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A Decision Methodology for Six-Sigma Implementation in the Nigerian Small and Medium Scale Enterprise (SME)

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ABSTRACT

Businesses are in a constant quest for solutions to their organizational needs, and many enterprises have adopted Six Sigma (SS) as the most suited approach for adequately matching cost, quality, and delivery. However, researchers in the last two decades have thus been trying to overcome difficulties and constraints associated with SS implementation. In Nigeria, SS is unpopular, and there is a shortage of studies on the implementation of SS in SMEs. The present research was motivated by the lack of research on SS critical success factor (CSF) appraisal in Nigeria, and none in the literature has discreetly described the criticality of the SS implementation factors in Small-Medium Enterprise (SMEs). Therefore, this study proposed to develop a suitable hierarchical model and illustrate the interrelationships between factors that facilitate SS implementation in Small and Medium Enterprises (SMEs) using an integrated approach that consists of interval-valued neutrosophic analytical hierarchy process (IVN-AHP) and criteria importance through inter-criteria correlation (CRITIC). The investigated success factors were conceptualized into four aspects and verified with the aid of the inputs of experts within the small and medium enterprises in Nigeria. Primarily, the content of the work is structured and streamlined perfectly to awaken curiosity among researchers who intend to explore the SS implementation success factors further.

1. Introduction

Astute businesses can make significant progress in satisfying customer needs and preserving their financial leverage by methodically determining the causes of issues and modifying internal procedures. Recent studies have documented wide applications of Six Sigma techniques in improving processes in manufacturing and transactional firms [1]. Many sectors can benefit from the application of the SS technique; nevertheless, attaining the intended outcomes and comprehending the purpose of the implementation are essential [2]. Although implementing Six Sigma in small and medium-sized enterprises can be extremely challenging, when done properly, it can be advantageous [3]. In addition, [4] believes that Six Sigma's technical complexity makes it unsuitable for SMEs. Furthermore, there are several assertions that SMEs lack the economies of scale and resource availability that benefit their larger counterparts [5, 6]. It is important to remember that SMEs are prevalent in developing nations and are essential to regional economic development. They significantly contribute to the creation of jobs, the reduction of poverty, and economic expansion [7]. But when compared to industrialized countries, they also face a variety of

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challenges such as capital problems, institutional weaknesses, limited capacities, brittle structures, lack of technological know-how, and funding that make it difficult for them to survive and thrive as businesses [8]. Comparably, in Nigeria, SMEs face a variety of internal and external challenges, such as hard competition from larger businesses, a lack of working capital, trouble locating raw materials, low-capacity utilization, a lack of management strategies, low operator education, and severe financial difficulties [9; 10]. There isn't enough data in the academic literature about the successful application of Six Sigma practice in Micro, Small, and Medium-Sized Enterprises (MSMEs) to support and offer a road map for doing so [11]. Furthermore, because small businesses encounter several obstacles, the application of SS in Micro, Small, and Medium-Sized Enterprises (MSMEs) in developing nations is restricted. [11; 12] and the level of repeatability for which SS was designed is frequently lacking in SMEs' production processes [13]. Thus, during the past 20 years, researchers have been working to overcome obstacles and limitations related to the implementation of SS. According to [14; 15], many important variables must be met for Six Sigma to be successful in SMEs. Prior research has found a few critical aspects that impact SME success, and it is necessary to identify a few important variables that serve as growth drivers [16; 17]. SS is not well-liked in Nigeria, and there aren't many studies on how SS is applied in SMEs. The dearth of literature on SS critical success factor (CSF) appraisal in Nigeria and the absence of any research that specifically describes the criticality of SS implementation factors in small and medium-sized enterprises (SMEs) served as the impetus for this study. Consequently, the following are the study's precise objectives:

1. Identify SS implementation CSFs that are relevant in the Small- medium Enterprise.
2. To prioritize and rank these factors based on their level of influence, and significance.
3. To recommend strategies for a wider application and acceptance of the SS approach in Nigerian SMEs.

This study identified and categorized twenty-four important SS critical implementation success factors into social, organizational, knowledge, and project-based (SKOP) dimensions. Based on the views of relevant stakeholders in the Nigerian industry, an integrated strategy comprising an interval-valued neutrosophic analytical hierarchy process (IVN-AHP) and criteria importance through inter-criteria correlation (CRITIC) was utilized to examine the identified SS CSFs in SMEs. This study adds to the literature on SS adoption in African emerging markets, as there aren't many studies that are similar to the current body of work, focusing on small and medium-sized businesses in Nigeria.

2. Literature Review

This section presents an overview of the recent studies on Six Sigma Implementation Critical Success Factors, applications of SS strategy on Small-and-medium scale enterprises and the use of MCDM methods in SS studies.

2.1. Recent Studies on Six Sigma Implementation Critical Success Factors

SS is a generic solution and its application strategies are always novel, and various business processes have successfully implemented this methodology. A uniform way of implementing SS techniques is not explicitly stated in the extant literature, other than the typical five-phase framework of DMAIC. However, to implement SS, some factors are critical and can influence the success of any particular adventure [18; 19]. Most of the recent studies on SS applications have focused on critical success factors for facilitating the implementation of SS in terms of classification and prioritization in different industries. For example, a model of critical success factors of SS was built for Indonesian small and medium industries and their relation to industry performance was ascertained [20]. The method used in this study is Structural Equation Modeling (SEM) based on Partial Least Square (PLS) by using SmartPLS software. This study uses data from Indonesian small and medium industries that have implemented Six Sigma. The results of the study indicate that a critical success factor that has a positive impact on successful SS implementation is the involvement and commitment to top management, training and education, cultural change, and industrial infrastructure. Generally, successful determination of the key factors that affect the output will help in managing as well as optimization of the process output [18]. In recent times, a review study on the CFs for various process improvement techniques including SS strategies was conducted, and vital CFs were stratified from the trivial ones and the ranked ones [20]. The study outcome revealed the most important factors are top management commitment, training, and education, cultural change, linking SS to customer, linking SS to supplier, organizational infrastructure, linking SS to business goals, project management skills, communication, understanding tools and techniques, teamwork and project prioritization. [21; 22] investigate the mediating effect of absorbing capacity on the link between SS's critical success factors and productivity improvement. The result findings revealed that absorbing capacity significantly mediates the influences of training & education, top management commitment and involvement, project selection, and organizational resources. [23] analyzed SS implementation CSFs in an Indian auto component-making company. The study results revealed that among the eleven (11) examined factors, linking SS to the employee and linking SS to the supplier are the non-significant factors. [24] developed a structural equation model (SEM) based on Partial Least square (PLS) to study the relationship between CSFs and for success of SS in SMEs in Indonesia. Table 1 captures concisely other relevant works of literature on the subject matter.

Table 1*: Critical Success factors of SS Implementation adopted from the literature*

Aspects	**Critical Success factors**	**References**
Organizational-based	Economic benefits	(19; 25)
	Organisational resources	(22)
	Organisational infrastructure	(26;27;28; 29; 30)
	Top management support	(31;32;33;34;35;36)
	Linking Six Sigma to corporate goals and strategies	28;37;23)
	Linking SS to employees	(38)
Project-based	Selecting appropriate project	(39;40;34; 41; 42)
	Formation of cross-functional project team &Teamwork	(43;44;29; 30)
	Project management skills	(45; 46; 1; 44)
	Team members commitment	(2;30)
Knowledge-based	Relevant training and education	(28;29)
	IT & Innovation	(1)
	Employee Involvement and empowerment	(18; 38)
	Uniformity in SS Process Implementation	(20)
	Effective communication and information flow	(47;26;44)
	Understanding SS tools and methods	(46; 48)
	Knowledge sharing among the workforce	(44)
Socio-Institutional based	Government policies on quality	(49)
	Government-established incentives and reward system	(49)
	Continual motivation of the workforce	(44)
	Organizational cultural change	(21; 20; 13)
	linking Six sigma projects to customers' needs	(46;50;51)
	Supplier capability enhancement and collaboration	(49; 38; 44)
	Human resource management	(44)

2.2. Successful applications of SS strategy on small and medium enterprises

In academic literature, there is the unavailability of sufficient evidence of the successful implementation of Six Sigma practice in Micro Small and Medium Enterprises (MSMEs) to encourage and provide a roadmap for its implementation [11]. Claims abound that SMEs do not enjoy the same benefits as their bigger counterpart due to economies of scale and availability of resources [5; 6]. Application of SS in Micro Small Medium Enterprises (MSMEs) in developing economies is limited due to several barriers faced by these firms [11; 12], and production processes of SMEs often do not present the degree of repeatability for which SS has been created [13]. Few successful applications of SS strategy have also been reported in the literature. For example, SS was implemented in the process of product quality control in metallurgical operations of annealing to ensure the required metallurgical product quality with reduced cost [52]. An integrated DEMATEL Six Sigma hybrid framework was developed and validated in MSMEs in India to significantly increase the sigma level [11]. SS methodology was applied in a North American small- and medium-sized plumbing enterprise using a cross-functional team to reduce cycle time and increase sales [43]. An SS framework that describes the fundamental elements of the Six Sigma methodology and the relationships between them was proposed [53]. In the same vein, managers in manufacturing SMEs need to address customers' wants and strive to surpass their expectations by implementing quality improvement programmes [54]. Lastly, an integrated SS model was developed to achieve organizational excellence at the aged care facilities in Victoria, Australia [55].

2.3. Multiple criteria methods in Six Sigma studies

Most real-life decision-making problems have several conflicting criteria and objectives to be considered simultaneously [56]. Large numbers of SS studies are focused on real-life case study applications in terms of defect reductions and quality improvements, and most recent studies have focused on SS implementation requirements, with few advances in SS theory. The typical MCDM problem deals with the evaluation of a set of alternatives in terms of a set of decision criteria, and some problems that necessitate SS applications are characterized as multi-criteria decision-making types. For example, a methodology using the KEMIRA-M method to prioritize and select alternative SS projects in healthcare organizations was developed [39], and the study assigns the highest ranks to patient satisfaction, revenue enhancement, and sigma-level benefit criteria; while resource utilization and process cycle time receive the lowest rank. The readiness of the Iranian steel industry to implement SS projects was investigated using fuzzy DEMATEL to prioritize CSF [50], and findings revealed senior management involvement, leadership, corporate strategy, and focus on the customer as the important factors. A systematic combination of methods of fuzzy Analytical Hierarchy Process (AHP), an easily defuzzified number of Trapezoidal Fuzzy Numbers (TrFN), and Grey Relational Analysis (GRA) was proposed for a suitable selection of SS project [40]. [57] integrated the AHP approach in SS-DMAIC methodology for defect identification in a cable manufacturing industry. Add to this, the Selection of the most ideal choice of Six Sigma project was achieved using GREY TOPSIS and TRIZ improvement strategies [58].

3. Research Methodology

The purpose of this study is to ascertain the weights and pairwise comparisons of crucial success criteria for Six Sigma implementation in Nigerian SMEs. As shown in Figs. 1 and 2, a hybrid methodology based on IVN-AHP and CRITIC with a number of modeling phases was used. The flowchart in Figure 1 illustrates how the research process was followed.

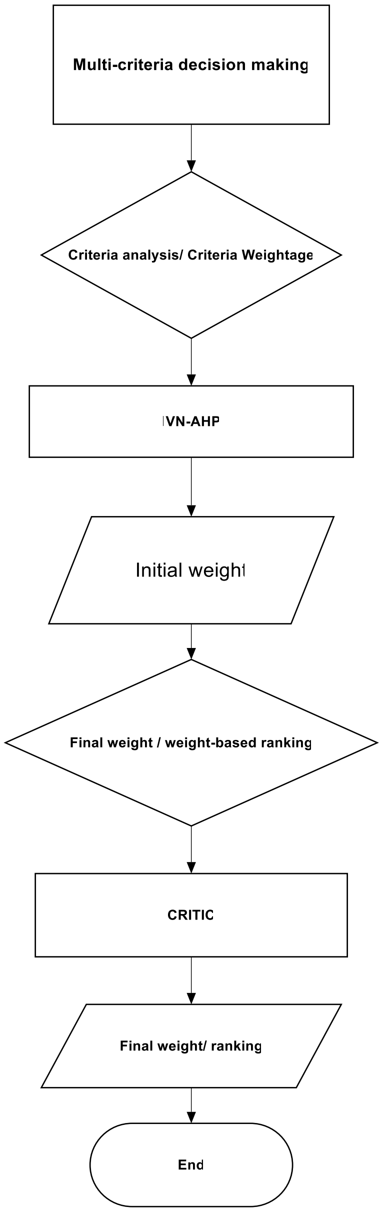

Fig 1. Proposed IVN-AHP-CRITIC multi-criteria decision making process

A. Interval-valued neutrosophic analytical hierarchy process (IVN-AHP)

AHP is the most known multi-criteria decision-making (MCDM) technique devised for solving complex management decision problems [59]. Although AHP is a frequently used method in MCDM problems, it sometimes fails to reflect human thought. In contrast to traditional AHP, IVN-AHP is able to effectively incorporate human reasoning into the decision-making process and describe uncertainty with three variables (T, I, and F). They all aim to improve AHP's efficacy in the face of ambiguity. Neutrophic sets (NS) allow decision makers to completely articulate their opinions since they distinguish between "relative truth" and "absolute truth" based on three separate parameters: truthiness (T), indeterminacy (I), and falsity (F). In this work, we use NS's representation power to rank interval numbers in our neutrosophic AHP approach using the possibility degree method [60]. Similarly, there are effective IVN-AHP applications in the literature that is now available [58; 61], such as in the supply chain sector [62; 63] and in university ranking for the university evaluation problem [64]. The steps in the IVN-AHP are as follows: **Step 1:** Design the pairwise comparison matrix of the CSFs for SS implementation in Nigerian SMEs and contexts using IVN numbers for the experts. In this step, IVN numbers shown in Table 2 are applied to develop pairwise comparisons of investigated CSFs based on the preferential judgment of experts in Nigeria.

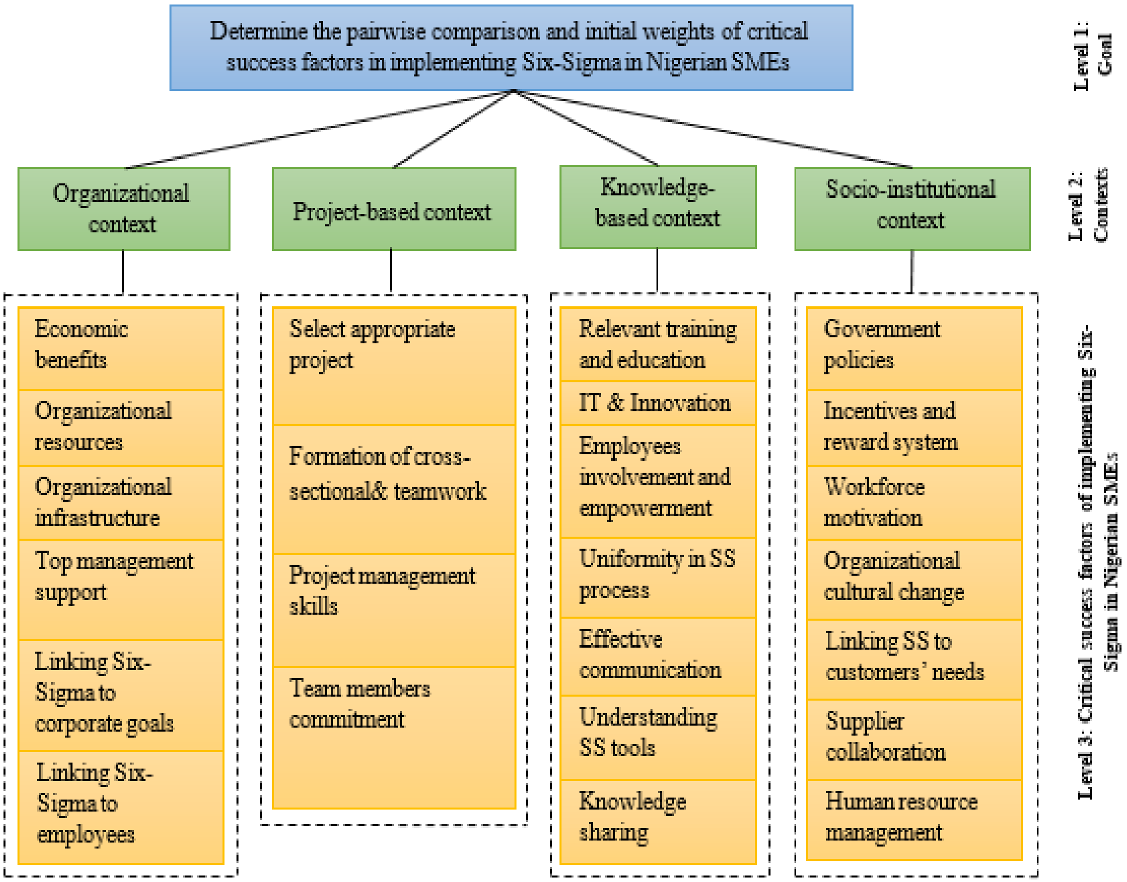

Fig. 2. IVN-AHP hierarchical structure of SS CSF evaluation problem

Step 2: Aggregate the pairwise comparison matrices for the groups of experts

In this step, the pairwise compassion matrices are aggregated for the experts in groups based on the similarity of managerial roles/functions.

Step 3: Transform the pairwise comparison matrices with IVN numbers into crisp comparison matrices via the deneutrosphication process.

Table 2 Linguistic scale for IVN-AHP pairwise comparison matrix

Linguistic attributes	Interval-valued neutrosophic numbers
	$[(TR^L, TR^U), (ID^L, ID^U), (FS^L, FS^U)]$
Extremely high importance (EH)	[(0.85,0.99), (0.05,0.15), (0.1,0.3)]
Very high importance (VH)	[(0.8,0.95), (0.15,0.2), (0.2,0.35)]
High importance (HI)	[(0.7, 0.9), (0.2, 0.25), (0.3, 0.4)]
Above average importance (AA)	[(0.6, 0.85), (0.25, 0.3), (0.4, 0.5)]
Average importance (AI)	[(0.5, 0.6), (0.3, 0.35), (0.5, 0.6)]
Below average importance (BA)	[(0.4, 0.45), (0.25, 0.3), (0.6, 0.85)]
Low importance (LI)	[(0.3, 0.4), (0.2, 0.25), (0.7, 0.9)]
Very low importance (VL)	[(0.2, 0.35), (0.15, 0.2), (0.8, 0.95)]
Certainly low importance (CL)	[(0.1, 0.3), (0.05, 0.15), (0.85, 0.99)]

In this step, the pairwise comparison matrices with *IVN* numbers are converted into crisp pairwise comparison matrices via the deneutrosophication process.

Step 4: *Consistency check of the pairwise comparison matrices*

Here, the pairwise comparison matrices are checked for consistency by using the consistency ratio which if <0.1, the pairwise comparison is accepted as consistent and if the consistency ratio>0.1, then the pairwise comparison is inconsistent. It should also be noted that if the crisp pairwise comparison matrix is consistent, then its parent pairwise comparison matrix with *IVN* numbers is also consistent. The consistency ratio is computed using Eqn. (1) and (2).

$$CoR = \frac{CoI}{RI} \tag{1}$$

$$CoI = \frac{\alpha_{\max} - n}{n-1} \tag{2}$$

Where *CoR* represents the consistency ratio, *CoI* represents the consistency index, *n* represents the size of the matrix, α_{max} represents the mean weighted sum vector of the matrix and *RI* represents the random consistency index.

Step 5: Estimate priority weights of contexts and CSFs for SS implementation in the Nigerian SMEs as well as the relative weights for each expert group

In this step, each consistent pairwise comparison matrix with IVN numbers is normalized using Eqs. (3) - (4).

$$\boxed{Z_{ij}^{*} = \left[\left[\frac{TR_{ij}^{L}}{\sum_{k=1}^{n} TR^{U}}, \frac{TR_{ij}^{U}}{\sum_{k=1}^{n} TR^{U}}\right], \left[\frac{ID_{ij}^{L}}{\sum_{k=1}^{n} ID_{ij}^{U}}, \frac{ID_{ij}^{U}}{\sum_{k=1}^{n} ID_{ij}^{U}}\right], \left[\frac{FS_{ij}^{L}}{\sum_{k=1}^{n} FS_{ij}^{U}}, \frac{FS_{ij}^{U}}{\sum_{k=1}^{n} FS_{ij}^{U}}\right]\right]; \forall i, j} \tag{3}$$

$$Z_{ij}^{*} = \left[\left[TR_{ij}^{*L}, TR_{ij}^{*U}\right], \left[ID_{ij}^{*L}, ID_{ij}^{*U}\right], \left[FS_{ij}^{*L}, FS_{ij}^{*U}\right]\right]; \forall i, j \tag{4}$$

Eq. (5) is used to obtain the arithmetic mean of each row and weights of strategies, which are then converted to crisp priority weights for contexts and relative weights of strategies via Eq. (1) for each expert group. Then, the priority weight of each CSF for SS implementation in the Nigerian SMEs is computed by finding the product of the relative weight and the respective category.

$$W_j = \left[\frac{\sum_{k=1}^{n} \frac{TR_{1j}^{L}}{\sum_{k=1}^{n} TR_{kj}^{U}}}{n}, \frac{\sum_{k=1}^{n} \frac{TR_{1j}^{U}}{\sum_{k=1}^{n} TR_{kj}^{U}}}{n}\right], \left[\frac{\sum_{k=1}^{n} \frac{ID_{1j}^{L}}{\sum_{k=1}^{n} ID_{kj}^{U}}}{n}, \frac{\sum_{k=1}^{n} \frac{ID_{1j}^{U}}{\sum_{k=1}^{n} ID_{kj}^{U}}}{n}\right], \left[\frac{\sum_{k=1}^{n} \frac{FS_{1j}^{L}}{\sum_{k=1}^{n} FS_{kj}^{U}}}{n}, \frac{\sum_{k=1}^{n} \frac{FS_{1j}^{U}}{\sum_{k=1}^{n} FS_{kj}^{U}}}{n}\right] \tag{5}$$

A. Criteria importance through inter-criteria correlation (CRITIC)

In this method, the weights are determined based on the contrast intensity and conflict evaluation of the decision problem. Add to this, human intervention is not required for the evaluation process. Thus, after the IVN-AHP, we applied CRITIC in this study. The CRITIC method determines the relative importance of criteria by analyzing their inter-correlations and impact on the overall decision without relying on subjective judgments. CRITIC is shown to have additional worth because it takes into account both the contrast intensity and the conflicting relationships held between criteria [65]. To the best of our current understanding, this research is the first effort to apply the IVN-AHP-CRITIC techniques for the purpose of assessing and prioritizing SS implementation CSFs in SMEs. The modeling steps that are involved in the CRITIC method are as follows:

Step 1: *Develop the initial decision matrix of criteria scores*

The performance score w_{ij} of the i^{th} ($i = 1,\ldots, m$) alternative concerning the j^{th} ($j = 1,\ldots, n$) criterion is presented to form the initial decision matrix. In this study CSFs for SS implementation in the Nigerian SMEs are the alternatives while the expert groups are considered as criteria. Then, the performance scores are the IVN-AHP weights computed for the expert groups.

Step 2: *Construct the linear normalization of criteria scores for groups*

Here, the normalized matrix is designed to consist of normalized scores g_{ij}, computed by normalizing the performance scores derived in Step 1 as shown in Eq. (6).

$$g_{ij} = \frac{w_{ij} - \min w_{ij}}{\max_i w_{ij} - \min_i w_{ij}} \tag{6}$$

Step 3: Generate a vector of normalized scores and compute the standard deviation

In this step, a vector of the normalized scores of all the alternatives is generated as indicated in Eq. (7).

$$g_j = \left(g_{1j}, g_{2j}, \ldots, g_{mj}\right) \tag{7}$$

Then, the standard deviation α_j of the generated vector is obtained using Eq. (8). $\alpha_j = \sqrt{\frac{\sum_{i=1}^{m}\left(g_{ij} - \bar{g}_j\right)^2}{m}}$, and,

$$\bar{g}_j = \frac{\sum_{i=1}^{m} g_{ij}}{m} \tag{8}$$

Step 4: Develop symmetric matrix

Here, a symmetric matrix is developed with an index q_{jb} using Eq. (9).

$$q_{jb} = \frac{\sum_{i=1}^{m}\left(g_{ij} - \bar{g}_j\right)\left(g_{ib} - \bar{g}_b\right)}{\sqrt{\sum_{i=1}^{m}\left(g_{ij} - \bar{g}_j\right)^2 \sum_{i=1}^{m}\left(g_{ib} - \bar{g}_b\right)^2}}, \text{ and, } q_{jb} \in [-1,1], q_{jb} = 1 \text{ if } j = b \tag{9}$$

Where, q_{jb} denotes the linear correlation coefficient of two vectors g_j and g_b, $j, b \in \{1,\ldots,n\}$.

Step 5: *Compute the information amount and obtain the criteria importance weight*

In this step, the amount of information h_j is calculated using Eq. (10) while the criteria importance weight c_j is computed using Eq. (11).

$$h_j = \alpha_j \sum_{b=1}^{n}\left(1 - q_{jb}\right) \tag{10}$$

$$c_j = \frac{h_j}{\sum_{b=1}^{n} h_b} \tag{11}$$

4.0 Results and discussions

4.1. Case description

In this study, the questionnaire was designed and utilized for data sourcing to highlight and investigate the CSFs to implement SS for achieving improved results. Initially, we reviewed the literature to identify the CSFs for implementing SS in SMEs. Within this context, 24CSFs were identified. Then, we utilized the identified factors to design a questionnaire for data collection in two phases. Necessary data was collected through designed a questionnaire that was administered to thirty-two (32) respondents from SMEs with annual revenue within the range of 50million-1billion Nigerian Naira and firm size within the range of 30- 500 employees. The considered SMEs gave their consent to participate in the survey and were assured of confidentiality and use of survey findings for academic purpose only. Particularly, the questionnaire respondents in the considered companies were managers that have a minimum of Bachelor degree educational qualification (See Table 3 for Respondents' demographic summary). Additionally, the managers have a minimum 7 years of experience in the company and within three managerial positions as Production Manager, General Manager and Sales Manager. The study respondents were considered to be knowledgeable to participate in the survey to ensure sufficient representation and survey accuracy due to their level of experience within the company and their managerial positions. In the first phase of the study survey, the questionnaire was designed and distributed to experts in SMEs domiciled in the south-east Nigeria to finalize the CSFs identified from the literature. The experts explicitly demanded that they provide their views on the relevance of each of the SS implementation CSFs in the Nigerian SME domain. The 24CSFs that were discovered were validated and verified based on the opinions of the experts.

A second questionnaire was designed in the survey's second phase to produce the paired comparison matrix for the ensuing analytical procedure. This questionnaire was created utilizing the eventual CSFs and a linguistic scale made up of interval-valued neutrosophic values. Specifically, the study's questionnaires were dimensioned into two sections: the first section is about the study participants' demographics, and the second section is concerned with the necessary information for the pairwise comparison matrix and CSF's finalization. Data collection took place over three months, from May to July 2024. The participants in the study were managers in the managerial echelon of SMEs as presented in Table 3. As part of the exclusion criteria used, only participants with over 10 years of relevant work experience in SMEs were deemed adequate for the study. We applied certain measures to ensure content validity, increase response rate and reduce response bias. For instance, we carried out a pilot study by requesting four PhD holders in business management discipline and three production managers in manufacturing enterprises to peruse through the designed questionnaire before embarking on the two phases of the survey. Feedbacks from the pilot study aided in the design of the questionnaire for the study survey. Also, email conversations, phone calls and personal company visits were implemented as reminders to the experts that participated in the study survey which led to a total number of 15 completed questionnaires out of the 32 questionnaires sent out, a response rate of 50%, and this is on the acceptable bias range for any survey.

Table 3. Demographic information of study participants

Attribute	Number of managers
Age	
30- 40	8
41- 60	24
Education	
Bachelor's degree	28
Postgraduate degree	4
Gender	
Male	30
Female	2
Years of experience	
11- 20	32
21- 30	Nil
Managerial role	
Procurement manager	18
General manager	10
Sales Manager	12
Annual revenue (Million Nigerian Naira)	
50- 200	32
201- 400	Nil
>400	Nil
Number of employees	
< 500	32
501- 1000	Nil

4.2 *Initial weights of* SS implementation CSF *via IVN-AHP*

Figure 1 shows an IVN-AHP hierarchical structure that includes the goal, four contexts, and Six-Sigma (SS) critical success factors (CSFs), which are the initial steps in the IVN-AHP process. Fifteen experts in Nigerian small and medium-sized businesses used the IVN ratings in Table 2 to pairwise compare the SS CSFs in SMEs. Based on the managerial titles of procurement managers, operations managers, and sales managers, the pairwise comparison was aggregated into three groups. Subsequently, the expert groups' contexts and SS implementation CSFs' aggregated pairwise comparison matrices with IVN values were transformed into clear pairwise comparison matrices. Egs. (1) and (2) were used to perform consistency checks on the crisp pairwise comparison matrices, and the findings indicated consistency ratios of less than 0.1. These indicate consistency between their parent pairwise comparison matrices with IVN scores and the crisp pairwise comparison matrices. Equations (3) and (4) were then used to normalize the pairwise comparison matrices. Eq. (5) was used to calculate the priority weights of the SS implementation CSFs and contexts for the expert groups under consideration. After that, crisp weight scores were created using the IVN weight scores. The contexts of the SS CSFs and their corresponding CSFs' priority weights for an expert group are displayed in Table 4. The implementation CSFs for other expert groups and the priority weights of SS contexts were left out of the appendix because of space constraints, which is relevant to note.

Table 4. IVN-AHP-based priority weights of SS CSFs for an expert group

Contexts	**Context priority weights**	**SS implementation CSFs in Nigerian SMEs**	**Relative weights**	**Priority weights**
Organizational (OB)	0.29	Economic benefits (OB_1)	0.192	0.0557
		Organizational resources (OB_2)	0.142	0.0412
		Organizational infrastructure (OB_3)	0.137	0.0397
		Top management support (OB_4)	0.285	0.0826
		Linking SS to corporate goals (OB_5)	0.132	0.0383
		Linking SS to employees (OB_6)	0.112	0.0325
Project-based (PB)	0.22	Select the appropriate project (PB_1)	0.271	0.0596
		Formation of cross-functional &Teamwork (PB_2)	0.233	0.0513
		Project management skills (PB_3)	0.270	0.0594
		Team member's commitment (PB_4)	0.226	0.0497
Knowledge-based (KB)	0.21	Relevant training and education (KB_1)	0.147	0.0309
		IT & Innovation (KB_2)	0.151	0.0317
		Employee involvement and empowerment (KB_3)	0.122	0.0256
		Uniformity in SS Process Implementation (KB_4)	0.136	0.0286
		Effective communication and information flow (KB_5)	0.122	0.0256
		Understanding SS tools and methods (KB_6)	0.131	0.0275
		Knowledge sharing among workforce (KB_7)	0.191	0.0401
Socio-institutional (SI)	0.28	Government policies on quality (SI_1)	0.112	0.0314
		Government-established incentives and reward system (SI_2)	0.171	0.0479
		Continual motivation of workforce (SI_3)	0.124	0.0347
		Organizational cultural change (SI_4)	0.179	0.0501
		Linking Six Sigma projects to customers' needs (SI_5)	0.131	0.0367
		Supplier capability enhancement and collaboration (SI_6)	0.126	0.0353
		Human resource management (SI_7)	0.157	0.044

4.3. Final weights and ranking of SS implementation CSF via CRITIC

Using the IVN-AHP weight scores of the CSFs for the expert groups taken into consideration in this study, an initial decision matrix of the SS implementation CSFs was created for the expert groups using Eq.(6). The same process was applied to normalize the contexts. The SS implementation CSFs' vector of normalized weight scores was generated using Eq. (7). Then, the standard deviation of the generated vector was calculated using Eq. (8). We developed a symmetric matrix using the CSFs from the SS implementation in SMEs using Eq. (9). The information amount and the weights of the SMEs implementation CSFs were computed using Eqs. (10) and (11) respectively. Table 5 shows the information amount and priority weights of the SS implementation CSFs in SMEs as well as their weight-based ranking. The percentage weight scores of the contexts of SS implementation CSFs in SMEs were computed by obtaining the sum of the percentage weights of respective challenges in each context.

Table 5. Priority weights and ranking of SS implementation CSFs

Context	SS implementation CSFs in Nigerian SMEs	h_j	c_j	Rank	Context score (%)
Organizational (OB)	Economic benefits (OB_1)	3.983	0.0542	4	23.33
	Organisational resources (OB_2)	3.587	0.0488	10	
	Organisational infrastructure (OB_3)	3.222	0.0438	13	
	Top management support (OB_4)	3.711	0.0505	8	
	Linking SS to corporate goals (OB_5)	1.269	0.0173	23	
	Linking SS to employees (OB_6)	1.378	0.0187	22	
Project-based (PB)	Select the appropriate project (PB_1)	4.205	0.0572	2	18.97
	Formation of cross-functional &Teamwork (PB_2)	2.550	0.0347	19	
	Project management skills (PB_3)	3.277	0.0446	12	
	Team member's commitment (PB_4)	3.912	0.0532	6	
Knowledge-based (KB)	Relevant training and education (KB_1)	2.544	0.0346	18	25.24
	IT & Innovation (KB_2)	3.988	0.0542	3	
	Employee involvement and empowerment (KB_3)	2.884	0.0392	16	
	Uniformity in SS Process Implementation (KB_4)	3.191	0.0434	14	
	Effective communication and information flow (KB_5)	1.932	0.0263	20	
	Understanding SS tools and methods (KB_6)	2.863	0.0389	17	
	Knowledge sharing among workforce (KB_7)	1.165	0.0158	24	
Socio-institutional (SI)	Government policies on quality (SI_1)	4.335	0.059	1	32.46
	Government-established incentives and reward system (SI_2)	3.722	0.0506	7	
	Continual motivation of workforce (SI_3)	3.914	0.0542	5	
	Organizational cultural change (SI_4)	3.659	0.0498	9	
	Linking Six Sigma projects to customers' needs (SI_5)	2.991	0.0407	15	
	Supplier capability enhancement and collaboration (SI_6)	1.649	0.0222	21	
	Human resource management (SI_7)	3.389	0.0481	11	

4.4. Ranking of factors of SS implementation CSFS in SMEs

As the percentage score column in Table 4 makes evident, the most important CSFs for SS implementation in Nigerian SMEs are the enablers within the socio-institutional framework. In Nigerian SMEs, the Knowledge-based (KB) CSFS context is placed second in terms of SS implementation. The project-based context is ranked lowest among the contexts under investigation, and the organizational (OB) context is placed penultimate among the CSFs in SS implementation. The visual description of the ranking is shown in Figure 2. To buttress further on the socio-technical context, the result outcome is in tandem with previous studies on Six Sigma tenets that have empirically proven the level of thrust some of the prioritized SS factors in this study has on implementation success of SS in SMEs in Nigeria. Based on empirical evidence, a number of studies have aligned SS implementation success factors to appropriate project selection [66; 43], organizational cultural change [67; 68], supplier capability enhancement [69], linking of Six sigma projects to customers' needs [70] etc.

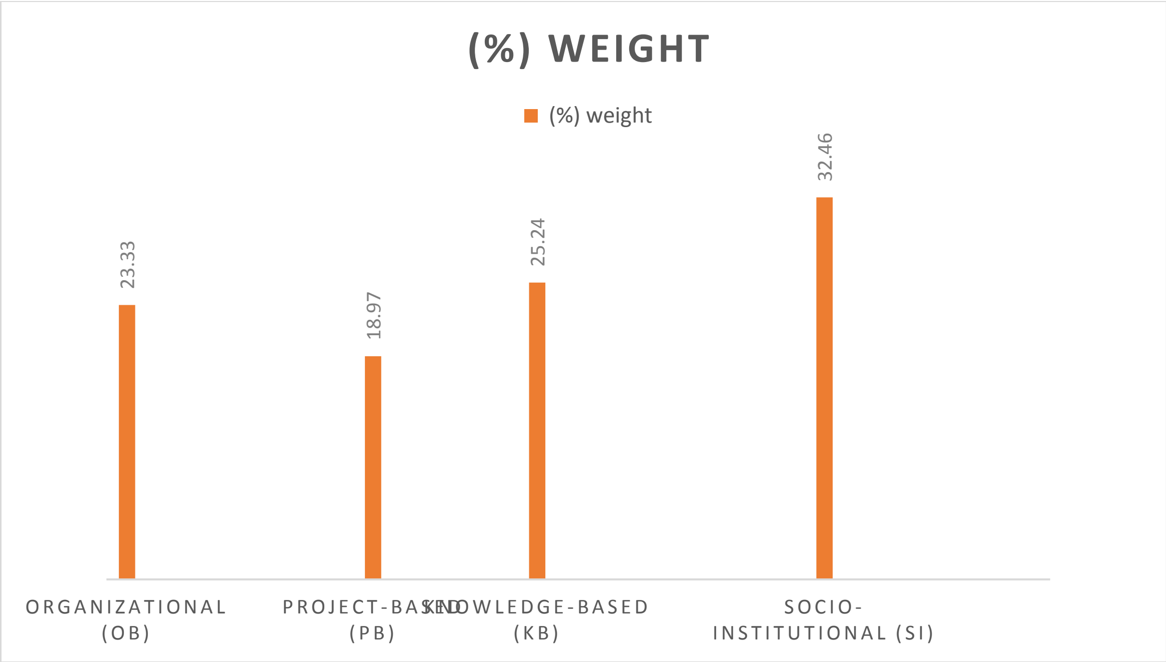

Fig.2 % weight of contexts of SS implementation CSFs in the Nigerian SMEs

Furthermore, according to the rankings of the individual variables in Figure 3, the most significant CSF among the components under investigation is government policies on quality (SL1), which are followed by the right project selection (PB1) and IT & Innovation (KB2), with economic benefits (OB1) coming in at number four. These clearly support the existing body of research showing that government policies help SMEs in Nigeria achieve a sustainable performance perspective [51]. A key factor in the success of SS implementation in SMEs is strict adherence to government regulations that align with the operational procedures of pertinent quality certification organizations, like ISO, etc. The effectiveness of Six Sigma initiatives depends on choosing and prioritizing the appropriate projects, according to the second-placed factor [71; 72; 66]. Projects that are viable to execute, significantly affect important indicators, and in line with strategic goals should be identified by organizations. It is pertinent to also note that other least ranked factors exert a level of influence on the vital few factors. However, the interacting effects of these factors among each other are not documented in this study, thus beckoning for further study. In conclusion, it is advised that for a successful and sustainable implementation of SS in Nigerian SMEs, due cognizance should be given to all these factors to ensure that the goal of choosing an SS strategy is attained.

Fig.2 Ranking of SS implementation CSFs in the Nigerian SMEs

4.5. Study implications

This paper makes a theoretical contribution to the extant literature on SS implementation within SMEs and presents insights into the key factors that can influence SS implementation in SMEs. In addition to this, the study introduces the **SKOP** (Socio-institutional-based-Knowledge-based-Organizational-based-Project-based) framework of categorization of SS implementation CSFs, thus constituting a new addition to existing SS implementation theories. In the same vein, this study has a noteworthy contribution to SS literature presenting a multi-criteria decision model that shows the significant impact of SS factors on the successful deployment in SMEs. The proposed decision methodology can be utilized to accurately evaluate and likewise predict the significance of the key factors during the decision to implement SS in SMEs. The study is of immense advantage to policymakers, business owners, organizational managers, etc. It is an objective statement to note that understanding the influence and interrelationships amongst the CSFs by business owners will encourage improved practices and reduce failure rates in SS improvement studies.

6. Conclusion

The SME market environment has been greatly distorted by myriads of events most especially the Covid-19 pandemic outbreak. As a result, firms are in constant exploration of opportunities to effectively manage their products and processes optimally. SME supply chain practices were distorted due to multilevel factors such as border closures, government restrictions, dwindling workforce, negative financial reports and other social effects. In this post-Pandemic era, there still exist salient threats to the economic survival of SMEs especially in the developing nations with spontaneity on inflationary indices and humbling multiple government taxations. Most enterprises within the product and service industry have started to deep further into understanding strategies to overcome the odds prevalent in the current marketplace and ways to manouvre the effects. SMEs are significant drivers of economic development, especially in transition economies like Nigeria [73], and often act as suppliers to bigger companies and these companies rely more on the SMEs to meet their production targets. The complexity of discussing the SS implementation success factor in an exploratory framework is exciting and the successful implementation of the SS strategy depends on many variables that can be controlled with the knowledge of their effects and influences. However, there is a dearth of relevant studies that understudy the criticality of SS enablers on SMEs, particularly in a Nigerian geographical landscape. To this end, this study proposed an integrated decision methodology based on IVN-AHP-CRITIC, where IVN-AHP was used to develop the pairwise comparison matrices and hierarchical structure of the enablers to SS implementation in SMEs in the Nigerian context, the weight of these factors was determined based on the contrast intensity and conflict evaluation of the decision problem.

Like all research studies, this one has certain limitations, but these don't take away from the findings; rather, they provide a basis for further theorization and investigation of the study problem. Because this study was carried out in Nigeria, its findings might only apply to a limited geographic area. In this regard, future research might think about carrying out this study in a different region of Africa or anywhere else in the world. A large-scale research project might think about tackling this issue in several nations and then comparing and contrasting the outcomes. Furthermore, although this paper concentrated on mitigating threats to the survey validity using well-established strategies, we acknowledge that regional bias is a limitation of this study, as we focused on selecting respondents within the south east geo-political region, meaning that other eligible respondents from other regions were excluded.

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Appendix:

Table 1: Pairwise comparison matrix of SS CSFs' contexts for an expert group

Contexts	Organizational **(OB)**	Project-based **(PB)**	Knowledge-based**(KB)**	Socio-institutional**(SI)**
Organizational	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.7,0.9),(0.2,0.25),(0.3,0.4)]	[(0.4,0.5),(0.75,0.7),(0.6,0.85)]	[(0.2,0.35),(0.85,0.8),(0.8,0.95)]
Project-based	[(0.8,0.95),(0.15,0.2),(0.2,0.35)]	[(0.85,0.99),(0.05,0.15),(0.1,0.3)]	[(0.8,0.95),(0.15,0.2),(0.2,0.35)]	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]
Knowledge-based	[(0.6,0.85),(0.25,0.3),(0.4,0.5)]	[(0.6,0.85),(0.25,0.3),(0.4,0.5)]	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.2,0.35),(0.85,0.8),(0.8,0.95)]
Socio-institutional	[(0.3,0.4),(0.8,0.75),(0.7,0.9)]	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.4,0.5),(0.75,0.7),(0.6,0.85)]	[(0.1,0.3),(0.95,0.85),(0.85,0.99)]

Table 2. Pairwise comparison of CSFs for an expert group

CSFs	OB_1	OB_2	OB_3	OB_4	OB_5	OB_6
Economic benefits (*OB_1*)	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.85,0.99),(0.05,0.15),(0.1,0.3)]	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.4,0.5),(0.75,0.7),(0.6,0.85)]	[(0.7,0.9),(0.2,0.25),(0.3,0.4)]	[(0.3,0.4),(0.8,0.75),(0.7,0.9)]
Organizational resources(*OB_2*)	[(0.2,0.35),(0.85,0.8),(0.8,0.95)]	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.6,0.85),(0.25,0.3),(0.4,0.5)]	[(0.5,0.6),(0.7,0.65),(0.5,0.6)]	[(0.5,0.6),(0.7,0.65),(0.5,0.6)]	[(0.6,0.85),(0.25,0.3),(0.4,0.5)]
Organizational infrastructure(*OB_3*)	[(0.7,0.9),(0.2,0.25),(0.3,0.4)]	[(0.4,0.5),(0.75,0.7),(0.6,0.85)]	[(0.5,0.6),(0.3,0.35),(0.5,0.6)]	[(0.8,0.95),(0.15,0.2),(0.2,0.35)]	[(0.6,0.85),(0.25,0.3),(0.4,0.5)]	[(0.4,0.5),(0.75,0.7),(0.6,0.85)]
Top management support(*OB_4*)	[(0.8,0.95),(0.15,0.2),	[(0.5,0.6),(0.3,0.35),	[(0.2,0.35),	[(0.5,0.6),(0.3,0.35),	[(0.5,0.6),(0.3,0.35),	[(0.5,0.6),(0.3,0.35),

	(0.2,0.35)]	(0.5,0.6)]	(0.85,0.8), (0.8,0.95)]	(0.5,0.6)]	(0.5,0.6)]	(0.5,0.6)]
Linking SS to corporate goals(*OB_5*)	[(0.8,0.95), (0.15,0.2), (0.2,0.35)]	[(0.85,0.99), (0.05,0.15), (0.1,0.3)]	[(0.8,0.95) , (0.15,0.2), (0.2,0.35)]	[(0.4,0.5), (0.75,0.7), (0.6,0.85)]	[(0.6,0.85), (0.25,0.3), (0.4,0.5)]	[(0.4,0.5), (0.75,0.7), (0.6,0.85)]
Linking SS to employees(*OB_6*)	[(0.3,0.4), (0.8,0.75),(0.7,0.9)]	[(0.5,0.6), (0.3,0.35), (0.5,0.6)]	[(0.3,0.4), (0.8,0.75), (0.7,0.9)]	[(0.5,0.6),(0.7,0.65),(0.5,0.6)]	[(0.5,0.6), (0.3,0.35), (0.5,0.6)]	[(0.5,0.6), (0.7,0.65), (0.5,0.6)]

Table 3: Normalized matrix of SS implementation CSFs' contexts for an expert group

Contexts	Organizational **(OB)**	Project-based **(PB)**	Knowledge-based**(KB)**	Socio-institutional**(SI)**
Organizational	[(0.11,0.14),(0.5,0.47), (0.3,0.38)]	[(0.15,0.18), (0.29,0.33),(0.28,0.33)]	[(0.16,0.2),(0.38,0.36), (0.23,0.32)]	[(0.06,0.19),(0.34,0.3), (0.24,0.28)]
Project-based	[(0.21,0.3),(0.16,0.19), (0.17,0.21)]	[(0.18,0.25), (0.24,0.29),(0.22,0.28)]	[(0.2,0.24),(0.15,0.18), (0.19,0.23)]	[(0.13,0.22),(0.3,0.29), (0.23,0.27)]
Knowledge-based	[(0.29,0.34), (0.09,0.13),(0.09,0.15)]	[(0.25,0.3),(0.05,0.14), (0.06,0.17)]	[(0.3,0.4),(0.08,0.17), (0.08,0.13)]	[(0.31,0.38), (0.11,0.13),(0.14,0.17)]
Socio-institutional	[(0.18,0.21), (0.19,0.22),(0.21,0.26)]	[(0.21,0.27), (0.19,0.24),(0.17,0.22)]	[(0.16,0.2),(0.38,0.36), (0.23,0.32)]	[(0.13,0.22),(0.3,0.29), (0.23,0.27)]

Table 4: Normalized matrix of CSFs for an expert group

CSFs	OB_1	OB_2	OB_3	OB_4	OB_5	OB_6
Economic benefits (*OB_1*)	[(0.4,0.5), (0.75,0.7), (0.6,0.85)]	[(0.25,0.29), (0.08,0.1), (0.06,0.12)]	[(0.3,0.4), (0.8,0.75), (0.7,0.9)]	[(0.85,0.99), (0.05,0.15),(0.1,0.3)]	[(0.7,0.9),(0.2,0.25),(0.3,0.4)]	[(0.15,0.18),(0.15,0.18), (0.17,0.2)]
Organizational resources(*OB_2*)	[(0.08,0.14),(0.26, 0.25),(0.2,0.25)]	[(0.5,0.6), (0.3,0.35), (0.5,0.6)]	[(0.6,0.85),(0.25,0.3), (0.4,0.5)]	[(0.5,0.6),(0.7,0.65), (0.5,0.6)]	[(0.5,0.6),(0.7,0.65), (0.5,0.6)]	[(0.3,0.35), (0.06,0.08), (0.08,0.1)]
Organizational infrastructure(*OB_3*)	[(0.3,0.35),(0.06, 0.08),(0.08,0.1)]	[(0.12,0.15), (0.38,0.36),(0.2, 0.28)]	[(0.5,0.6), (0.3,0.35), (0.5,0.6)]	[(0.8,0.95), (0.15,0.2), (0.2,0.35)]	[(0.6,0.85), (0.25,0.3),(0.4,0.5)]	[(0.5,0.6),(0.7,0.65), (0.5,0.6)]
Top management support(*OB_4*)	[(0.04,0.12), (0.3,0.26), (0.22,0.26)]	[(0.15,0.18), (0.15,0.18), (0.17,0.2)]	[(0.2,0.35), (0.85,0.8), (0.8,0.95)]	[(0.5,0.6), (0.3,0.35), (0.5,0.6)]	[(0.3,0.35), (0.06,0.08), (0.08,0.1)]	[(0.7,0.9),(0.2,0.25),(0.3,0.4)]
Linking SS to corporate goals(*OB_5*)	[(0.2,0.24), (0.09,0.1), (0.13,0.16)]	[(0.5,0.6), (0.7,0.65), (0.5,0.6)]	[(0.85,0.99), (0.05,0.15),(0.1,0.3)]	[(0.6,0.85), (0.25,0.3),(0.4,0.5)]	[(0.5,0.6), (0.3,0.35), (0.5,0.6)]	[(0.15,0.18) , (0.15,0.18), (0.17,0.2)]
Linking SS to employees (*OB_6*)	[(0.12,0.16), (0.25,0.2), (0.2,0.2)]	[(0.15,0.18), (0.2,0.2), (0.2,0.2)]	[(0.4,0.5), (0.75,0.7), (0.6,0.85)]	[(0.5,0.6), (0.7,0.65), (0.5,0.6)]	[(0.4,0.5), (0.75,0.7), (0.6,0.85)]	[(0.5,0.6), (0.3,0.35),(0.5,0.6)]