Barriers and Strategies for Implementing Lean Six Sigma in Small and Medium-Sized Enterprises (SMEs) in Construction Industry: A Fuzzy TOPSIS Analysis

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Abstract

Purpose: Quality management barriers have been discovered in construction small and medium-sized enterprises (SMEs), determining their long-term survival. Despite the recognition of Lean Six Sigma (LSS) as a valuable quality management technique for addressing the barriers faced by SMEs, LSS implementation within the construction SME context is alarmingly low. Therefore, this study aims to investigate the barriers for implementing LSS within construction SMEs and to determine the most effective strategies for overcoming these barriers.

Methodology: A quantitative research approach was employed, and data was collected in two stages: a questionnaire survey with forty-four construction professionals and an expert opinion survey with twelve LSS specialists. The collected data was then analysed using the fuzzy TOPSIS method, achieving a higher degree of sensitivity.

Findings: The findings revealed the fifteen most significant LSS barriers that need to be addressed. In addition, the ten most important strategies to be implemented in overcoming the identified barriers prior to LSS implementation were discovered and thematised, most notably the hiring of LSS specialists for project monitoring and the formation of a committee for strategic planning through LSS.

Originality: Previous research on LSS examined barriers and strategies for SMEs in general, but this study is the first of its kind, focusing especially on the construction SME context and involving the unique fuzzy TOPSIS approach.

Keywords: **-** Construction Industry; fuzzy TOPSIS; Lean Six Sigma (LSS); Small and Medium Sized Enterprises (SMEs).

Article Classification: - Research Article

Introduction

The small and medium-sized enterprises (SMEs) play a critical role in the global construction industry, representing 90% of businesses and contributing to economic growth, job creation, and support for larger companies (Tezel et al., 2020; Kamal & Flanagan, 2014; Ranadewa et al., 2021). Despite this, it has been observed that construction SMEs face several significant challenges, including poor management control, an increase in non-value-added activities (NVAA) which leads to output quality deficiencies (Ranadewa et al., 2018; Ankomah et al., 2017). These quality management-related challenges can have significant impacts on productivity, leading to time and cost overruns and disputes (Mughal et al., 2020). Thus, Gaikwad et al. (2020) highlighted the critical importance of addressing the quality management issues faced by SMEs, as they can determine the survival of these socioeconomically vulnerable enterprises (Gaikwad et al., 2020).

In light of the numerous challenges faced by construction SMEs with regard to poor management control, increased NNVA, and output quality deficiencies, it is imperative that these entities adopt quality management strategies. Amongst the available quality management tools, Lean, Total Quality Management (TQM), and Lean Six Sigma (LSS) have been proven to be particularly effective in reducing waste and improving productivity while maintaining quality (Ranadewa et al., 2021; Sony, Naik, & Therisa, 2019). The adoption of LSS has been found to be particularly advantageous in terms of improving productivity through the implementation of data discipline, customer-focused approach, maximising value, minimising waste, and continuously managing and improving processes (Mughal et al., 2020; Sony et al., 2019). Furthermore, LSS has been shown to deliver better outcomes compared to other quality management tools whilst preserving customer satisfaction (Singh & Rathi, 2018). As in general, LSS is a process and product improvement methodology that addresses both managerial and technical aspects in order to optimise value through continuous process and quality improvement and reduce costs through the elimination of NVAA (Dursun et al., 2020; Singh, Kumar, & Rathi, 2019). However, as like any technology or process adoption in the construction industry, applying new practises in construction SMEs requires prior feasibility study. Hence, investigating barriers and strategies to overcome such barriers in implementing LSS has been identified as a valuable context to be investigated.

Considering the existing literature related to the subject, Gaikwad *et al.* (2020) and Yadav *et al.* (2018) are directed towards identifying barriers and strategies SMEs may face in LSS implementation in a general context. However, to the best of the authors' knowledge, no research work was found in the construction SME context, which was also found to be attributable to the low rate of LSS implementation at the latter stage of this study. On the other hand, identifying the most critical barriers and strategies for LSS implementation would provide an invaluable opportunity for construction SMEs to prioritise the most impactful strategies because of SMEs' intrinsic resource limitations in implementing all the strategies at once (Adam and Alarifi, 2021). Considering the above facts, this study identified an emerging need to answer the research problem of "what are the most critical strategies to overcome barriers related to LSS implementation in construction SMEs?"

Accordingly, this study aimed to investigate the critical barriers and strategies for successful LSS implementation in construction SMEs. A literature review was first conducted to examine the barriers and strategies related to LSS implementation. Subsequently, the empirical data was collected in two stages through a questionnaire survey and an expert opinion survey, which aimed to explore the critical nature of each barrier and strategy in the context of construction SMEs. The collected data was analysed using the Fuzzy TOPSIS method, and a radar-web diagram was generated to present the most critical LSS implementation barriers in construction SMEs. Finally, a ranking list was developed to identify the most effective strategies for overcoming each LSS implementation barrier for construction SMEs. This ranking list would provide SMEs with a roadmap for prioritising strategies in achieving an effective LSS implementation, which is a novel contribution of this study.

Literature review

SMEs in Construction Industry

Though SMEs are considered the backbone of the economy and are bridging the supply disparities, the unique competitive risks involved in the construction industry have prompted SMEs to strengthen their capabilities by analysing market possibilities as well as challenges in order to remain competitive (Thurairajah *et al*., 2022). Despite government assistance and programmes aimed at boosting the entry of new SMEs, their survival has been continuously reduced, with their owners being unaware of the obstacles, particularly in terms of financial and management abilities (Rahman, Yaacob, & Radzi, 2016). The perception that SMEs possess flexibility and flattened organizational structures enabling direct communication between employers and workers is not without its challenges, as noted by Van Hoinaru and Stănilă (2019).

Rassool and Dissanayake (2019), Rahman et al. (2016), and Ranadewa et al. (2018) constitute seminal contributions to the investigation of the deep-inherent and persistent challenges that construction SMEs grapple within the course of executing construction activities. The critical issues identified by these scholars encompass a broad spectrum of challenges, including deficient management control, suboptimal staff efficiency, limited resource endowments, inadequate workforce knowledge and skills, and quality lapses in project deliverables. As noted by Krndzija and Pilav-Velic (2022), these impediments pose significant obstacles to the timely and successful completion of construction projects, exposing SMEs to heightened risk and undermining their financial performance. In specific to the construction context, Eze et al. (2020) have also highlighted that procurement mismanagement, storage resource constraints, and communication gaps often plague contractor SMEs, leading to project underperformance. Furthermore, Ranadewa et al. (2018) and Thurairajah et al. (2022) have underscored the financial resource constraints and limited expertise to recruit and evaluate resources that stress material and equipment supplying SMEs. To counteract these challenges, the Enterprise Research Centre (ERC, 2022) has highlighted the need for construction SMEs to embrace innovation, particularly through the adoption of lean tools, as a means of attaining growth and productivity.

Particularly, as highlighted by Tezel et al. (2020), Poshdar et al. (2019), Ranadewa et al. (2021), and Tezel et al. (2018), the long-term survival of construction SMEs has been found to be highly dependent on addressing quality deficiencies. Thus, to minimise quality deficiencies, the lean concept has been identified as a potential solution in these studies that construction SMEs can adopt. By implementing lean principles, SMEs can streamline their operations and enhance their quality management processes to deliver projects that meet or exceed client expectations, improve their competitiveness, and secure their long-term viability in the industry.

The Lean Methodology

The lean methodology was initiated by Toyota Motors in Japan and became popular specifically in the manufacturing industry due to its capability of reducing NVAA (Rymaszewska, 2014). Consequently, lean implementation has been gradually transmitted through various industries, including construction, as a means of reducing NVAA due to higher construction costs (Womak & Jones, 1996; Manos *et al.*, 2006; Ankomah *et al.*, 2017). Lean construction applies lean thinking and ideas from the manufacturing industry as a new technique for managing construction projects (Ranadewa *et al.*, 2021; Al-Aomar, 2012). The goal of lean construction, according to Koskela (2020), is to build while enhancing value, decreasing waste, and reaching excellence through continuous improvement. As a result, numerous lean techniques, such as Building Information Modelling (BIM), Last Planner System (LPS) and Kanban have been effectively used to decrease waste in the construction projects (Zhang & Chen, 2016). However, Poshdar et al. (2019) found that SMEs in the housing sector were hesitant to adopt lean due to the associated complexity and barriers. Similarly, Tezel et al. (2018) examined the current state of lean for road construction SMEs and discovered that it was failing because the SMEs were struggling to improve their product design and quality. Therefore, lean has been scrutinised owing to its low productivity in comparison to its higher initial cost, and consequently, researchers have emphasised the necessity of enhancing lean with possible integration with other concepts such as Kaizen and Six Sigma (Miina, 2012).

Lean Six Sigma (LSS)

Lean Six Sigma (LSS) was introduced to maximise value via continuous process and quality improvement while reducing costs through the elimination of NVAA (Dursun *et al.*, 2020). Generally, Six Sigma contributes to reduction of energy consumption, waste generation, pollution during constructions (Negi *et al.*, 2017). Six Sigma is used to reduce defects and variations while improving quality by using the DMAIC (Define, Measure, Analyse, Improve, and Control) approach (Singh *et al.*, 2019). Therefore, LSS practises this DMAIC approach integrated with lean tools as in Figure 1 to facilitate waste elimination, defect reduction, and quality improvement (Mughal *et al.*, 2020).

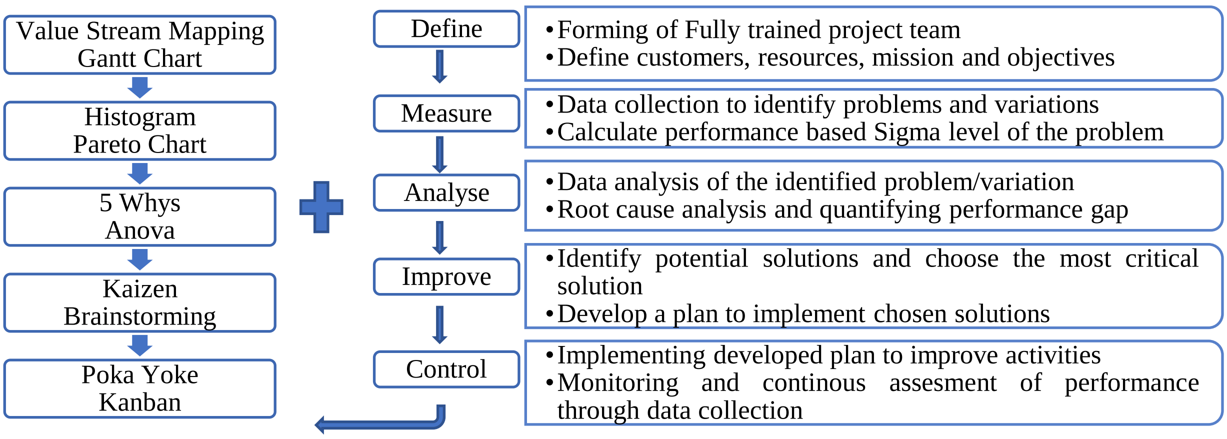

Figure 1: Integration of Lean tools with DMAIC approach

Source: (Negi et al., 2017; Salah et al., 2010)

Thus, LSS follows a stepwise problem-solving procedure with the use of Lean tools to provide relevant solutions (Sony *et al.*, 2019). Amitha and Shanmugapriya (2016) mentioned that LSS would act as a powerful process improvement tool in SMEs. Several studies (Paslawski, 2013; Singh & Rathi, 2018; Sony *et al.*, 2019) discussed the elimination of waste, effective resource management, planning reliability, prior identification of critical factors for maintaining productivity, and improvement in overall productivity as benefits that can be achieved through implementing LSS. Therefore, the benefits of LSS are evidently acknowledged for addressing SME challenges, yet implementation of LSS in the construction SME context is limited and with a need for further empirical investigations.

Implementation of LSS in construction SMEs

The implementation of LSS in the construction sector has been extensively investigated by many studies including Al-Aomar (2012), Siddiqui *et al.* (2016), and Negi *et al.* (2017). In one case study, Dutch construction company successfully solved project delay issue by using LSS under DMAIC approach (Van den Bos *et al.*, 2014). Van den Bos et al. (2014) and Linde and Philippov (2020) assert that the successful implementation of LSS is not solely the responsibility of top or middle-level management in a construction organisation. Instead, it requires a collective effort from all management levels, from top to bottom. The studies suggest that LSS implementation promotes collaborative efforts among stakeholders such as project teams, employers, design teams, suppliers, and contractors. Furthermore, LSS can be applied by construction contracting firms to improve their design, logistics, and construction processes. Additionally, as noted by Linde and Philippov (2020), LSS can be utilised to establish a clear critical path in planning and enhance risk management, making it a viable option for construction consulting firms to improve their construction planning methodologies. Consequently, Paslawski (2013) demonstrated the feasibility of applying LSS in construction SMEs using multiple case studies. Following an assessment of the advantages of LSS implementation, Paslawski (2013) concluded that LSS is successful in addressing the majority of the difficulties in construction SMEs such as increase of waste and productivity issues. However, the LSS adoption rate is not as high as predicted in construction SMEs (Desale & Deodhar, 2013). Paslawski (2013) revealed that several barriers are affecting the LSS adoption rate in construction SMEs, such as unfamiliarity with LSS and lack of resources. Meanwhile, it can be expensive for construction SMEs if LSS is not deployed appropriately, considering their limited financial resources (Desale & Deodhar, 2013). Due to the risks involved, SMEs are found to be hesitant to employ innovative tactics like LSS (Pulakanam, 2012). Therefore, it is important to carefully investigate the true nature of LSS implementation barriers to identify the most effective and critical strategies for successful LSS implementation, which the subsequent sections are aimed at.

Barriers to LSS implementation in construction SMEs

LSS can be implemented in any organisation if the barriers for implementing LSS are properly managed (Laureani & Antony, 2018). However, it can be quite costly for construction SMEs to recover with an unsuccessful LSS implementation (Desale & Deodhar, 2013). Hence, this study identified barriers for LSS implementation as illustrated in Table 1 using combined keywords of "Lean Six Sigma", "barriers", "construction" and "SMEs".

Table 1: LSS Implementation Barriers in construction SMEs

Barrier code	Name of the Barrier	Description of the Barrier	References
B1	Insufficient involvement of Top management	Top management frequently argues that spending money on quality improvement programs is a waste of money.	[1], [2], [3], [4], [7]
B2	Lack of specialized LSS training	Many organisations have failed to implement LSS because significant amount of money must be committed to make the training possible.	[1], [2], [3], [5], [7], [8], [9]
B3	Lack of resources	For a successful LSS implementation, efficient resources are required (Human resources, money).	[1], [6], [7], [8], [9]

B4	Unawareness of LSS needs and benefits	Employees should have sufficient knowledge to implement LSS.	[2], [3], [6], [7]
B5	Cultural and organisational resistance	Due to the complexity and uncertainty of new systems, managers and employees may be hesitant to change the current quality management status.	[1], [2], [3], [7]
B6	Insufficient time for execution of new quality management method	It consumes more time adapting for an organisation to implement LSS.	[1], [2], [4], [10]
B7	Satisfied with the current quality management method	If an organisation has a well-managed quality management system presently, there is no need for LSS implementation.	[1], [8], [9]
B8	Poor communication between management and workers	To deploy LSS in a company, a good communication platform between management and workers is required.	[2], [4], [5]
B9	Insufficient consultants in the field	There is lack of LSS experts (black belts, champions).	[1], [3], [6]
B10	Improper project selection and prioritization	Every project should be chosen with the goal of enhancing the company's competitive edge and profitability.	[2], [3], [7]
B11	Poor overall performance in previous projects	If the company had not completed/abandoned work or received poor feedback from previous projects in the past.	[3], [10]
B12	Poor organisational structure	The effectiveness of new quality management system implementation might be hampered by issues with the organisational structure.	[4], [6]
B13	Risk of not achieving anticipated benefits of improvement	Companies are unable to achieve the anticipated benefits of new quality management system, resulting in the project's failure.	[4], [5]
B14	Poor employee relationship	Employees must improve their relationships with one another in order to increase the likelihood of project success and create a productive working environment.	[3], [4], [5]
B15	Risk of disruption to current operations	Disruption in current operations can occur throughout the LSS program's implementation phase.	[1], [4]

Sources: {[1] – (Gaikwad et al., 2020), [2] – (Yadav et al., 2018), [3] – (Singh et al., 2019), [4] – (Albliwi, 2017), [5] – (Mustapha et al., 2018), [6] – (Hussain et al., 2019), [7] – (Fernando, 2017), [8] – (Lande et al., 2016), [9] – (Raghunath & Jayathirtha, 2013), [10] – (Singh & Rathi, 2018)}

The abovementioned barriers were assigned codes for use in empirical data analysis. It is identified that most LSS barriers are management-related barriers since LSS requires proper management to apply adequate precautions in assessing work culture, process environment, and readiness, and thereafter, LSS implementation must be planned (Psomas & Antony, 2015). Hence, it is critical to understand the LSS barriers that could hinder its execution (Gaikwad *et al.*, 2020). Consequently, SMEs are compelled to navigate the challenges posed by low-impact barriers and develop strategies to effectively overcome the most significant obstacles.

Strategies to overcome LSS barriers

Many organisations attempt LSS adoption without understanding possible barriers, and strategies for overcoming LSS implementation barriers (Desale & Deodhar, 2013). Identification of strategies and their connections to barriers is essential to ensure successful LSS implementation (Gaikwad *et al.*, 2020). This study solely considers the strategies that may be devised prior to the implementation of LSS. Table 2 shows strategies derived from literature using the search terms "Lean Six Sigma," "Strategies," "construction," and "SMEs."

Table 2: Strategies to overcome LSS implementation Barriers.

Strategy Code	Name of the Strategy	Description of the Strategy	References
S1	Establishing reward and recognition system	It will encourage, employees to eliminate waste and learn about LSS tools and to measure the performance of each employee.	[1], [4], [5]
S2	Acquiring effective support of top management	Uncompromising top management support and approval for LSS implementation.	[1], [2], [3], [6]
S3	Allocating additional funds for overall LSS implementation	Management has to take some risk to pay for short term cost of LSS implementation for long term benefits	[1], [2], [4], [5]
S4	Implementing effective LSS training programs for employees	Proper LSS training programs conducted by a Master Black Belt to each employee level.	[2], [6], [9]
S5	Hiring LSS experts to projects (Black-belts, Green-belts)	They can help team members how to implement LSS properly and in the long-term plan and proper belt system will be established in the organisation.	[2], [4], [5], [6]
S6	Precise selection of LSS tools and techniques	The proper selection of LSS tools according to the organisation's capacity can improve overall efficiency in adaption.	[1], [6]
S7	Establishing strategic planning committee	The committee can oversee LSS implementation and provide guidance to the employees how to use it and who will be using it.	[1], [3], [4]
S8	Appropriate selection of staff for effective LSS training	It can improve the productivity of the team as well as the procedure when it comes to preparing training for LSS implementation.	[1], [7], [9]
S9	Adapting government support available for SMEs	Make use of special loan schemes from government banks available for SME development for proper implementation of LSS	[8], [10]
S10	Implementing leadership and management training programs	High standard leadership and management skills of employees lead for proper implementation of LSS and development of SMEs	[8], [9]
Sources: {[1] – (Gaikwad et al., 2020), [2] – (Yadav et al., 2018), [3] – (Laureani & Antony, 2018), [4] - (Jeyaraman et al. 2012), [5] – (Antony et al., 2012), [6] – (Bakar et al., 2015), [7] – (Lande et al., 2016)}, [8] – (Ranadewa et al., 2018), [9] – (Linde & Philippov, 2020), [10] – (Dursun et al., 2020)			

For further investigations into this study, the above-mentioned strategies were assigned codes. However, it is required for organisations to prioritise the most effective strategies to overcome more barriers according to a plan rather than implementing every strategy from time to time. By implementing the most effective strategies prior to implementing LSS, construction SMEs can maximise the benefits of LSS implementation as preliminary precautions are established (Gaikwad *et al.*, 2020). However, as noted by Yadav et al. (2018), construction SMEs may face financial barriers which limit their ability to implement multiple strategies simultaneously. Hence the prioritisation of available strategies is vital to optimise the benefits of LSS implementation for construction SMEs. In light of this, the fuzzy TOPSIS method (discussed in next section) was found appropriate to investigate the most effective strategies to overcome LSS implementation barriers, thereby providing a wider opportunity for LSS implementation in construction SMEs.

Research methodology

A compressive literature review uncovered several theoretical explanations for the research problem. Thereafter, the study adopted the ontological assumption that "reality is pre-determined" and the epistemological assumption that "knowledge exists externally and its properties should be measured through objective measures rather than being inferred subjectively through sensation, reflection, or intuition" as suggested by Saunders *et al.* (2015). Hence, in terms of axiology, the research has adopted the value-free stance, making the overall research design in line with the positivism stance. Research approaches fall into three main clusters: quantitative, qualitative, and mixed research (Creswell, 2014). A quantitative approach is best suited for research that tests theories or explanations. Such an approach is also suited for research where the research problem involves identifying factors that influence outcomes or understanding the "best predictors" of outcomes (Creswell, 2014; Bryman, 2008). Quantitative research aims to provide a "general picture of trends, associations, and relationships," focusing on cause-and-effect relationships, whereas qualitative research aims to explain the mechanisms behind those relationships by exploring "why people responded as they did" (Creswell, 2014). This study aims to investigate the critical barriers and strategies for successful LSS implementation in construction SMEs. Accordingly, it is particularly not concerned with gaining an "in-depth" understanding of the phenomenon within its real-world context but focuses on identifying the relationships of an existing theory. Moreover, the research in question resides mainly within the philosophical territory characterised by positivism. Thus, a more quantitative approach seems better suited to achieve the aim of this research, as data collection questions were predetermined, observatory data was collected, and statistical data analysis was used (Creswell, 2014). According to the research aim, criticality will be affected due to variable opinions of the sample. Hence, a survey was selected as the research technique for this study (Creswell, 2014). As a part of this, a questionnaire survey was selected as the research strategy because close-ended questions were required to collect data for fuzzy TOPSIS analysis. Due to the limited number of specialists and practitioners in the construction sector possessing LSS expertise, this study was constrained in its sample size, and snowball sampling was utilised to expand it. To confirm the reliability and validity of the results from the questionnaire survey, an expert opinion survey was conducted, as recommended by Ameyaw and Chan (2015), resulting in data collection occurring in two rounds to improve data sensitivity and validation, as described in the following section.

The data collection instruments in both rounds were administered under a rigorous ethical protocol, reflecting a principled approach to research ethics. Participants were duly informed that any personal information they provided would be treated as strictly confidential, and that it would not be disclosed or distributed without their express written consent. In addition, the data collection instruments were subject to robust data protection policies that ensured the security and management of the data collected. Moreover, participants were assured that the results of the survey would be openly accessible following publication. By enacting these ethical and legal measures, the data collection protocol enabled the researchers to obtain informed consent from the participants while also safeguarding their privacy rights.

Data collection round 1

The first round of data collection was conducted through a questionnaire survey, targeting construction industry practitioners who possessed a high level of awareness of LSS and had more than five years of experience in the industry. To expand the sample size, the snowball sampling technique was used to reach indirect contacts. Prior to the distribution of questionnaires, a pilot study was conducted to acquire feedback on the clarity of language and length of the questionnaire from two practitioners, as recommended by Ameyaw and Chan (2015). Out of a population of 100 professionals, only 46 responded to the questionnaire, with two responses being irrelevant due to incomplete answers, resulting in a response rate of 44%. This response rate was deemed to have reached the saturation limit, given the limited population with the desired expertise, which was supported by other studies utilising questionnaire survey sample sizes ranging from 33 to 40 (Enshassi & Jubeh, 2009; Yogeshwaran *et al.*, 2018; Zou *et al.*, 2014). The profile of the acknowledged respondents is presented in Table 3.

Table 3: Profile of respondents in data collection round- 1

<table>
<tr><th>Variable (core business of organisation)</th><th>Professional Designation</th><th>Frequency</th><th>Frequency Percentage</th></tr>
<tr><td rowspan="4">Professional consultancy</td><td>Head of Contracts</td><td>1</td><td rowspan="4">15.9 %</td></tr>
<tr><td>DGM Contracts</td><td>2</td></tr>
<tr><td>Senior Quantity Surveyor</td><td>2</td></tr>
<tr><td>Contracts Manager</td><td>2</td></tr>
<tr><td rowspan="5">Contractor/ builder</td><td>Project Manager</td><td>5</td><td rowspan="5">31.8 %</td></tr>
<tr><td>Quantity Surveyor</td><td>3</td></tr>
<tr><td>Civil engineer</td><td>2</td></tr>
<tr><td>Architect</td><td>2</td></tr>
<tr><td>Facilities Manager</td><td>2</td></tr>
</table>

Variable (core business of organisation)	Professional Designation	Frequency	Frequency Percentage
Sub-contractor (inc. suppliers)	Quantity Surveyor	8	**38.7 %**
	Civil engineer	3	
	Maintenance Engineer	1	
	Technical Officer (T.O)	1	
	Resident Engineer	1	
	Facilities Manager	1	
	Structural Engineer	2	
University/ research institution	Lecturer	2	**13.6 %**
	Lean Six Sigma consultant	2	
	Ph.D. Researcher	2	
Total Count		**44**	

The collected data from questionnaire survey was used to identify and validate LSS implementation barriers and strategies found in the literature. Then, verified data was enrolled into data collection round 2 to bring more sensitivity and reliability.

Data collection round 2

This study employed an expert opinion survey to further validate and prioritise the strategies and barriers identified in the first round of data collection through the questionnaire survey. A judgmental sampling method was utilised to select a sample of experts with over ten years of experience in the construction industry, including experience in construction SMEs and LSS Belt certification, to increase the sensitivity of the data. Thus, the study conducted an expert opinion survey with twelve respondents, as shown in Table 4, and reached the saturation limit for data collection. Moreover, prior Fuzzy-TOPSIS related studies used 7-10 experts as sample size for expert opinion survey (Gaikwad et al., 2020; Taylan et al., 2014), whereas this study surpassed this sample size threshold.

Table 4: Profiles of respondents in data collection round- 2

Respondent ID	Professional Designation	Level of Education	LSS Awareness	Experience in Construction Industry	Experience in Construction SMEs	Acquisition of a LSS Belt
LSSE-1	Lecturer	Ph.D.	☑	> 10 years	2-5 years	Green Belt
LSSE-2	Senior Quantity Surveyor	M.Sc.	☑	>10 years	< 2 years	Black Belt
LSSE-3	DGM Contracts	B.Sc. (QS)	☑	> 10 years	< 2 years	Black Belt

Respondent ID	Professional Designation	Level of Education	LSS Awareness	Experience in Construction Industry	Experience in Construction SMEs	Acquisition of a LSS Belt
LSSE-4	Contracts Manager	B.Sc. (Eng.)	☑	> 10 years	< 2 years	Black Belt
LSSE-5	Quantity Surveyor	B.Sc. (QS)	☑	> 10 years	< 2 years	Green Belt
LSSE-6	Ph.D. Researcher	B.Sc. (QS)	☑	> 10 years	< 2 years	Green Belt
LSSE-7	Head of Contracts	M.Sc.	☑	> 10 years	< 2 years	Black Belt
LSSE-8	Civil engineer	B.Sc. (Eng.)	☑	> 10 years	< 2 years	Green Belt
LSSE-9	Maintenance Engineer	B.Sc. (Eng.)	☑	> 10 years	-	Black Belt
LSSE-10	Lean Executive Enterprise	B.B.A.	☑	> 10 years	-	Black Belt
LSSE-11	Lean Six Sigma consultant	M.B.A.	☑	> 10 years	-	Master Black Belt
LSSE-12	Senior Operations Executive	M.B.A.	☑	> 10 years	-	Black Belt

Then, collected data were subjected to the Fuzzy TOPSIS method to identify the most critical barriers and effective strategies for implementing LSS in construction SMEs.

Fuzzy TOPSIS analysis

TOPSIS is a widely used Multi-Criteria Decision-Making (MCDM) method, and it is understood that traditional TOPSIS cannot deal with the imprecision and inherent ambiguity in the decision-making process, hence fuzzy-based TOPSIS is most preferred (Chowdhury and Paul, 2020). Fuzzy numbers are a subset of real numbers that express values that are uncertain (Amini, 2015). There are several types of fuzzy sets such as triangular and trapezoidal. However, triangular fuzzy numbers (TFN) are highly convenient to work with because of their computational simplicity in fuzzy environments. Hence, the following triangular fuzzy number set in Table 5 is used in this study.

Table 5: Qualitative scale to fuzzy numbers

Point on Scale	Fuzzy Numbers
Very Low (VL)	(1, 1, 3)
Low (L)	(1, 3, 5)
Moderate (M)	(3, 5, 7)
High (H)	(5, 7, 9)
Very High (VH)	(7, 9, 9)

Source: (Amini, 2015; Nguyen et al., 2015)

Table 5 is used to complete ***Step 1*** of the fuzzy TOPSIS analysis of this study. Considering the applications of the fuzzy TOPSIS method, studies by Palczewski and Saabun (2019) and Chowdhury and Paul (2020) have demonstrated the effectiveness of the fuzzy TOPSIS method as an analysis method in software and computation fields. In addition, Gaikwad *et al.* (2020) and Amini (2015) have successfully implemented the fuzzy TOPSIS method to investigate critical barriers and strategies in varied contexts. Therefore, the fuzzy TOPSIS approach was selected considering the nature of this study, as it can examine a relationship matrix between two types of variables, such as barriers and strategies, and determine the variables' weightages (Gaikwad *et al.*, 2020). The steps depicted in Table 6 were used to complete the fuzzy TOPSIS analysis for this study.

Table 6: Fuzzy TOPSIS process of the study

Step No	Description	Equation Used in Step	Equation Code
Step 1	Replace linguistic relationship terms with fuzzy numbers according to Table 3 of the collected data from expert survey for decisions of each respondent as shown in Appendix-1 and Appendix-2.	---	---
Step 2	Create combined decision matrix; LSS barriers as criteria weights, a combined weightage is determined by EQ-1 as shown in Appendix-1.	$\mathbf{w_j = (w_{j1}, w_{j2}, w_{j3})}$ Where, $w_{j1} = \min_k\{w_{j1}^k\}$; $w_{j2} = \frac{1}{k}\sum_{k=1}^{k} w_{j2}^k$; $w_{j3} = \max_k\{w_{j3}^k\}$	**EQ-1**
	Similarly, combined decision matrix is calculated to achieve mean decision matrix of Appendix-2 using EQ-2 as shown in Table 5.	$\tilde{X} = \mathbf{(aij, bij, cij)}$ Where, $a_{ij} = \min_k\{a_{ij}^k\}$; $b_{ij} = \frac{1}{k}\sum_{k=1}^{k} b_{ij}^k$; $c_{ij} = \max_k\{c_{ij}^k\}$	**EQ-2**
Step 3	Create a normalized fuzzy decision matrix. Calculate elements of combined decision matrix using benefit criteria as shown in Appendix-3.	$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$ **where,** $c_j^* = \max_i\{c_{ij}\}$	**EQ-3**
Step 4	Create a weighted normalized fuzzy decision matrix by multiplying each element of this matrix with a combined weightage of the corresponding criteria by EQ-4 as shown in Appendix-4.	$v_{ij} = r_{ij} . w_j$	**EQ-4**
Step 5	Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) for each alternative which shown in Appendix-4. These solutions are calculated using the formula EQ-5 and EQ-6.	**FPIS:** $A^* = (\widetilde{v_1^*}, \widetilde{v_2^*}, \widetilde{v_3^*}, \ldots . \widetilde{v_n^*})$ **where** $\widetilde{v_j^*} = \max_i\{v_{ij3}\}$	**EQ-5**
		FNIS: $A^- = (\widetilde{v_1^-}, \widetilde{v_2^-}, \widetilde{v_3^-}, \ldots . \widetilde{v_n^-})$ **where** $\widetilde{v_j^-} = \min_i\{v_{ij1}\}$	**EQ-6**
Step 6	In this step, the distance of each alternative from the ideal solutions is calculated. The formula used to calculate the distance from ideal solutions are derived by EQ-7 as output in Table 6 and Table 7.	$\mathbf{d}(\tilde{x}, \tilde{y}) = \sqrt{\frac{1}{3}\{(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\}}$	**EQ-7**

Step No	Description	Equation Used in Step	Equation Code
	The average distances are represented as matrix format by EQ-8 and EQ-9 as last column in Table 6 and Table 7.	$d_i^* = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \widetilde{v_j^*})$	**EQ-8**
		$d_i^- = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \widetilde{v_j^-})$	**EQ-9**
Step 7	As the final step, the closeness coefficient of each alternative is determined using EQ-10. After calculating the coefficient, each alternative is ranked by a decreasing order of closeness coefficient as it ranges from 0 to 1. So, a higher number denotes the alternative is closer to the solution as in Table 8.	$CC_i = \frac{d_i^-}{d_i^* - d_i^-}$	**EQ-10**

Source: (Gaikwad et al., 2020; Nguyen et al., 2015)

Data from the expert opinion survey were analysed in seven steps of fuzzy TOPSIS analysis, as shown in Table 6. At the end of ***step-2,*** a ranked list of the most critical barriers was derived as a by-product and the output was illustrated in a radar web diagram by using primary data from expert opinion survey. Radar web diagram is used for its capability to illustrate data with three dimensions and for its aesthetic look (Burch & Weiskopf, 2012). At the end of ***step 7,*** the final output of the ranking list was derived to identify critical strategies to overcome LSS barriers in implementing LSS in construction SMEs.

Research findings and discussion

In questionnaire survey round 1, forty-four construction industry professionals verified and agreed that most of the LSS implementation barriers and strategies collected through the literature survey were related to the construction SME context. Figure 2 represents the responses of questionnaire survey round 1.

Most respondents did not agree to the barrier code B7 in the construction SMEs context, which enhanced the requirement for a quality management tool for construction SMEs, and more than 70% agreed and verified all the LSS implementation barriers in Table 1 under the construction SMEs context. Furthermore, more than 80% of respondents agreed to all the strategies for overcoming LSS barriers in Table 2 under the construction SMEs context. Thus, every respondent agreed to strategy codes S5, S7, S8, and S10.

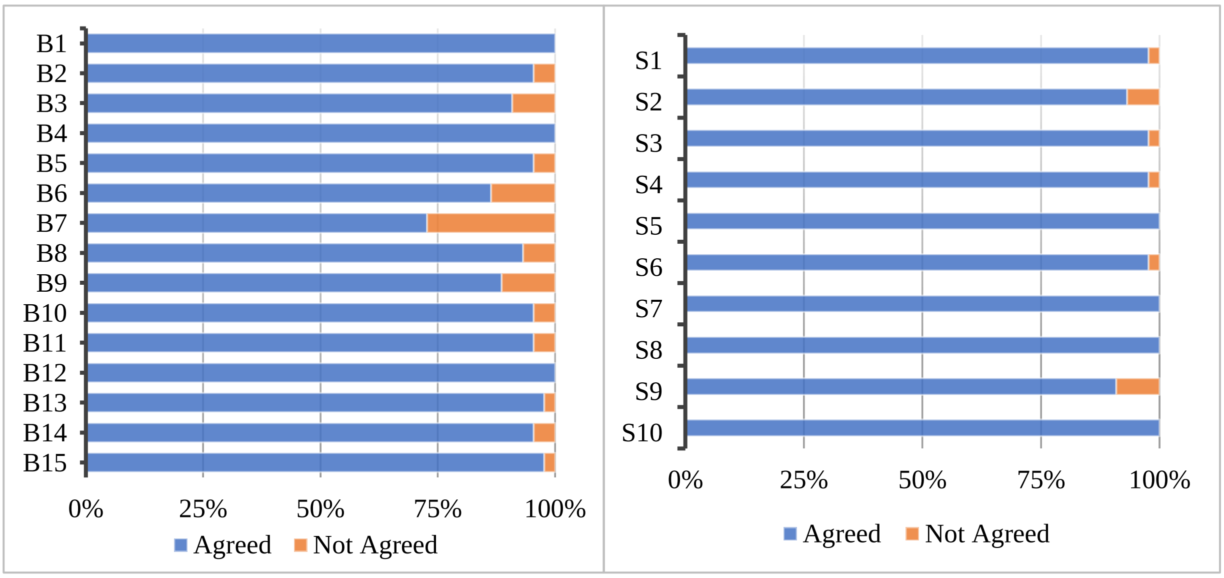

Figure 2: Responses of questionnaire round-1 to identify LSS implementation barriers and strategies under construction SMEs

Under the data collection round 2, each expert was asked about weightage allocated for each identified LSS barrier as in scale answers from Very Low (VL) to Very High (VH). Then, they were asked about the effect of each strategy on the context of overcoming each LSS barrier as in scale answers from VL to VH. After the data collection from twelve experts, it seemed each expert had divergent opinions about weightage of each LSS barrier and effect of each strategy on overcoming LSS implementing barriers. Therefore, a proper measurable relationship had to be established using fuzzy TOPSIS analysis.

Therefore, ***Step-1*** of fuzzy TOPSIS analysis was achieved using Table 5, by generating a response matrix for the impact of each LSS implementation barrier (refer Table A under Appendix-1 for calculations), and the response matrices for the impact of each strategy on overcoming LSS implementation barriers were also generated (Refer Table B1-B12 in Appendix-2 for calculations).

Then, under ***Step-2,*** the mean TFN (weightage) of each LSS implementation barrier was calculated by using EQ-1 and the weightage for each barrier was recorded (refer Table A under Appendix-1 for calculations). It helped to identify the most weighted barriers to apply more focus on overcoming. The output of ***Step-2*** was further illustrated by Figure 3 as a radar web chart by using collected primary data from the expert opinion survey.

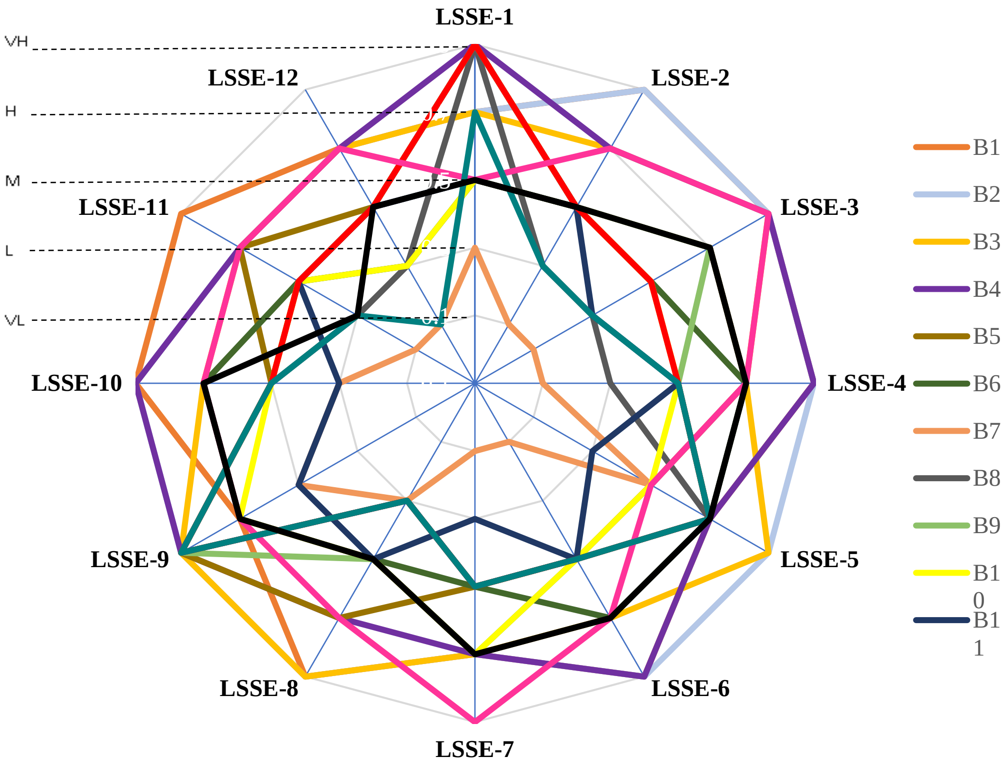

Figure 3: Distribution of Impact of LSS Barriers in Implementing into Construction SMEs

According to Figure 3, there are five circles in the radar web representing VL to VH from inner circles into outer circles. A further radius into each of the twelve corners of the outer web circle represents the answer proposition of each respondent. Further, Figure 3 provides a comparison of the impact of each LSS barrier when implemented into construction SMEs. Hence, LSS barriers were compared by comparing the conceded surplus of each LSS barrier in the web diagram.

Therefore, it was highlighted that barrier codes B2, B1 and B4 had the largest surpluses, while B7 and B11 had the smallest surpluses compared to other barriers. However, this graphical representation lacked a quantifiable approach to compare each barrier, as then, weightages of each barrier extracted from ***Step-2*** of fuzzy TOPSIS analysis were used to establish and prove the above outcome. Hence, ranked LSS implementation barriers in the construction SME context were derived as follows:

1. Lack of specialized LSS training **(B2)**
2. Insufficient involvement of Top management **(B1)**
3. Unawareness of LSS needs and benefits **(B4)**
4. Lack of resources **(B3)**
5. Risk of not achieving anticipated benefits of improvement **(B13)**
6. Cultural and organisational resistance **(B5)**
7. Insufficient consultants in the field **(B9)**
8. Risk of disruption to current operations **(B15)**
9. Poor organisational structure **(B12)**
10. Insufficient time for execution of new quality management method **(B6)**
11. Improper project selection and prioritization **(B10)**
12. Poor communication between management and workers **(B8)**
13. Poor employee relationship **(B14)**
14. Poor overall performance in previous projects **(B11)**
15. Satisfied with the current quality management method **(B7)**

Under ***Step-2*** calculation, the criticality of barriers was derived from taking the weightage set, which has a maximum value of the 3rd number of weightage rows. If there were two or more weightage sets with similar maximum 3rd numbers, then it was derived from taking the weightage set which had the maximum 3rd number and the 2nd number of weightage rows.

According to the outcome of ***Step-2***, the lack of specialised LSS training, which was discussed by several authors (Gaikwad *et al.*, 2020; Yadav *et al.*, 2018, Singh *et al.*, 2019), was identified as the most critical LSS implementation barrier in the construction SMEs context. For instance, as indicated by Linde and Philippov (2020), the provision of proper LSS training to all employees within the hierarchy of construction SMEs can result in a uniform understanding of client needs and a focus on creating value for the client. The contribution of top management decisions, supervisors, and labour force that have received LSS training can also lead to improvements in the monitoring of project requirements and testing of structural assemblies and other construction processes. This can result in higher quality, cost reduction, and time savings for the construction SME. According to the fuzzy TOPSIS approach, it further elaborates that there will be a major possibility of failing LSS implementation in construction SMEs without overcoming that barrier (B2). Similarly, other identified most critical LSS implementation barriers are primarily managerial in nature rather than financial in nature, implying that construction SMEs must be provided with LSS awareness and top management support for a successful LSS implementation. However, Barrier code B7, "satisfied with the current quality management method," as discussed by Raghunath and Jayathirtha (2013) and Lande et al. (2016), has been identified as the least critical barrier to the implementation of LSS in construction SMEs. This suggests that most construction SMEs are lacking in quality management methods and therefore, have the potential and dire need to introduce LSS.

Then, as a continuation of fuzzy TOPSIS steps, the mean impact of each LSS respondent for each strategy on overcoming LSS implementation barriers was derived using EQ-2, and the combined decision matrix is demonstrated in Table 7.

Table 7: Combined Decision Matrix of Appendix-2

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	3,7.17,9	7,9,9	1,5.67,9	5,8.83,9	1,6.17,9	1,4.17,9	1,4.17,9	1,4.67,9	1,6.33,9	1,5.83,9	1,4.17,9	1,5.67,9	3,5.83,9	1,4.83,9	1,4.33,9
S2	7,9,9	1,6.33,9	1,6.83,9	1,6,9	1,6.83,9	1,6,9	1,4.83,9	3,6.67,9	1,5,9	1,5.17,9	1,4.83,9	3,6.67,9	1,5.67,9	1,4.33,9	1,5.5,9
S3	3,6.67,9	3,7,9	5,8.67,9	3,6.5,9	3,6.5,9	1,5.5,9	1,5,9	1,3.83,9	3,6.33,9	1,4.5,9	1,4,9	1,5.33,9	1,4.67,9	1,3.67,9	1,4.67,9
S4	3,7.17,9	3,6.33,9	3,6.33,9	3,7,9	3,7.33,9	3,7,9	1,5.67,9	3,6.67,9	1,4.83,9	1,7.17,9	1,5.5,9	3,6.33,9	1,6.33,9	1,5.33,9	3,6.33,9
S5	3,6.83,9	5,8.17,9	3,7.67,9	5,8,9	3,7.17,9	3,6,9	1,6.17,9	5,7.33,9	1,8,9	3,6.83,9	1,5.33,9	3,6.5,9	3,6.5,9	1,6.17,9	3,5.83,9
S6	1,5.67,9	1,6,9	3,7.17,9	1,6.5,9	1,5.67,9	1,6.67,9	1,5.67,9	1,4.17,9	1,4.67,9	1,7.33,9	1,5.67,9	3,6,9	3,6.83,9	1,4.5,9	3,7.17,9
S7	3,6.83,9	1,6.5,9	1,5.83,9	1,7.67,9	5,8,9	3,7.17,9	1,6.33,9	3,7,9	1,4.5,9	1,4.5,9	1,5.83,9	3,6.5,9	1,5.67,9	1,6.67,9	1,5.83,9
S8	3,7.33,9	5,8,9	1,7,9	3,7.33,9	3,7.33,9	1,5.67,9	1,6.5,9	3,7,9	1,6,9	1,5.83,9	1,5.33,9	3,7,9	3,6.17,9	1,6,9	1,4.83,9
S9	1,7,9	1,5.83,9	5,8.67,9	1,6,9	1,6.5,9	1,5.83,9	1,6.33,9	1,4,9	1,5.17,9	1,4.33,9	1,4.83,9	1,5.17,9	1,5.83,9	1,4,9	1,6.33,9
S10	5,8.67,9	3,6.83,9	1,7.33,9	3,7,9	3,7.17,9	1,6.33,9	1,6.33,9	5,8.33,9	1,5.67,9	5,7,9	1,6.67,9	5,7.33,9	3,6.67,9	1,5.67,9	3,6.5,9

The combined fuzzy decision matrix in Table 7 was derived by combining the fuzzy converted respondent data from Table B1-B12 in Appendix 2. Accordingly, Table 7 had to be normalised as part of ***Step 3***. The purpose of normalising each value in the combined decision matrix was to conform into standard value set. Normalized fuzzy Decision Matrix is presented in Table C under Appendix-3 and was obtained by using EQ-3. In ***Step-4***, the weighted normalised fuzzy matrix was prepared using EQ-4. Because of respondents' subjective opinions about individual strategies to overcome LSS barriers versus another to make an objective in terms of the impact of each barrier, a weighted normalised fuzzy matrix decision was obtained (Refer to Table D under Appendix-4 for calculations).

In ***Step-5***, the values for FPIS (A*) and FNIS (A^-) were calculated using EQ-5 and EQ-6, respectively (Refer to Table D in Appendix-4 for calculations). The purpose of calculating FPIS and FNIS was to provide a more reliable and straightforward method of ensuring that the chosen alternative is closer to the positive ideal solution than the ultimate negative ideal solution. As in ***Step-6***, the distances from FPIS and FNIS were calculated using EQ-7. The purpose of calculating distances was to check the distance of a selected alternative to a positive ideal solution and a negative ideal solution. Then, d_i^* and d_i^- were calculated using EQ-8 and EQ-9, respectively. The purpose of calculating was to demonstrate the overall distance of each alternative from positive and negative ideal solutions. The results are shown in Table 8 and Table 9.

Table 8: Distances from FPIS (A^*)

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	d_i^*
S1	1.604	0.000	1.955	0.000	1.066	1.122	0.323	1.172	0.675	0.479	0.699	0.644	0.445	0.543	1.116	**11.843**
S2	0.000	2.413	1.571	1.933	0.912	0.446	0.225	0.548	1.172	0.716	0.497	0.261	0.649	0.704	0.670	**12.717**
S3	1.785	1.674	0.000	1.372	0.735	0.636	0.196	1.415	0.776	0.924	0.745	0.762	0.970	0.895	0.978	**13.863**
S4	1.604	1.942	1.327	1.138	0.492	0.069	0.110	0.548	1.247	0.029	0.323	0.382	0.452	0.404	0.346	**10.413**
S5	1.723	0.769	0.822	0.416	0.517	0.427	0.035	0.335	0.000	0.197	0.375	0.323	0.162	0.139	0.520	**6.76**
S6	2.604	2.502	0.968	1.769	1.226	0.234	0.110	1.336	1.316	0.000	0.271	0.475	0.000	0.647	0.000	**13.458**
S7	1.723	2.356	1.887	1.431	0.000	0.000	0.023	0.436	1.386	0.924	0.225	0.323	0.649	0.000	0.535	**11.898**
S8	1.577	0.828	1.524	1.028	0.492	0.574	0.000	0.436	0.785	0.479	0.375	0.165	0.475	0.191	0.910	**9.839**
S9	2.196	2.566	0.000	1.933	0.995	0.507	0.023	1.387	1.137	0.987	0.497	0.827	0.586	0.814	0.369	**14.824**
S10	0.663	1.738	1.459	1.138	0.517	0.353	0.023	0.000	0.924	0.276	0.000	0.000	0.081	0.300	0.277	**7.749**

In Table 8 and Table 9, distances in each cell were derived from EQ-7, which involved subtracting that particular cell value in Table D under Appendix-4 with the A^* demonstrated for that particular column. Therefore, each cell in Table 8 and Table 9 represents the distance of each strategy from each barrier. This distance was interpreted as a negative ideal solution in Table 8 and a positive ideal solution in Table 9 from a relevant weighted normalised fuzzy number. Then, to find out d_i^* for a particular strategy, each row was calculated by adding up all the distances in a particular row.

Table 9: Distances from FNIS (A^-)

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	d_i^-
S1	1.023	2.566	0.000	1.933	0.219	0.000	0.000	0.248	0.710	0.508	0.046	0.196	0.649	0.352	0.000	**8.45**
S2	2.604	0.242	0.577	0.000	0.473	0.687	0.098	0.870	0.214	0.271	0.248	0.574	0.445	0.191	0.450	**7.944**
S3	0.821	0.894	1.955	0.676	0.503	0.491	0.127	0.000	0.806	0.064	0.000	0.069	0.381	0.000	0.139	**6.926**
S4	1.023	0.680	0.707	0.813	0.761	1.053	0.214	0.870	0.139	0.958	0.421	0.446	0.727	0.491	0.773	**10.076**
S5	0.882	1.805	1.164	1.649	0.726	0.699	0.289	1.088	1.386	0.847	0.370	0.507	0.894	0.756	0.602	**13.664**
S6	0.000	0.098	0.988	0.231	0.000	0.918	0.214	0.081	0.069	0.987	0.473	0.353	1.042	0.248	1.116	**6.818**
S7	0.882	0.341	0.092	0.831	1.226	1.122	0.300	0.984	0.000	0.064	0.520	0.507	0.445	0.895	0.589	**8.798**
S8	1.060	1.738	0.664	0.906	0.761	0.554	0.323	0.984	0.600	0.508	0.370	0.699	0.687	0.704	0.208	**10.766**

S9	0.704	0.000	1.955	0.000	0.329	0.624	0.300	0.029	0.248	0.000	0.248	0.000	0.525	0.081	0.762	**5.805**
S10	2.025	0.828	0.797	0.813	0.726	0.785	0.300	1.415	0.462	0.932	0.745	0.827	0.967	0.595	0.841	**13.058**

Following those steps, the overall distance of each strategy from positive and negative ideal solutions for overcoming LSS barriers in the construction SMEs was determined.

In the final step (***Step-7***), the closeness coefficient ($\boldsymbol{CC_i}$) for each alternative/strategy was calculated using EQ-10. The purpose of calculating the closeness coefficient was to establish a quantitative criteria or relationship between unrelated variables. As in this study, $\boldsymbol{CC_i}$ demonstrated comparable quantitative criteria of criticality of strategies to overcome LSS barriers in construction SMEs based on the impact of each LSS barrier and the opinions of each expert. Subsequently, each strategy was ranked based on criticality in Table 10.

Table 10: Final Ranking of LSS strategies based on criticality

Strategy To Overcome LSS Barriers in Construction SMES	$\boldsymbol{d_i^*}$	$\boldsymbol{d_i^-}$	$\boldsymbol{CC_i}$ (Using EQ-10)	Rank of The LSS Strategy Based on Criticality
S1	11.843	8.45	**0.41640**	**6**
S2	12.717	7.944	**0.38449**	**7**
S3	13.863	6.926	**0.33316**	**9**
S4	10.413	10.076	**0.49178**	**4**
S5	6.76	13.664	**0.66902**	**1**
S6	13.458	6.818	**0.33626**	**8**
S7	11.898	8.798	**0.42511**	**5**
S8	9.839	10.766	**0.52249**	**3**
S9	14.824	5.805	**0.28140**	**10**
S10	7.749	13.058	**0.62758**	**2**

The fuzzy TOPSIS method has established the ascending criticality based on the ascending order of ratio for d_i^- relative to the distance between d_i^* and d_i^-. Therefore, in Table 10, the ranking of strategies was sorted out by considering higher $\boldsymbol{CC_i}$ values. It was derived that the strategy of hiring LSS experts for projects (black-belts, green-belts), discussed by Yadav *et al.* (2018) and Bakar *et al.* (2015), is the most effective strategy to implement LSS construction in a SME context. According to the calculation, the strategy-S5 can overcome most identified LSS implementation barriers under the construction SME context. As an illustration, the top management of contraction SMEs may find it challenging to allocate time for LSS training sessions due to workload pressures. Therefore, the most effective strategy for top management is to hire LSS experts as supervising employees and provide LSS training to subordinates through on-site experiences. Other critical strategies to overcome LSS barriers in construction SMEs were identified as establishing leadership and management training, which was acknowledged by Ranadewa *et al.* (2021); establishing LSS training and proper staff selection for training and establishing a strategic planning committee, which were noted by Gaikwad *et al.* (2020); and establishing a reward recognition system, which was discussed by Laureani and Antony (2018). According to the list of the most effective strategies, it is apparent that top management in construction SMEs are required to exercise discretion and patience when implementing LSS as resource constraints may pose a challenge. Nevertheless, the benefits of LSS can be realised over time. For instance, construction SMEs should initially prioritize appropriate leadership and management training programs, as top management's clear and confident decisions will greatly influence the selection of staff for LSS training. Following a comprehensive evaluation, the authors have identified three emerging themes from the ranking of the most effective strategies, namely: human resource management and training, governance and rewards, and financial stability (as shown in Figure 4).

Figure 4: Three main themes of effective strategies for LSS implementation in construction SMEs

The ranking of strategies derived from the study highlights the importance of implementing LSS strategies that focus on human resource management, governance and rewards, and financial stability. The results indicate that construction SMEs should prioritise the acquisition of knowledge, education, and intellectual skills, along with top management decisions and governance, rather than relying on additional funding or government loans. This approach is more financially feasible for construction SMEs who are considering implementing LSS.

Before embarking on the implementation of LSS, construction SMEs must address the critical barriers and focus on executing the most critical strategies. Table 10 provides an overview of the most critical strategies to overcome barriers in the implementation of LSS, considering the limited resources available to most construction SMEs. In order to ensure the successful and effective implementation of LSS, SMEs should select the most significant strategies from the ranking list to overcome the majority of the LSS implementation barriers.

Conclusions and way forward

This study examined the potential of LSS as a solution for alleviating quality management issues in construction SMEs. The study aimed to identify fifteen barriers and ten strategies for successful LSS implementation, evaluating their criticality. This study represents a novel approach in offering a roadmap for construction SMEs to adopt LSS and the findings were refined through the application of the fuzzy TOPSIS method. The results indicated that "lack of specialised LSS training" was the most critical barrier to implementation, followed by "insufficient involvement of top management" and "unawareness of LSS needs and benefits." The most effective strategies for overcoming the barriers of LSS implementation in construction SMEs were found to be "hiring LSS experts for the projects," followed by "establishing leadership training," "forming a strategic planning committee," and "establishing a reward system." Methodologically, this research demonstrated the suitability of the fuzzy TOPSIS method in determining the criticality of barriers and strategies for LSS implementation. Notably, the study makes a seminal contribution to the literature by offering construction SMEs practical advice on overcoming the most critical barriers and implementing LSS through effective strategies. The focus on human resource management and training highlights the importance of these factors for successful LSS implementation in construction SMEs, as opposed to simply relying on financial support. In terms of practical application, the findings of this study can inform a structured LSS implementation in construction SMEs, taking into account the unique characteristics of these organisations. However, it is crucial to acknowledge the limitations of this study, which only considered the barriers and strategies in the pre-implementation stage of LSS in a construction SME context. Hence, further research is required to address the implementation and post-implementation stages, such as identifying the most appropriate LSS tools for construction SMEs and developing a framework for effective LSS implementation in the construction industry.

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Declaration of competing interest

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Appendices

Fuzzy Converted Response Matrixes of Expert Survey for impact of Each LSS Implementation Barriers

APPENDIX 1

Table A: Fuzzy Response Matrix for Weightage of Each LSS Implementation Barrier

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
LSSE-1	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	3,5,7	1,3,5	7,9,9	7,9,9	3,5,7	3,5,7	7,9,9	3,5,7	5,7,9	3,5,7
LSSE-2	7,9,9	7,9,9	5,7,9	5,7,9	3,5,7	3,5,7	1,1,3	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	1,3,5	3,5,7
LSSE-3	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	1,1,3	1,3,5	5,7,9	3,5,7	1,3,5	3,5,7	7,9,9	1,3,5	5,7,9
LSSE-4	7,9,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	1,1,3	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9
LSSE-5	5,7,9	7,9,9	7,9,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	3,5,7	1,3,5	5,7,9	3,5,7	5,7,9	5,7,9
LSSE-6	7,9,9	7,9,9	5,7,9	7,9,9	3,5,7	5,7,9	1,1,3	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9
LSSE-7	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	1,1,3	3,5,7	5,7,9	5,7,9	1,3,5	3,5,7	7,9,9	3,5,7	5,7,9
LSSE-8	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	3,5,7	1,3,5	1,3,5	3,5,7	3,5,7	3,5,7	1,3,5	5,7,9	1,3,5	3,5,7
LSSE-9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	7,9,9	7,9,9	5,7,9	3,5,7	7,9,9	5,7,9	7,9,9	5,7,9
LSSE-10	7,9,9	7,9,9	5,7,9	7,9,9	3,5,7	5,7,9	1,3,5	3,5,7	3,5,7	3,5,7	1,3,5	3,5,7	5,7,9	3,5,7	5,7,9
LSSE-11	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,1,3	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	1,3,5	1,3,5
LSSE-12	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	1,1,3	1,3,5	3,5,7	1,3,5	3,5,7	3,5,7	5,7,9	1,1,3	3,5,7
Allocated weightage using EQ-1	**5,8.17,9**	**5,8.33,9**	**5,7.67,9**	**5,8,9**	**3,6.33,9**	**1,5.67,9**	**1,2.17,7**	**1,4.83,9**	**3,6.17,9**	**1,5.17,9**	**1,4.33,7**	**1,5.67,9**	**3,7,9**	**1,4.67,9**	**1,6,9**

Fuzzy Converted Response Matrixes of Expert Survey for impact of Each LSS Strategy on Overcoming LSS Implementation Barriers

APPENDIX 2

Table B1: Fuzzy Response Matrix from LSSE-1

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	7,9,9	7,9,9	3,5,7	5,7,9	3,5,7	1,3,5	1,3,5	1,3,5	5,7,9	3,5,7	1,1,3	5,7,9	3,5,7	5,7,9	3,5,7
S2	7,9,9	1,1,3	1,3,5	1,1,3	1,3,5	5,7,9	3,5,7	5,7,9	1,1,3	1,1,3	1,3,5	3,5,7	1,3,5	5,7,9	1,3,5
S3	3,5,7	7,9,9	5,7,9	7,9,9	5,7,9	1,3,5	1,3,5	1,3,5	5,7,9	1,1,3	1,3,5	3,5,7	1,1,3	3,5,7	1,3,5
S4	7,9,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	1,1,3	5,7,9	1,1,3	1,3,5	1,1,3	5,7,9	1,1,3	7,9,9	3,5,7
S5	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	1,1,3	7,9,9	1,1,3	5,7,9	1,1,3	7,9,9	5,7,9	7,9,9	5,7,9
S6	1,3,5	1,1,3	3,5,7	1,3,5	1,1,3	1,1,3	1,3,5	3,5,7	1,1,3	1,3,5	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7
S7	3,5,7	1,1,3	1,3,5	1,1,3	5,7,9	3,5,7	3,5,7	5,7,9	1,1,3	3,5,7	3,5,7	3,5,7	1,3,5	5,7,9	3,5,7
S8	5,7,9	7,9,9	5,7,9	3,5,7	3,5,7	1,3,5	1,1,3	3,5,7	1,1,3	3,5,7	1,3,5	5,7,9	3,5,7	5,7,9	3,5,7
S9	5,7,9	7,9,9	5,7,9	5,7,9	1,3,5	3,5,7	1,3,5	3,5,7	5,7,9	3,5,7	1,3,5	1,3,5	1,3,5	3,5,7	3,5,7
S10	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	7,9,9	3,5,7

Table B2: Fuzzy Response Matrix from LSSE-2

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	3,5,7	7,9,9	1,3,5	7,9,9	7,9,9	1,1,3	1,3,5	3,5,7	5,7,9	5,7,9	1,1,3	1,3,5	3,5,7	1,1,3	1,3,5
S2	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	3,5,7	3,5,7	3,5,7	1,1,3	3,5,7	3,5,7	3,5,7	3,5,7
S3	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	1,3,5	3,5,7	3,5,7	1,3,5	5,7,9	3,5,7	3,5,7	3,5,7
S4	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	3,5,7
S5	3,5,7	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	3,5,7
S6	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9
S7	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	5,7,9	5,7,9	3,5,7	5,7,9	1,3,5
S8	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	1,3,5	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7
S9	5,7,9	3,5,7	7,9,9	3,5,7	5,7,9	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	1,3,5	1,3,5	1,3,5
S10	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	3,5,7

Table B3: Fuzzy Response Matrix from LSSE-3

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	5,7,9	7,9,9	5,7,9	7,9,9	3,5,7	1,1,3	1,3,5	1,3,5	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	3,5,7	1,1,3
S2	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	1,3,5	3,5,7
S3	5,7,9	5,7,9	7,9,9	5,7,9	3,5,7	3,5,7	5,7,9	1,3,5	5,7,9	3,5,7	1,3,5	3,5,7	3,5,7	1,1,3	1,3,5
S4	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9
S5	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7	3,5,7
S6	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	7,9,9	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9
S7	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	1,3,5	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9
S8	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	7,9,9	5,7,9	3,5,7	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	1,3,5
S9	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9
S10	7,9,9	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	7,9,9	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9

Table B4: Fuzzy Response Matrix fromLSSE-4

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	3,5,7	3,5,7	3,5,7	5,7,9	5,7,9	1,3,5	3,5,7	3,5,7	5,7,9	1,3,5
S2	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7
S3	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	3,5,7	1,3,5	1,3,5	5,7,9	3,5,7	1,3,5	3,5,7
S4	5,7,9	5,7,9	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	3,5,7	7,9,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9
S5	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7
S6	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	3,5,7	5,7,9	3,5,7	3,5,7	5,7,9	1,3,5	5,7,9
S7	5,7,9	5,7,9	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7
S8	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	1,3,5
S9	5,7,9	3,5,7	7,9,9	5,7,9	5,7,9	3,5,7	5,7,9	1,3,5	1,3,5	1,3,5	1,3,5	5,7,9	5,7,9	1,3,5	1,3,5
S10	7,9,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9

Table B5: Fuzzy Response Matrix from LSSE-5

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	5,7,9	7,9,9	1,3,5	7,9,9	3,5,7	3,5,7	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9
S2	7,9,9	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	5,7,9
S3	3,5,7	5,7,9	7,9,9	5,7,9	3,5,7	5,7,9	1,3,5	1,3,5	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9
S4	3,5,7	5,7,9	5,7,9	3,5,7	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	7,9,9
S5	5,7,9	7,9,9	3,5,7	5,7,9	7,9,9	3,5,7	3,5,7	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	3,5,7	5,7,9	7,9,9
S6	1,3,5	5,7,9	7,9,9	3,5,7	1,3,5	5,7,9	3,5,7	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	7,9,9
S7	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	1,3,5	7,9,9	3,5,7	5,7,9	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9
S8	3,5,7	5,7,9	1,3,5	3,5,7	7,9,9	7,9,9	5,7,9	7,9,9	5,7,9	3,5,7	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9
S9	1,3,5	3,5,7	5,7,9	1,3,5	1,3,5	1,3,5	1,3,5	1,3,5	7,9,9	1,3,5	3,5,7	1,3,5	5,7,9	3,5,7	7,9,9
S10	5,7,9	5,7,9	1,3,5	5,7,9	3,5,7	1,3,5	3,5,7	5,7,9	3,5,7	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9

Table B6: Fuzzy Response Matrix from LSSE-6

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	5,7,9	7,9,9	5,7,9	7,9,9	3,5,7	3,5,7	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	3,5,7
S2	7,9,9	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	1,3,5	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7
S3	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	1,3,5	3,5,7	3,5,7	1,3,5	1,3,5
S4	5,7,9	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	3,5,7	5,7,9	3,5,7	7,9,9	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9
S5	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7
S6	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	1,3,5	3,5,7	3,5,7	7,9,9	3,5,7	3,5,7	5,7,9	1,3,5	5,7,9
S7	5,7,9	5,7,9	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	3,5,7	1,3,5	3,5,7	3,5,7	3,5,7	5,7,9	1,3,5
S8	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	3,5,7	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9
S9	7,9,9	3,5,7	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9
S10	7,9,9	3,5,7	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9

Table B7: Fuzzy Response Matrix from LSSE-7

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
S1	5,7,9	7,9,9	1,3,5	7,9,9	1,3,5	3,5,7	3,5,7	1,1,3	3,5,7	1,3,5	1,3,5	5,7,9	3,5,7	1,1,3	1,3,5
S2	7,9,9	3,5,7	5,7,9	3,5,7	5,7,9	1,3,5	1,3,5	5,7,9	3,5,7	3,5,7	1,3,5	5,7,9	3,5,7	1,1,3	5,7,9
S3	3,5,7	5,7,9	7,9,9	3,5,7	3,5,7	1,3,5	3,5,7	3,5,7	5,7,9	1,3,5	1,1,3	1,3,5	1,3,5	1,3,5	5,7,9
S4	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	1,3,5	5,7,9	5,7,9	3,5,7	5,7,9	1,1,3	3,5,7
S5	5,7,9	5,7,9	5,7,9	7,9,9	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9	5,7,9	3,5,7	3,5,7	3,5,7	1,3,5	3,5,7
S6	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	1,3,5	3,5,7	5,7,9	5,7,9	3,5,7	3,5,7	1,1,3	5,7,9
S7	3,5,7	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9
S8	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	1,3,5	3,5,7	3,5,7	1,3,5	3,5,7
S9	5,7,9	1,3,5	7,9,9	3,5,7	5,7,9	3,5,7	5,7,9	1,3,5	1,3,5	1,3,5	1,3,5	1,3,5	3,5,7	1,1,3	5,7,9
S10	7,9,9	3,5,7	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	1,1,3	3,5,7

Table B8: Fuzzy Response Matrix from LSSE-8

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
S1	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	1,3,5	1,3,5	1,1,3	3,5,7	3,5,7	1,3,5	3,5,7	3,5,7	1,3,5	5,7,9
S2	7,9,9	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	3,5,7	1,3,5	5,7,9	5,7,9	1,3,5	3,5,7
S3	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	3,5,7	1,3,5	1,3,5	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7	1,3,5	1,3,5
S4	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	3,5,7
S5	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9
S6	5,7,9	3,5,7	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	5,7,9
S7	5,7,9	3,5,7	3,5,7	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	1,3,5	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9	1,3,5
S8	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	5,7,9	7,9,9	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7
S9	5,7,9	3,5,7	7,9,9	3,5,7	5,7,9	3,5,7	3,5,7	1,3,5	5,7,9	3,5,7	3,5,7	3,5,7	1,3,5	1,3,5	3,5,7
S10	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	3,5,7

Table B9: Fuzzy Response Matrix from LSSE-9

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
S1	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9
S2	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9
S3	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9
S4	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9
S5	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	7,9,9	5,7,9
S6	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9
S7	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9
S8	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9
S9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	7,9,9
S10	7,9,9	7,9,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	7,9,9	7,9,9	7,9,9	7,9,9	7,9,9

Table B10: Fuzzy Response Matrix from LSSE-10

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
S1	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	3,5,7	1,3,5
S2	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	3,5,7	3,5,7	3,5,7
S3	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	5,7,9	3,5,7	1,3,5	1,3,5	1,3,5	1,3,5	5,7,9
S4	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	7,9,9	1,3,5	3,5,7	5,7,9	1,3,5	3,5,7
S5	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9	5,7,9	1,3,5	5,7,9	3,5,7	3,5,7	3,5,7
S6	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	1,3,5	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7	7,9,9
S7	5,7,9	5,7,9	3,5,7	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7
S8	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	1,3,5	3,5,7	7,9,9	3,5,7	3,5,7	3,5,7
S9	5,7,9	3,5,7	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,3,5	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	5,7,9
S10	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9

Table B11: Fuzzy Response Matrix from LSSE-11

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	1,3,5	5,7,9	3,5,7	1,3,5	5,7,9	3,5,7	5,7,9	5,7,9	1,3,5	3,5,7
S2	7,9,9	5,7,9	5,7,9	3,5,7	5,7,9	1,3,5	3,5,7	5,7,9	3,5,7	1,3,5	3,5,7	5,7,9	5,7,9	1,3,5	3,5,7
S3	5,7,9	3,5,7	7,9,9	3,5,7	5,7,9	3,5,7	5,7,9	1,3,5	5,7,9	3,5,7	3,5,7	3,5,7	1,3,5	1,3,5	1,3,5
S4	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	3,5,7	5,7,9
S5	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	5,7,9	5,7,9	7,9,9	3,5,7	1,3,5	3,5,7	5,7,9	1,3,5	3,5,7
S6	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,1,3	1,3,5	7,9,9	3,5,7	5,7,9	5,7,9	1,1,3	3,5,7
S7	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	5,7,9	1,3,5	1,3,5	1,1,3	5,7,9	3,5,7	1,3,5	5,7,9
S8	5,7,9	7,9,9	3,5,7	5,7,9	5,7,9	1,3,5	5,7,9	5,7,9	3,5,7	5,7,9	3,5,7	5,7,9	5,7,9	1,3,5	1,1,3
S9	5,7,9	3,5,7	7,9,9	3,5,7	5,7,9	3,5,7	5,7,9	1,3,5	1,3,5	3,5,7	3,5,7	5,7,9	5,7,9	1,1,3	5,7,9
S10	7,9,9	5,7,9	3,5,7	5,7,9	7,9,9	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9

Table B12: Fuzzy Response Matrix from LSSE-12

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
S1	5,7,9	7,9,9	3,5,7	7,9,9	3,5,7	3,5,7	1,1,3	1,3,5	3,5,7	1,3,5	1,3,5	1,3,5	3,5,7	1,3,5	1,3,5
S2	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	1,1,3	5,7,9	3,5,7	3,5,7	3,5,7	5,7,9	5,7,9	1,1,3	3,5,7
S3	5,7,9	5,7,9	7,9,9	3,5,7	3,5,7	3,5,7	1,1,3	1,3,5	3,5,7	3,5,7	1,3,5	3,5,7	3,5,7	1,1,3	1,1,3
S4	5,7,9	3,5,7	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7
S5	3,5,7	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	7,9,9	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	3,5,7
S6	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	1,1,3	1,3,5	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7	5,7,9
S7	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	1,3,5	1,3,5	3,5,7	3,5,7	3,5,7	3,5,7	7,9,9
S8	5,7,9	5,7,9	5,7,9	5,7,9	5,7,9	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7	1,3,5	3,5,7	3,5,7	1,1,3	1,3,5
S9	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	1,3,5	1,3,5	1,3,5	3,5,7	5,7,9	1,3,5	5,7,9
S10	5,7,9	5,7,9	5,7,9	3,5,7	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	5,7,9	3,5,7	5,7,9	3,5,7	1,1,3	3,5,7

Normalized Decision Matrix of Fuzzy Converted Responses **APPENDIX 3**

Table C: Normalized Fuzzy Decision Matrix

Weightage	5,8.17,9	5,8.33,9	5,7.67,9	5,8,9	3,6.33,9	1,5.67,9	1,2.17,7	1,4.83,9
	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**
S1	0.33,0.80,1	0.78,1.00,1	0.11,0.63,1	0.56,0.98,1	0.11,0.69,1	0.11,0.46,1	0.11,0.46,1	0.11,0.52,1
S2	0.78,1.00,1	0.11,0.70,1	0.11,0.76,1	0.11,0.67,1	0.11,0.76,1	0.11,0.67,1	0.11,0.54,1	0.33,0.74,1
S3	0.33,0.74,1	0.33,0.78,1	0.56,0.96,1	0.33,0.72,1	0.33,0.72,1	0.11,0.61,1	0.11,0.56,1	0.11,0.43,1
S4	0.33,0.80,1	0.33,0.70,1	0.33,0.70,1	0.33,0.78,1	0.33,0.81,1	0.33,0.78,1	0.11,0.63,1	0.33,0.74,1
S5	0.33,0.76,1	0.56,0.91,1	0.33,0.85,1	0.56,0.89,1	0.33,0.80,1	0.33,0.67,1	0.11,0.69,1	0.56,0.81,1
S6	0.11,0.63,1	0.11,0.67,1	0.33,0.80,1	0.11,0.72,1	0.11,0.63,1	0.11,0.74,1	0.11,0.63,1	0.11,0.46,1
S7	0.33,0.76,1	0.11,0.72,1	0.11,0.65,1	0.11,0.85,1	0.56,0.89,1	0.33,0.80,1	0.11,0.70,1	0.33,0.78,1
S8	0.33,0.81,1	0.56,0.89,1	0.11,0.78,1	0.33,0.81,1	0.33,0.81,1	0.11,0.63,1	0.11,0.72,1	0.33,0.78,1
S9	0.11,0.78,1	0.11,0.65,1	0.56,0.96,1	0.11,0.67,1	0.11,0.72,1	0.11,0.65,1	0.11,0.70,1	0.11,0.44,1
S10	0.56,0.96,1	0.33,0.76,1	0.11,0.81,1	0.33,0.78,1	0.33,0.80,1	0.11,0.70,1	0.11,0.70,1	0.56,0.93,1

Weightage	3,6.17,9	1,5.17,9	1,4.33,7	1,5.67,9	3,7,9	1,4.67,9	1,6,9
	B9	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
S1	0.11,0.70,1	0.11,0.65,1	0.11,0.46,1	0.11,0.63,1	0.33,0.65,1	0.11,0.54,1	0.11,0.48,1
S2	0.11,0.56,1	0.11,0.57,1	0.11,0.54,1	0.33,0.74,1	0.11,0.63,1	0.11,0.48,1	0.11,0.61,1
S3	0.33,0.70,1	0.11,0.50,1	0.11,0.44,1	0.11,0.59,1	0.11,0.52,1	0.11,0.41,1	0.11,0.52,1
S4	0.11,0.54,1	0.11,0.80,1	0.11,0.61,1	0.33,0.70,1	0.11,0.70,1	0.11,0.59,1	0.33,0.70,1
S5	0.11,0.89,1	0.33,0.76,1	0.11,0.59,1	0.33,0.72,1	0.33,0.72,1	0.11,0.69,1	0.33,0.65,1
S6	0.11,0.52,1	0.11,0.81,1	0.11,0.63,1	0.33,0.67,1	0.33,0.76,1	0.11,0.50,1	0.33,0.80,1
S7	0.11,0.50,1	0.11,0.50,1	0.11,0.65,1	0.33,0.72,1	0.11,0.63,1	0.11,0.74,1	0.11,0.65,1
S8	0.11,0.67,1	0.11,0.65,1	0.11,0.59,1	0.33,0.78,1	0.33,0.69,1	0.11,0.67,1	0.11,0.54,1
S9	0.11,0.57,1	0.11,0.48,1	0.11,0.54,1	0.11,0.57,1	0.11,0.65,1	0.11,0.44,1	0.11,0.70,1
S10	0.11,0.63,1	0.56,0.78,1	0.11,0.74,1	0.56,0.81,1	0.33,0.74,1	0.11,0.63,1	0.33,0.72,1

Weighted Normalized Decision Matrix of Fuzzy Converted Responses

APPENDIX 4

Table D: Weighted Normalized Fuzzy Decision Matrix

	B1	B2	B3	B4	B5	B6	B7	B8
S1	1.65,6.54,9	3.90,8.33,9	0.55,4.83,9	2.80,7.84,9	0.33,4.37,9	0.11,2.61,9	0.11,1.00,7	0.11,2.51,9
S2	3.90,8.17,9	0.55,5.83,9	0.55,5.83,9	0.55,5.36,9	0.33,4.81,9	0.11,3.80,9	0.11,1.17,7	0.33,3.57,9
S3	1.65,6.05,9	1.65,6.50,9	2.80,7.36,9	1.65,5.76,9	0.99,4.56,9	0.11,3.46,9	0.11,1.22,7	0.11,2.08,9
S4	1.65,6.54,9	1.65,5.83,9	1.65,5.37,9	1.65,6.24,9	0.99,5.13,9	0.33,4.42,9	0.11,1.37,7	0.33,3.57,9
S5	1.65,6.21,9	2.80,7.58,9	1.65,6.52,9	2.80,7.12,9	0.99,5.06,9	0.33,3.80,9	0.11,1.50,7	0.56,3.91,9
S6	0.55,5.15,9	0.55,5.58,9	1.65,6.14,9	0.55,5.76,9	0.33,3.99,9	0.11,4.20,9	0.11,1.37,7	0.11,2.22,9
S7	1.65,6.21,9	0.55,6.00,9	0.55,4.99,9	0.55,6.80,9	1.68,5.63,9	0.33,4.54,9	0.11,1.52,7	0.33,3.77,9
S8	1.65,6.62,9	2.80,7.41,9	0.55,5.98,9	1.65,6.48,9	0.99,5.13,9	0.11,3.57,9	0.11,1.56,7	0.33,3.77,9
S9	0.55,6.37,9	0.55,5.41,9	2.80,7.36,9	0.55,5.36,9	0.33,4.56,9	0.11,3.69,9	0.11,1.52,7	0.11,2.13,9
S10	2.80,7.84,9	1.65,6.33,9	0.55,6.21,9	1.65,6.24,9	0.99,5.06,9	0.11,3.97,9	0.11,1.52,7	0.56,4.49,9
A*	3.90,8.17,9	3.90,8.33,9	2.80,7.36,9	2.80,7.84,9	1.68,5.63,9	0.33,4.54,9	0.11,1.56,7	0.56,4.49,9
A^-	0.55,5.15,9	0.55,5.41,9	0.55,4.83,9	0.55,5.36,9	0.33,3.99,9	0.11,2.61,9	0.11,1.00,7	0.11,2.08,9

	B9	B10	B11	B12	B13	B14	B15
S1	0.33,4.32,9	0.11,3.36,9	0.11,1.99,7	0.11,3.57,9	0.99,4.55,9	0.11,2.52,9	0.11,2.88,9
S2	0.33,3.46,9	0.11,2.95,9	0.11,2.34,7	0.33,4.20,9	0.33,4.41,9	0.11,2.24,9	0.11,3.66,9
S3	0.99,4.32,9	0.11,2.59,9	0.11,1.91,7	0.11,3.35,9	0.33,3.64,9	0.11,1.91,9	0.11,3.12,9
S4	0.33,3.33,9	0.11,4.14,9	0.11,2.64,7	0.33,3.97,9	0.33,4.90,9	0.11,2.76,9	0.33,4.20,9
S5	0.33,5.49,9	0.33,3.93,9	0.11,2.55,7	0.33,4.08,9	0.99,5.04,9	0.11,3.22,9	0.33,3.90,9
S6	0.33,3.21,9	0.11,4.19,9	0.11,2.73,7	0.33,3.80,9	0.99,5.32,9	0.11,2.34,9	0.33,4.80,9
S7	0.33,3.09,9	0.11,2.59,9	0.11,2.81,7	0.33,4.08,9	0.33,4.41,9	0.11,3.46,9	0.11,3.90,9
S8	0.33,4.13,9	0.11,3.36,9	0.11,2.55,7	0.33,4.42,9	0.99,4.83,9	0.11,3.13,9	0.11,3.24,9
S9	0.33,3.52,9	0.11,2.48,9	0.11,2.34,7	0.11,3.23,9	0.33,4.55,9	0.11,2.05,9	0.11,4.20,9
S10	0.33,3.89,9	0.56,4.03,9	0.11,3.20,7	0.56,4.59,9	0.99,5.18,9	0.11,2.94,9	0.33,4.32,9
A*	0.33,5.49,9	0.11,4.19,9	0.11,3.20,7	0.56,4.59,9	0.99,5.32,9	0.11,3.46,9	0.33,4.80,9
A^-	0.33,3.09,9	0.11,2.48,9	0.11,1.91,7	0.11,3.23,9	0.33,3.64,9	0.11,1.91,9	0.11,2.88,9

Note: the values of each cell in Table D were derived from multiplying values of Table C in Appendix 3 and barrier weightages of columns extracted from Table A in Appendix-1