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Ranking of Vital Enablers Impacting Lean Production System in SME through Integrated MCDM Approaches

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Abstract

In today's global competitive situation, every industry (irrespective of its size) is compelled to optimize their production processes, with a focus on delivering high-quality products in most cost-effective and efficient manner while ensuring swift delivery. This is continuously forcing every industry for adopting diverse manufacturing strategies. Lean Production System (LPS) is one such manufacturing strategy that can be adopted and monitored continuously to eliminate non-value activities, thereby facilitating the efficient and swift production of cost-effective and high-quality goods. It is observed from the analysis of the literature that most of the large manufacturing industries have successfully implemented LPS. However, in general, Small and Medium Enterprises (SME) often struggle to effectively implementing LPS. This is mainly due to the non-availability of literature support to indicate the list of vital enablers and ranking of the same towards implementation of LPS in SME. This study is attempting to address this research gap. To address this research gap, this study follows the research activities (a) identification of all possible list of enablers which would impact the implementation of LPS in SME, (b) determination of 'vital enablers' from the identified list of enablers, and (c) finding the ranking of the determined vital enablers by applying an integrated Multicriteria Decision-making Methods (MCDM). Particularly this study demonstrates the workability of the integrated AHP-BWM methods for finding ranking of the determined vital enablers for implementing LPS in SME.

Keywords

Lean Production System, Small and Medium Enterprises, Vital Enablers for LPS, Multicriteria Decision-Making Method, Ranking of Vital Enablers

1. Introduction

In today's global market, characterized by intense competition, SME are encountering challenges in maintaining their competitiveness. To remain competitive, SME must enhance their organizational efficiency by reducing various forms of waste, which are categorized as non-value added in Lean Production System (LPS). Therefore, the effective implementation of LPS in SME becomes crucial. Further, existing literature provides ample evidence that SME can indeed benefit from LPS if they can successfully tailor its principles to suit their individual needs and circumstances (Hu et al., 2015).

To ensure the effective implementation of LPS in SME, it is essential to identify key enablers. The review of the literature reveals that many researchers have identified different sets of enablers for implementing LPS in various industries. However, there is a lack of a universally applicable, vital set of enablers that transcends industry types. This literature gap also highlights the absence of a clear understanding of the relative importance and priority weightage of these enablers. To address this research gap, the authors employ a Multicriteria Decision Method (MCDM) to weigh and rank all the enablers.

The paper is organized as follows: Section 2 presents a literature review of lean enablers and Pareto analysis in obtaining vital enablers with a brief description for implementation of LPS in SME. Section 3 outlines the research methodology followed to determine the ranking of the identified vital enablers for implementation of LPS in SME. The final section discusses the results and presents the conclusion.

2. Literature Review

Lean Production System (LPS) is an operational business strategy in eliminating non-values activities (generally these are called as ***waste***). Broadly, the non-valued activities have been categorized into different types: over-production, waiting, unnecessary transport and handling, unnecessary over-processing, inventories, unnecessary motions, defects, etc. (Ohno, (1988)). Commonly referred wastes in LPS include overproduction, inventory, waiting time over-processing, transportation, motion, and defects (Chaple, et al. (2021)). LPS when implemented successfully increase production output per person and a reduction in the finished goods inventory and work-in-process (Seth and Gupta, (2005)). LPS is being adopted by many industries to improve quality and service, eliminate waste, reduce time and costs, enhance overall organizational effectiveness, and maintain a competitive position (Shah, and Ward (2007), Wilson (2010), Bhasin (2013), Bhamu et al. (2014), Zhou, (2016)). Overall, the main goal of an LPS is to produce products of higher quality at the minimum possible cost and in the least time by eliminating waste (Dennis, 2007). The analysis of the literature clearly indicates that there are multiple factors or enablers are involved in successful implementation of LPS. However, there is no focused study consolidated all the factors required for successful implementation of LPS, particularly for SME. Keeping this research gap, a systematic literature review was carried out with an objective of identifying unique enablers which are expected to impact the successful implementation of LPS.

After the rigorous analysis of the closely related existing literature, considering the period: 1990-2023, 32 unique enablers were identified. Further, pareto analysis were carried out considering the 32 identified unique enables and determined 16 vital enablers for successful implementation of LPS in SME [Sankar and Mathirajan, 2023]. A brief description of each of these 16 vital enablers is presented in Table 1.

The analysis of the literature indicated that there is no explicit study in determining the importance (or ranking) of each of the enablers expected to impact the successful implementation of LPS in general, particularly to implementation of LPS in SME. However, different MCDM have been used in the literature for determining the importance of the factors/enablers related to different areas of study such as Supplier selection (Singh et al. 2023), Material selection (Emovon and Oghenenyerovwho, 2020), Mining technology selection (Dogan,2021), New Product development (Ayag, 2021), etc. Recently researchers have started to use multiple MCDM in an integrated perspective to determine the importance (ranking) of the factors considered in their study (Javaid et al, 2023; Youssef, 2020). So, in this study, both AHP and BWM are used in an integrative perspective to determine the rankings of the 16 vital enablers determined for successful implementation of LPS in SME.

3 Proposed Methodology

The procedure followed in the proposed integrated MCDM methodologies (AHP-BWM) is schematically presented in Figure 1 and the same is demonstrated using the following step-by-step procedure:

Step 1: Define objective or goal of the study: The study aims to ascertain the relative significance and ranking of Vital Enablers (EB), identified from the analysis of literature (Table 1), for the implementation of LPS in SME.

Step 2: Construction of Decision Hierarchy: Considering the identified vital enablers, a 'decision hierarchy model' is constructed and presented in Figure 2. The topmost level in the 'decision hierarchy model' delineates the overarching goal: the implementation of LPS in SME. The lower level encompasses 16 distinct vital enablers (EB) denoted as EB1 through EB16. These 16 unique EB include: EB1- availability and allocation of resources (AAR), EB2-Continuous improvement(CI), EB3-Commitment and support from top management(CSTM), EB4-Effective Communication, EB5- Empowerment of Employees, EB6- Effective Leadership, EB7- Financial capabilities(FC), EB8-Involvement of all employees(IE), EB9-Lean Consultant(LC), EB10-Oragnizational cultural change(OCC), EB11-Performance measurement and quick feedback Response(PMQR), EB12-Skills and expertise(SE), EB13-Shared Improvement Vision(SIV), EB14-Training and education(TE), EB15-Teamwork(TW), EB16- Understanding Lean Tools and Their Techniques(ULT).

Step 3: Computation of a set of pairwise comparisons: This process entails the creation of a pairwise comparison matrix, which employs a scale to illustrate the degree of relative importance or dominance of one Enablers over others concerning the implementation of LPS in SME. To gather the necessary data for the pairwise comparison of the enablers, a questionnaire was developed and administered to 30 experts from both industrial and academic backgrounds. Each of these 30 experts independently evaluated the relative importance of each of the 16 enablers over the others using a scale ranging from 1 to 9, as established by Satty (1980). The result of these assessments is represented in the pairwise comparison matrix denoted in Matrix form, which is shown in Table 2.

Table 1: Vital Enablers with brief description for Implementation of LPS

Enabler	Brief Descriptions
Availability and Allocation of Resources (AAR)	In the context of implementing lean manufacturing in SME, ensuring the availability and effective allocation of resources is crucial for achieving efficiency and sustainability in the lean initiatives. This includes allocating human resources, time, and financial investments to optimize the lean processes and outcomes
Continuous Improvement (CI)	Continuous improvement is a core principle. It involves a commitment to identifying and eliminating inefficiencies, reducing waste, and making incremental advancements in operations over time. This iterative process of making small, consistent improvements is key to achieving greater efficiency and competitiveness in the long term. It often involves employee involvement, data-driven decision-making, and a culture of adaptability and innovation.
Commitment and Support from Top Management (CSTM)	The unwavering dedication and active backing extended by top management to foster the adoption of lean manufacturing principles within small and medium-sized enterprises (SME). This commitment entails financial support, encouragement, active involvement, and oversight to ensure the successful integration of lean practices
Effective Communication (EC)	Effective communication emphasizing communication among employees and departments throughout the program is crucial for the successful implementation of lean manufacturing
Empowerment of Employees (EE)	Empowerment of employees" signifies the practice of granting individuals within an organization the authority, autonomy, and responsibility to make decisions and take ownership of their work. In the context of lean manufacturing in SME, empowering employees is crucial for fostering a culture of continuous improvement. It encourages them to identify and address inefficiencies, suggest improvements, and actively participate in the lean initiatives, ultimately leading to increased productivity and efficiency in the organization.
Effective Leadership (EL)	Effective leadership Signifies the influential role that capable leadership plays in the context of implementing lean manufacturing within SME. Effective leadership significantly impacts an organization's performance and the successful execution of lean principles.
Financial Capabilities (FC)	Financial capabilities" refers to the financial resources and capacities that an organization possesses, including its ability to budget, allocate funds, and manage its finances effectively. In the context of lean manufacturing in SME, having strong financial capabilities is vital to support and sustain the implementation of lean principles and practices. This includes allocating funds for training, process improvements, and other aspects of lean manufacturing to ensure its success.
Involvement of All Employees (IE)	It implies that all individuals, regardless of their roles or positions, play a part in contributing to and supporting lean practices. In the context of SME, involving all employees is crucial for creating a culture of collective responsibility, where everyone actively participates in identifying waste, improving processes, and driving continuous improvement efforts to enhance overall operational efficiency.
Lean Consultant (LC)	A "lean consultant" is a professional who specializes in lean manufacturing and provides expert guidance and support to organizations, including SME, looking to implement lean principles and improve operational efficiency. These consultants possess in-depth knowledge of lean methodologies, tools, and best practices. They work with businesses to assess their current processes, identify areas for improvement, and develop and implement lean strategies to eliminate waste, streamline operations, and enhance overall performance.

	Lean consultants play a crucial role in helping organizations achieve their lean manufacturing objectives
Performance Measurement and Quick feedback Response (PMQR)	Performance measurement and quick feedback response" involve the systematic assessment of key performance indicators and the prompt response to data and feedback in order to enhance efficiency and effectiveness in the context of lean manufacturing in SME. Accurate measurement and timely response are vital components of continuous improvement and adaptation to achieve lean goals.
Skills and Expertise (SE)	"Skills and Expertise" refer to the competencies and knowledge possessed by individuals or teams within an organization and essential for successfully implementing and maintaining lean practices, ensuring that they have the necessary expertise to effectively participate in lean initiatives, contribute to process improvements, and support the lean culture within the organization.
Shared Improvement Vision (SIV)	Shared improvement vision Refers to the establishment of a unified and clear policy that provides a distinct direction for the overall lean program within the context of SME. This shared vision aims to guide and align all stakeholders towards common improvement goals and objectives associated with lean practices.
Organizational Cultural Change (OCC)	Organizational cultural change" refers to the deliberate transformation of an organization's values, beliefs, norms, and behaviors. In the context of implementing lean manufacturing in SME, this change typically involves shifting the company's culture to one that prioritizes continuous improvement, waste reduction, and a focus on customer value. It may require altering long-standing practices, promoting collaboration, and fostering a mindset of adaptability and efficiency throughout the organization. Organizational cultural change is often a fundamental component of successfully embracing lean principles.
Training and Education (TE)	Training and education" encompass the processes of providing instruction, knowledge, and skill development to employees, which is essential for the successful implementation of lean manufacturing in SME. This includes educating personnel about lean principles, tools, and methodologies, as well as providing them with the necessary training to apply these concepts effectively in their work. Training and education are crucial for building a workforce that can actively contribute to lean practices and process improvements within the organization.
Teamwork (TW)	Effective teamwork is critical for the successful implementation of lean principles and practices. It involves employees from different departments or areas of expertise coming together to streamline processes, reduce waste, and drive continuous improvement in the organization. Teamwork fosters communication, collaboration, and a shared commitment to lean methodologies.
Understanding Lean Tools and Their Techniques (ULTT)	Understanding Lean tools and their techniques" encompasses the knowledge and proficiency in the various tools and methods associated with lean manufacturing. This understanding is essential for effectively implementing lean practices in SME. It involves familiarizing employees with tools such as value stream mapping, 5S, kanban, and other lean techniques. A comprehensive understanding of these tools and how to apply them is crucial for optimizing processes, reducing waste, and improving efficiency within the organization.

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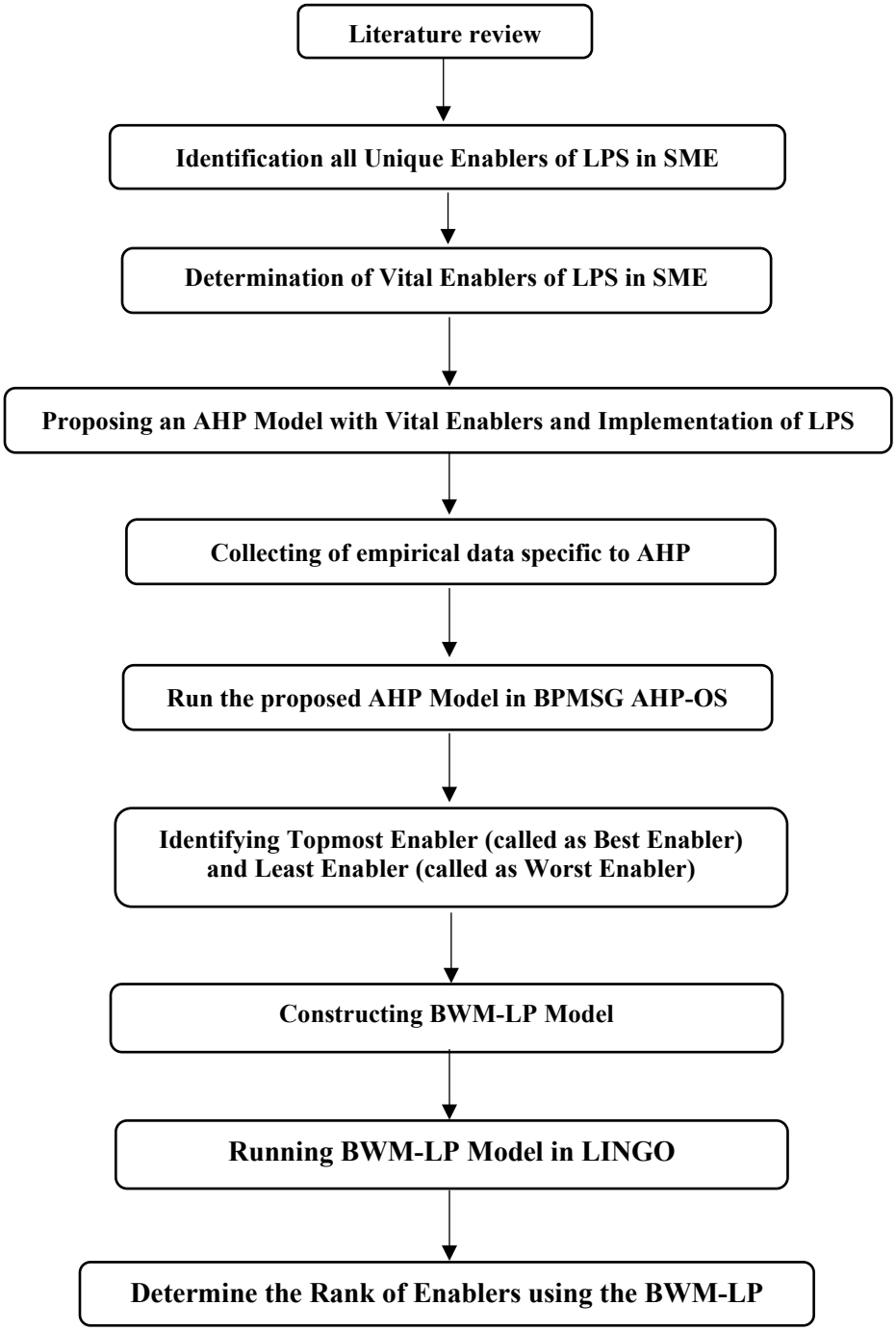

Figure 1: A Schematic Diagram of the Proposed Integrated AHP-BWM

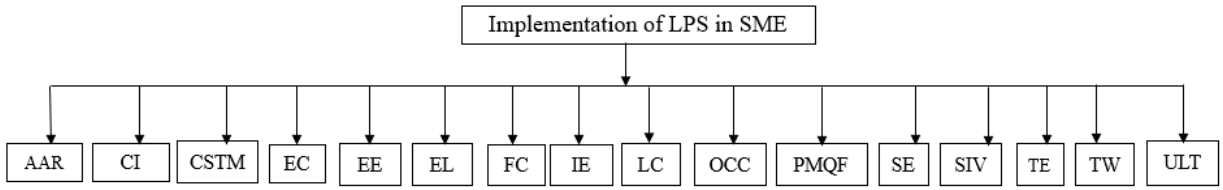

Figure 2: A two level decision hierarchy model

Table 2: A Pairwise comparison matrix of Respondent 1

*Note * indicate suggestion by AHP-OS calculator improve consistency.*

	AAR	CI	CSTM	EC	EE	EL	FC	IE	LC	OCC	PMQF	SE	SIV	TE	TW	ULT
AAR	1	1	1/9	1	3	1/3	1/3	1	1	5*	1	1	1	1	1	1
CI	1	1	1/7	1	1	1	1	1/2	1/2	1	1/3	1/3	1	1/3	1/3	1/9
CSTM	9	7	1	3	7	1	7	1	1	7	1	1	1	1	1	1
EC	1	1	1/3	1*	7	1	1	1	1	3	1	1	1/3	1	1	1
EE	1/3	1	1/7	1/7	1	1/9	1/2	1	1	1	1/7	1/7	1/7	1/7	1/7	1/4
EL	3	1	1	1	9	1	3	2	1	7	1	1	1/3	1	1	1
FC	3	1	1/7	1	5	1/3	1	1	1	7	1	1	1	1	1	1
IE	1	2	1	1	1	1/2	1	1	1	7	1	1/5	1	1	1	1
LC	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1/5
OCC	1/5	1	1/7	1/3	1	1/7	1/7	1/7	1	1	1/7	1/7	1/3	1/7	1/7	1/3
PMQF	1	3	1	1	7	1	1	1	1	7	1	1/5	1	1	1	1
SE	1	3	1	1	7	1	1	5	1	7	5	1	1	3	3*	1
SIV	1	1	1	3	7	3	1	1	1	3*	1	1	1	1	1	1
TE	1	3	1	1*	7	1	1	1	1	7	1	1/3	1	1	1	1
TW	1	3	1	1	7	1	1	1	1	7	1	1/3	1	1	1	1
ULT	1	9	1	1	4	1	1	1	5	3	1	1	1	1	1	1

Step 4: Check the consistency and find priority weights: This step involves the assessment of consistency and the determination of priority weights for the enablers, and it is focuses on evaluating whether the pairwise comparisons provided by each of the experts exhibit consistency. For instance, if Expert 1 assigns a relative importance rating of 1 for the comparison of EB_1 to EB_2 and a rating of 3 for the comparison of EB_2 to EB_3, then the perfect consistency would mean that EB_1 to EB_3 should have a relative importance rating of 1 multiplied by 3, which equals 3. If the rating assigned by Expert 1 for the EB_1 to EB_3 comparison was 1 or 2, it would indicate the presence of inconsistency (Anderson et al. 2005). AHP allows for the computation of consistency in pairwise comparisons through the Consistency Ratio (CR). A CR value less than 0.10 indicates consistency in the pairwise comparisons, while a CR value greater than 0.10 suggests inconsistency. If inconsistency is detected, the pairwise comparisons should be revised before conducting the AHP analysis.

To calculate the priority weights for each of the enablers, in this study the ***BPMSG AHP-OS priority tool***, a web-based tool, is employed. The relative importance ratings from all 30 responses are separately given as input into the *BPMSG AHP-OS priority tool* to determine the priority or weights of each enabler. The *BPMSG AHP-OS priority tool* itself provides feedback on the consistency of the pairwise comparisons. If inconsistencies are identified, the tool

highlights the most inconsistent judgments. To enhance consistency, decision makers should review and adjust the highlighted pairwise judgments data according to the *BPMSG AHP-OS priority* tool's recommendations. In this case, each of the respondent's' input initially displayed inconsistency in the analysis. Subsequently, the suggestions provided by the *BPMSG AHP-OS priority tool* is followed to enhance consistency until the consistency ratio reached less than 0.10. Finally, priority weights for each of the enablers were computed with respect to each of the 30 respondents. In Table 2 the symbol '*' depicts the pairwise comparison matrix following Consistency check for respondent 1.

Step 5: Determine priority weight for each of the enablers: Using the *BPMSG AHP-OS priority tool* the priority weights have been individually computed, considering each of the 30 respondents' data, and the same is presented in Table 3 along with the information on the consistency ratio (CR).

Step 6: Obtain the required data for BWM Method - Considering the weights obtained for each of the enablers w.r.t. each of the respondents using AHP (Table 3), the best and worst enablers are identified (the enabler which has highest weight among the 16 enablers is called as best enabler and the enabler which has least weight among the 16 enablers is called as worst enabler) w.r.t. each of the 30 respondents are determined,. Further, considering each of the 30 respondents the pairwise comparison data used in AHP w.r.t. (a) each of the identified best enabler to all the other 16 vital enablers, and (b) each of the 16 vital factors to the worst enabler are considered as input to BWM method and presented in Table 4 and 5 respectively.

Step 7: Obtaining Optimal Weight for each of the Enablers using Linear Programming (LP) Model of BWM – Considering each of the 30 respondents Best and Worst Enablers along with the respective required pairwise data (Table 4 and Table 5), the required LP model for BWM is generated by developing a LINGO Setcode. The generated LP model w.r.t. each of the 30 respondents are solved using LINGO Solver. The LP Model of BWM gives the optimal weight of each of the 16 vital enablers. [Respondent 1 Pair wise data w.r.t. the Identified Best and Worst enablers using AHP and LINGO Set Code for generating BWM LP Model for any Respondent's Data are presented in Annexure]. The optimal weight obtained for each of the enablers w.r.t. each of the 30 respondents' data is presented in Table 6.

Step 8: Determine the ranking of Enablers: Considering the optimal weight obtained for each of the enablers w.r.t. each of the 30 respondents' data (Table 6), the average weights of each enabler is computed. The rank is then determined based on these average weights [the enabler which has highest average weight amount the 16 enablers is represented as topmost rank and the enabler which has least average weight among the 16 enablers is represented as least rank], which reflect the collective preferences and priorities of all respondents for each enabler. Accordingly, Table 7 presents the ranking of all 16 enablers.

Table 3. Respondent wise weights of enablers for LPS-SME Using AHP

	AAR	CI	CSTM	EC	EE	EL	FC	IE	LC	OCC	PMQF	SE	SIV	TE	TW	ULT	Consistency Ratio
R1	0.0489	0.0309	0.1227	0.0547	0.0169	0.0794	0.0602	0.0546	0.0527	0.0157	0.064	0.1089	0.0766	0.0648	0.0648	0.0842	0.0951
R2	0.0654	0.0078	0.1582	0.159	0.0352	0.1549	0.0471	0.0099	0.0087	0.0104	0.037	0.079	0.1295	0.0495	0.0381	0.0104	0.0973
R3	0.0596	0.0093	0.2125	0.0487	0.0176	0.1933	0.0474	0.0115	0.0106	0.011	0.0339	0.0492	0.207	0.027	0.0478	0.0135	0.0916
R4	0.0263	0.0144	0.1855	0.1379	0.0177	0.1395	0.0845	0.0161	0.0139	0.0185	0.0345	0.0467	0.1865	0.0173	0.0454	0.0154	0.0978
R5	0.0495	0.0082	0.1895	0.1265	0.0546	0.1139	0.0591	0.0537	0.0252	0.0277	0.0428	0.0455	0.1101	0.0322	0.0491	0.0124	0.0944
R6	0.0785	0.0088	0.1683	0.1136	0.0305	0.1538	0.121	0.0147	0.0114	0.0113	0.0366	0.0345	0.1466	0.03	0.0311	0.0093	0.0914
R7	0.0724	0.0057	0.1239	0.1311	0.0187	0.1643	0.0953	0.0142	0.0054	0.012	0.0329	0.0564	0.1857	0.0317	0.0414	0.009	0.0943
R8	0.1118	0.0126	0.2318	0.0707	0.0159	0.1311	0.0668	0.0118	0.0116	0.0134	0.0366	0.066	0.1664	0.0106	0.0334	0.0095	0.0988
R9	0.041	0.0156	0.2294	0.0988	0.0348	0.1436	0.0362	0.0358	0.0138	0.0406	0.0381	0.0644	0.0839	0.0313	0.0817	0.0111	0.0963
R10	0.0338	0.0084	0.1735	0.1473	0.0362	0.143	0.1223	0.0114	0.0085	0.0119	0.0362	0.0414	0.1393	0.0389	0.037	0.011	0.0967
R11	0.0614	0.014	0.2206	0.0566	0.0172	0.144	0.0658	0.0221	0.012	0.021	0.0583	0.0503	0.1643	0.0168	0.0548	0.0206	0.0942
R12	0.0617	0.016	0.1814	0.1576	0.0164	0.1181	0.0417	0.0235	0.0175	0.0188	0.0203	0.0711	0.1117	0.0395	0.0897	0.0149	0.0976
R13	0.0487	0.0085	0.2023	0.1673	0.0118	0.1642	0.0376	0.0126	0.0125	0.0106	0.0368	0.0517	0.1539	0.0262	0.0441	0.0113	0.0959
R14	0.066	0.0182	0.2404	0.0467	0.0463	0.1258	0.0635	0.0458	0.0111	0.0208	0.0202	0.0778	0.0827	0.0496	0.0693	0.0158	0.0931
R15	0.0342	0.0097	0.1976	0.123	0.0215	0.1396	0.1093	0.0188	0.0101	0.0279	0.0302	0.0536	0.1467	0.0328	0.0354	0.0097	0.0953
R16	0.0712	0.0425	0.1121	0.0663	0.0285	0.1038	0.156	0.0488	0.0078	0.012	0.0491	0.0445	0.144	0.0488	0.0562	0.0086	0.0899
R17	0.0751	0.009	0.2139	0.1283	0.0129	0.1324	0.0513	0.0114	0.0088	0.0122	0.0437	0.07	0.1378	0.0397	0.0423	0.0113	0.094
R18	0.0453	0.0235	0.2357	0.1066	0.0181	0.0982	0.1214	0.0171	0.0256	0.0182	0.0317	0.0664	0.0631	0.0379	0.0672	0.024	0.0995
R19	0.0552	0.0204	0.1934	0.1024	0.0305	0.1484	0.1008	0.021	0.012	0.0116	0.0475	0.0529	0.1151	0.0271	0.0473	0.0143	0.0964
R20	0.0693	0.0087	0.1679	0.1502	0.0157	0.1724	0.0801	0.0141	0.013	0.013	0.0568	0.056	0.116	0.0226	0.0314	0.0127	0.0962
R21	0.0575	0.0066	0.243	0.1415	0.0246	0.086	0.0657	0.0163	0.0349	0.0269	0.0477	0.0345	0.1169	0.0402	0.0234	0.0342	0.0949
R22	0.0669	0.0103	0.2373	0.0972	0.0581	0.0971	0.1143	0.0148	0.0099	0.0137	0.0334	0.0621	0.1111	0.0223	0.0418	0.0097	0.0996
R23	0.0445	0.0091	0.2107	0.1297	0.0236	0.1503	0.0866	0.0163	0.0114	0.0171	0.0297	0.0365	0.1352	0.0342	0.0566	0.0085	0.0978
R24	0.0427	0.0094	0.1848	0.058	0.0378	0.1627	0.0573	0.047	0.0143	0.0177	0.0429	0.0883	0.1557	0.0248	0.0442	0.0125	0.0967
R25	0.0416	0.0271	0.1933	0.1401	0.0205	0.1353	0.0625	0.029	0.0134	0.015	0.0417	0.043	0.1152	0.0557	0.0332	0.0333	0.0946
R26	0.0301	0.0095	0.2371	0.0719	0.0179	0.1761	0.0426	0.0158	0.026	0.0171	0.0543	0.0395	0.1879	0.022	0.0293	0.0231	0.0992
R27	0.1052	0.0385	0.1106	0.0679	0.0211	0.1084	0.0832	0.0612	0.0123	0.0159	0.0427	0.0704	0.0616	0.0613	0.0933	0.0464	0.0972
R28	0.1214	0.0525	0.1291	0.0884	0.0235	0.103	0.127	0.0381	0.0115	0.0111	0.0311	0.0493	0.1266	0.0289	0.0442	0.0144	0.0667
R29	0.0349	0.0095	0.1609	0.0786	0.0158	0.1543	0.1234	0.0192	0.0138	0.0345	0.045	0.0648	0.1373	0.0523	0.0438	0.0119	0.0977
R30	0.0604	0.0093	0.2017	0.0559	0.0187	0.1959	0.0484	0.0116	0.0107	0.0112	0.0322	0.0504	0.209	0.0277	0.0417	0.0153	0.0912

Table 4: Respondents wise the Pairwise comparison data considered in AHP w.r.t. the Best Enabler and each of other enablers for LPS-SME

	BEST Enablers	AAR	CI	CSTM	EC	EE	EL	FC	IE	LC	OCC	PMQF	SE	SIV	TE	TW	ULT
R1	CSTM	9	7	1	3	7	1	7	1	1	7	1	1	1	1	1	1
R2	EC	2	9	1/2	1	9	1	9	7	7	9	9	2	1	8	7	7
R3	CSTM	9	9	1	6	8	2	6	7	9	9	7	9	1	8	9	9
R4	SIV	9	8	1	2	6	2	6	9	8	5	5	8	1	6	9	8
R5	CSTM	5	9	1	2	3	2	6	9	5	3	5	7	1	5	7	9
R6	CSTM	5	8	1	2	5	1	2	9	9	8	5	9	2	7	8	9
R7	SIV	9	4	1/2	8	6	6	6	9	8	5	9	7	1	1	9	6
R8	CSTM	1	9	1	9	9	1	9	9	9	9	5	7	5	9	9	9
R9	CSTM	7	7	1	2	5	4	7	5	7	7	6	6	6	6	5	9
R10	CSTM	7	9	1	5	7	2	1	9	9	9	4	4	2	5	4	7
R11	CSTM	8	9	1	9	6	2	1	6	9	5	9	8	2	8	7	5
R12	CSTM	7	9	1	1	9	5	1	4	9	7	5	5	1	7	3	9
R13	CSTM	9	9	1	2	7	2	9	7	8	8	8	7	2	8	8	9
R14	CSTM	6	7	1	3	5	5	3	6	9	7	6	7	5	5	7	6
R15	CSTM	8	9	1	2	7	2	2	6	9	5	8	7	5	4	7	9
R16	FC	1	5	1	1/2	9	1	1	3	9	7	5	7	1/2	9	8	8
R17	CSTM	3	9	1	2	9	2	7	8	9	7	7	3	6	8	9	8
R18	CSTM	5	8	1	5	9	1	2	9	9	9	8	8	3	8	9	9
R19	CSTM	6	8	1	5	8	3	1	8	8	8	5	7	2	3	4	6
R20	EL	7	8	1	1	9	1	6	8	5	6	5	6	1	8	8	5
R21	CSTM	9	9	1	2	5	6	9	9	4	7	5	9	4	7	7	5
R22	CSTM	8	9	1	2	6	6	5	8	9	9	7	9	2	9	4	9
R23	CSTM	8	9	1	2	9	2	4	9	9	7	8	9	2	9	9	9
R24	CSTM	6	9	1	7	7	3	1	3	5	6	4	1	3	4	9	8
R25	CSTM	5	6	1	5	6	5	1	3	9	7	4	6	3	1	5	3
R26	CSTM	8	8	1	8	7	4	4	5	5	9	7	9	4	5	6	4
R27	CSTM	4	1	1	2	7	1	1	1	5	6	7	2	2	1	1	1
R28	CSTM	2	1	1	2	3	1	1	2	6	9	7	5	2	5	4	6
R29	CSTM	5	7	1	3	5	4	1	6	9	2	3	2	3	6	2	9
R30	SIV	8	9	1	8	6	1	7	9	9	9	9	8	1	8	9	9

Table 5: Respondents wise the Pairwise comparison data considered in AHP w.r.t. each of other enablers with Worst Enablers for LPS-SME

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	R28	R29	R30
Worst Enabler	**OCC**	**LC**	**CI**	**CI**	**LC**	**CI**	**CI**	**ULTT**	**ULT**	**CI**	**LC**	**ULT**	**CI**	**LC**	**ULT**	**LC**	**LC**	**IE**	**OCC**	**CI**	**CI**	**ULTT**	**ULTT**	**CI**	**LC**	**CI**	**CI**	**LC**	**CI**	**CI**
AAR	5	9	9	5	2	7	6	9	5	7	4	7	8	9	9	9	8	1	5	7	9	7	7	5	4	9	6	9	2	5
CI	1	1	1	1	1/2	1	1	1	1	1	1	1	1	1/2	1	3	1	1	1	1	1	1	1	1	1	1	1	3	1	1
CSTM	7	5	9	9	8	9	8	9	9	9	9	9	9	9	9	9	9	9	8	9	9	9	9	9	9	8	5	6	7	9
EC	3	7	9	6	7	7	8	9	5	8	3	9	8	2	5	9	8	9	8	8	9	5	9	5	5	8	5	7	8	6
EE	1	8	7	3	2	7	8	2	5	8	2	1	2	9	6	9	2	1	4	5	9	5	5	6	2	4	2	2	2	3
EL	7	8	9	8	8	9	8	9	9	7	7	9	9	9	8	9	8	6	9	8	9	9	8	9	5	8	8	7	8	8
FC	7	8	6	6	4	4	8	9	3	8	4	1	7	9	6	9	5	5	6	7	9	9	7	5	2	9	8	9	8	6
IE	7	6	2	2	2	5	2	2	4	2	2	1	2	9	3	9	2	1	2	2	3	2	5	4	6	2	8	5	2	2
LC	1	1	1	2	1	7	2	1	1	1	1	1	2	1	1	1	1	1	1	4	9	1	1	4	1	1	1	1	2	2
OCC	1	7	2	2	1	7	2	1	6	2	5	1	2	3	6	2	2	1	1	2	9	2	5	4	1	2	1	1	7	2
PMQF	7	8	7	5	4	7	7	7	4	7	5	1	8	1	6	9	7	3	4	8	9	8	6	9	9	9	7	5	9	5
SE	7	8	9	5	3	7	7	8	5	8	4	7	8	9	5	9	8	3	8	7	9	9	5	6	7	9	6	7	8	5
SIV	3	8	9	9	8	9	8	9	5	9	7	6	8	9	7	9	9	4	6	8	9	7	8	9	5	9	7	7	7	9
TE	7	9	9	5	1	7	6	1	6	8	2	7	3	9	7	7	7	5	3	7	9	2	9	2	8	3	7	2	8	5
TW	7	8	9	5	5	7	8	9	6	6	4	9	8	9	6	9	6	9	6	6	9	8	7	9	3	9	8	7	8	5
ULT	3	9	2	2	2	2	1	1	1	2	5	1	2	2	1	1	2	1	1	1	9	1	1	1	7	3	3	1	2	2

Table 6. Respondent wise weights of Enablers of LPS in SME using BWM

	AAR	CI	CSTM	EC	EE	EL	FC	IE	LC	OCC	PMQF	SE	SIV	TE	TW	ULT
R1	0.0145	0.0187	0.0904	0.0438	0.0187	0.1006	0.0187	0.1006	0.0494	0.0852	0.1006	0.1006	0.0665	0.1006	0.1006	0.0665
R2	0.0282	0.063	0.1532	0.0317	0.0422	0.0422	0.0423	0.0281	0.012	0.0507	0.0281	0.0362	0.165	0.205	0.0281	0.0422
R3	0.0975	0.0900	0.1462	0.134	0.0216	0.1462	0.0216	0.0278	0.0278	0.0216	0.0216	0.0975	0.1462	0.0243	0.0278	0.0278
R4	0.0302	0.0179	0.2140	0.0454	0.034	0.1320	0.0454	0.0389	0.0302	0.0302	0.0389	0.0302	0.214	0.034	0.0302	0.0302
R5	0.0263	0.0296	0.1828	0.1184	0.0394	0.1184	0.0394	0.0263	0.016	0.0474	0.0472	0.0296	0.1828	0.0394	0.0262	0.0296
R6	0.0425	0.0118	0.1590	0.1060	0.0709	0.1060	0.0354	0.0236	0.0425	0.0709	0.0425	0.0303	0.1590	0.0425	0.0303	0.0236
R7	0.0459	0.0118	0.1606	0.1134	0.0454	0.1607	0.1134	0.0252	0.0252	0.0283	0.0453	0.0252	0.1134	0.0324	0.0287	0.0252
R8	0.1902	0.0300	0.1902	0.0300	0.0300	0.1902	0.0300	0.0300	0.0300	0.0300	0.0540	0.0386	0.0541	0.0300	0.0300	0.1223
R9	0.4039	0.0403	0.2120	0.1413	0.0566	0.0706	0.0404	0.0566	0.0403	0.0404	0.0471	0.0471	0.0471	0.0471	0.0566	0.0157
R10	0.0340	0.0122	0.1743	0.0477	0.0340	0.1191	0.1191	0.0264	0.0264	0.0264	0.0595	0.0595	0.1191	0.0477	0.0595	0.0340
R11	0.0317	0.0281	0.1931	0.0282	0.0423	0.1270	0.1322	0.0423	0.0178	0.0508	0.0282	0.0317	0.127	0.0317	0.0363	0.0508
R12	0.0318	0.0248	0.1637	0.1041	0.0248	0.0446	0.119	0.0558	0.0248	0.0318	0.0446	0.0446	0.1637	0.0318	0.0744	0.0148
R13	0.0303	0.1337	0.1969	0.1367	0.3907	0.1367	0.0303	0.3907	0.0341	0.0341	0.0341	0.3907	0.1367	0.0341	0.0341	0.0303
R14	0.0489	0.0151	0.1997	0.0979	0.0587	0.0587	0.0979	0.0489	0.0326	0.0489	0.0489	0.0489	0.0587	0.0587	0.0419	0.0489
R15	0.0314	0.0279	0.1783	0.1258	0.0359	0.1258	0.1258	0.0419	0.0279	0.0503	0.0314	0.0359	0.0535	0.0629	0.0359	0.0116
R16	0.1249	0.0337	0.1249	0.1249	0.0187	0.1249	0.1155	0.0562	0.0798	0.0241	0.0377	0.0241	0.1249	0.0187	0.021	0.0210
R17	0.0890	0.0296	0.193	0.1336	0.0296	0.1336	0.0381	0.0344	0.0131	0.0381	0.0381	0.089	0.0445	0.0344	0.0296	0.0344
R18	0.0544	0.0346	0.1951	0.0554	0.0308	0.1574	0.1386	0.0125	0.0308	0.0308	0.0346	0.0346	0.0924	0.0346	0.0308	0.0308
R19	0.0399	0.0299	0.1713	0.0479	0.0299	0.0799	0.1456	0.0299	0.0299	0.0128	0.0479	0.0342	0.1199	0.0799	0.0599	0.0399
R20	0.0304	0.0121	0.1549	0.1549	0.0233	0.1549	0.0354	0.0266	0.0425	0.0354	0.0425	0.0354	0.1549	0.0266	0.0266	0.0425
R21	0.0327	0.0134	0.2070	0.1476	0.0327	0.0492	0.0327	0.0327	0.0738	0.0421	0.0590	0.0327	0.0738	0.0421	0.0421	0.0590
R22	0.0359	0.0319	0.2021	0.1436	0.0478	0.0478	0.0574	0.0359	0.0319	0.0319	0.0410	0.0319	0.1436	0.0319	0.0718	0.0130
R23	0.0340	0.0302	0.1917	0.1362	0.0302	0.1362	0.0681	0.0302	0.0302	0.0389	0.0341	0.0303	0.1362	0.0302	0.0303	0.0123
R24	0.0379	0.0103	0.1601	0.0324	0.0325	0.0758	0.1180	0.0758	0.0455	0.0379	0.0569	0.1292	0.0758	0.0569	0.2528	0.0288
R25	0.0430	0.0358	0.1520	0.0430	0.0358	0.0430	0.0889	0.0716	0.0129	0.0307	0.0537	0.0358	0.0716	0.1668	0.0430	0.0716
R26	0.0383	0.0144	0.2110	0.0383	0.0438	0.0767	0.0767	0.0613	0.0613	0.034	0.0438	0.034	0.0767	0.0613	0.0511	0.0767
R27	0.0286	0.0980	0.0621	0.0572	0.0163	0.1143	0.1143	0.1143	0.0228	0.0191	0.0163	0.0572	0.0572	0.1143	0.1143	0.0816
R28	0.0783	0.0783	0.1112	0.0783	0.0522	0.1221	0.1441	0.0783	0.0109	0.0174	0.0223	0.0313	0.0783	0.0313	0.0391	0.0261
R29	0.0382	0.0111	0.1344	0.0638	0.0382	0.0478	0.1455	0.0319	0.0212	0.0956	0.0638	0.0957	0.0638	0.0319	0.0957	0.0212
R30	0.0331	0.0157	0.2031	0.0331	0.0441	0.1874	0.0377	0.0294	0.0294	0.0294	0.0294	0.0331	0.2031	0.0331	0.0294	0.0294

Table 7: Average weights and Ranking of each enabler of LPS in SME

Ranking of Enablers using integrated MCDM techniques			
Enabler Code	**Enabler**	**Average weights**	**Rank**
CSTM	Commitment and Support from Top Management	0.1696	1
SIV	Shared Improvement Vision	0.1107	2
EL	Effective Leadership	0.1076	3
EC	Effective Communication	0.0864	4
FC	Financial Capabilities	0.0789	5
AAR	Availability and Allocation of Resources	0.0608	6
SE	Skills and Expertise	0.0591	7
IE	Involvement of All Employees	0.0561	8
TE	Training and Education	0.0538	9
TW	Teamwork	0.0526	10
EE	Empowerment of Employees	0.0483	11
PMQF	Performance Measurement and Quick Feedback Response	0.0431	12
OCC	Organizational Cultural Change	0.0388	13
ULT	Understanding Lean Tools and Their Techniques	0.0387	14
CI	Continuous Improvement	0.0344	15
LC	Lean Consultant	0.0324	16

4. Conclusion

The lean production system (LPS) offers effective solutions to a variety of industrial challenges, especially within the context of small and medium-sized enterprises (SME). By embracing LPS, SME can achieve a stable competitive advantage in today's fiercely competitive business landscape. The adoption of LPS in SME holds significant importance, as these enterprises play a pivotal role in economic growth in both developed and developing countries. However, the successful implementation of LPS in SME hinges on the identification of key enablers.

Numerous enablers have been discussed in the existing literature, but considering all of them practically presents challenges and adds complexity to the system. Therefore, 16 vital enablers are obtained using Pareto-analysis by considering 32 enablers identified from the analysis of the literature. To ascertain the relative importance of these vital enablers, we administered a questionnaire to 30 experts from both academia and industries. Their input was then processed using an integrated multiple-criteria decision-making (MCDM) technique, specifically the Analytic Hierarchy Process (AHP) combined with the Best-Worst Method (BWM).

Based on the integrated multiple-criteria decision-making (MCDM) processes, the top five enablers emerged for implementation of LPS in SME are "commitment and support from top management, shared improvement vision, effective leadership, effective communication, and financial capabilities.

Annexure: Respondent 1 - Pair wise data w.r.t. the Identified Best and Worst enablers using AHP

	AAR	CI	CSTM	EC	EE	EL	FC	IE	LC	OCC	PMQF	SE	SIV	TE	TW	ULT
AAR										5*						
CI										1						
CSTM	9	7	1	3	7	1	7	1	1	7	1	1	1	1	1	1
EC										3						
EE										1						
EL										7						
FC										7						
IE										7						
LC										1						
OCC										1						
PMQF										7						
SE										7						
SIV										3*						
TE										7						
TW										7						
ULT										3						

LINGO Set Code for generating BWM LP Model for any Respondent's Data

```
SETS:
! Set containing weight, Best to other values, and others to worst Values;
E :W, BO, OW;
ENDSETS
DATA:
E = E1 E2 E3 E4 E5 E6 E7 E8 E9 E10 E11 E12 E13 E14 E15 E16;
BST = 3; ! Best one chosen by respondent1.
WST = 10; ! worst one chosen by respondent1;
BO = 9 7 1 3 7 1 7 1 1 7 1 1 1 1 1 1 ;! best to others vector;
OW = 5 1 7 3 1 7 7 7 1 1 7 3 7 7 7 3 ;!others to worst vector;
ENDDATA
MIN = KSI; !Ksi - Consistency rate;
!Absolute absolute difference between weight of best driver and product of 'best to other and
'weight of driver' is less than consistency rate;
@For(E(J):
 @ABS(W(BST)- (BO(J)*W(J)))<=KSI);
!absolute difference between weight of the driver and product of 'others to worst score and
'weight of worst driver' is less than consistency rate;
@For(E(J):
 @ABS(W(J)- OW(J)*W(WST))<=KSI);
@FOR(E(J): W(J)>=0); !Non negativity constraint;
@SUM(E(J): W(J))=1; !Sum of weights should be one;
```

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