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A readiness assessment of lean six sigma implementation in the ceramic industry: India's small and medium enterprises perspective

Deepak Sharma[a], Dharmendra Singh[a]*, Jaiprakash Bhamu[a], Mahender Singh Kaswan[b] & Jose Arturo Garza Reyes[c&d]

[a]Department of Mechanical Engineering, Engineering College Bikaner, Rajasthan, 334 004, India

[b]Department of Mechanical Engineering, Lovely Professional University, Punjab, 144 411, India

[c]Centre for Supply Chain Improvement, College of Business, Law and Social Sciences, The University of Derby, UK

[d]Department of Management Studies, Graphic Era Deemed to be University, Dehradun, Uttarakhand, 248 002, India

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In present work readiness assessment for LSS implementation in ceramic industry (RAL$_i$CI) has been made using Fuzzy rules based on LSS readiness factors (enablers, criteria and attributes) and critical success factors (CSF). The CSF factors have been identified by conducting the questionnaire in 90 small and medium scale ceramic industries (SMEs) located in India. Both CSF and LSS readiness factors have been integrated with each other in RAL$_i$CI model. In RAL$_i$CI model total 3 enablers, 8 criteria and 54 attributes have been developed using literature and questionnaire. It has been observed that fuzzy readiness assessment for LSS implementation in ceramic industry is 2.59, 4.03, 5.46, which indicates that the industry is less ready. Therefore, essential corrective actions have been recommended for improvement by employing a fuzzy performance importance index (FPII) where 31 from 54 attributes have been observed as weaker attributes. The model will help the managers and researchers to check the potential of the industries.

Keywords: Attributes, Ceramic industry, Critical success factors, Enablers, Fuzzy rules, Lean six sigma, Readiness assessment, SMEs

1 Introduction

Organizations of various sizes and functioning in a wide range of areas are constantly confronted with a more competitive market, as well as persistent customer demand to maximize value in both their products and services[1,2]. Approaches such as Lean, Six Sigma, and Lean Six Sigma (LSS) are becoming popular and implemented in the manufacturing industries as methods for the continual improvement of both output and quality. The LSS lowers the amount of process variation by getting rid of activities that did not bring any value[3]. LSS is the result of the combination of both Lean and Six Sigma, which are widely acknowledged as outstanding operational excellence approaches in both manufacturing and service, small- and medium-sized enterprises (SMEs), as well as their bigger counterparts[4]. This technique is employed extensively in manufacturing companies[5,6] services[7] commercial health care and logistics[8,9], hospital[10], Agro food[11], Aerospace[12]. LSS implementation requires a proper understanding of tools/ techniques/ practices by management and employees of the organization[13]. Aside from a few opinion pieces that centre on human resource issues and readiness for LSS implementation in the service sector[14], no rigorous research evidence has emerged that explores the role of organizational and individual behavioural factors in promoting readiness and enabling LSS in manufacturing SMEs[15]. This is the case even though there have been several studies that have been conducted on LSS implementation. Although the benefits of LSS are known and proven, its proper implementation is still in necent stage in SMEs, where its deployment is more challenging than in organizations with large scale industries[16].

The SMEs play a major role in the economic development of countries like India by providing employment opportunities. According to a report, MEs produce about 8000 different products with 40% industrial production & exports[17]. These SMEs contribute about 7% to the GDP, whichreflects the importance of SMEs in India.However, SMEs face potential barriers and hence need to explore tools and techniques to improve productivity and quality for sustainability[18]. The lack of knowledge of LSS

*Corresponding author (E-mail: dharmendra3103@gmail.com)

deployment and the involvement of employees and managers in the process makes the situation even more obvious[19], thus attracting policymakers and academics to develop frameworks to streamline their operations and achieve success.

The literature shows that the ceramic sector is the fastest-growing industry in India and around the globe due to economic activity, artistic value, and cultural heritage. The demand for ceramics will rise in the future due to an increase in population around the world and the expansion of industrial production to fulfil the requirements of the products[20]. The Indian ceramic industries are expected to continue growing due to the government focus on in housing and construction sector, infrastructure, industrial corridors and smart cities. This will lead to increasing demand for tiles, bricks, glass, table wares, sanitary ware, tableware and insulators[18]. Ceramic SMEs make up around 50% of the industries production in India and is the second largest producer of tiles in the world. This sector, being labour-intensive, encounters many issues of unstructured infrastructure, more rejections, overproduction and lack of capability to produce high-quality end products, resistance to change from employees and management, therefore they hesitate to implement any quality improvement concepts[21,22].

The ceramic waste is generated due to high rejections during production, inventory, over production, and the sector is having sustainability issues[23]. Therefore, LSS approach could be a comprehensive approach in achieving sustainability, and there is a need to develop frame works to assess the readiness to implement LSS in their production systems to improve efficiency and productivity. A review of the published research reveals that very few studies have been conducted on the application of lean in the ceramic sector, but no study on LSS implementation to bridge the gap in the academic literature, a LSS readiness evaluation model framework is proposed using fuzzy logic. The model is based on 3 enablers, 8 criteria and 54 attributes that were determined by conducting a literature review and employing a questionnaire. The usage of a triangular fuzzy set in the evaluation process allowed the consideration of not only the preferences of the person making the choice but also the suitability of a worker. The developed model will help to judge the potential of the ceramic industry for its readiness to implement LSS. The changes in the weaker attributes as identified in this study will motivate managers to successfully implement LSS. This work examines the barriers to growth in the ceramic industries in India. The study finds that a lack of commitment and leadership from top management and engineers is the most significant barrier. The model developed in the study suggests a practical implementation programme and can assist policymakers in developing strategies for LSS implementation in Indian SMEs in the ceramic industry.

1.1 Literature review

The selection of the problem, the keywords and databases to use, as well as the examination of the published literature, were the three distinct processes that were applied to compile the papers that were reviewed, see the methodology presented in Fig. 1. During the problem identification phase, it was found that there is a dearth of literature on leanness evaluation in the ceramic sector. The authors utilized Scopus database as a starting point for our literature search. Several selection criteria and keywords words were employed, including Lean, Six Sigma, LSS, leanness and leanness evaluation, lean performance, fuzzy logic rules, lean framework, Implementation, leanness Index, LSS in SME, and CSFs were among the other search phrases. Lastly, descriptive and content analysis was carried out on the investigated literature. The LSS advancements satisfy customers demand, financial enhancement, better efficiency and process cycle time improvement[14]. They achieve this by lowering process variance, decreasing non-value-adding operations, improving decision-making, and boosting staff morale. These objectives are accomplished by enhancing staff morale, enhancing decision-making, and enhancing employee morale[24]. These benefits are also applicable to small and medium-sized manufacturing enterprises, where the usage of LSS is gaining popularity[25]. By adopting the LSS five-phased systematic technique of define, measure, analyze, improve, and control (DMAIC), small and medium-sized firms (SMEs) can address their own unique difficulties[5], despite this, some companies remain dubious of LSS.

Other research has found that “internal resistance”, “the availability of resources”, “changing company focus”, and “lack of leadership” are the most significant impediments to change in manufacturing SME[2]. LSS is a combination” of two inadequately specified and incompatible instruments. Alongitudinal

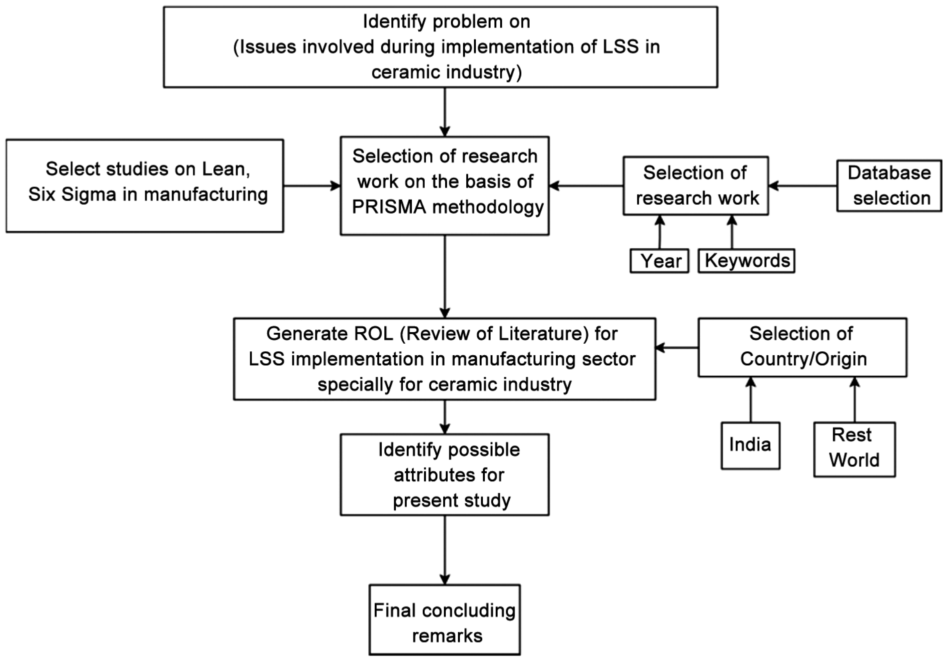

Fig. 1 — Research methodology selected for literature review.

research made on LSS demonstrated a beneficial relationship between total quality management (TQM) and human resource management methods such as empowerment, intensive training, and collaboration in the industrial and service sectors[26]. Other LSS research conducted in the "national health service" indicated that human characteristics such as culture, educational level, and understanding of statistics influence success[27].Evaluating the degree of preparation for LSS in an organization is essential for ensuring the success of the LSS implementation. This allows the identification of any weaknesses or deviations from initiating LSS project implementations inside a company. Organizations can better understand their potential and whether or not they are prepared to carry out reforms as a result of this identification of a readiness index. To determine the degree of leanness level, scoring models have been employed. This has been accomplished using three layers of evaluation criteria, which included lean enablers, criteria, and qualities of interest[24]. Researchers have applied Multi-Criteria Decision Making (MCDM) approaches to evaluate lean assessment methodologies, such as Analytic Hierarchy Process (AHP) to create a road map for the adoption of Lean[28], and a hybrid AHP-modified TOPSIS framework in India to analyze 27 LSS obstacles[29]. The weights ranking were derived for the evaluation of these obstacles using a collection of literature reviews and input from experts. In another study Kumar *et al.*[5] prioritized LSS implementation barriers in Indian manufacturing industries in the context of Industry 4.0 (I4.0) to get over the impediments in the path of successful implementation using Fuzzy AHP approach. Using these MCDM techniques for decision-making in the evaluation of alternatives based on the opinion of experts makes the process complicated and generates vagueness, mainly due to the inclusion of subjective metrics and opinions. Therefore, Fuzzy logic is an alternative approach to deal with complex decision problems to solve the issues related to subjective measures and avoid the data complexity of not having exact numbers[24]. It also has the capability to facilitate decision-makers to manage uncertainty, and fuzziness and thus put up a realistic approach to decision-making.

Vinodh *et al.*[30] has developed an evaluation methodology for the Lean level based on a total of thirty criteria, following the application of the Euclidean distance methodology to the analysis, and the organizations fuzzy leanness index was measured, and the leanness level was uncovered. After reducing the list of criteria to 59, they employed a tool called the Fuzzy Performance Importance Index (FPII) to identify the 19 characteristics that were considered the least significant. Sreedharan *et al.*[31] created an LSS readiness evaluation model tailored specifically for the industrial industry that takes advantage of fuzzy logic. The model developed for assessment of LSS readiness (LESIRE), includes 46 LSS features, 16 criteria, and 4 enablers, in three distinct manufacturing firms. Similarly, Yadav *et al.*[32] demonstrated the drivers for the productive execution of lean manufacturing using Fuzzy-AHP and DEMATEL approach in manufacturing companies for developing countries. In order to strengthen their evaluation model, the researchers in these studies did not make use of their own critical success factors (CSFs); rather, they relied on CSFs that were found in the relevant literature. To put it another way, the manufacturing companies awareness of the CSF plays a crucial part in maintaining their efforts on these elements to ensure effective improvements. However, once LSS is implemented, its practitioners find it difficult to maintain control over these aspects[33]. In the case of SMEs, a lack of competence regarding the tools and practices of Lean Six contributed to the failure of the majority of the sectors.

The Readiness models aim is to maximize the possibility that LSS will be effectively deployed and to guarantee that quality will continue to improve over time. These goals were established to ensure that our model will be successful. The present study aims to contribute to the development and implementation of a novel LSS evaluation model employing fuzzy logic for assessing the LSS readiness of ceramic enterprises, which constitutes one of the primary objectives of this research. It integrates the Critical Success Factors (CSFs) of ceramic SME into the LSS Readiness Assessment for Ceramic Industry (LSRACI) evaluation model. The study delineates the outcomes obtained through the application of the LSRACI evaluation methodology. The most important enablers and criteria selected for the present investigation are shown in Fig. 2.

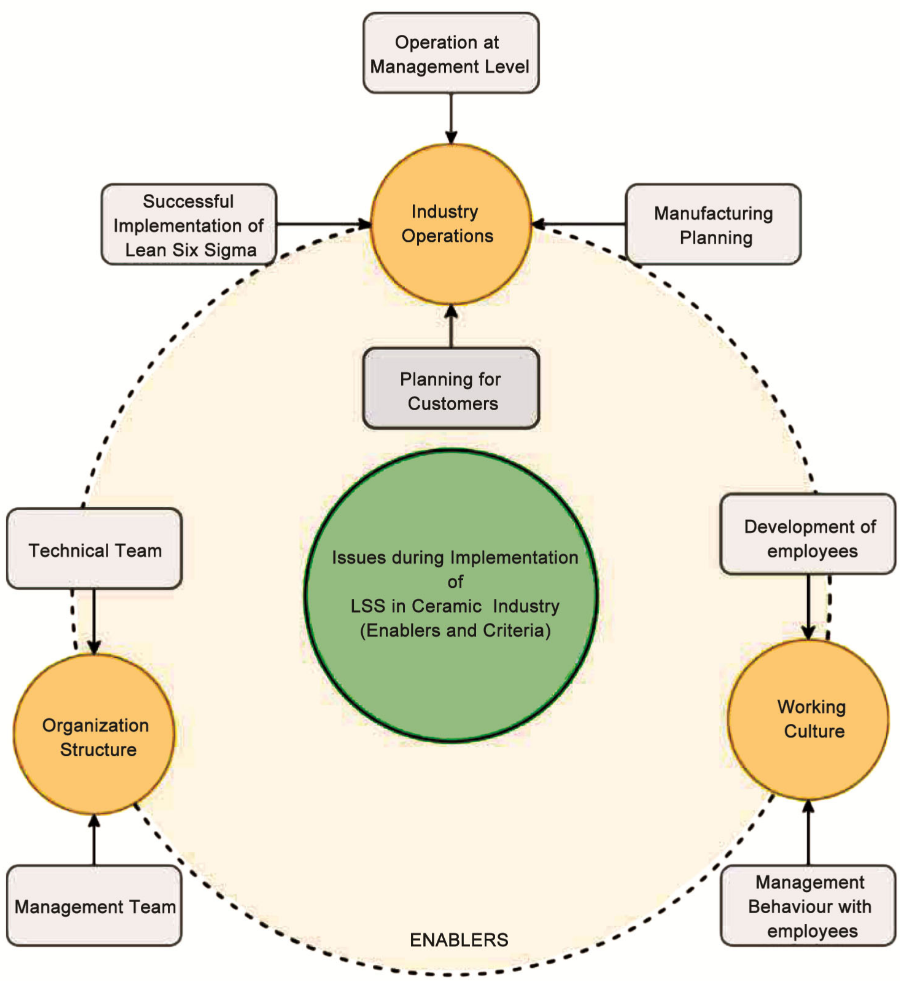

Fig. 2 — Possible enablers and criteria selected for the development of LSS framework.

As a method for reaching the objectives, the proposal of an innovative framework for the Fuzzy LSS readiness evaluation model is offered as a possible solution. Using a questionnaire, the essential component of LSS's performance was gleaned from clothing SMEs, and the LSS components (enablers, criteria, and attributes) were uncovered in the research published in academic journals.

The model was built using these two different sources as its foundation. The usage of a triangular fuzzy set in the evaluation process allows for consideration of not only the preferences of the person making the choice but also of the suitability of a worker. Utilizing this methodology, which was developed specifically for that objective, allows for the level of LSS preparation of the ceramic SME to be evaluated and analyzed. The company will have the desire to effectively embrace the LSS implementation if the characteristics that were identified as having a lower level of strength by this model are improved through reinforcement and reinforcement training. The relevant attributes identified based on the ceramic industry from the literature were finalized based on the opinions of 2 experts from industry and academia. Their research background is listed in Table 1, which was used to improve the LSS framework for the ceramic industry.

Table 1 — Attributes selected for the readiness model development for the present study.

Enablers (RAL_iCI_i)	Criteria (RAL_iCI_{ij})	Attributes (RAL_iCI_{ijk})		References
Industry Operation Level RAL_1	Successful Implementation of Lean Six Sigma RAL_{11}	Planning for LSS	RAL_{111}	Kumar *et al.*[5]
		Waste Control in the plants using Lean Principles	RAL_{112}	Bhadu *et al.*[34];Swarnkar *et al.*[35]
		Proper maintenance of Machines or Instruments	RAL_{113}	Trehan *et al.*[4]; Abbes *et al.*[33]
		Cleaning and management at the Plant Floor	RAL_{114}	Lemon and Verhoef[1]
		Finding and removal of extra material	RAL_{115}	Bhadu *et al.*[34]
		Sustainability development	RAL_{116}	Dora *et al.*[36];Sohal *et al.*[37]
		Use of AI/ML dependent system for Inventory control	RAL_{117}	Kumar *et al.*[3]
		Proper control of computation power in industries	RAL_{118}	Kumar *et al.*[38]
		Proper inspection facility	RAL_{119}	Gijo *et al.*[39]
	Operation at Management Level RAL_{12}	Storage of Waste at proper location	RAL_{121}	Dora *et al.*[36]
		Waste collection as per category	RAL_{122}	Lemon and Verhoef[1]
		Measurement of waste as per category	RAL_{123}	Kumar *et al.*[38]
		Planning for waste disposal	RAL_{124}	Hilton *et al.*[40]
		Value aided/non value aided activities in plant	RAL_{125}	Bhadu *et al.*[22]
		Identification and elimination of waste generation sources	RAL_{126}	Kumar *et al.*[3]; Abbes *et al.*[33]
		Planning for customer-oriented production	RAL_{127}	Bhadu *et al.*[3]; Attar *et al.*[41]
		Execution and management of optimal product lot sizes	RAL_{128}	Kumar *et al.*[5]
		Planning for plant operation improvement	RAL_{129}	Hilton *et al.*[40]
		Optimal delivery systems for customers	RAL_{1210}	Lam *et al.*[15]
		Pull Flow Production	RAL_{1211}	Trehan *et al.*[4]; Abbes *et al.*[33]
	Manufacturing Planning RAL_{13}	Identification of various manufacturing steps	RAL_{131}	Bhadu *et al.*[18]
		Standardization and simplification of operating procedures	RAL_{132}	Bhadu *et al.*[34]
		Application of quality improvement techniques	RAL_{133}	Vaishnavi and Suresh[24]
		Product quality improvement as per customers requirements	RAL_{134}	Fajarika *et al.*[42]
		Apply cost control techniques during manufacturing phase	RAL_{135}	Wong *et al.*[43]; Attar *et al.*[41]
		Apply DMAIC phase in manufacturing phase	RAL_{136}	Ruben *et al.*[44]
		Identification of value aided/non value aided activities during manufacturing phase	RAL_{137}	Bhadu *et al.*[34]; Kumar *et al.*[3]
		Productivity improvement using DMAIC-DOE tools	RAL_{138}	Kumar *et al.*[3]
		Resource management and planning	RAL_{139}	Zhang *et al.*[45]; Abbes *et al.*[33]
		Apply optimization techniques in various manufacturing phases	RAL_{1310}	Timans *et al.*[46]

(*contd.*)

Table 1 — Attributes selected for the readiness model development for the present study. (*contd*..)

Enablers (RAL_iCI_i)	Criteria (RAL_iCI_{ij})	Attributes (RAL_iCI_{ijk})	References	
		Cost reduction using Value aided/non value aided activities	RAL_{1311}	Jose Arturo *et al.*[47]
		Safety Planning	RAL_{1312}	Rosa *et al.*[48]
	Planning for Customers RAL_{14}	Identify customers problems	RAL_{141}	Lemon and Verhoef[1]
		Develop effective call centers	RAL_{142}	Vashishth *et al.*[14]
		Provide training to staff to behave with customers	RAL_{143}	Attar *et al.*[41]
		Use VOC like tools for more better study	RAL_{144}	Dursun[16]
		Optimal Transportations for fast delivery	RAL_{145}	Almutairi *et al.*[49]
Working Culture in Industry RAL_2	Management Behaviour with Employees RAL_{21}	Mixture of soft and hard working culture	RAL_{211}	Calvo-Mora *et al.*[50]
		Communication of management with employees	RAL_{212}	Lameijer *et al.*[51]
		Empowerment development of employees	RAL_{213}	Albliwi *et al.*[52]; Yadav *et al.*[6]
		Medical and Social development	RAL_{214}	Stanton *et al.*[26]
		Sustainable development of employee	RAL_{215}	Yadav *et al.*[32]
	Development of Employees RAL_{22}	Training for Employees	RAL_{221}	Bhadu *et al.*[34]
		New Technologies for employees	RAL_{222}	Attar *et al.*[41]
		Incentives for new skill development	RAL_{223}	Yadav *et al.*[6]
		Job security	RAL_{224}	Lameijer *et al.*[51]
Organization Structure RAL_3	Management Team RAL_{31}	Team Development for decision	RAL_{311}	Albliwi *et al.*[52]
		Continues investment planning	RAL_{312}	Albliwi *et al.*[52]
		Fair information sharing with other stake holders like customers	RAL_{313}	Yadav *et al.*[29]; Sohal *et al.*[37]
		Continues flow of data	RAL_{314}	Vinodh *et al.*[30]
		Make positive relation with staff	RAL_{315}	Gaikwad *et al.*[53]
	Technical Team RAL_{32}	Establish Relation among management and helpers	RAL_{321}	Gaikwad *et al.*[53]
		Planning for new technology or upgradation	RAL_{322}	Albliwi *et al.*[52]; Lin *et al.*[54]
		Establish LSS certification as per organizations requirements	RAL_{323}	Lameijer *et al.*[51]
Total Enablers	Total Criteria	Total Attributes		
3	8	54		

2 Materials & Methods

2.1 Research methodology

A comprehensive assessment of the existing research was carried out, and a methodology was defined and followed, (Fig. 3), to fulfil the objectives. Crucial information on the RAL_i CI was provided by various researchers[24,29]. There are primarily three distinct facets of these that RAL_i CI has figured out. In the subsequent phase, a thorough survey was produced and distributed to the specialists from various fields who were working in the various ceramic production businesses. This survey included these three elements and consisted of a questionnaire to find the critical success factors for the successful implementation of LSS in the ceramic industry.

The study was divided into three distinct stages. The first step was to identify essential success factors/parameters for LSS deployments within small and medium ceramic enterprises. This involved identifying enablers, criteria, and attributes (qualities) from the literature research on LSS. In the second step of the process, an appropriate SME (Ceramic industry) was selected to validate the proposed model. In the last phase, the model was applied to the ceramic sector to get the industry ready to effectively deploy LSS.

2.2.1 Fuzzy Logic Rules for RAL_iCI

The steps to develop Readiness Assessment for Lean (Six Sigma) Implementation needed in the Ceramic Industry (RAL_iCI) utilizing Fuzzy are discussed as follows;

Step-I*: Enablers, Criteria and Attribute Selection for LSS Readiness in the Ceramic Industry:*

A comprehensive assessment of the relevant literature served as the basis for the identification of the essential tenets. After that, these parameters were changed and ranked with the assistance of experts in

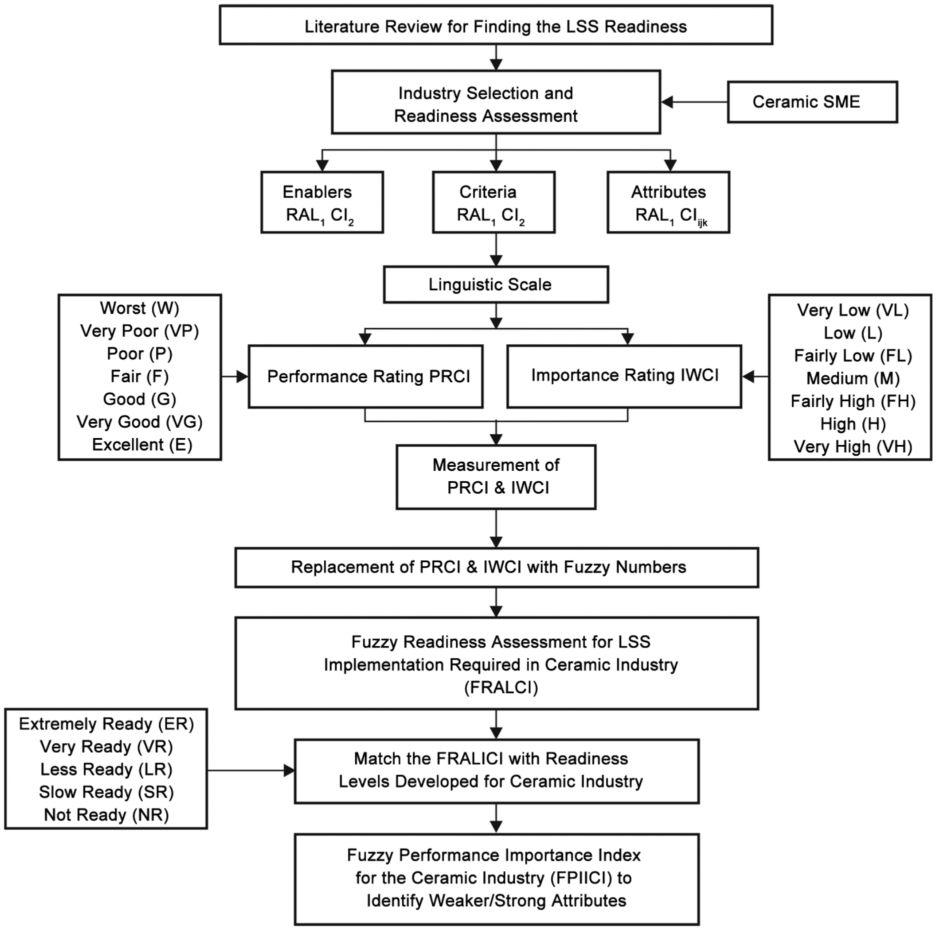

Fig. 3 — Research methodology.

accordance with the features of ceramic SMEs in India. In the present study, a questionnaire was used to determine the most significant enablers, criteria, and attributes. The initial step involved conducting personal interviews to establish the enablers, criteria, and attributes. A panel of 6 experts from various fields, including industry (2), academic institutions (2) and researchers (2) having technical expertise in LSS with a minimum of 10 years of working were requested to finalize these components. Subsequently, a detailed questionnaire was developed based on these selections and distributed among engineers, management team members, operators, and staff in ceramic industries, predominantly SMEs. The researchers initially distributed 90 questionnaires through online survey forms and personal visits to the industries. The respondents were asked to fill out the questionnaire without any bias. Due to bias impact on human judgments, the data may vary and affect the outcome of the study. The response rate was around 61%. To maintain the reliability of survey results and to measure the internal consistency, Cronbach's Alpha coefficient was calculated. According to Bonnetti and Thomas[55], a value of more than 0.70, is considered acceptable for the study. The Cronbach's Alpha value for the data compiled under the present survey was 0.849 and is considered acceptable and reliable.In the current paradigm, there are three different stages utilized to carry out readiness studies for the ceramic sector. The first level consists of Enablers (RAL_iCI_i), and a total of three Enablers were chosen for this study. The second level consists of Criteria (RAL_iCI_{ij}), and a total of eight Criteria were chosen. The third and final level consists of the Attributes (RAL_iCI_{ijk}) of the Ceramic Industry, and a total of 54 Attributes were chosen and are listed in Table 1.

Step-II*: Select the proper Linguistic Scale for Performance rating and importance weighing:*

It is important to find the right linguistic scale to use to evaluate the performance rating and important weights of the flexibility characteristics. In most conditions, it is practically impossible for experts to directly evaluate the score of a nebulous sign, for example, the degree to which information systems are ideal, the way information is gathered, displacement compatibility, and so on. Thus, language phrases are utilized to analyze the performance rating and important weights associated with agility skills. The haphazard use of linguistic concepts and the membership functions that correspond to them is always called into question by fuzzy logic. Notably, a large number of common language words and the membership functions that correspond to them have been proposed for use in linguistic assessment[56]. For ease, rather than elicitation from the experts, linguistic terms and corresponding membership functions can be incurred directly from historical data. Alternatively, historical data can be used as a basis, and then the terms can be modified to incorporate individual circumstances and the needs of various users. In addition, it is generally recommended that the number of linguistic levels not go beyond nine levels, as this number represents the limitations of the human ability to discriminate absolutely. The linguistic variables opted to measure the performance rating (PRCI) varies from excellent (E) to worst (W), whereas variables to measure importance weightage vary from very high (VH) to very low (VL) based on literature and experts opinion to assess the readiness of LSS implementation. The final Linguistic variables with fuzzy approximation are present in Table 2.

Step-III: *Measurement for Performance rating and importance weighting parameters:*

The linguistic variables were used to evaluate the performance ratings and the important weights for the agility capabilities have been decided. This is carried out in accordance with the company policy and strategy, the company profile, the company characteristics, business changes and practices, marketing competition information, and the experience and knowledge of the experts. Thereafter experts can evaluate the rating, which encapsulates the overall performance of the company, by directly utilizing linguistic terms. The expert scan simultaneously evaluate the relative value of each agility capacity by comparison. This evaluation is based on the company's strategies and policies, the trend in marketing competition, the trend in technological advancement, as well as the expertise and knowledge. The findings are shown in Table 3, which includes integrated performance ratings as well as integrated important weights of preparatory skills based on linguistic characteristics.

Step-IV: *Replace the Performance rating and importance weighting parameters with Fuzzy numbers:*

The competitive circumstances and requirements differ from business to business; as a result, businesses need to devise their own distinctive membership functions. By making use of the connection that exists between linguistic words and fuzzy numbers, the linguistic terms that are presented in Table 2 are converted into the fuzzy numbers (Table 4).Table 3 details the Importance of Weighting (IWCI) and Performance Rating (PRCI) for the Ceramic Company, highlighting the attributes identified as weaker barriers to LSS implementation. For instance, attributes like "Cleaning and Floor Management" (RAL_{114}) and "Use of AI/ML dependent system for Inventory control" (RAL_{117}) are critical factors that are rated with high importance but low performance, indicating key areas where improvements are necessary for successful LSS adoption. Table 4 converts these qualitative assessments into fuzzy numbers, offering a quantified view that supports rigorous analysis. It translates linguistic terms into a numerical form that can be processed using fuzzy logic methods, thereby enhancing the precision of our readiness assessment.

Step-V: *Aggregate Fuzzy Ratings for Enablers and Criteria selected for Ceramic Industry*

The ceramic manufacturing industrys Fuzzy readiness assessment for the Lean (FRAL) index may be obtained by combining fuzzy ratings with fuzzy weights and aggregating the results. The FRAL system is an information fusion that combines the ratings and ambiguous weights of the criteria which influence readiness. The calculated values of Aggregate fuzzy RAL for Enablers and Criteria are used to find the $FRAL_iCI$ for the ceramic industry by using Eq. (i) and Eq. (ii) (Abbes *et al.*[33]).

$$RAL_{ij} = \sum_{k=1}^{n}\left(PRCI_{ijk} \otimes IWCI_{ijk}\right)/\sum_{k=1}^{n} IWCI_{ijk} \quad \ldots (1)$$

Where $PRCI_{ijk}$ and $IWCI_{ijk}$ are Fuzzy performance ratings and fuzzy importance weighting values repetitively. RAL_{ij} represents the Aggregate fuzzy index for the criteria developed for the Readiness Assessment of the Ceramic industry.

$$RAL_{i} = \sum_{k=1}^{n}\left(RAL_{ij} \otimes IWCI_{ij}\right)/\sum_{k=1}^{n} IWCI_{ij} \quad \ldots (2)$$

Table 2 — Linguistic variables and fuzzy approximation terms for performance rating and importance weighting for the ceramic industry[55].

Performance Rating (PRCI)			Importance Weighting (IWCI)		
Linguistic Variable		Fuzzy Number	Linguistic Variable		Fuzzy Number
Worst	W	(0,0.5,1.5)	Very Low	VL	(0,0.05,0.15)
Very Poor	VP	(1,2,3)	Low	L	(0.1,0.2,0.3)
Poor	P	(2,3.5,5)	Fairly Low	FL	(0.2,0.35,0.5)
Fair	F	(3,5,7)	Medium	M	(0.3,0.5,0.7)
Good	G	(5,6.5,8)	Fairy High	FH	(0.5,0.65,0.8)
Very Good	VG	(7,8,9)	High	H	(0.7,0.8,0.9)
Excellent	E	(8 ,9,10)	Very High	VH	(0.8,0.9,1.0)

PRCI: Performance rating for the Ceramic Industry, IWCI: Importance weighing for Ceramic Industry

Table 3 — Measured IWCI and PRCI for the ceramic company.

Enablers (RAL_iCI_i)	Criteria (RAL_iCI_{ij})	Attributes (RAL_iCI_{ijk})	Importance Weighting			Performance Rating
			$IWCI_i$	$IWCI_{ij}$	$IWCI_{ijk}$	$PRCI_{ijk}$
RAL_1	RAL_{11}	RAL_{111}	FL	M	L	G
		RAL_{112}			M	E
		RAL_{113}			VL	F
		RAL_{114}			VH	G
		RAL_{115}			M	VP
		RAL_{116}			M	F
		RAL_{117}			H	VP
		RAL_{118}			VH	VG
		RAL_{119}			VL	W
	RAL_{12}	RAL_{121}		FL	VH	P
		RAL_{122}			M	F
		RAL_{123}			L	W
		RAL_{124}			FL	E
		RAL_{125}			VH	E
		RAL_{126}			FL	E
		RAL_{127}			VL	VG
		RAL_{128}			VH	E
		RAL_{129}			FH	VG
		RAL_{1210}			M	F
		RAL_{1211}			H	W
	RAL_{13}	RAL_{131}		H	H	VG
		RAL_{132}			L	VG
		RAL_{133}			M	W
		RAL_{134}			H	VP
		RAL_{135}			L	E
		RAL_{136}			FH	F
		RAL_{137}			H	VP
		RAL_{138}			H	G
		RAL_{139}			VL	VG
		RAL_{1310}			VH	P
		RAL_{1311}			FL	G
		RAL_{1312}			FL	F
	RAL_{14}	RAL_{141}		M	FL	F

(*contd.*)

Table 3 — Measured IWCI and PRCI for the ceramic company. (*contd.*)

Enablers (RAL_iCI_i)	Criteria (RAL_iCI_{ij})	Attributes (RAL_iCI_{ijk})	Importance Weighting			Performance Rating
			$IWCI_i$	$IWCI_{ij}$	$IWCI_{ijk}$	$PRCI_{ijk}$
		RAL_{142}			FH	G
		RAL_{143}			L	VP
		RAL_{144}			VL	G
		RAL_{145}			L	VG
RAL_2	RAL_{21}	RAL_{211}	M	FH	VH	VP
		RAL_{212}			H	W
		RAL_{213}			FH	G
		RAL_{214}			FH	W
		RAL_{215}			VH	W
	RAL_{22}	RAL_{221}		L	H	E
		RAL_{222}			VH	G
		RAL_{223}			FH	VP
		RAL_{224}			VL	G
RAL_3	RAL_{31}	RAL_{311}	L	VL	VL	G
		RAL_{312}			VH	P
		RAL_{313}			L	VP
		RAL_{314}			FL	W
		RAL_{315}			H	E
	RAL_{32}	RAL_{321}		M	FH	G
		RAL_{322}			H	G
		RAL_{323}			H	G

Table 4 — Linguistic terms replaced by fuzzy numbers for ceramic company.

Enablers (RAL_iCI_i)	Criteria (RAL_iCI_{ij})	Attributes (RAL_iCI_{ijk})	Importance Weighting			Performance Rating
			$IWCI_i$	$IWCI_{ij}$	$IWCI_{ijk}$	$PRCI_{ijk}$
RAL_1	RAL_{11}	RAL_{111}	(0.2,0.35,0.5)	(0.3,0.5,0.7)	(0.1,0.2,0.3)	(5,6.5,8)
		RAL_{112}			(0.3,0.5,0.7)	(8.5,9.5,10)
		RAL_{113}			(0,0.05,0.15)	(3,5,7)
		RAL_{114}			(0.85,0.95,1.0)	(5,6.5,8)
		RAL_{115}			(0.3,0.5,0.7)	(1,2,3)
		RAL_{116}			(0.3,0.5,0.7)	(3,5,7)
		RAL_{117}			(0.7,0.8,0.9)	(1,2,3)
		RAL_{118}			(0.85,0.95,1.0)	(7,8,9)
		RAL_{119}			(0,0.05,0.15)	(0,0.5,1.5)
	RAL_{12}	RAL_{121}		(0.2,0.35,0.5)	(0.85,0.95,1.0)	(2,3.5,5)
		RAL_{122}			(0.3,0.5,0.7)	(3,5,7)
		RAL_{123}			(0.1,0.2,0.3)	(0,0.5,1.5)
		RAL_{124}			F(0.1,0.2,0.3)	(8.5,9.5,10)
		RAL_{125}			(0.85,0.95,1.0)	(8.5,9.5,10)
		RAL_{126}			F(0.1,0.2,0.3)	(8.5,9.5,10)
		RAL_{127}			(0,0.05,0.15)	(7,8,9)
		RAL_{128}			(0.85,0.95,1.0)	(8.5,9.5,10)
		RAL_{129}			(0.5,0.65,0.8)	(7,8,9)
		RAL_{1210}			(0.3,0.5,0.7)	(3,5,7)
		RAL_{1211}			(0.7,0.8,0.9)	(0,0.5,1.5)
	RAL_{13}	RAL_{131}		(0.7,0.8,0.9)	(0.7,0.8,0.9)	(7,8,9)

(*contd.*)

Table 4 — Linguistic terms replaced by fuzzy numbers for ceramic company. (*contd.*)

Enablers (RAL_iCI_i)	Criteria (RAL_iCI_{ij})	Attributes (RAL_iCI_{ijk})	Importance Weighting			Performance Rating
			$IWCI_i$	$IWCI_{ij}$	$IWCI_{ijk}$	$PRCI_{ijk}$
		RAL_{132}			(0.1,0.2,0.3)	(7,8,9)
		RAL_{133}			(0.3,0.5,0.7)	(0,0.5,1.5)
		RAL_{134}			(0.7,0.8,0.9)	(1,2,3)
		RAL_{135}			(0.1,0.2,0.3)	(8.5,9.5,10)
		RAL_{136}			(0.5,0.65,0.8)	(3,5,7)
		RAL_{137}			(0.7,0.8,0.9)	(1,2,3)
		RAL_{138}			(0.7,0.8,0.9)	(5,6.5,8)
		RAL_{139}			(0,0.05,0.15)	(7,8,9)
		RAL_{1310}			(0.85,0.95,1.0)	(2,3.5,5)
		RAL_{1311}			F(0.1,0.2,0.3)	(5,6.5,8)
		RAL_{1312}			F(0.1,0.2,0.3)	(3,5,7)
	RAL_{14}	RAL_{141}		(0.3,0.5,0.7)	F(0.1,0.2,0.3)	(3,5,7)
		RAL_{142}			(0.5,0.65,0.8)	(5,6.5,8)
		RAL_{143}			(0.1,0.2,0.3)	(1,2,3)
		RAL_{144}			(0,0.05,0.15)	(5,6.5,8)
		RAL_{145}			(0.1,0.2,0.3)	(7,8,9)
RAL_2	RAL_{21}	RAL_{211}	(0.3,0.5,0.7)	(0.5,0.65,0.8)	(0.85,0.95,1.0)	(1,2,3)
		RAL_{212}			(0.7,0.8,0.9)	(0,0.5,1.5)
		RAL_{213}			(0.5,0.65,0.8)	(5,6.5,8)
		RAL_{214}			(0.5,0.65,0.8)	(0,0.5,1.5)
		RAL_{215}			(0.85,0.95,1.0)	(0,0.5,1.5)
	RAL_{22}	RAL_{221}		(0.1,0.2,0.3)	(0.7,0.8,0.9)	(8.5,9.5,10)
		RAL_{222}			(0.85,0.95,1.0)	(5,6.5,8)
		RAL_{223}			(0.5,0.65,0.8)	(1,2,3)
		RAL_{224}			(0,0.05,0.15)	(5,6.5,8)
RAL_3	RAL_{31}	RAL_{31}	(0,0.05,0.15)	(0,0.05,0.15)	(0,0.05,0.15)	(5,6.5,8)
		RAL_{312}			(0.85,0.95,1.0)	(2,3.5,5)
		RAL_{313}			(0.1,0.2,0.3)	(1,2,3)
		RAL_{314}			F(0.1,0.2,0.3)	(0,0.5,1.5)
		RAL_{315}			(0.7,0.8,0.9)	(8.5,9.5,10)
	RAL_{32}	RAL_{321}		(0.3,0.5,0.7)	(0.5,0.65,0.8)	(5,6.5,8)
		RAL_{322}			(0.7,0.8,0.9)	(5,6.5,8)
		RAL_{323}			(0.7,0.8,0.9)	(5,6.5,8)

Here RAL_i represent the Aggregate fuzzy index for the enablers developed for the Readiness assessment of the Ceramic industry. The final calculated values of the Aggregate fuzzy index for the enablers and criteria are shown in Table 4.Finally, Eq. (i) and Eq. (ii) were used to develop the Fuzzy Readiness Assessment for Lean (Six Sigma) Implementation required in Ceramic Industry ($FRAL_iCI$) Eq. (iii) (Abbes *et al.*[33]), were calculated and shown in Table 5.

$$FRALiCI = \sum_{k=1}^{n}(RAL_i \otimes IWCI_i)/\sum_{k=1}^{n} IWCI_i \quad \text{... (3)}$$

Table 5 plays a crucial role in our analysis by presenting the Fuzzy Index for Ceramic Company Enablers and Criteria, a pivotal aspect of the RAL_iCI model. It quantitatively represents the readiness levels of different enablers (RAL_i) and their corresponding criteria (RAL_{ij}) in the ceramic industry. For example, Enabler RAL_1, which encompasses various criteria like RAL_{11} to RAL_{14}, is quantified with a fuzzy index of (3.93, 5.33, 6.64), indicating its position on the readiness scale The overall Fuzzy Readiness Assessment for Lean (Six Sigma) Implementation required in the Ceramic Industry ($FRAL_iCI$) is calculated as (2.59, 4.03, 5.46). This score encapsulates the readiness state across different enablers and criteria, providing a comprehensive view

Table 5 — Fuzzy index for ceramic company enablers and criteria.

Enablers	Fuzzy Index	Criteria	Fuzzy Index
RAL_i		RAL_{ij}	
RAL_1	(3.93,5.33,6.64)	RAL_{11}	(4.46,5.60,6.67)
		RAL_{12}	(4.98,6.10,7.15)
		RAL_{13}	(3.16,4.52,5.89)
		RAL_{14}	(4.50,5.81,7.19)
RAL_2	(1.69,2.88,4.15)	RAL_{21}	(0.99,1.83,2.99)
		RAL_{22}	(5.22,6.29,7.23)
RAL_3	(5.0,6.39,7.69)	RAL_{31}	(4.43,5.34,6.25)
		RAL_{32}	(5.0,6.5,8.0)

Fuzzy Readiness Assessment for Lean (Six Sigma) Implementation required in Ceramic Industry ($FRAL_iCI$) (2.59,4.03,5.46)

of the areas that need attention for successful LSS implementation in the ceramic industry.

***Step-VI**: Match the $FRAL_iCI$ with readiness levels developed for the Ceramic Industry*

A suitable readiness level specifically designed for the ceramic sector should be matched up with the $FRAL_iCI$. After the $FRAL_iCI$ has been obtained, it can be matched further with the linguistic label whose membership function is the same as (or closest to) the membership function of the $FRAL_iCI$ from the natural-language expression set of readiness level. This will allow the level of readiness to be identified. Several other approaches have been offered as potential ways to match the membership function with linguistics concepts. There are fundamentally three methods: (1) the Euclidean distance method, (2) successive approximation, and (3) piecewise decomposition. The human impression of closeness is the most in line with common sense, the Euclidean distance approach is the one that should be used[29,54]. Natural language (NL) expression levels [0-10 scale], including extremely ready (ER) to not ready (NR) were listed for the ceramic sector in Table 6.

The linguistics and the relevant membership functions are then compared with each other for $FRAL_iCI$. Since the Less Ready and Slowly Ready options were found to closely coincide with $FRAL_iCI$ values, the present inquiry requires adequate identification of the weak qualities. The Euclidean distance between each fuzzy number of the natural language expression set of readiness level for the deployment of LSS and the triangle membership function linked to the fuzzy set FRALiCI can be found using the following equation: According to the findings of the investigation, the membership function of the LSS Readiness Index (RAL_iCI) corresponds to

Table 6 — NL expressions for different readiness levels for the ceramic industry.

Linguistic Variable	Coded	Fuzzy Number
Extremely Ready	ER	(7,8.5,10)
Very Ready	VR	(5.5,7,8.5)
Less Ready	LR	(3.5,5,6.5)
Slowly Ready	SR	(1.5,3,4.5)
Not Ready	NR	(0,1.5,3)

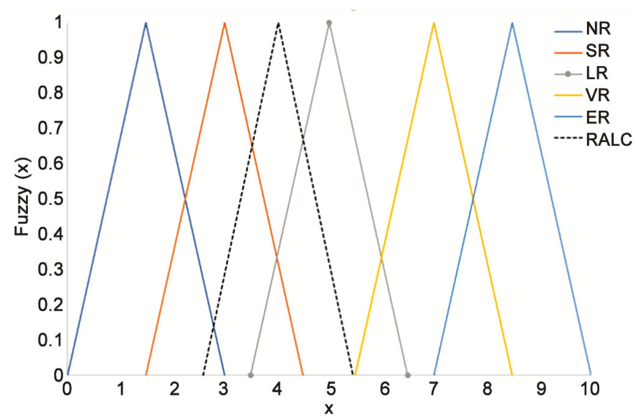

Fig. 4 — Fuzzy RALCI for present investigation (Less Ready).

the values 2.59, 4.03, and 5.46 as seen in Fig. 4. After that, it is transformed back into a phrase that is used in linguistics; in order to evaluate the level of readiness of the ceramic sector for LSS, we made use of the Euclidean distance technique and Eq. (iv) (Abbes *et al.*[33]).

$$D(\mathrm{FRALiCI}, \mathrm{NLCI_i}) = \{\textstyle\sum_{\mathrm{xep}}\left(f_{\mathrm{FRALiCI}}(x) - f_{\mathrm{NLCI}}(2)\right)^2\}^{\frac{1}{2}} \quad \ldots(4)$$

Here $D(\mathrm{FRALiCI}, \mathrm{NLCI_i})$represents the Euclidean distance among $FRAL_iCI$ and NLCI(i). The FRALiCI represents the Fuzzy Readiness Assessment for Lean (Six Sigma) Implementation required in the Ceramic Industry, NLCI(i) represents the natural language fuzzy number for the ceramic industry. The results of the model computation for D ($FRAL_iCI$, ER) are displayed below:

$$D(FRALiCI, ER) = \{(2.59 - 7.0)^2 + (4.03 - 8.5)^2 + (5.46 - 10.0)^2\}^{1/2} \quad \ldots(5)$$

The full calculations for the Euclidean distance are presented for each readiness level and are shown here.

D($FRAL_iCI$, ER) = 7.74
D($FRAL_iCI$, VR) = 5.15
D($FRAL_iCI$, LR) = 1.68
D($FRAL_iCI$, SR) = 1.78
D($FRAL_iCI$, NR) = 4.37

***Step-VII**: Identification and analysis of the attributes for LSS implementation in the ceramic industry*

In addition to determining the level of preparedness of the LSS implementation, the approach described above may also be used to find the obstacles that must be overcome to successfully execute the necessary improvements. It is necessary for us to identify the limitations to enhance the level of readiness of the organization for the LSS implementation. In the end, it is necessary for us to determine a Fuzzy performance importance index for the Ceramic Industry (FPIICI) which includes the performance scores ($PRCI_{ijk}$) and the important weights of performance ($IWCI_{ijk}$) for each characteristic. Based on this index, it may be mentioned that all qualities that are listed with high-performance significance weights evaluated with a low-performance score ($PRCI_{ijk}$) are important constraints for improvement. FPIICI can be calculated by using Eq. (vi).

$$FPIICI_{ijk} = I\grave{W}CI_{ijk} \otimes PRCI_{ijk} \quad \ldots(6)$$

Here $$I\grave{W}CI_{ijk} = \{(1,1,1) - IWCI_{ijk}\} \quad \ldots(7)$$

The Fuzzy Performance Importance Index for the Ceramic Industry (FPIICI) and the score for each attribute (RAL_{ijk}) was calculated by using Eq. (vi) and Eq. (vii), respectively. Table 7 displays the results of these computations for your convenience.

3 Results and Discussion

The ceramic manufacturing industry in India has several barriers, such as the selection of a wide range of products that are manufactured, the regular introduction of new products, the frequent incidence of product faults throughout the production line, customer requirements, employee development and so on[18]. Toapply the model, the selection of ceramic manufacturing businesses to work with was predicated on several different parameters. These businesses are interested in contemporary approaches to enhancing work processes with the goal of optimizing their production and quality management systems to better fulfil the demands of their customers. Therefore, to implement and test our assessment technique, we have decided to pick small and medium-sized enterprises (SMEs) from the ceramic manufacturing sector in India. To ensure that the experts serving as assessors were well-suited to the concepts and could produce results that were close to reality, a training session was conducted prior to the proposed models implementation. This was done in order to ensure that the model would be implemented successfully. During these training sessions, the linguistic variables, their membership functions, and their relative priority that is assigned to each component were discussed. After that, specialized research is conducted with the participation of the companys experts to determine the language phrases and correlate them with the significance of weights and the performance ratings of every component (Indicator, criterion, attribute). These ratings were decided by the professionals during the round-table discussions. Table 3 outlines the significance of evaluated weights and provides performance ratings for all lean capabilities (indicator, criteria, and attribute). These ratings are decided upon by the professionals during the round of round-table discussions that were arranged. Now, linguistic terms have been converted into fuzzy numbers and are displayed in Table 4 as a result of applying the link that exists between linguistic terms and the membership functions that correspond to Table 2. The fuzzy Readiness Assessment for Lean (Six Sigma) Implementation required in the Ceramic Industry ($FRAL_iCI$) is calculated and presented in Table 5. According to the findings of the research investigation, the membership function of the $FRAL_iCI$ version of the LSS Readiness Index equals (2.59; 4.03; and 5.46). After that, it is changed back into a linguistic phrase, and in order to figure out the level of LSS Readiness of a ceramic manufacturing firm, we made use of the Euclidean distance approach using Eq. (v). The minimum value of the Euclidean distance approach (D) is 1.68 which is equal to “Less Ready” as seen in Fig. 4. Indeed, the results obtained indicate that the organization is now at an intermediate level of LSS Readiness. Therefore, it was necessary to identify the weak facilitators. The

Table 7 — Raking score generation for ceramic company (FPIICI).

Attributes (RAL_iCI_{ijk})	$IWCI_{ijk}$	$PRCI_{ijk}$	$IWCI`_{ijk}$	FPIICI	Rank
RAL_{111}	(0.1,0.2,0.3)	(5,6.5,8)	(0.9,0.8,0.7)	(3.5,5.2,7.2)	5.25
RAL_{112}	(0.3,0.5,0.7)	(8.5,9.5,10)	(0.7,0.5,0.3)	(2.55,4.75,7)	4.76
RAL_{113}	(0,0.05,0.15)	(3,5,7)	(1,0.95,0.85)	(2.55,4.75,7)	4.76
RAL_{114}	(0.85,0.95,1.0)	(5,6.5,8)	(0.15,0.05,0)	(0,0.325,1.2)	0.42
RAL_{115}	(0.3,0.5,0.7)	(1,2,3)	(0.7,0.5,0.3)	(0.3,1,2.1)	1.07
RAL_{116}	(0.3,0.5,0.7)	(3,5,7)	(0.7,0.5,0.3)	(0.9,2.5,4.9)	2.63
RAL_{117}	(0.7,0.8,0.9)	(1,2,3)	(0.3,0.2,0.1)	(0.1,0.4,0.9)	0.43
RAL_{118}	(0.85,0.95,1.0)	(7,8,9)	(0.15,0.05,0)	(0,0.475,1.35)	0.49
RAL_{119}	(0,0.05,0.15)	(0,0.5,1.5)	(1,0.95,0.85)	(0,0.475,1.5	0.57
RAL_{121}	(0.85,0.95,1.0)	(2,3.5,5)	(0.15,0.05,0)	(0,0.175,0.75)	0.24
RAL_{122}	(0.3,0.5,0.7)	(3,5,7)	(0.7,0.5,0.3)	(0.9,2.5,4.9)	2.63
RAL_{123}	(0.1,0.2,0.3)	(0,0.5,1.5)	(0.9,0.8,0.7)	(0,0.4,1.35)	0.49
RAL_{124}	F(0.1,0.2,0.3)	(8.5,9.5,10)	(0.9,0.8,0.7)	(5.95,7.6,9)	7.56
RAL_{125}	(0.85,0.95,1.0)	(8.5,9.5,10)	(0.15,0.05,0)	(0,0.475,1.5)	0.57
RAL_{126}	F(0.1,0.2,0.3)	(8.5,9.5,10)	(0.9,0.8,0.7)	(5.95,7.6,9)	7.56
RAL_{127}	(0,0.05,0.15)	(7,8,9)	(1,0.95,0.85)	(5.95,7.6,9)	7.56
RAL_{128}	(0.85,0.95,1.0)	(8.5,9.5,10)	(0.15,0.05,0)	(0,0.475,1.5	0.57
RAL_{129}	(0.5,0.65,0.8)	(7,8,9)	(0.5,0.35,0.2)	(1.4,2.8,4.5)	2.85
RAL_{1210}	(0.3,0.5,0.7)	(3,5,7)	(0.7,0.5,0.3)	(0.9,2.5,4.9)	2.63
RAL_{1211}	(0.7,0.8,0.9)	(0,0.5,1.5)	(0.3,0.2,0.1)	(0,0.1,0.45)	0.14
RAL_{131}	(0.7,0.8,0.9)	(7,8,9)	(0.3,0.2,0.1)	(0.7,1.6,2.7)	1.63
RAL_{132}	(0.1,0.2,0.3)	(7,8,9)	(0.9,0.8,0.7)	(4.9,6.4,8.1)	6.43
RAL_{133}	(0.3,0.5,0.7)	(0,0.5,1.5)	(0.7,0.5,0.3)	(0,0.25,1.05)	0.34
RAL_{134}	(0.7,0.8,0.9)	(1,2,3)	(0.3,0.2,0.1)	(0.1,0.4,0.9)	0.43
RAL_{135}	(0.1,0.2,0.3)	(8.5,9.5,10)	(0.9,0.8,0.7)	(5.95,7.6,9)	7.56
RAL_{136}	(0.5,0.65,0.8)	(3,5,7)	(0.5,0.35,0.2)	(0.6,1.75,3.5)	1.85
RAL_{137}	(0.7,0.8,0.9)	(1,2,3)	(0.3,0.2,0.1)	(0.1,0.4,0.9)	0.43
RAL_{138}	(0.7,0.8,0.9)	(5,6.5,8)	(0.3,0.2,0.1)	(0.5,1.3,2.4)	1.35
RAL_{139}	(0,0.05,0.15)	(7,8,9)	(1,0.95,0.85)	(5.95,7.6,9)	7.56
RAL_{1310}	(0.85,0.95,1.0)	(2,3.5,5)	(0.15,0.05,0)	(0,0.175,0.75)	0.24
RAL_{1311}	F(0.1,0.2,0.3)	(5,6.5,8)	(0.9,0.8,0.7)	(3.5,5.2,7.2)	5.25
RAL_{1312}	F(0.1,0.2,0.3)	(3,5,7)	(0.9,0.8,0.7)	(2.1,4,6.3)	4.07
RAL_{141}	F(0.1,0.2,0.3)	(3,5,7)	(0.9,0.8,0.7)	(2.1,4,6.3)	4.07
RAL_{142}	(0.5,0.65,0.8)	(5,6.5,8)	(0.5,0.35,0.2)	(1,2.275,4)	2.35
RAL_{143}	(0.1,0.2,0.3)	(1,2,3)	(0.9,0.8,0.7)	(0.7,1.6,2.7)	1.63
RAL_{144}	(0,0.05,0.15)	(5,6.5,8)	(1,0.95,0.85)	(4.25,6.175,8)	6.16
RAL_{145}	(0.1,0.2,0.3)	(7,8,9)	(0.9,0.8,0.7)	(4.9,6.4,8.1)	6.43
RAL_{211}	(0.85,0.95,1.0)	(1,2,3)	(0.15,0.05,0)	(0,0.1,0.45)	0.14
RAL_{212}	(0.7,0.8,0.9)	(0,0.5,1.5)	(0.3,0.2,0.1)	(0,0.1,0.45)	0.14
RAL_{213}	(0.5,0.65,0.8)	(5,6.5,8)	(0.5,0.35,0.2)	(1,2.275,4)	2.35
RAL_{214}	(0.5,0.65,0.8)	(0,0.5,1.5)	(0.5,0.35,0.2)	(0,0.175,0.75)	0.24
RAL_{215}	(0.85,0.95,1.0)	(0,0.5,1.5)	(0.15,0.05,0)	(0,0.025,0.225)	0.05
RAL_{221}	(0.7,0.8,0.9)	(8.5,9.5,10)	(0.3,0.2,0.1)	(0.85,1.9,3)	1.91
RAL_{222}	(0.85,0.95,1.0)	(5,6.5,8)	(0.15,0.05,0)	(0,0.325,1.2)	0.42
RAL_{223}	(0.5,0.65,0.8)	(1,2,3)	(0.5,0.35,0.2)	(0.2,0.7,1.5)	0.75
RAL_{224}	(0,0.05,0.15)	(5,6.5,8)	(1,0.95,0.85)	(4.25,6.175,8)	6.16
RAL_{311}	(0,0.05,0.15)	(5,6.5,8)	(1,0.95,0.85)	(4.25,6.175,8)	6.16

(*contd.*)

Table 7 — Raking score generation for ceramic company (FPIICI). (*contd.*)

Attributes (RAL_iCI_{ijk})	$IWCI_{ijk}$	$PRCI_{ijk}$	$IWCI`_{ijk}$	FPIICI	Rank
RAL_{313}	(0.1,0.2,0.3)	(1,2,3)	(0.9,0.8,0.7)	(0.7,1.6,2.7)	1.63
RAL_{314}	F(0.1,0.2,0.3)	(0,0.5,1.5)	(0.9,0.8,0.7)	(0,0.4,1.35)	0.49
RAL_{315}	(0.7,0.8,0.9)	(8.5,9.5,10)	(0.3,0.2,0.1)	(0.85,1.9,3)	1.91
RAL_{321}	(0.5,0.65,0.8)	(5,6.5,8)	(0.5,0.35,0.2)	(1,2.275,4)	2.35
RAL_{322}	(0.7,0.8,0.9)	(5,6.5,8)	(0.3,0.2,0.1)	(0.5,1.3,2.4)	1.35
RAL_{323}	(0.7,0.8,0.9)	(5,6.5,8)	(0.3,0.2,0.1)	(0.5,1.3,2.4)	1.35

calculated Fuzzy Performance Importance Index for the Ceramic Industry (FPIICI) is listed in Table 7.

Using the methodology described above, one may arrive at a ranking score for the characteristics that will be assessed. It was decided that a score of 2 (Yadav *et al.*,) [6] would be the bare minimum needed to discern between critical and non-critical barriers to progress in the organizations level of preparation for LSS, so it was made the minimum required score. Every single quality that received a score of less than two is regarded as a significant barrier to development. After everything is said and done, the computation shows that 31 characteristics have scores that are lower than the threshold, including the following (Table 8). The FLSS results indicate that the degree of readiness of the Ceramic manufacturing firm is "Lessready," and the company has 31 weaker traits out of 54 attributes that have been detected using FPIICI (Table 7).

The management must focus on these aspects to increase the LSS readiness level of the company as it is now structured. At the top of the list of poorer characteristics were “Pull Flow Production (Kanban technique)” (RAL_{1211}), “Mixture of soft and hard-working culture” (RAL_{211}), “Communication of management with workers” (RAL_{212}), and “Sustainable growth” (RAL_{215}). Identification of 31 weaker attributes that may serve as barriers to the effective implementation of LSS within the ceramic industry, a detailed analysis has been conducted to understand their individual and collective impact on the LSS adoption process. These attributes were identified through a systematic process that involved both quantitative and qualitative evaluations. The scoring methodology employed a combination of importance weighting and performance rating, where each attribute was assessed for its significance in the LSS implementation and its current performance level in the participating companies. This dual-axis evaluation helped in pinpointing areas where the gap between importance and performance was significant, indicating weaknesses. For each weak attribute, we propose specific strategies to facilitate improvement. Addressing these barriers with targeted interventions will not only pave the way for a smoother LSS implementation but will also ensure sustainable improvements in quality, efficiency, and customer satisfaction in the ceramic industry. The possible recommendations and suggestions for these 31 attributes were mentioned in Table 8, in which possible solutions were discussed after consultation with experts and engineers.

It indicates that the senior management of the ceramic company is unaware of the benefits that may be gained by utilizing the LSS technique. This issue may be remedied by carrying out management review meetings, training programs, awareness campaigns about tangible and intangible benefits and implementing quality policies and benefits. The organization needs to increase its preparedness level by communicating the benefits of LSS as a priority. On the other hand, it is required to begin the LSS project with training and participation of management and employees into the LSS program to deal with the challenges of employees being resistant to change and lacking flexibility. Employees hesitate to implement innovative technologies due to fear of losing their job, if they cannot contribute significantly. It is important to implement a reward system that is tailored to each individual workers level of performance to motivate them to actively participate in the organization. As a result of this, the resistance to change will be reduced, and the level of collaboration between the employees will increase. Training on LSS tools and procedures, as well as ongoing training on technologies, is necessary for this organization. Also, preventative maintenance should be conducted on a regular basis in accordance with the downtime of equipment. As a result, the resources will be utilized at the maximum and will increase productivity. According to the findings of the research, some of the most significant challenges include the unwillingness of workers

Table 8 — 31-week attributes (barriers) identified for the LSS implantation with recommendations.

Attributes	Description	Recommendations
RAL_{114}	Cleaning and Floor Management	Implement 5S methodology for better workplace organization.
RAL_{115}	Finding and Removal of extra Materials	Introduce systematic processes for material waste reduction.
RAL_{117}	Use of AI/ML dependent system for Inventory control	Invest in AI/ML technologies for efficient inventory management.
RAL_{118}	Proper control of computation power in ceramic Industry like CNC machines	Upgrade and optimize computational resources like CNC machines.
RAL_{119}	Proper inspection facility at plant site	Establish robust quality inspection protocols at the plant.
RAL_{121}	Storage of Waste at proper location at plant site	Implement a systematic waste management system with designated storage areas.
RAL_{123}	Measurement of waste as per materials category	Develop a detailed waste categorization system to better track and reduce waste types.
RAL_{125}	AV/NAV activities in plant	Increase focus on value-added activities and minimize non-value-added processes.
RAL_{128}	Execution and Management of optimal product lot sizes	Utilize demand forecasting and lean inventory techniques to optimize lot sizes.
RAL_{1211}	Pull Flow Production (Kanban method)	Implement Kanban systems to streamline production and reduce inventory levels.
RAL_{131}	Identification of various required manufacturing steps	Conduct process mapping to identify and streamline all critical manufacturing steps.
RAL_{133}	Application of quality improvement techniques at plant site	Adopt continuous improvement practices like Total Quality Management (TQM).
RAL_{134}	Product quality improvement as per customers feedback and requirements	Integrate customer feedback into product development for continuous quality improvement.
RAL_{136}	Apply DMAIC phase in manufacturing of Ceramic products	Implement DMAIC methodology for systematic, data-driven quality improvement.
RAL_{137}	Identification of AV/NAV during manufacturing phase	Conduct regular audits to identify and eliminate non-value-adding activities.
RAL_{138}	Productivity improvement using DMAIC-DOE tools	Apply Design of Experiments (DOE) within the DMAIC framework to enhance productivity.
RAL_{1310}	Apply optimization techniques in various manufacturing phases to control the Defects	Leverage Six Sigma tools for defect reduction and process optimization.
RAL_{143}	Provide training to staff to behave with customers	Develop comprehensive customer service training programs to enhance staff interaction skills.
RAL_{211}	Mixture of soft and hardworking culture	Foster a balanced work culture that values both employee well-being and productivity.
RAL_{212}	Communication of management with employees	Implement open and transparent communication channels between management and staff.
RAL_{214}	Medical and Social development of the employees	Introduce wellness programs and social development initiatives for employees.
RAL_{215}	Sustainable development	Adopt eco-friendly practices and continuous learning for sustainable growth.
RAL_{221}	Training for Employees	Regularly conduct skill development and LSS methodology training for employees.
RAL_{222}	New Technologies for employees like Ergonomics, MSD controls etc	Invest in ergonomic tools and technologies to enhance workplace safety and efficiency.
RAL_{223}	Incentives for new skill development (Encourage the employees)	Offer incentives for employees who pursue additional training or skill development.
RAL_{312}	Continues investment planning in Industry	Establish a strategic plan for ongoing investment in technology and process improvements.
RAL_{313}	Fair information sharing with other stake holders like customers	Ensure transparent and equitable information sharing with customers and other stakeholders.

(*contd.*)

Table 8 — 31-week attributes (barriers) identified for the LSS implantation with recommendations. (*contd.*)

Attributes	Description	Recommendations
RAL_{314}	Continues flow of data for applying the LSS tools in industry	Implement a robust data management system to support LSS tools and decision-making.
RAL_{315}	Make positive relation with staff	Build a strong, positive organizational culture that values and supports staff.
RAL_{322}	Planning for new technology up gradation specially for Engineers	Develop a forward-looking technology upgrade plan, focusing on the needs of engineering staff.
RAL_{323}	Establish LSS certification as per organizations requirements	Create an internal certification program for LSS to ensure standardization and expertise.

(Sustainable Development) to adapt to new ways of doing things, a lack of available time to get LSS projects off the ground, the immaturity of the ceramic manufacturing SME market, and a lack of familiarity with the various LSS tools and methods. The implementation of the RAL_iCI model has provided a quantifiable measure of readiness within the targeted ceramic companies, serving as a precursor to any LSS improvement initiatives. This models application echoes the work of Sreedharan *et al.*[3], who also engaged in readiness assessment across various manufacturing firms, revealing varied levels of preparedness and pinpointing specific areas in need of development such as employee well-being and organizational learning. Similarly, Vaishnavi and Suresh[24] identified critical yet underdeveloped attributes like management involvement and employee trust, which are instrumental for the successful deployment of LSS. In our investigation, it became evident that employee resistance to change, time constraints for initiating LSS projects, and a nascent understanding of LSS methodologies are among the significant hurdles faced by the ceramic industry in India. These barriers are not isolated but reflect a broader trend in sectors like manufacturing SMEs like the ceramic industry, where LSS tools and techniques have yet to be fully embraced and integrated into the operational culture. Our study extends the discourse on LSS readiness by highlighting these contextual challenges, thereby contributing to a more nuanced understanding of the factors that influence the success of process improvement programs in manufacturing industries.

4 Conclusion

In the present study, a comprehensive LSS readiness assessment model (RAL_iCI) for small and medium-sized ceramic industries was developed using a fuzz logic approach. The RAL_iCI model incorporates LSS readiness factors (Enablers, Criteria, and Attributes) and Critical Success Factors (CSFs), derived through an extensive literature review and a questionnaire survey conducted in 90 Indian ceramic SMEs. The model includes a total of 3 enablers, 8 criteria, and 54 attributes, making it a comprehensive tool for evaluating the LSS readiness level of ceramic industries.The present analysis reveals that the companys $FRAL_iCI$ scores are nearest to the “Less Read” (LR) and “Slowly Ready” (SR) linguistic variables. This indicates that, while the organization has started laying the groundwork for LSS practices, considerable advancements are required to elevate its state of readiness. Specifically, the “Less Ready” state, as implied by the smallest distance $D(FRAL_iCI, LR) = 1.68$, signifies that the company is in the nascent stages of readiness, requiring substantial improvements in both infrastructural capacities and process optimization techniques to progress towards “Very Ready” or “Extremely Ready” states. To provide context and enhance the practical significance of these scores, benchmarks were established based on expert consultations and a comprehensive analysis of the literature. These benchmarks categorize the readiness state and provide a roadmap for organizations to identify areas of improvement.

Using the fuzzy performance importance index (FPII), 31 attributes out of 54 were observed as weaker attributes and corrective action is required to improve the readiness level. These 31 attributes posing as potential barriers underscore the critical areas hindering LSS adoption in the ceramic sector. Among these, issues like inadequate floor management and surplus material removal, as well as a shortfall in harnessing AI/ML for inventory and computational control, mark significant opportunities for enhancing operational efficacy. Addressing these key areas, alongside improving communication and fostering a culture supportive of LSS, is pivotal. Such targeted improvements are essential for bolstering the industrys readiness for LSS, ultimately driving quality and efficiency. By addressing the limitations of traditional assessment methods, the RAL$_i$CI model effectively evaluates the complexities and fuzziness inherent in the concept of readiness.

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References

1 Lemon K N & Verhoef P C, *J Market*, 80 (2016) 69.
2 Bhadu J, Bhamu J P, Singh D, Kumar P, Garza-Reyes J A & Phanden R K, *Int J Inter Des Manuf*, 1-18 (2024) 1.
3 Kumar P, Singh D & Bhamu, *Int J Qual Reliab Manag*, 38 (2021) 1964.
4 Trehan R, Gupta A & Handa M, *Int J Six Sigma Comp Adv*, 11 (2019) 23.
5 Kumar M, Antony J & Tiwari M K, *Inter J Prod Res*, 49 (2011) 5449.
6 Yadav G, Seth D & Desai T N, *Int J Lean Six Sigma*, 9 (2018) 270.
7 Bloj M, Moica S & Veres C, *Proc Manuf*, 46 (2020) 352.
8 Antony J, Forthun S C, Trakulsunti Y, Farrington T, McFarlane J, Brennan A & Dempsey M, *Leader Health Serv*, 32 (2019) 509.
9 Paul S K & Chowdhury P, *Int J Phys Distrib Logist Manag*, 51 (2021) 104.
10 Singh A & Ravi P, *Int J Prod Perform Manag*, 72 (2023) 2270.
11 Utama D M & Abirfatin M, *Clean Eng Tech*, 17 (2023) 1.
12 Bhat S, Gijo E V & Bhat V S, *Benchmarking Int J*, (2025) 1.
13 Kumar S, Swarnakar V, Phanden R K, Antony J, Jayaraman R & Khanduja D, *Benchmarking Int J*, 31 (2023) 2960.
14 Vashishth A, Lameijer B A, Chakraborty A, Antony J & Moormann J, *Int J Qual Reliab Manag*, 41 (2024) 509.
15 Lam M, O'Donnell M & Robertson D, *Inter J Oper Prod Manag*, 35 (2015) 201.
16 Dursun M, Goker N & Mutlu H, *Adv Intell Syst Comput*, 1029 (2020) 1138.
17 Website: https://www.dsir.gov.in/small-and-medium-enterprises-smes-india, (Accessed on 21.10.2024).
18 Bhadu J, Bhamu J, Singh D & Sangwan K S, *Int J Prod Perf Manag*, 35 (2022) 1.
19 Murmura F, Bravi L, Musso F & Mosciszko A, *TQM J*, 33 (2021) 351.
20 Hossain S K & Roy P K, *J Asian Ceram Soc*, 8 (2020) 984.
21 Kleszcz D, *Prod Eng Ah*, 19 (2018) 48.
22 Bhadu J, Bhamu J, Singh D, Saraswat P, Agrawal R, *Eng Manag J*, (2025) 1.
23 Bhamu J, Sangwan K S & Mehta D, *Int J Prod Perf Manag*, 63 (2020) 569.
24 Vaishnavi V & Suresh M, *Int J Lean Six Sigma*, 11 (2020) 597.
25 De Silva S H, Ranadewa K A T O & Rathnasinghe A P, *Const Innov*, 25 (2025), 510.
26 Stanton P, Gough R, Ballardie R, Bartram T, Bamber G J & Soha A, *Int J Hum Resour Manag*, 25 (2014) 2926.
27 Antony J, Lancastle J, McDermott O, Bhat S, Parida R & Cudney E A, *Int J Qual Reliab Manag*, 40 (2023) 25.
28 Ravikumar M M, Marimuthu K & Parthiban P, *Int J Serv Oper Manag*, 22 (2015) 21.
29 Yadav G & Desai T N, *Int J Qual Reliab Manag*, 34 (2017) 1167.
30 Vinodh S & Vimal K E K, *Int J Adv Manuf Tech*, 60 (2012) 1185.
31 Sreedharan R, Raju V R, Sunder V & Antony M J, *Int J Qual Reliab Manag*, 36 (2019) 137.
32 Yadav G, Kumar A, Luthra S, Garza-Reyes J A, Kumar V & Batista L, *Comput Ind*, 122 (2020) 103280.
33 Abbes N, Sejri N, Jun X & Morched C, Alex *Eng J*, 61 (2022) 9079.
34 Bhadu J, Singh D & Bhamu J, *Int J Prod and Perf Manag*, (2021), 1.
35 Swarnakar V, Singh A R & Tiwari A K *Mater Today Proc*, 469 (2021), 9617.
36 Dora M & Gellynck X, *Qual Reliab Eng Int*, 31 (2015) 1151.
37 Sohal A, De Vass T & Vasquez T, *J Manag Control*, 33 (2022) 215.
38 Kumar P, Brar P S, Singh D & Bhamu J, *Inter J Prod Perform Manag*, 72 (2023) 2559.
39 Gijo E V, Antony J, Kumar M, McAdam R & Hernandez J, *J Manuf Tech Manag*, 25 (2014) 125.
40 Hilton R J & Sohal A, *Int J Qual Reliab Manag*, 29 (2012) 54.
41 Attar M T, The Sou Afr Jof Ind Eng, 34 (2023) 59.
42 Fajarika D, Trapsilawati F & Sopha B M, *Int J Eng Bus Manag*, 16 (2024) 1.
43 Wong W P, Ignatius K L & Soh K L, *Prod Plan Control*, 25 (2014) 273.
44 Ruben B, Vinodh S & Asokan P, *Prod Plan Control*, 28 (2017) 1193.
45 Zhang A, Venkatesh V G, Wang J X, Venkatesh M, Wan M & Qu T, *Prod Plan Control*, 34 (2019) 1.
46 Timans W, Antony A, Ahaus K & Van Solingen R, *J Oper Res Soc*, 63 (2012) 339.
47 Jose Arturo G, Al-Balushi M, Antony J & Kumar V, *Prod Plan Control*, 27 (2016) 1.
48 Rosa A, Capolupo N, Romeo E, McDermott O, Antony J, Sony M &Bhat S, *TQM J*, 36 (2024) 392.
49 Almutairi A M, Salonitis K & Al-Ashaab A, *Int J Lean Six Sigma*, 10 (2019) 81.
50 Calvo-Mora A, Ruiz-Moreno C, Picón-Berjoyo & Cauzo-Bottala L, *J Bus Res*, 67 (2024) 769.
51 Lameijer B A, Pereira W & Antony J, *J Manuf Tech Manag*, 32 (2021) 260.
52 Albliwi A, Antony J & Lin S, *Bus Proc Manag*, 2 (2015) 665.
53 Gaikwad S K, Paul A, Moktadir M A, Paul S K & Chowdhury P, *Benchmarking Int J*, 27 (2020) 2365.
54 Lin D, Lee C K M, Lau H & Yang Y, *Ind Manag Data Syst*, 118(2018) 589.
55 Bonnetti & Thomas A, *J Organ Behav*, 36 (2014) 3.
56 Karwowski W & Mital A, *Adv Hum Factors*, E, 6 (1986) 227.