# Development of a model of critical failure factors for integrated LSS–AM practices in Indian manufacturing industries: a fuzzy TISM approach

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**Abstract** The purpose of the present study is to identify the critical failure factors (CFFs) for implementing integrated practices of lean six sigma (LSS) and agile manufacturing (AM) in Indian manufacturing industries and develop a framework that prioritizes the CFFs. Total nine CFFs were identified through a vast review of research articles. A framework of CFFs was developed by the fuzzy-total interpretive structural modeling (TISM) approach with the help of academia and industry experts' opinions. Fuzzy-MIC-MAC (Matrice d'Impacts Croisés Multiplication Appliqués à un Classement) analysis was performed to categorise CFFs into four clusters. The findings of the present study suggest that there are nine CFFs to LSS–AM implementation in Indian manufacturing industries. From the fuzzy-TISM model it is revealed that top management commitment and organisational culture change CFFs are major roadblocks to LSS–AM implementation strategy in any organization. Further, this research helps LSS–AM decision-makers and practitioners to prioritize CFFs based on their driving and dependence. Accordingly, they can make strategies to mitigate these CFFs and create a smooth pathway for the LSS–AM implementation process. This in turn can enhance the performance of the organization. This study is one of the pioneer studies of the integration of LSS–AM CFFs, which analyzed the contextual relationship among the CFFs through fuzzy-TISM.

## 1 Introduction

From the past two years, we are living in a world of the COVID-19 pandemic. The manufacturing sector has already been facing fierce competition and turbulence globally. Covid-19 crisis has made the situation worst. Now, the manufacturing sector is looking forward to long-term business strategies to come out of such critical situations. As customers are demanding customized products, wider product variety at low-cost and shorter lead-time without compromising in quality. Integration of LSS and AM can be seen as a captivating strategy for the long run. But most manufacturing industries have failed to implement the integrated approach because of roadblocks in the implementation process. For successful implementation of LSS–AM, identification and mitigation of CFFs are necessary. The research objectives of this paper are.

- To identify CFFs for LSS–AM implementation and develop a hierarchy model, through the fuzzy-TISM approach.
- To categorize CFFs into four clusters through fuzzy-MICMAC

To cater the above objectives this chapter is divided into 5 sections i.e. Section 2 describes the concise literature review of LSS; AM and their CFFs; Sect. 3 explains the fuzzy-TISM and MICMAC approaches; Sect. 4 describes the modeling of CFFs for LSS–AM through fuzzy-TISM; Sect. 5 describes the grouping of CFFs through MICMAC analysis, Sect. 6 discusses the results obtained by the study

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and is summed up by Sect. 7 which elucidates the conclusion and future perspectives of work. From the literature review, it is found that this study is among the foremost attempts to integrate LSS–AM CFFs and build a hierarchy structure framework through a hybrid methodology of fuzzy-TISM.

## 2 Literature review

### 2.1 Background of LSS and agile manufacturing

In 1986, George's group has integrated Lean and Six Sigma (LSS) but this synergy received widespread popularity in the year the early 2000s' when several research articles about LSS were published. LSS is a manufacturing strategy, which brings the process into control; eliminates waste hence enhancing the bottom-line results of any organization (Snee 2010). According to Mandahawi et al. (2012), both Lean and Six Sigma are mutually compatible and the DMAIC approach becomes the core framework for process improvement and lean tools are embedded in each phase. But in today's dynamic market low cost and quality are merely order qualifiers while product variety; customization and shorter lead-time have become order-winning criteria. The major constraint of lean is, it is incapable to fulfill orders speedily in a dynamic environment (Kompalla et al. 2016). So the focus shifted towards Agile Manufacturing (AM). A group of researchers from Lehigh University coined term "agile" in 1991. Further, in 1999, Gunasekaran outlined AM as a burgeoning manufacturing originated from the novel concept of LM.

In literature, AM is defined as the capability to reconstruct and communicative flexibility to operate in unstable environments (Leite and Braz 2016). It is mutually fit with other approaches such as LM; computer-integrated manufacturing (CIM); total quality management; material requirement planning; and employee empowerment (Kidd 1994). Ustyugová et al. (2014) argued that Lean and Agile manufacturing are conceptually dissimilar, however along with the attention to customer satisfaction and production of superior-quality goods, an elevated level of competitiveness can be achieved.

### 2.2 LSS and AM CFFs

Critical failure factors are defined as factors, which impede the implementation of any framework or approach. These are hindrances to the alignment of resources of any organization to attend to the desired results. So identification and diminution of these factors are necessary for the success of any project. Various authors have identified a different set

of CFFs for LSS, and AM individually and only two articles represent this LSS–AM integration from CFFs' point of view. To analyse the CFFs, most of the authors used ISM (interpretive structural modeling), AHP (Analytic hierarchy process) and TOPSIS (the technique for order preference by similarity to ideal solution) and none of the articles used the fuzzy-TISM approach to analyse the contextual relationship and hierarchy level of each CFF.

Hasan et al. (2007) identified 11 CFFs to AM implementation through an extensive literature review and developed a contextual relationship among the CFFs through the ISM approach. Psychogios and Tsironis (2012) investigated the barriers to LSS implementation through a case study in the airline service industry. Dibia and Onuh (2012) identified LSS implementation barriers in an agile environment during the implementation of LPPO (Lean leadership, people, process, and outcome) in Laundry manufacturing machines. Antony et al. (2012) identified various roadblocks to LSS implementation through a systematic literature review.

Albliwi et al. (2014) identified barriers to the LSS implementation in manufacturing through a systematic literature review of 12 research papers. In addition, Douglas et al. (2015) identified barriers to LSS implementation during a pilot run of the LSS project at the Kenya Institute of Management in Nairobi.

Sindhwani and Malhotra (2017) evaluated the performance of AMs barriers through the Fuzzy Performance Importance Index (FPII) approach. Yadav et al. (2018) Identified 27 LSS adoption barriers and prioritized those barriers with the help of the fuzzy AHP and TOPSIS method, provided 22 solutions to these roadblocks through a case study, and robustness of the framework was tested through a sensitivity analysis. Sreedharan et al. (2018) identified 44 critical failures from the literature review and ranked 24 vital CFFs through the TOPSIS SIMO method. Sony et al. (2019) identified 11 reasons for discontinuing the LSS approach through case studies in the manufacturing and service sectors. Gaikwad et al. (2020) identified and ranked the 12 CFFs to LSS deployment in SMEs through the Fuzzy TOPSIS method. Kumar et al. (2020) identified 17 CFFs to AM implementation and categorized them into five groups. Based on their severity, these groups were ranked through VIekriterijumsko KOmpromisno Rangiranje (VIKOR) analysis. Rathi et al. (2021) identified 31 Lean Six Sigma barriers through a questionnaire survey of automotive parts manufacturing, and the internal consistency of responses was checked using statistical tools like Importance-indexed. Hariyani et al. (2022) identified 24 barriers to green LSS–AM from a literature review and ranked them through the mean median method.

**Table 1** CFFs to LSS and AM from literature

| S. No | Authors | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Hasan et al. (2007) | * | * | * | * | * | * | * | | |
| 2 | Chen et al. (2009) | * | * | * | * | * | * | * | * | * |
| 3 | Huang and Li (2010) | * | * | * | * | * | | | | |
| 4 | Snee (2010) | | * | * | * | * | * | | * | |
| 5 | Shahin and Jaberi (2011) | | * | * | * | * | | | * | |
| 6 | Carvalho et al. (2011) | | * | * | * | * | * | * | * | * |
| 7 | Antony et al. (2012) | | * | * | | * | * | * | * | |
| 8 | Psychogios and Tsirnois (2012) | | * | * | * | * | | | * | |
| 9 | Albliwi et al. (2014) | | | * | * | * | | * | * | |
| 10 | Douglas et al. (2015) | | | | | * | | | | |
| 11 | Antony et al. (2017) | | | | * | * | * | | * | * |
| 12 | Potdar et al. (2017) | * | | * | * | | * | | | |
| 13 | Virmani et al. (2017b) | | | * | | | | * | | |
| 14 | Yadav et al. (2018) | | | * | * | * | * | * | * | |
| 15 | Sreedharan et al. (2018) | * | | * | * | * | * | * | | |
| 16 | Raval et al. (2018) | * | | * | * | * | * | * | * | * |
| 17 | Sony et al. (2019) | | | | * | | * | * | * | |
| 18 | Sindhwani et al. (2019) | * | | * | * | | * | * | | * |
| 19 | Patel et al. (2019) | | | * | | | | * | | |
| 20 | Gaikwad et al. (2020) | | | * | * | * | | * | | |
| 21 | Kumar et al. (2020) | | | | | * | | | | |
| 22 | Haider and Khan (2020) | | | | | * | | | | |
| 23 | Patel and Patel (2021) | | | * | * | * | * | * | * | |
| 24 | Mishra et al. (2021) | | | * | * | * | * | * | | * |
| 25 | Kaswan et al. (2021) | * | | * | * | * | | | * | |
| 26 | Hariyani et al. (2022) | | * | | * | * | * | * | | |

B1, Lack of training and skill development; B2, Insufficient resources; B3, Poor project selection; B4, Lack of top management commitment; B5, Organization culture support; B6, Lack of communication and collaboration with stockholders; B7, Poor infrastructure; B8 Lack of employee involvement; B9, Lack of Good Quality Data

Based on this review total of nine CFFs for LSS–AM were identified (see Table 1).

## 3 Fuzzy TISM approach and MICMAC analysis

In present study, to identify the CFFs of LSS–AM, a multi-step methodology was adopted. In the first step, we identified the CFFs from a vast literature review and prepared a compressive list of CFFs. In a second step, this list was discussed with an expert panel, which comprises 11 industry experts and 14 academia experts through semi-structured interviews. According to them all the CFFs were incorporated and relevant to LSS–AM. To identify the influence of one factor over another fuzzy-TISM methodology was adopted. Further to categorize the CFFs into four clusters MICMAC analysis was performed.

### 3.1 Fuzzy-TISM approach

Fuzzy-TISM is a hybrid approach of fuzzy theory and the TISM approach. TISM approach is itself an extended version of ISM. ISM is a multi-criteria decision-making (MCDM) approach in which a group of people come together and work as a team to develop a hierarchy structure which depicts the direction of contextual relationships among variables in a set (Sage 1977; Mishra et al. 2015). But the limitation of ISM is, it does not answer how one CFF is contextually related to the other CFFs. To overcome this limitation Sushil (2012) developed TISM, which explains the interrelationship among the CSFs by adding interpretive matrix steps in the ISM approach (Jena et al. 2017). But TISM does not include the fuzziness during the decision making process. To overcome this limitation Khatwani et al. (2015) integrated fuzzy theory with the TISM approach and named as fuzzy-TISM.

**Table 2** Linguistic scales for the influence

| Linguistic terms | Linguistic values |
|---|---|
| Very high influence (VH) | (0.8,1,1) |
| High influence (H) | (0.6,0.8,1) |
| Medium influence (M) | (0.4,0.6,0.8) |
| Low influence (L) | (0.2,0.4,0.6) |
| No influence (No) | (0,0,0.2) |

Considering the advantages of fuzzy TISM in decision-making, Mohanty and Shankar (2017); Virmani et al. (2017a) and Jain and Soni (2019) applied fuzzy-TISM to analyze sustainable CSFs, key performance indicators of Leagile and flexible manufacturing system performance variables respectively in the recent past. After that MIC–MAC analysis was performed to classify the CFFs into four groups.

Khatwani et al. (2015) have suggested the following steps to carry out the fuzzy TISM approach:

*Step 1*: Determine CFFs that are roadblocks for implementing integrated LSS–AM in manufacturing by a comprehensive literature review and industries and academia experts' opinion. Several linguistics terms (VH-very high; H-high; M-medium; L-low; VL: very low) have been used to analyze the influence of one CFF over another. The crisp method has been applied in fuzzy TISM. The Table 2 presents the linguistic scale.

*Step 2*: Collecting the replies and develop a Structural self-interaction matrix (SSIM).

As per industry and academia experts' opinion, the relationship among the CFFs was established and given by the following various symbols:

- V: Indicates the CFFs x influences y but y does not influence x; the complementary link is shown by V followed by {(VH) if very high; (H) if high, (M) if medium impacts, (L) if low impact; or (NI) if no impact}
- A: Indicates the CFFs y influences x but x does not influence y; complementary link is shown by A followed by {(VH) if very high; (H) if high, (M) if medium impacts, (L) if low impact; or (NI) if no impact}
- X: Indicates both the CFFs x and y influence each other; complementary link is shown by X trailed by {(VH) if very high; (H) if high, (M) if medium impacts, (L) if low impact; or (NI) if no impact}
- O: Indicates both CFFs x and y have no relation; complementary link is displayed by O trailed by no influence (NI)

*Step 3*: Development of Aggregated Self-Structured Interaction Matrix (SSIM) and final Fuzzy Reachability Matrix.

**Table 3** Fuzzy triangular linguistic terms for fuzzy reachability matrix

| (X, Y) entry aggregated SSIM | (X, Y) entry in fuzzy reachability matrix | (Y, X) entry in fuzzy reachability matrix |
|---|---|---|
| V(VH) | (0.8,1,1) | (0,0,.2) |
| V(H) | (.6,.8,1) | (0,0.2) |
| V(M) | (.4,.6,.8) | (0,0,.2) |
| V(L) | (.2,.4,.6) | (0,0,.2) |
| V(Ni) | (0,0,.2) | (0,0,.2) |
| A(VH) | (0,0,.2) | (0.8,1,1) |
| A(H) | (0,0.2) | (.6,.8,1) |
| A(M) | (0,0,.2) | (.4,.6,.8) |
| A(L) | (0,0,.2) | (.2,.4,.6) |
| A(Ni) | (0,0,.2) | (0,0,.2) |
| X(VH) | (0.8,1,1) | (0.8,1,1) |
| X(H) | (.6,.8,1) | (.6,.8,1) |
| X(M) | (.4,.6,.8) | (.4,.6,.8) |
| X(L) | (.2,.4,.6) | (.2,.4,.6) |
| X(NO) | (0,0,.2) | (0,0,.2) |
| O(NO) | (0,0,.2) | (0,0,.2) |

- For Aggregated SSIM development, the mode method has been applied. In Aggregated SSIM, the responses, which have maximum frequency, are separated and chosen to analyze subsequently and assigned the linguistic values as per Table 3. To develop a fuzzy reachability matrix following different possible scenario has been considered:
- If (x, y) entry is V (VH): in this scenario, (x, y) entry will be represented as (0.8,1.0,1.0) and entry (y, x) will be represented as (0,0,0.2)
- If (x, y) entry is V (H): In this scenario (x, y) entry will be represented as (0.6, 0.8 1.0) and entry (y, j) will be expressed by as 0{NI} which is shown as (0, 0, 0.2).
- If the entry (x, y) is V (M): In this scenario, entry (x, y) will be represented as (0.4, 0.6,0.8) and entry (y, x) will be expressed by as 0{NI} which is expressed as (0, 0, 0.2).
- If the entry (x, y) is V (L): In this scenario, entry (x, y) will be represented as (0.2,0.4,0.6) and entry (y, x) will be represented by as 0{NI} which is shown as (0, 0, 0.2).
- If the entry (x, y) is A (VH): In this scenario, entry (x, y) will be represented as O{NI} and will be represented by (0, 0.2, 0.5) and entry (y, x) will be shown as (0.8, 1.0, 1.0).
- If the entry (x, y) is A (H): In this scenario, entry (x, y) will be represented as O{NI} and will be shown by (0, 0,0.2) and entry (y, x) will be represented as (0.6, 0.8, 1.0).
- If the entry (x, y) is A (M): In this scenario, entry (y, x) will be represented as O{NI} and will be expressed by

(0, 0,0.2) and entry (x, y) will be represented as (0.4, 0.6, 0.8).

- If the entry (x, y) is A (L): In this scenario, entry (x, y) will be represented as O{NI} and will be expressed by (0, 0, 0.2) and entry (y, x) will be expressed as (0.2,0.4,0.6).
- If the entry (x, y) is X (VH): In this scenario, entry (x, y) will be represented by (0.8, 1.0, 1.0) and entry (y, x) will be expressed as (0.8, 1.0, 1.0).
- If the entry (x, y) is X (H): In this scenario, entry (x, y) will be represented by (0.6,0.8, 1.0) and entry (y, x) will be expressed as (0.6,0.8, 1.0).
- If entry (x, y) is X (M): In this scenario, entry (x, y) will be represented by (0.4,0.6, 0.8) and entry (y, x) will be expressed as (0.4,0.6, 0.8)
- If the entry (x, y) is X (L): In this scenario, entry (x, y) will be represented by (0.2, 0.4, 0.6) and entry (y, x) will be expressed as (0.2,0.4,0.6).
- If the entry (x, y) is O In this scenario, entry (x, y) will be represented by (0.0, 0, 0.2) and entry (y, x) will be expressed as (0,0, 0.2).

Table 3 represents the different scenario discussed for triangular linguistic terms for the fuzzy reachability matrix.

*Step 4*: Crisp value of each CFF was analyzed as per the subsequent procedure given by Khatwani et al. (2014).

*Step 4.1:* Calculating:

$$DELTA = R - L \tag{1}$$

$$R = \max(uk) \quad L = \min(lk)$$

*Step 4.2*: Calculation for lower, middle, and upper values.

$$X_{lk} = (l_k - L)/DELTA, X_{mk} = (m_k - L)/DELTA, X_{uk} = (u_k - L)/DELTA. \tag{2}$$

*Step 4.3*: Calculation of normalized left score (ls) and right score (rs) values:

$$x_j^{ls} = x_{mj}(1 + x_{mk} - x_{lk}) \text{ And } x_k^{rs} = x_{uk}(1 + x_{uk} - x_{mk}) \tag{3}$$

*Step 4.4*: Calculation of total normalized crisp values by the following equation:

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

*Step 4.5*: Calculation of crisp value for $B_K$

$$B_K^{Crisp} = L + x_k^{crisp}*DELTA \tag{5}$$

*Step 5*: Defuzzified the reachability matrix and the transitivity is taken into account i.e. if CFF 1 is related to CFF 2, and CFF 2 is related to CFF 3 then there must be some relation between factor 1 and 3.

*Step 6*: Driving power and dependence was computed by adding the rows 1's and column 1's of each CFF respectively.

*Step 7*: Partition of levels takes place by the no. of iteration.

*Step 8*: Based on linguistic terms TISM digraphs have been drawn.

*Step 9*: Development of Fuzzy TISM model by removing and substituting the transitivity links and factors nodes by statement respectively in digraphs.

## 3.2 MICMAC analysis

The main purpose of MICMAC (Matrice d' Impacts Croisés-Multiplication Appliquée. un Classement) analysis of this study is to identify and analysis of CFFs to LSS–AM implementation in a fuzzy environment. After calculating the dependence and driving power of all factors, MICMAC analysis for final fuzzified reachability matrics and final defuzzified reachability matrics was performed to group the CFFs into the subsequent four clusters:

1. Autonomous cluster: In this, CFFs which driving power and dependence are weak fall under this cluster. The factors of the autonomous cluster are isolated from the system
2. Dependent cluster: In this, CFFs those have strong dependence and weak driving power come under this group.
3. Linkage cluster: In this, CFFs those have high driving power and high dependence come under this group
4. Independent cluster: In this, CFFs those have low dependence and high driving power fall under this group.

# 4 Development of LSS–AM CFF model through fuzzy TISM approach

In this section model of CFFs for LSS–AM implementation is developed through the fuzzy-TISM approach based on the steps discussed in the previous section.

*Step 1*: Total 9 CFFs were recognized that impediment the execution of LSS–AM in the manufacturing industry from a vast literature review and expert panel opinion. They are discussed below:

- *Lack of training and skill development* (B1): Implementation of LSS–AM, training and skill development of employees is very important; it would be a barrier if the organization misses taking it to account.
- *Insufficient resources* (B2): While implementing LSS–AM in an organization, the project team may need resources such as investment, human resources, IT resources etc. Lack of such resources will be a barrier to implementing Lean-AM
- *Poor project selection* (B3): Poor project selection and prioritization can lead to wrong or delayed results. Hence it's a barrier to the deployment of Lean-AM
- *Lack of top management commitment* (B4): To commence any business process improvement initiatives in any organization, top management commitment, and constant involvement is an essential factors. Missing this commitment from top management can be a huge CFF to the deployment of LSS–AM.
- *Lack of organization culture support* (B5): An organizational culture that does not support a change and value learning and development, can be a roadblock to the deployment of LSS- AM.
- *Lack of communication and collaboration with stockholders* (B6): Communication is the key to driving change in an organization, and poor communication in an organization may result in poor implementation of Lean AM. Suppliers are valuable partners of an organization and this change may also impact them, hence if an

organization does not have a good collaboration with the supplier it's an impediment to Lean-AM deployement. Most of the change starts from the voice of the customer and the result of change should also result in favor of customers. Poor collaboration with customers is a barrier to Lean AM implementation

- *Poor infrastructure* (B7): Lean-AM implementation will require a basic infrastructure and a poor infrastructure of an organization can be a barrier to its implementation
- *Lack of employee involvement* (B8): Employees are important assets to the organization. They lead and drive change in an organization, hence if the organization does involve employees in change may fail change.
- *Lack of good quality data* (B9): Incorrect or missing data can lead to incorrect LSS–AM projects and results hence it is a barrier

*Step 2*: Development of structural self-interaction matrix (SSIM) and aggregated structural self-interaction.

The degree of mutual relationship among the CFFS has been given in several linguistics terms (VH-very high; H-high; M-medium; L-low; VL: very low) by an expert's panel to analyze the influence of one CFF over another through a semi-structural interview. The crisp method has been applied in Fuzzy TISM. For easier interpretation of these, a small example is explained here.

1. B1 has a very high influence on achieving B3 but B3 does not influence achieving the contextual relationship between them is labeled as V (VH)
2. B5 has a high influence on achieving B2 and but if B2 does not influence achieving B5 then the contextual relationship between them is labeled as A (H)
3. B 1 and B 6 have a high influence on achieving each other than the contextual relationship among them is labeled as X (H)

**Table 4** Aggregated SSIM matrix for CFFs

| CFFs | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 |
|------|------|------|------|------|------|------|------|------|------|
| B1 | V (H) | V (H) | X (H) | X (H) | A (VH) | A (VH) | V (VH) | A (VH) | |
| B2 | V (VH) | V (VH) | V (VH) | V (VH) | A (H) | A (M) | V (VH) | | |
| B3 | V (VH) | X (VH) | A (H) | A (M) | A (VH) | A (VH) | | | |
| B4 | V (VH) | V (VH) | V (H) | V (VH) | X (H) | | | | |
| B5 | V (VH) | V (H) | V (VH) | V (VH) | | | | | |
| B6 | V (M) | V (VH) | V (VH) | | | | | | |
| B7 | V (H) | V (H) | | | | | | | |
| B8 | V (VH) | | | | | | | | |
| B9 | | | | | | | | | |

**Table 5** Fuzzy reachability matrix of CFFs based on aggregated fuzzy SSIM matrix

| CFFs | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 |
|------|----|----|----|----|----|----|----|----|----|
| B1 | _ | NO | VH | NO | NO | H | H | H | H |
| B2 | VH | _ | H | NO | NO | VH | VH | VH | VH |
| B3 | NO | NO | _ | NO | NO | NO | NO | VH | VH |
| B4 | VH | M | VH | _ | H | VH | H | VH | VH |
| B5 | VH | H | VH | H | _ | VH | VH | H | VH |
| B6 | H | NO | M | NO | NO | _ | VH | VH | M |
| B7 | H | NO | H | NO | NO | NO | _ | H | H |
| B8 | NO | NO | VH | NO | NO | NO | NO | _ | VH |
| B9 | NO | NO | NO | NO | NO | NO | NO | NO | _ |

Table 4 depicts aggregated SSIM, which was developed by taking the mode of responses obtained from the expert panel.

*Step 3*: A fuzzy reachability matrix is first obtained from aggregated SSIM matrix of CFFs (see Table 5). Based on this fuzzy reachability final Fuzzy reachability matrix was obtained by converting (i,j) and (j, i) entries as per the scenario discussed in Fuzzy-TISM methodology and is shown in Table 6

*Step 4*: Computation of driving power and Dependence from fuzzy reachability matrix.

To compute the driving power and dependence for every CFF, it is necessary to calculate the Crisp Value of each CFF. The crisp value is computed by Eqs. 1–5. Driving Power for fuzzy value (3.2, 4.2, 5.6) of CFF 1.

*Step 4.1* Calculating:
DELTA = R-L; R = 7.8, L = 0.
DELTA = 7.8

*Step 4.2*: Calculation for lower, middle, and upper values using Eq. 2:

$$X_{l1} = \frac{3.2 - 0}{7.8}, X_{m1} = (4.2 - 0)/7.8 X_{u1} = (5.6 - 0)/7.8$$

$(X_{l1}, X_{m1}. X_{u1}) = (0.410256; 0.538462; 0.717949)$

*Step 4.3*: Calculation of normalized left score (ls) and right score (rs) values by Eq. 3:

$$x_1^{ls} = 0.410256 * (1 + 0.538462 - 0.410256)$$

$$x_1^{ls} = 0.477273$$

a n d $x_1^{rs} = 0.717949(1 + 0.717949 - 0.538462)$ $x_1^{rs} = 0.608696$

*Step 4.4*: Calculation of total normalized crisp values using Eq. 4: $x_1^{crisp} = [0.477273 * (1 - 0.477273) + 0.608696 * 0.608696]/[1 - 0.477273 + 0.608696] x_1^{crisp} = 0.547977$

*Step 4.5*: Computation of crisp value for $B_K$ using Eq. 5:

$$B_{1driving}^{Crisp} = 0 + 0.547977 * 7.8$$

$$B_{1driving}^{Crisp} = 4.274221$$

Similarly the crisp value of dependence of B 1:
$B_{1depdence}^{Crisp} = 3.8864206$.

Like this, we obtained the driving power and dependence of each CFF by calculating respective crisp values. (see Table 3).

*Step 5*: Development of final reachability matrix:

Defuzzified the fuzzy reachability matrix by replacing all VH, H, and M entries as 1 and L, with No entry as 0. Further transitivity has been checked and marked as * in Table 7

*Step 6*: Calculation of Driving power and Dependence.

Summing the rows 1's and column 1 s of every CFF in the final defuzzified reachability matrix has given the driving power and dependence respectively (see Table 8).

*Step 7*: Level Partitions.

After the calculation of the driving power and dependence of all CFFs, level partitioning was performed. To identify the level of each CFF, a total of five iterations have been done. As a result, all CFFs were divided into five levels of hierarchy. (see Tables 8 and 9).

*Step 8*: Fuzzy TISM digraph.

Based on the linguistic term; a fuzzy digraph (see Fig. 1) has been developed. In this, both direct and indirect relationships are analyzed. CFFs' are represented in nodes and connected by arrows. Each arrow indicates the different levels of influence of CFFs on each other. The digraph is formed in a tree-like structure where parent node CFFs and child node CFFs are joined through branches. These branches have four types of child nodes containing CFFs. Leftmost child nodes having CFFs which have very high

**Table 6** Final fuzzy reachability matrix

| CFFs | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | ** | ## |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | – | (0,0,.2) | (.8,1,1) | (0,0,.2) | (0,0,.2) | (.6,.8,1) | (.6,.8,1) | (.6,.8,1) | (.6,.8,1) | (3.2,4.2,5.6) | 4.274221482 |
| B2 | (.8,1,1) | – | (.6,.8,1) | (0,0,.2) | (0,0,.2) | (.8,1,1) | (.8,1,1) | (.8,1,1) | (.8,1,1) | (4.6,5.8,6.4) | 5.651341991 |
| B3 | (0,0,.2) | (0,0,.2) | – | (0,0,.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | (.8,1,1) | (.8,1,1) | (1.6,2,3.2) | 2.180989325 |
| B4 | (.8,1,1) | (.4,.6,.8) | (.8,1,1) | – | (.6,.8,1) | (.8,1,1) | (.6,.8,1) | (.8,1,1) | (.8,1,1) | (5.6,7.2,7.8) | 6.987521306 |
| B5 | (.8,1,1) | (.6,.8,1) | (.8,1,1) | (.6,.8,1) | – | (.8,1,1) | (.8,1,1) | (.6,.8,1) | (.8,1,1) | (5.6,7.2,8) | 6.99823784 |
| B6 | (.6,.8,1) | (0,0,.2) | (.4,.6,.8) | (0,0,.2) | (0,0,.2) | – | (.8,1,1) | (.8,1,1) | (.4,.6,.8) | (3,4,5.2) | 4.039890096 |
| B7 | (.6,.8,1) | (0,0,.2) | (.6,.8,1) | (0,0,.2) | (0,0,.2) | (0,0,.2) | – | (.6,.8,1) | (.6,.8,1) | (1.8,2,4,4) | 2.635720365 |
| B8 | (0,0,.2) | (0,0,.2) | (.8,1,1) | (0,0,.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | – | (.8,1,1) | (1.6,2,3.2) | 2.180989325 |
| B9 | (0,0.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | (0,0,.2) | – | (0,0,1.6) | 0.19311412 |
| * | (2.8,3.6,4.8) | (1,1.4,3) | (4.8,6.2,7) | (0.6,0.8,2.4) | (0.6,0.8,2.4) | (3.3,8,4.8) | (3.6,4.6,5.6) | (5.6,4.7,2) | (5.6,7.2,7.8) | | |
| ## | 3.864206269 | 2.282608781 | 5.140480625 | 1.978632153 | 2.006132085 | 3.937720168 | 4.210926319 | 5.338674502 | 5.357142857 | | |

* Dependence; ** Driving power; # Bk crisp Dependence; ## Bk crisp Driving

linguistic values are linked to the parent node enablers by a Bold thick arrow; the Child node containing CFFs with high linguistic values is joined to the parent node enablers through a light arrow; while the child node containing CFFs with medium linguistic values joined to parent node CFFs' by semi-broken line and transitivity links are connected by a dotted line to parent CFF. Each Parent CFF is connected to the other same-level parent nodes and parent CFF, which is one level above as per the hierarchy obtained from the level partition. At the bottom of this digraph, CFF B4 and CFF B5 come. For parent node B4, the left-most child nodes contained CFFs B1, B3, B6, B8, and B9 which are having very high linguistics terms given by experts, joined to the parent node B 4 by dark bold line; the second child node containing CFFs B5, B7 joined to CFF B4 by light line, denotes the linguistic term "high" as per the expert's decision to the B4; while next child node consisting B2 and connected by B4 through a dashed line which represents the linguistic term "medium" as per experts choice. Hence the relation of B4 in the parent node to the other CFFs is shown by the several branches to denote different linguistic terms. Similarly, each CFF is considered a parent node and connected to the other CFFs by various branches. Further to connect CFF's parent nodes, the parent node of B4 is joined to the same level parent node B5 by a light arrow, depicts the linguistic term "High" as per the expert's replies while the parent node of B4 is connected through the just above parent node B2 by dashed arrow respectively to determines the linguistic term medium condition between them. In this similar way, the final Fuzzy-TISM model of CFFs for LSS–AM implementation has been developed.

*Step 9*: Fuzzy -TISM model.

Removing all the transitivity links and L and NI degree of influence links from the Fuzzy-TISM digraph, has developed fuzzy-TISM model. Only the direct links among the CFFs, which were having VH, H, and M degree of influence, were denoted by a dark bold thick line, thick line and dashed line respectively (See Fig. 2).

## 5 MICMAC analysis

After calculating the dependence and driving power of each CFF, MICMAC analysis was performed to classify the CFFs into 4 clusters. (1) Autonomous clusters: In both fuzzified and de-fuzzified cases, no CFF falls under this category, which depicts all CFFs considered in this study, which is significantly useful. (2) Dependent clusters: In the fuzzified case, CFFs 3,7,8,9 comes under this category while in the defuzzified case CFFs 3,8,9 falls under this because of their dominant driving power and low driving power. (3) Linkage

**Table 7** Defuzzified final reachability Matrix

| CFFs | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | DRIVING |
|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 6 |
| B2 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 7 |
| B3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 3 |
| B4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| B5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| B6 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 6 |
| B7 | 1 | 0 | 1 | 0 | 0 | 1* | 1 | 1 | 1 | 6 |
| B8 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 3 |
| B9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Dependence | 6 | 3 | 8 | 2 | 2 | 6 | 6 | 8 | 9 | 50/50 |

**Table 8** Level partition (Iteration 1)

| CFFs | Reachability | Antecedent | Intersection set | Level |
|---|---|---|---|---|
| B1 | (1,3,6,7,8,9) | (1,4,5,6,7) | 1,6,7 | |
| B2 | (1,2,3,6,7,8,9) | (2,4,5) | 2 | |
| B3 | (3,8,9) | (1,2,3,4,5,6,7,8) | 3,8 | |
| B4 | (1,2,3,4,5,6,7,8,9) | (4,5) | 4,5 | |
| B5 | (1,2,3,4,5,6,7,8,9) | (4,5) | 4,5 | |
| B6 | (1,3,6,7,8,9) | (1,4,5,6,7) | 1,6,7 | |
| B7 | (1,3,6,7,8,9) | (1,4,5,6,7) | 1,6,7 | |
| B8 | (3,8,9) | (1,2,3,4,5,6,7,8) | 3,8 | |
| B9 | 9 | (1,2,3,4,5,6,7,8,9) | 9 | I |

**Table 9** Level partition of each CFF

| S.NO | CFF | Level No |
|---|---|---|
| 1 | B9 | I |
| 2 | B3, B8 | II |
| 3 | B1, B6, B7 | III |
| 4 | B2 | IV |
| 5 | B4, B5 | V |

clusters dependence CFFs 1,6 come under this category in a fuzzified case while in a defuzzified case CFFs 1,6,7 fall under the linkage category because of their high driving and high dependence. The last cluster is an independent cluster, in which CFFs 2, and 4,5 have low dependence and high driving power in both fuzzified and defuzzified. Together Figs. 3 and 4 represent the transition of CFF from one cluster to another due to their fuzziness and sensitivity. The strength of Fuzzified-MICMAC analysis is as it separates the autonomous; dependent; independent and linkage CFFs during uncertainty. The developed fuzzy-TISM and result of MICMAC analysis assist the organization to identify which CFFs are pivot roadblocks of LSS–AM implementation and their degree of influence on other CFFs. This will guide

practitioners to pay more attention to mitigate the major impediments.

# 6 Results and discussions

Fuzzy-TISM model for LSSfter calculating the dependence and driAM CFFs has placed 9 CFFS for LSS–AM implementation across the five levels of the hierarchy through five no. of iterations.

V level: Two CFFs lack of top management commitment towards LSS–AM implementation (B4) and lack of supportive organization culture (B5) form the base of the hierarchy structure. This indicates that the lack of top management commitment and reluctance to culture change is the major roadblock to the LSS–AM implementation journey in the manufacturing industry which influences the next levels of CFFs.

IV level: CFF insufficient resources (B2), was kept at the fourth level of the hierarchical structure. Insufficient resources (financial, human etc.) are the hindrance to LSS–AM implementation.

## 6.1 III level:

Lack of training and skill development (B1), poor infrastructure (B6) and Lack of communication and collaboration with stakeholders (B7) came at the III level of the hierarchy. For LSS–AM implementation automation, training and multiskilling are required a good amount of investment in the short term. Insufficient resources become the leads lack of training and poor infrastructure. Poor infrastructure causes poor communication among the stakeholders. Lack of communication among internal and

**Fig. 1** Fuzzy-TISM Digraph of CFFs to LSS–AM implementation
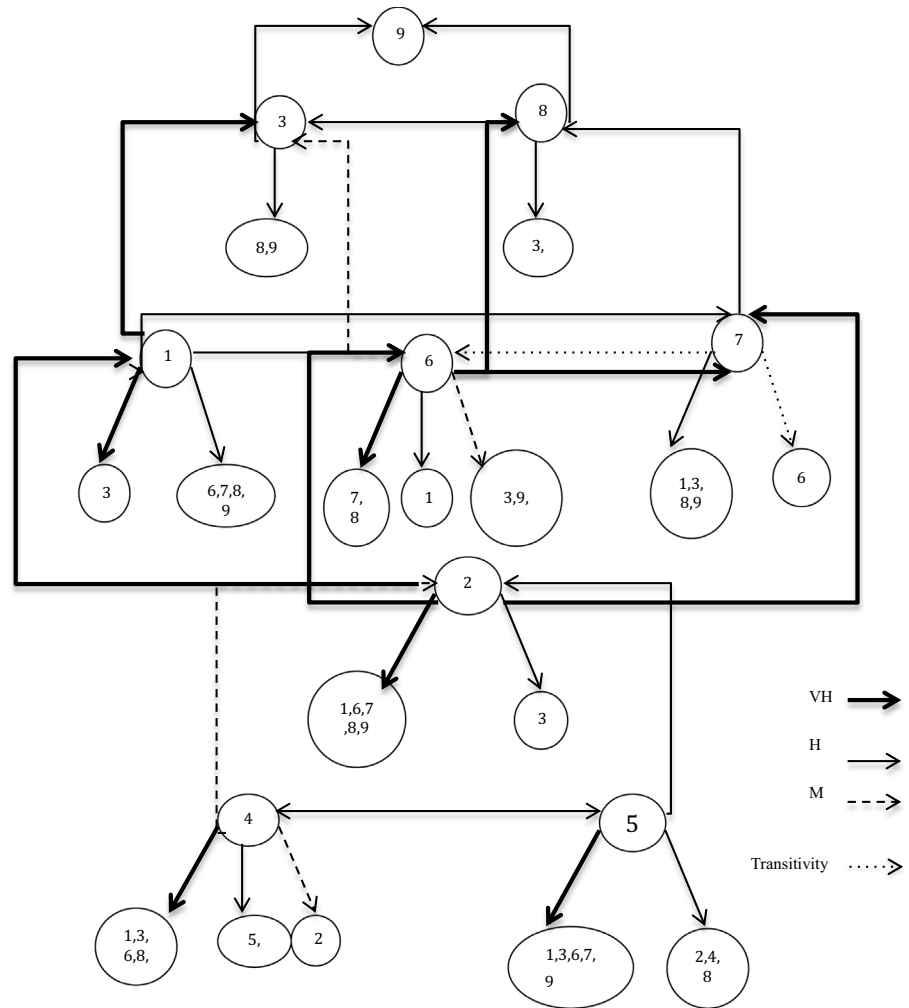


external stakeholders becomes a hindrance to LSS–AM project success. Lack of collaboration with suppliers causes longer lead-time to fulfil the dynamic demand of customers. In addition to this, if the VOC is not taken into account during LSS–AM implementation, the project outcome will leave the organization with dissatisfied customers, which is a huge failure of the LSS–AM project.

II level: CFFs poor project selection (B3) and lack of employee involvement (B8) was kept at the second level of the hierarchical structure. Poor project selection results in a waste of time, and wastage of resources and outcomes, which is not desired. Lack of communication between employees and top management causes a lack of involvement of employees in LSS–AM implementation.

I level: At the top of the hierarchy lack of good quality data (B9) was placed. Poor project selection (B3) and lack of employee involvement (B8) lead to poor quality data, which ultimately causes a failure of LSS–AM project.

This study amplified the most influential CFFs through the Fuzzy-TISM model, which are the roadblocks to the implementation of LSS–AM. This helps manufacturing industries to utilize their resources most effectively to mitigate the most impactful impediment. CFFs, which fall under independent clusters of MIC-MAC analysis, can be deliberated as strategic CFFs. The outcome of MICMAC analysis for CFFs reveals that lack of commitment from top management towards implementation of LSS–AM (B4), and lack of supportive organizational culture (B5) and insufficient resources (B2) are the independent CFFs.

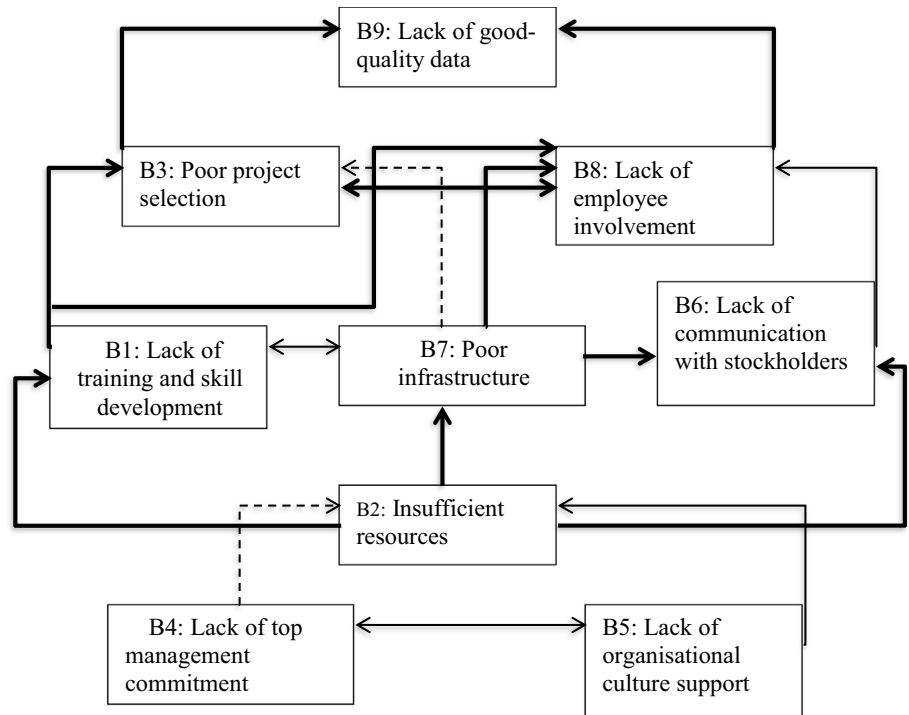**Fig. 2** Fuzzy TISM Model of CFFs to LSS–AM implementation



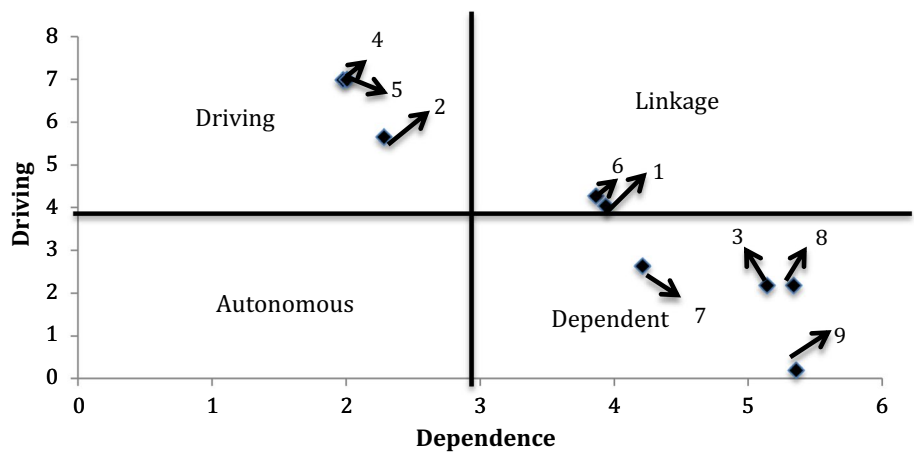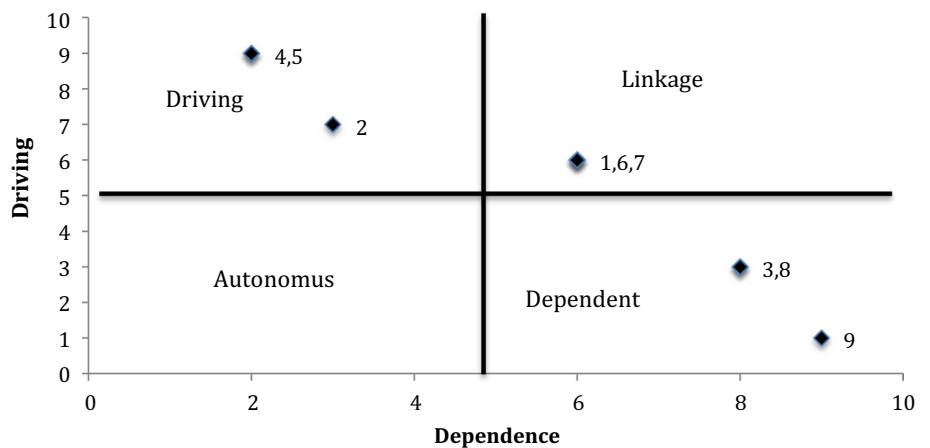**Fig. 3** Fuzzy MIC-MAC Analysis of CFFs



**Fig. 4** MICMAC analysis of CFFs

These are major CFFs because these have superior driving power and help the remaining CFFs to become impediments in the LSS–AM implementation process. This implies that the remaining CFFs of LSS–AM were influenced by these CFFs, and earlier attention on these CFFs helps policymakers or decision-makers to make strategies to alleviate these CFFs for smooth implementation of LSS–AM.

## 7 Conclusions

In the present study, the CFFs to LSS and AM execution in the manufacturing industry were identified, structured, and analyzed. Fuzzy TISM based model was created which not only to depict a proper hierarchy among the identified LSS–AM CFFs but also to represent the level of influence of one CFF on other CFFs in manufacturing industries. These are further grouped into 4 clusters using fuzzy-MICMAC. This study is different from prior studies on the implication of integrated LSS–AM throughout the implementation in India's manufacturing industries. First, no significant efforts have been made to identify a comprehensive array of CFFS for LSS–AM implementation under one umbrella. Second, no previous relevant scientific research work has been found to integrate the fuzzy-TISM-MICMAC approach for categorizing the CFFs of LSS–AM implementation in the manufacturing sector. This model offers more robust results as it allows decision-makers to evaluate the effects of system variables on each other. This integrated model of LSS–AM CFFs would provide step-by-step guidance to decision providers, scholars, and consultants to implement LSS–AM successfully. Accordingly, they can focus on the LSS–AM CFFs and prioritize them to utilize the available resources in a better way. This study has limitations too as only 9 CFFs were considered. The model is also not statistically validated. Further, the proposed model is manufacturing sector-centric A more generic LSS–AM framework can be viewed as the underpinning for future work.

**Declarations**

**Conflict of interest** All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

**Research involving human participants and/or animals** Not applicable for present study.

**Informed consent** Not applicable for present study.

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