the table indicate the relations greater than threshold values

5. The Research Study Findings

All the $(r + c)$ values were taken on the y-axis whereas the $(r - c)$ values were taken on the x-axis. The threshold value represents the mean value of all the final values obtained in the total relation and direct-indirect matrix. All the values above the threshold values have influence on the other driver. If any comparison in total relation and direct-indirect matrix appeared to be more than threshold value then it represented mutual relationships among both LM drivers. All the drivers above the x-axis were causal drivers and the drivers that were below the x-axis were effect drivers. The second phase in the figure represents the inter-relationships of each driver with the others.

The causal digraph and relationship diagram for main criteria drivers were shown in Figure 3.

Figure 3: Causal digraph and relationship diagram for main criteria drivers

The results revealed that shop floor management, manufacturing strategies and quality management were the cause drivers whereas, the manufacturing process, supplier and customer management, and work force management were found to be effect drivers which, were later developed by successful penetration of causal drivers. The shop floor management supports the development of all other drivers similar to manufacturing strategy and quality management.

However, work force management and supplier and customer management were completely dependent upon other cause drivers. It was found within the case organisation that the management was struggling to achieve effective supplier and customer management. Hence, the management directly concluded from Figure 3, that the shop floor management and quality management had strong influence on SCM.

By adopting the suggested framework, the customer complaints/returns were reduced by 6.6 percent (212 to 198 complaints per year) (Table 9). This is consistent with the findings of Drohomeretski et al. (2014) who underscored the importance of involvement of shop-floor management personnel in enhancing LM adoption.

Table 9: Performance metrics mapped in the case company

S. No.	Performance metrics	Description	July 2017 (Before LM adoption)	July 2018 (After LM adoption)	Percentage change
1	Manufacturing cycle time	It was the total time taken from beginning of manufacturing process to obtain a finished product	114 hours	106 hours	7% reduction
2	Changeover time	It was the time measured by the process that maps the converting of line/machine from one part to the other	85 seconds	80 seconds	5.9% reduction
3	Throughput	It indicated the average number of parts produced over a specific period of time	4824 pieces per month	4935 pieces per month	2.3% increase
4	Overall equipment effectiveness	Overall equipment effectiveness represents the effectiveness of the entire production line	88 percent	91 percent	3.7% increase
5	Planned maintenance percentage	Total number of planned maintenance times spent on the defined activities for a given period of time.	75 percent	81 percent	8.4% increase
6	First pass yield	It indicates the percentage of products manufactured accurately in the very first time (no rework, no re-run)	1035 pieces per week	1081 pieces per week	4.4% increase
7	Overall yield	It indicates the percentage of products that may or may not require reworking to meet the desired specifications	1125 pieces per week	1151 pieces per week	2.3% increase
8	Customer return/complaint	It represents the number of malfunctioning products that were returned	212 pieces per year	198 pieces per year	6.6% reduction
9	Supplier defect rate	It indicates the percentage of poor quality materials received from suppliers	1.8 percent lots per year	1.6 percent lots per year	11% reduction
10	Number of training sessions	It indicates the total number of training sessions conducted for enhancing the	4 training sessions	6 training sessions	50% increase

	(Every year)	organisational performance	per year	per year	
11	Safety metrics (Every year)	It represents the occurrence of accidents during production	48 accidents per year	38 accidents per year	21% reduction
12	Daily target achievement rate	It indicates the percent of the target achieved during each working shift	78 percent	82 percent	5.1% increase
13	Net operating profit	It indicates the net financial profit accounted by the firm after consideration of all expenses	12.1 percent per annum	13.9 percent per annum	15% increase
14	On time delivery	It indicates the percentage of on time deliveries to the customers	91 percent	94 percent	3.2% increase

The causal digraph and relationship diagram for shop floor management drivers were shown in Figure 4.

Figure 4: Causal digraph and relationship diagram for shop floor management drivers

The results revealed that there was improved management of the inventory (SFM3), reduction of cycle times (SFM5), improvements in safety from the initiatives implemented (SFM6) and improvements due to enhanced production scheduling (SFM1) which were the cause drivers whereas, effective utilisation of resources (SFM2), control of product flow (SFM4) and reduction of setup times (SFM7) were effect drivers. The relationship diagram shows that the safety improvement initiatives hold mutual relationships with the other sub-drivers and reduced the occurrence of accidents on the shop floor by 21 percent (48 to 38 accidents per year).

Effective inventory management was interconnected with all shop floor management activities and it helps in optimal utilisation of available resources on the shop floor. It was

found that prior to the improvements, that the shop floor supervisors encountered long manufacturing cycle times, while, after adoption of the LM framework their manufacturing cycle times was reduced to 106 hours from 114 hours (Table 9). Thomas et al. (2016) obtained similar significant improvements underscored significance of effective management of inventory in achieving control of product flow and efficient utilisation of resources.

The causal digraph and relationship diagrams for the manufacturing strategy drivers were shown in Figure 5. The results of the causal digraph reveals that quality product design (MS1), aligned distribution management across networks (MS2) and the standardised product development approach (MS4) were cause drivers whereas, an effective strategy for marketing management (MS3) was found to be the most significant effect driver as it depends on the effective execution of other manufacturing strategies. According to relationship diagram, the aligned distribution management emerged as the root cause for the related sub-criteria drivers.

Figure 5: Causal digraph and relationship diagram for manufacturing strategy drivers

It was observed, within the case company, that the production planners were able to reduce the change over time by 5.9 percent and increased the throughput by 2.3 percent after adopting the suggested LM framework. Garza-Reyes et al. (2016) stated that standardised product development approaches lead to improved quality product design and improved distribution management across networks; therefore, their findings are in accord with the findings of this research.

The causal digraph and relationship diagram for quality management drivers were presented Figure 6.

Figure 6: Causal digraph and relationship diagram for quality management drivers

The causal digraph results revealed that 5S (QM1), waste analysis (QM3), total quality management (QM4) and total productive maintenance (QM5) were the cause drivers whereas, value stream mapping (QM2) was found to be the most prominent effect driver. Basically, the implementation of value stream mapping was performed in two stages, where previously the state map was developed which, represented the previous process structure of the organisation but after incorporating the new quality management initiatives, QM1, QM3, QM4 and QM5 the new state map was developed that includes the improvement initiatives. It was found that 5S and waste analysis have strong inter-linkages with other quality management inputs as was clarified in the relationship diagram. This underscores that improved productive maintenance can be successfully executed with the help of 5S, waste analysis and value stream mapping. It was documented within the case organisation that the management initiated the implementation of 5S, value stream mapping and total productive maintenance and obtained an increase of 8.4% in planned maintenance percentage and 3.7% increase in overall equipment effectiveness. These results underscore Duarte and Cruz-Machado (2009) findings of the importance of implementation of quality management practices as a prerequisite of successful LM adoption.

The causal digraph and the relationship diagram for the manufacturing process drivers were shown in Figure 7.

Figure 7: Causal digraph and relationship diagram for manufacturing process drivers

The causal digraph results revealed that cellular manufacturing (MP1), standardisation of work (MP3) and visual management (MP6) were the cause drivers whereas, technology management (MP2), process focus (MP4) and employing continuous improvement approaches (MP6) were found to be the most critical effect drivers. The relationship diagram shows that cellular manufacturing plays a vital role in adopting LM within the organisation under manufacturing process drivers because it supports all other drivers within its sub-criteria. Similarly, standardisation of work across each process and machine set-up was essential; hence, it supports all other sub-criteria drivers. It was found within the case company that the manufacturing process strongly influences the performance metrics.

After adoption of the suggested LM framework the first pass yield increased to 4.4 percent, while, the overall yield was increased to 2.3 percent. However, the on-time delivery was increased by 3.2 percent (Table 9). These findings are in agreement with those of Ramos et al. (2018) who reported process focus, continuous improvement and technology management as the essential driver components for LM adoption.

The causal digraph and relationship diagram for supplier and customer management drivers were shown in Figure 8.

Figure 8: Causal digraph and relationship diagram for supplier and customer management drivers

The causal digraph results revealed that appropriate supplier evaluation strategies (SCM1) and supplier development (SCM3) were the cause drivers whereas, mapping the delivery performance (SCM2), identifying the requirements of customers (SCM4) and monitoring feedback from customers (SCM5) were observed as the key effect drivers. The relationship diagram shows that appropriate supplier evaluation strategies and supplier development helps in achieving all other sub-criteria drivers whereas, mapping the delivery performance emerged as a strong effect variable, which was highly dependent on other cause drivers.

It was found within the case company that customer returns were reduced to 198 pieces per year (6.6 % reduction) and supplier defect rate was reduced by 11% after adoption of the suggested LM framework. This finding is in accord with Henao et als. (2019) who highlighted the importance of mapping of delivery performance, identifying customer requirements and adopting appropriate supplier evaluation strategies to improve supplier coordination and to improve customer satisfaction. Additionally, it helped in achieving daily targets.

The causal digraph and relationship diagram for work force management drivers were shown in Figure 9.

Figure 9: Causal digraph and relationship diagram for workforce drivers

The causal digraph results reveal that good work force evaluation strategies (WM1), work force training and education system (WM2) were the cause drivers whereas, employee proficiency (WM3) and work force empowerment and involvement (WM4) were found to be the most essential effect drivers. The relationship diagram reflects that the findings that employee proficiency was highly dependent on other sub-criteria drivers which, were

interconnected to successful implementation of other drivers. It was observed within the case company that the workforce management had significant influence in company performance. The framework suggested to them, improved the net operating profits by 15% and increases in training sessions drastically helped to improve overall performance of the company, which was in accord with the findings of Gandhi et al. (2018) who highlighted the importance of involvement of the workforce in improving operational performance and in achieving the company's goals by using appropriate workforce evaluation strategies, by providing focussed training for LM adoption and by involving them in strategic decision-making.

6. Implications of the findings of this research

This research made valuable contributions to the LM domain for company leaders and for researchers in the following ways:

- The authors of this paper utilised a hybrid fuzzy AHP-DEMATEL approach for developing the LM framework for manufacturing companies in the context of emerging economies. It was found from the literature that many researchers had computed LM driver weights but they did not assess the inter-relationships among the drivers. The authors of this paper not only computed the driver weights but also assessed the effects of various drivers upon the others.
- This investigation will help researchers to obtain a comprehensive, driver-based data set that can be utilised for building LM specific frameworks for their companies. The framework developed in this research can support company leaders in planning their strategies for effectively implementing LM by assessing the inter-relationships of LM drivers.
- The researchers in this study initially assessed the existing LM frameworks reported by various authors. The comparison of frameworks developed within the existing frameworks will help to stimulate new research within the academic community and will assist them in developing better LM frameworks that can be used to help leaders of SMEs and large companies to more effectively to implement LM.
- The LM framework developed within this research was applied as a case study within a manufacturing company, which documented improvements in organisational performance across 14 different performance metrics as shown in Table 9. Similar companies can effectively utilise the study outcomes within their companies.

- The LM framework developed and tested within this study was designed for manufacturing organisations of developing nations. However, the authors recommend that the LM this framework can also be utilised in other industrial sectors in developed countries by modifying the initial inputs with the help of experts of their respective sectors.
- In the future, researchers can broaden and strengthen the set of performance drivers included in this study and can use the framework within different companies to expand and deepen application.
- The researchers of this paper identified a set of thirty-one key LM drivers that included the shop-floor management, the manufacturing strategies, the quality management, the manufacturing processes, the suppliers and customers, and the workforce management, based drivers. The authors documented that much of the previous research on LM drivers, mainly focussed upon managerial aspects as LM drivers. Therefore, this research, with its more holistic and comprehensive perspective and scope provided a broader and deeper foundation for supporting future research and broader implementation of LM in companies in a wide array of industrial sectors and in diverse country contexts.
- In the literature, many of LM frameworks were reported; those were more theoretical and often lacked real world documentation. But, this research was designed and tested via the hybrid fuzzy AHP-DEMATEL approach in a specific company. This increases and strengthens the applicability of the developed framework.
- It is further expected that the outcomes of the developed framework will provide directions to the policy makers for developing policies related to rebates and subsidies to the SMEs on LM adoption because SMEs make strong contribution to the economies of all countries.

7. Conclusions

In line with the research objectives, the researchers initially conducted an exhaustive literature review to explore the LM frameworks reported in the literature. The framework components (drivers) were identified and scrutinised, by keeping in mind the context of manufacturing organisations of developing economies. A manufacturing case company was selected to test the developed framework. The expert panel from within the case company

was formed and their inputs were obtained for using the hybrid fuzzy AHP-DEMATEL approach. The fuzzy AHP approach helped in computing the LM driver weights which, were then used as inputs for the DEMATEL approach. The DEMATEL approach analyses helped in finding the causes and effects of each of the LM drivers and provided insights into the inter-relationships among the drivers via the relationship diagrams.

The research results revealed that the shop floor management manufacturing strategies and the quality management practices were the causal drivers whereas, the manufacturing processes, the supplier and customer management, and the work force management were documented to be the effect drivers. The influence intensity of the shop floor management was higher than the threshold value of the other drivers, which documented its strong influence over the other drivers. The performance of the organisation was mapped after implementing the proposed LM framework in the case organisation for one year. There was a significant increase in the percentage of planned maintenance, overall equipment effectiveness, overall yield and net operating profits. There were significant reductions in manufacturing cycle times, customer complaints and supplier defect rates, and number of accidents.

This research was built upon input from an expert panel comprised of personnel from within the case organisation. However, to make the study more robust, the researchers could conduct a large-scale survey to obtain a more exhaustive list of LM drivers. Although, the present set of drivers was explored by specifically focussing on manufacturing organisations from developing economies, the set of LM drivers should be tested in an array of other sectors in the service industry, the healthcare sector and others. The validation of the developed LM framework was done via a single case study. The researchers can perform multiple case studies in various sub-domains of the manufacturing sector through the developed LM framework, to enrich the application insights. The hybrid fuzzy AHP-DEMATEL approach, utilised in this study, provided a unique balance by assessing the factor weights and computation of the inter-relationships among the selected factors. However, other hierarchical approaches can be used in developing the framework but those methods would not provide the threshold values of each group of factors, which is an essential component to be identified to predict the success of any framework.

If the researchers and company leaders wish to utilise this framework in the context of developed economies, especially in countries like United States, United Kingdom, Germany etc. then it is recommended that they consult with experts within the manufacturing domains of that respective country and accordingly ascertain the inputs for the framework that should

be modified to obtain the country-specific results. The researchers used the hybrid fuzzy AHP-DEMATEL approach, for this research but other researchers may elect to use other tools such as multi-criteria decision-making approaches to build upon the findings reported in this paper. In order to find the structural comparisons, the researchers may wish to use interpretive structural modelling, fuzzy cognitive maps, analytical network processes etc. for better visualisation of the proposed and tested framework used in this research.

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Research Highlights

- Studied existing Lean Manufacturing (LM) frameworks
- Proposed LM framework to enhance its adoption
- Documented drivers of LM among the manufacturing industries of emerging economies
- Implemented the developed framework in a pump manufacturing organisation
- Documented improvements in organisational performance metrics