# Modeling the Interrelationship of Critical Success Factors Adoption of Sustainable Lean Manufacturing Using DEMATEL Approach


**Naveen Kumar and K. Mathiyazhagan**

**Abstract** The aim of the study was to modeling the interrelation of critical success factors (CSFs) for sustainable lean manufacturing in Indian small and medium-scale enterprises. In the competitive era, small and medium-scale industries have partial resources and façade huge competition. Based on literature review, 10 critical success factors were extracted which suggested by experts. Same was followed by interviewing the ground leaders, and key managers have expertise in sustainable lean manufacturing. The decision-making trial and evaluation laboratory (DEMATEL) method was used to analyze the interrelationship of critical success factors for sustainable lean manufacturing adoption in Indian industries. CSFs' interrelationship has been identified and expended in industries through experts. This study proposes the key interrelationship of critical success factors to challenge obstacles in sustainable lean implementation in Indian industries. For sustainable lean manufacturing implementation, effectiveness, innovative technology usage, management review, agile manufacturing processes, teamwork, govt. regulations and follow-ups considered as critical success factors. Innovations are considered as input for sustainability and performance measured in economic, operational, environmental and CSR activities. Researcher focused on goal setting through bench marking in identical clusters. The findings may be helpful for industries' consultants and manager facing difficulties in implementing sustainable lean manufacturing in Indian industries. The study also suggests qualitative approach for improvement action to develop loss-making small and medium-scale enterprises in a reputed industry. This may help managers to prioritize resources allocation toward sustainability in process and organization's systems. The importance of presenting interrelationship of CSFs might helpful for new business practitioner to survive in competitive scenario.

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## 1 Introduction

Small and medium-sized industries (SMEs) are contributing regularly to the Indian gross domestic product in Indian manufacturing sector. As it already stated that SMEs have a major role in the economic growth of any nation and equally participated in the green environment collectively [1]. Global pollution contributed around 70% by SMEs and accountable for more than 50% of industrialized contamination in the Asia-Pacific region. Whitehead clearly explained the examples of SMEs contribution to environmental damages and emissions. By energy-efficient measures' implementation, 30% of consumption could reduce which is more energy than Japan and Korea consumption per year. India's manufacturing output served 45% by SMEs contribution and created 40% employment of workforce available in India [2]. Today's concern in industries is wanted to be remaining sustainable throughout the product life cycle. In SMEs, sustainability could be achieved by the continuous review among all three aspects: economic, environment and social [3, 4]. Challenges in the SMEs business process from both demand and supply. On one side, original equipment manufacturers (OEMs) are very challenging in demand, and on another side, a number of competitors in the market feed them. In continuation of supply side, a number of regulations and procurement are difficult to complete. Hence, most of the SMEs focused on economic aspects only without showing interest in environmental and social aspects unless there is rigorous regulation from government and major cost-saving projects. Researchers also explained that social and environmental practices are leading by customers' needs and government regulations [5]. Now, sustainability has become a necessity for industries to move business growth in the current scenario just because of old manufacturing practices and regulation implemented by authorities. For meeting the demands of customers effectively, SMEs need to adopt various improvement techniques like sustainable manufacturing, innovative technology, benchmarking processes, flexible manufacturing systems, etc. In this study, ten CSFs have been considered from literature review as shown in Table 1.

It would be very interactive for both researchers and experts to get involved in various approached for implementing sustainable manufacturing systems. Individual SMEs have to identify their weak aspects and work continuously to get their sustainable model [20]. In addition to above, all three aspects (economic, environmental and social) need to consider across the end-to-end processes including supply chain partners to the ultimate customer. By implementing lean in through process, all wastes out from operations and effective cost benefits are shown in the system which motivates the SMEs to move toward the sustainable lean manufacturing [21]. Innovation needed in the newly designed process and product to get efficient output with minimum resources utilization.

**Table 1** CSFs of SLM implementation in Indian SMEs

| S. No. | Critical success factors adoption of SLM | References |
|---|---|---|
| 1 | Management review | Baumgartner [6], Aboelmaged [7], Sangwan et al. [8] |
| 2 | Teamwork | Lannelongue et al. [9], Taubitz [10], Vinodh et al. [11] |
| 3 | Govt. regulation follow-ups and reviews | Ghazilla et al. [5], Mittal and Sangwan [12] |
| 4 | Innovative technology adoption | Sangwan et al. [8], Dora et al. [13] |
| 5 | Flexible/agile manufacturing processes | Engert et al. [14] |
| 6 | Goal setting through benchmarking | Aboelmaged [7], Ghazilla et al. [5] [57] |
| 7 | Employee focus | Martínez-Jurado and Moyano-Fuentes [15] |
| 8 | IT system robustness | Sangwan et al. [8], Panizzolo et al. [16] |
| 9 | Machine conditions | Singh et al. [17], Rose et al. [18] |
| 10 | Prevention of pollution | Jabbour et al. [19] |

Sustainability helps in growing business and manufacturing processes in a competitive era. In a literature review, sustainability directly relates to the environment, a social and economic subset of growth. Some researchers identified lean and green relation toward effective utilization of energy and reduction in pollution through waste optimization [22, 23]. Bergmiller and McCright [44] explained the positive relationship between lean and green operation with significant results. Today's SMEs (small and medium-sized enterprises) need to understand a product's life cycle considering base as increasing customer demands and global competition [24]. Sustainable manufacturing helps to achieve market share by improving the environmental efficiency of manufacturing SMEs, which need both technical and financial assistance.

Though lean is swiftly and attractive tool to reduce waste, companies may experience difficulties to sustain long-term success. Sustainable lean needs attention for performance improvement and capability development. Though still evolving the context to add theory and practice by relating developmental stages which help in lean capability development and sustainability, lean manufacturing (LM) is a decision-making method aimed at refining methods created on a difficult scheme of organized social and technical practices. Lean manufacturing practices are frequently used in growing industries and focusing on employee involvement techniques like small group activity, pieces of training, supplier development. The strategy for sustainability system will be driven by customer requirements and environmental conditions. Many researchers gave a lean model in which cost is given by customers, and as a manufacturer, we have to deliver a final product with respect to fit, form and function. In past decades, lot of research evolved for lean and sustainable manufacturing, but no

clear directions toward sustainability in manufacturing come across. Sustainability considering new manufacturing systems to understand the requirements of the manufacturing sector in large scale to identify bottlenecks and limitations. Management should focus on waste elimination, in the direction of profitability by lean implementation in their small-scale/medium-scale/large-scale organizations [25]. According to Ahmed et al. [42], inventory reduction, just in time, kanban, poka-yoke, helps to reduce cost occurred due to seven wastes. In human resource management practices, lean includes communication of objectives, employee training progress, kaizen and suggestions, relationship development, rewards and recognition, and employee safety and health [26]. Customers and suppliers linkage create a healthy working environment in plant and increase delivery success rate [43]. With reliable delivery, customer may adopt different supply chain activity like a focused factory, uniform workload and group technology. Flexible manufacturing needs to be driven by customer orders, to achieve market demand and increase production, in the journey of lean production [27]. Flexible manufacturing is an effective tool of lean manufacturing which affects total manufacturing cost and reduces market selling price [25].

## 2 Review Background

For sustainable growth that chances current desires without compromising the facility of the upcoming group toward encounter, current demand, innovation and social action should be aligned to escort further business practices. For sustainable operations, goal setting through benchmarking also focused on all aspects: pollution, economic growth and social equality [28, 29] on a long-term assignment. In surroundings, there are certain conditions; due to that, many human beings are not able to get adequate access to environmental services to maintain support to life cycle [30]. Sustainable lean manufacturing decides to create practices and techniques for converting raw material into finished goods by less use of resources like energy, manpower, toxic materials, emissions and defects [31]. Many industries are taking initiative by focusing on corporate social actions at operational level [28]. For sustainable process development, an interrelation between different areas with integration of business aspects is required [50]. Adoption of lean manufacturing creates synergy to support environmental management and improve environment performance [19]. An environment standard also helps to identify and reduce environment waste and focus on environment performance. Value stream mapping also maps the environmental waste as it covered complete supply chain from supplier to customer [11]. EMS mixing with lean manufacturing may lead growing industry and better subject understanding [32]. Jabbour et al. [19] explained that integration of lean and EMS

resulting in prevention of pollution and waste generation which directly impacts on cost [15].

It is important for an organization to produce more marginal profit value and contribute in social activities. Sustainable lean manufacturing concerns about the role of people, their development, efforts for solutions against their problems, rewarding for innovative ideas and rewarding them [15]. Researchers explained the key results of lean manufacturing implementation with social aspects like improved housekeeping, material handling, kaizen reduced several accidents, security risks and ergonomics [33]. Sustainable lean considers both worth and resource protection through initial pilots and salvos. Azevedo et al. [46] ruminate on lean reaction with expansive sustainability concerns further than being eco-friendly and considers a vice, supplier selection (top management interference), and supply chain issues come in front. We have to further explore barriers in sustainable lean manufacturing and how lean captures sustainability with confirmatory performance.

## *2.1 Review Result*

There is a fundamental relation between lean and sustainable manufacturing. Industries that have lean manufacturing always upgrade toward sustainable manufacturing. Sustainable manufacturing is focus to reduce the wastes in the organization with the help of sustainable practices. Waste reduction is a common focus in both lean and sustainable manufacturing, in addition long-term focus on profit, people and planet. Tools used for sustainable lean manufacturing are SMED (single minute exchange of die), VSM (value stream mapping), TQM (total quality management), TPM (total productive maintenance) and continuous improvement through quality circles. Focus areas of sustainable lean manufacturing are resource utilization to get maximum output in natural conditions, clear progression plan for lean capabilities, team building among employees and workshops on lean culture. By acting on the above focus areas, industries may achieve actual growth with improved processes, improvement in manufacturing capacity and capabilities and reduce overall unit cost.

The reason for identifying interrelationship of critical success factors of sustainable lean manufacturing are:

– to develop an understanding of factors to produce more with fewer resources and
– meeting customer demand efficiently.

Stonebraker et al. [47] stated that an effective and sustainable supply chain helps in improving the performance of an organization. The operational strategy can change the normal environment into a sustainable one in organizations. Lean helps in building potential for organizations to develop and achieve actual growth, improving manufacturing capacity and capability and lowering unit cost.

## 3 Problem Description

SMEs have a major role in the growth of Indian economy from last one decade. There is drastic increment seen in the last six years. This makes additional opportunity to create jobs at various levels. According to CII reports, 80% growth in employment generated through small and medium-scale industries from rural and urban areas in India. SMEs have 8% of total contribution in the country's gross domestic product. Now, researchers have special attention toward Indian SMEs which are preparing for sustainable manufacturing processes [34–36]. It is difficult to find the relationship in CSFs of SLM implementation in SMEs. The listed critical success factors of SLM are tabulated in Table 1.

## 4 Determination Approach

The procedure for CSFs' interrelationship is started with researchers' findings for sustainable lean manufacturing in Indian industries and briefly explained in Sect. 2. From summary research, gap and problem identified for implement DEMATEL methodology. A workshop was conducted with experts and researchers working with Indian SMEs. After data collection, DEMATEL methodology derived and interrelationship identified. Then finally, results are discussed and conclusion is explained in the last step.

### *4.1 DEMATEL*

The DEMATEL methodology used globally by many researchers and are interested to use the same to get solutions. It helps in capturing interrelationship strength and contextual relations between the critical success factors [37]. The methodology derived to identify cause and effect relations [51]. DEMATEL proposed by researchers to prioritize a portfolio of investment firm [38]. Researchers practice DEMATEL approach in automobiles industries to categorize indicators toward sustainable supply chain [49]. From the above research summary, we appreciate the DEMATEL and found

| STEPS OF DEMATEL METHODOLOGY | 1- Collect experts rating and execute average matrix Z |
|---|---|
| | 2 -Initial direct relationship matrix D |
| | 3- Derived total relation matrix T |
| | 4-Determine the sum of matrix column and row of matrix T |
| | 5-Set thresold value (a) |
| | 6-Build a cause and effect relationship diagram |
| | Step 7-Is relationship diagram acceptable ? if yes; then casue and effect interrealtionship of factors, if no; then review step 5 again. |

**Fig. 1** Steps of DEMATEL approach for CSFs interrelationship (established from researchers' study [39, 40])

appropriate approach for evaluating interrelationship of listed CSFs. The various steps for DEMATEL method are shown in Fig. 1:

Step 1 (Initial Average matrix)—Through a paired comparison degree of effect calculated between two CSFs by experts' rating between (0 and 4) as shown in Table 2.
Step 2 (Initial Influence matrix)—Normalizing average matrix and get normalized initial direct- relation. As shown in Table 3.
Step 3 (Full direct/indirect matrix)—In this step, matrix $T$ shows a interrelationship of CSFs and can transferred into visual display by diagraph mapping.
Step 4 (Total influence matrix $T$)—Total matrix $T$ is completed and defined by $T = X(\mathrm{I} - X)^1$ where $I$ is identical matrix. Respectively,

$$T = X + X^2 + \cdots + X^h = X(IX)^1$$

## 5 Results and Discussions

The results derived from DEMATEL study have been shown in Fig. 2. As relative vectors are listed in two different sets, i.e., cause set and effect set [41], four CSFs acquired in cause set are management review (P1), flexible/agile manufacturing processes (P5), goal setting through benchmarking (P6) and teamwork (P2).

**Table 2** Average relationship matrix

| Critical success factors | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Management review (P1) | 0 | 3 | 3 | 0 | 1 | 2 | 1 | 2 | 2 | 2 |
| Teamwork (P2) | 3 | 0 | 2 | 2 | 2 | 1 | 3 | 2 | 1 | 3 |
| Govt. regulation follow-ups and reviews (P3) | 1 | 1 | 0 | 1 | 3 | 2 | 2 | 1 | 0 | 2 |
| Innovative technology adoption (P4) | 2 | 2 | 3 | 0 | 3 | 3 | 3 | 3 | 3 | 0 |
| Flexible/agile manufacturing processes (P5) | 2 | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| Goal setting through benchmarking (P6) | 3 | 2 | 2 | 2 | 3 | 0 | 2 | 3 | 3 | 0 |
| Employee focus (P7) | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| IT system robustness (P8) | 2 | 2 | 2 | 0 | 3 | 1 | 1 | 0 | 0 | 0 |
| Machine conditions (P9) | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 2 |
| Prevention of pollution (P10) | 0 | 2 | 2 | 2 | 1 | 0 | 1 | 1 | 3 | 0 |

**Table 3** Direct influence matrix

| Critical success factors | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Management review (P1) | 0.12 | 0.24 | 0.27 | 0.08 | 0.19 | 0.17 | 0.16 | 0.19 | 0.18 | 0.20 |
| Teamwork (P2) | 0.25 | 0.13 | 0.25 | 0.16 | 0.25 | 0.15 | 0.25 | 0.20 | 0.16 | 0.25 |
| Govt. regulation follow-ups and reviews (P3) | 0.14 | 0.13 | 0.12 | 0.10 | 0.24 | 0.16 | 0.17 | 0.12 | 0.08 | 0.17 |
| Innovative technology adoption (P4) | 0.24 | 0.23 | 0.31 | 0.08 | 0.32 | 0.25 | 0.27 | 0.26 | 0.25 | 0.15 |
| Flexible/agile manufacturing processes (P5) | 0.16 | 0.12 | 0.18 | 0.05 | 0.09 | 0.15 | 0.07 | 0.07 | 0.07 | 0.16 |
| Goal setting through benchmarking (P6) | 0.27 | 0.22 | 0.26 | 0.16 | 0.30 | 0.12 | 0.22 | 0.25 | 0.24 | 0.14 |
| Employee focus (P7) | 0.02 | 0.02 | 0.07 | 0.02 | 0.07 | 0.02 | 0.02 | 0.02 | 0.06 | 0.07 |
| IT system robustness (P8) | 0.17 | 0.16 | 0.19 | 0.04 | 0.23 | 0.12 | 0.12 | 0.07 | 0.06 | 0.09 |
| Machine conditions (P9) | 0.10 | 0.11 | 0.13 | 0.08 | 0.12 | 0.05 | 0.11 | 0.10 | 0.06 | 0.15 |
| Prevention of pollution (P10) | 0.09 | 0.16 | 0.19 | 0.14 | 0.15 | 0.07 | 0.13 | 0.12 | 0.20 | 0.09 |

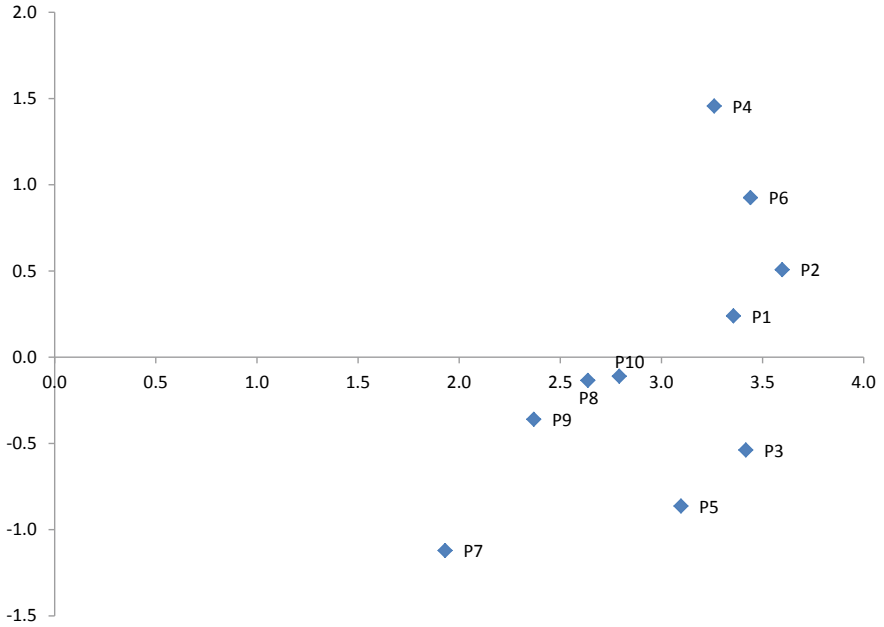


**Fig. 2** Diagraph of CSFs (casual diagram)

Six CSFs are like employee focus (P7), IT system robustness (P8), machine condition (P9), govt. regulation follow-ups and reviews (P3), innovative technology adoption (P4) and prevention of pollution (P10) are evaluated in effect group. Management review (P1) plays effective role CSFs for SLM implementation in Indian SMEs. As researcher [6–8] clearly stated that management review is important and considered as critical factor of SLM and becomes distinct care between professionals also. The relative importance of CSFs is shown in Table 3 ($D + R$ values). The outcomes are tabulated in Tables 4, 5, 6. Henceforth, CSFs with greater values are considered. From the prominence vector calculation, four factors are in the top priorities such as teamwork (P2), goal setting through benchmarking (P6), govt. regulation follow-ups and reviews (P3) and management review (P1). Prevention of pollution (P10), IT system robustness (P8), machine condition (P9) and employee focus (P7) get least priority in ten CSFs.

## 6 Conclusions and Recommendations

Now, sustainable manufacturing contributing significantly is the growth of the industry economically by reducing defects, wastes. Through process management, a manufacturing model has been carried out for sustainable lean manufacturing. Sustainable lean manufacturing geared process toward improvement by a set of tools, concepts,

**Table 4** Sum of rating received from experts for CSFs

| | D Sum | R sum | $D + R$ | $D - R$ |
|---|---|---|---|---|
| Management review (P1) | 1.80 | 1.56 | 3.36 | 0.24 |
| Teamwork (P2) | 2.05 | 1.55 | 3.60 | 0.51 |
| Govt. regulation follow-ups and reviews (P3) | 1.44 | 1.98 | 3.42 | −0.54 |
| Innovative technology adoption (P4) | 2.36 | 0.90 | 3.26 | 1.46 |
| Flexible/agile manufacturing processes (P5) | 1.12 | 1.98 | 3.10 | −0.86 |
| Goal setting through benchmarking (P6) | 2.18 | 1.26 | 3.44 | 0.93 |
| Employee focus (P7) | 0.40 | 1.53 | 1.93 | −1.12 |
| IT system robustness (P8) | 1.25 | 1.39 | 2.64 | −0.13 |
| Machine conditions (P9) | 1.00 | 1.36 | 2.37 | −0.36 |
| Prevention of pollution (P10) | 1.34 | 1.45 | 2.79 | −0.11 |

**Table 5** Prominence vector ($D + R$)

| Rank | CSFs | $D + R$ |
|---|---|---|
| 1 | Team work (P2) | 3.60 |
| 2 | Goal setting through benchmarking (P6) | 3.44 |
| 3 | Govt. regulation follow-ups and reviews (P3) | 3.42 |
| 4 | Management review (P1) | 3.36 |
| 5 | Innovative technology adoption (P4) | 3.26 |
| 6 | Flexible/agile manufacturing processes (P5) | 3.10 |
| 7 | Prevention of pollution (P10) | 2.79 |
| 8 | IT system robustness (P8) | 2.64 |
| 9 | Machine conditions (P9) | 2.37 |
| 10 | Employee focus (P7) | 1.93 |

**Table 6** Relative vector ri-si ($D - R$)

| Rank | Cause group—CSFs | $D - R$ |
|---|---|---|
| 1 | Management review (P1) | 1.456695 |
| 2 | Flexible/agile manufacturing processes (P5) | 0.925045 |
| 3 | Goal setting through benchmarking (P6) | 0.507141 |
| 4 | Teamwork (P2) | 0.239408 |
| | Effect group—CSFs | |
| 1 | Employee focus (P7) | −0.11071 |
| 2 | IT system robustness (P8) | −0.1347 |
| 3 | Machine conditions (P9) | −0.35999 |
| 4 | Govt. regulation follow-ups and reviews (P3) | −0.53842 |
| 5 | Innovative technology adoption (P4) | −0.86305 |
| 6 | Prevention of pollution (P10) | −1.12142 |

principles and systems [55]. Value stream mapping provides a graphical view of manufacturing processes and has been one of the tested techniques in the world lean application in industries [56]. In industries, inventory levels, non-value-added activities and productivity improvement controlled through value stream mapping [54]. Value stream is also tested in the medical sector to reduce the waiting time of patients [53].

In sustainable manufacturing, social aspects are related to operator safety, working environment, ergonomics and operator fatigue. The efficiency of manufacturing processes is monitored by the consumption of raw material versus output, water, energy, and machine breakdowns. To fulfill the present moment without affecting to future capacity, a set of actions required considered as sustainability [48, 52]. Sustainable lean manufacturing has ability to maintain growth as expected by stakeholders without compromising with environment and society [45].

Altogether, nations are aiming on decreasing the use of harmful material in their regular processes. SMES acted on implementation of sustainable lean manufacturing and govt. regulations enforcing to maintain environmental social action. Generally, identifying interrelationship of CSFs is challenging and their effect on SLM implementation. In this study, DEMETAL identifies the interrelationship of 10 critical success factors. The management review, teamwork and goal setting through benchmarking have direct relationships with SLM implementation in SMEs.

## *6.1 Research Suggestion and Limitation*

This review helps the executives and researchers to guide SLM implementation in Indian SMEs by identifying highly impacted critical success factors. In the current competitive scenario, SMEs need SLM implementation for creating a difference in terms of cost, quality and delivery. For initial start-ups, it may be helpful for getting desired results by considering critical factors assignment in right direction. This study considers only Indian SMEs for SLM implementation; for original equipment manufacturers, more critical success factors may be identified and evaluated through other techniques.

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