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A HYBRID BEST WORST - FUZZY TOPSIS METHODOLOGY FOR LEAN SIX SIGMA PROJECT SELECTION

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Abstract

Prioritizing Lean Six Sigma (LSS) projects that align with company objectives is crucial, yet traditional methods struggle with associated subjective criteria. This study proposed a hybrid Best Worst Method - Fuzzy TOPSIS approach to prioritize LSS projects for a project consulting company. The method integrates expert opinion from 3 decision-makers on 7 main criteria and 24 sub-criteria to select the optimal LSS projects in project management consulting company. Triangular fuzzy numbers were used to describe the responses. The fuzzy positive and negative solutions of the five alternatives were calculated. Results indicate project alternative 3 (ERP Deployment Project) is the optimal choice with the highest closeness coefficient (0.68651), while project alternative 2 (Warehouse Automation Project - 0.54077), project 1 (Data Warehousing Project – 0.46731), project 4 (Battery life improvement – 0.54077), and project 5 (Improvement of OEE – 0.34093) follow closely, thus ensuring efficient project selection. Emphasis should be placed on project 3 when considering the 7 criteria while the other projects are closely monitored in the ranking order. Future research can explore the combination of other multi-criterion decision making approaches that enrich criteria weights and address the subjectivity of decision-makers' opinion. The hybrid methodology used in this work is applicable in other disciplines where selection and ranking problems exists.

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1.0 INTRODUCTION

Lean Six Sigma (LSS) is a combination of lean manufacturing strategies and the techniques of six sigma [7], [15], [20]. It utilizes the Define Measure Analyze Improve Control (DMAIC) or Define Measure Analyze Design Verify (DMADV) frameworks to improve efficiency and reduce variability [2]. LSS has been widely adopted across several industries to drive productivity and quality enhancement [16], [22], [26]. However, the process of prioritizing and selecting LSS projects is key for effective resource optimization. Many organizations have suffered huge losses due to poor LSS project selection. In fact, LSS project selection is critical for success due to high failure rates [21]. It has also been argued that effective selection of LSS project ensures continuous improvement and goal achievement [1]. Therefore, the process of identifying, selecting and ranking LSS project from a pool of conflicting alternatives is crucial.

Now, multi-criterion decision-making (MCDM) methods are used for selection and ranking processes by considering qualitative and quantitative factors that affect decision making [5]. MCDM techniques like Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), and Analytic Hierarchy Process (AHP) offer systematic approaches for project selection [30], [29], [13]. These methods help to ensure clear, logical and reliable decisions that align with organizational goals and enhancing overall quality [13]. Methods like the Decision-Making Trail and Evaluation Laboratory (DEMATEL) technique (for elucidating complex relationships among components and clusters) [28], VIKOR (for compromise ranking, solution, and weight stability intervals for alternatives with conflicting criteria) [17], the Analytic Hierarchy Process (AHP) (for complex decision-making including pairwise comparisons across hierarchical levels) [6], [18], etc are all used for project selection [13].

The ELECTRE method (Elimination et choix traduisant la realité) method involves two phases of constructing outranking relations and exploitation for decision recommendations [4]. It facilitates paired comparisons and provides flexibility for fair judgments [5]. The data envelopment assessment (DEA) method weighs criteria to maximize efficiency for decision-making units [11]. Unlike other models, DEA assesses relative efficiency without predefined indexes [3]. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) selects the best options closest to the positive ideal solution and the farthest from the negative ideal solution by using Euclidean distances [21]. The Best-Worst Method (BWM) proposed by [19] helps to reduce pairwise comparisons between alternatives, ensure consistency and superior results [12].

1.1 Lean Six Sigma Project Selection Criteria

Different methods have been used to selecting the optimal LSS project to embark on. A number of studies exist in this area. Table 1 outlines several LSS project selection criteria identified from different literatures.

Table 1: LSS project selection criteria from selected literatures

S/N	Author	LSS Project Selection Criteria
1	[21]	(i) Pull production (ii) Customer satisfaction (iii) Reduction of cycle time (iv) Top management commitment and involvement
2	[20]	(i) Growth (ii) Customer development (iii) Financial status (iv) Management commitment and involvement (v) Project feasibility
3	[37]	(i) Cost (ii) Non-availability of rack system.
4	[39]	(i) Changeable personnel (ii) Degree of online solution (iii) Quick resource upgrade (iv) Demand management (v) Information Transparency (vi) Agile communication system (vii) Flexible manufacturing system.
5	[33]	(i) Cost (ii) Project complexity (iii) Communication between project members (iv) Project planning (v) Clear objectives (vi) Customer Involvement
6	[35]	(i) Health and safety (ii) Impact on customers (iii) Financial impact (iv) Impact on business strategy (v) Project risk (vi) Project duration
7	[22]	(i) Sustainable Manufacturing (ii) Quick financial return.
8	[32]	(i) Financial gain (ii) Operational benefits (iii) Organizational benefits
9	[38]	(i) Operational and technical feasibility (ii) Strategic orientation (iii) Finance and business development
10	[36]	(i) Quality (ii) Collaboration (iii) Safety stock (iv) Just-in-time delivery

1.2 Methods for Selecting Lean Six Sigma Projects

Project selection in Lean Six Sigma involves a systematic approach, considering various criteria such as budget, timeframe, expertise, and resources [23]. It is a continuous process, starting from requirement identification to monitoring [24]. In [34], a fuzzy DEMATEL approach was used to integrate industry 4.0 technologies with LSS methodologies to enhance manufacturing processes. Similarly, [9] used the Grey Relation Analysis method to rank Green Six Sigma (GLS) projects based on 6 sustainability criteria. The machine shop ranked the most significant GLS project, validated by the best-worst method and sensitivity analysis. Using a data envelopment analysis (DEA) method, [11] evaluated and ranked 18 LSS projects in the government sector.

The combination of different MCDM methods has been used to solve ranking and selection problems in different sectors. These hybrid methods have been observed to yield better solutions in terms of catering for the objectivity of decision makers and their specific abilities in ranking and selection [14]. Limited studies have used hybrid methods to prioritize LSS project selection criteria compared to Six Sigma. For example, [5] used a hybrid fuzzy AHP-ELECTRE method to prioritize 14 LSS barriers and 12 solution approaches. Also, [3] applied the data Envelopment Analysis Cross Efficiency Model DEA cross-efficiency model ranked 12 projects, identifying Project 4 as the optimal choice. [25] combined fuzzy best worst method and VIKOR to choose from 10 improvement projects. [22] integrated VIKOR with an improved TOPSIS method to select the assembly section as the optimal LSS project for quick returns and sustainable manufacturing from a pool of 8 projects for the company.

Similarly, [28] used a combined DEMATEL-AHP-TOPSIS method to select a project from a pool of 5 projects with lower failure risk, in an automobile component manufacturing organization. [27] used a hybrid fuzzy AHP-fuzzy TOPSIS and Grey Relation Analysis method to select optimal six sigma projects from 8 options in a car manufacturing company. [31] used the q-ROF CRITIC-ARAS method which thrives on the Additive Ratio Assessment (ARAS) technique, q-Rung Orthopair Fuzzy sets (q-ROFSs) and Criteria Importance Through Inter criteria Correlation (CRITIC) method for flexibility and effectiveness. [33] used an intuitionistic fuzzy COPRAS (IFCOPRAS) method to address hesitation in data and prevent information loss that can occur when working with fuzzy numbers. [32] integrated the Combinative distance-based Assessment (CODAS) and Analytic Hierarchy Process (AHP) into a AHP-CODAS framework for prioritizing and selection of lean six sigma projects. [35] combined the Analytic Hierarchy Process (AHP) method with the Failure Mode and Effect Analysis (FMEA) to support the LSS process.

However, the use of the best worst method for ranking and selecting LSS project has been shown to aid flexibility and improve the bias in choice of alternative. For example, [38] used the Best Worst Method to prioritize 22 LSS project selection criteria in a manufacturing setting, concluding that operational and technical feasibility, strategic orientation, finance, and business development were the top priorities.. Also, [24] ranked critical success factors (CSF) in healthcare using BWM, highlighting its sustainability for LSS criteria weighting due to efficiency and consistency. [20] used the best worst method to prioritize 19 LSS project criteria in an automotive parts manufacturing. Financial status, customer development and project feasibility were ranked as most crucial. However, its combination with other MCDM approach can improve its results. The use of fuzzy TOPSIS has a major advantage here. Because it considers both positive and negative ideal solutions, it can be used to supplement the comparative bias in ranking and selection.

The aim of this work is to use a hybrid Best-Worst Method-Fuzzy TOPSIS algorithm (BWM-fuzzy TOPSIS) to select the optimal LSS project among a pool of alternative projects. It is thought that prioritizing LSS projects will optimize financial, human and material resources, thus aiding the decision making process in selecting projects that align with organizational objectives. Other advantages of this method include the flexibility of use, reduced subjectivity of responses and effectiveness of method.

2.0 METHOD

This section describes the methodology behind this for LSS project selection in a manufacturing context. To make the ultimate decision, a panel of three decision-makers from the case study organization analyzed the criteria after conducting a thorough literature review and rated the LSS project alternatives. Figure 1 is a flowchart with seven steps explaining the approach for ranking the criteria used to select LSS projects.

2.1 Hybrid Best-Worst Method-Fuzzy TOPSIS Algorithm

The steps behind the Hybrid Best-Worst Method-Fuzzy TOPSIS algorithm used for this work are described as follows:

Step 1: Formation of the decision-making team
Experienced decision-makers formed a panel with expertise in LSS methodology, project management, risk management, data analysis, and continuous improvement.

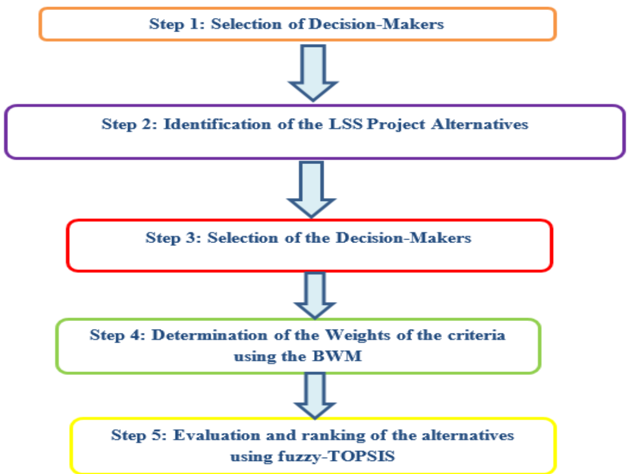

Figure 1: Research Method Flowchart for LSS Project Criteria Selection [Source: Author (2024)]

Step 2: Selection of alternatives
Decision-makers identify and evaluate potential projects aligned with organizational goals, narrowing down choices for further consideration.

Step 3: Identification and selection of LSS project criteria
The criteria for LSS project selection (as described in Table 2) are then provided to the DM for final selection. The criteria selection is finalized via consultation with the DM based on the importance and preference.

Step 4: Determine the weight of criteria
The Best-Worst Method (5 steps as below) is used to obtain the weight of the criteria.

4.1: A set of criteria are identified for making a decision, this set of decision criteria are recorded as $\{C_1, C_2, C_3....C_n\}$ for n number of criteria.
4.2: The best and worst criteria identified by each and every decision-maker are recorded
4.3: On a scale of 1 to 9 (Likert scale) where "1 = equally important" and "9 = more important", each decision-maker rate his best criterion over the rest criteria in the set. The pairwise comparison of best criterion over all other criteria can be written as

$$A_B = (a_{B1}, a_{B2}, a_{B3}, \dots \dots . . a_{Bn}) \quad (1a)$$

where a_{Bi} represents the rating of the best-selected criteria B over any other criteria j. In this case, a_{BB} = 1 (rating a criterion over itself should yield a 1).
4.4: In this step, the rating of all criteria in set over the worst criterion on the scale of 1 to 9 selected by the DMs. The pairwise comparison of other criteria over worst criterion can be written as

$$A_W = (a_{1W}, a_{2W}, a_{3W}, \dots \dots . . a_{nW}) \quad (1b)$$

where a_{Wi} represents the rating of any criteria j with the worst criteria W. In this case, a_{WW} = 1 (rating a criterion over itself should yield a 1)
4.5: The final step for BWM is finding the optimal weight of all the criteria $(W_1^*, W_2^*, W_3^*, \dots \dots, W_n^*)$. To obtain the optimal weight, the maximum absolute differences $\left|\frac{W_B}{W_j} - a_{Bj}\right|$ and $\left|\frac{W_j}{W_w} - a_{jW}\right|$ for all j is minimised, equation (2) follows:

$$\min max \left|\frac{W_B}{W_j} - a_{Bj}\right|, \left|\frac{W_j}{W_w} - a_{jW}\right| \quad (2)$$

s.t.

$$\textstyle\sum_j W_j = 1 \quad (3a)$$

$$W_j \geq 0, for\ all\ j \quad (3b)$$

Step 5: Evaluate and rank the alternatives using Fuzzy TOPSIS
A triangular fuzzy number is considered in this work for its simplicity, efficiency, flexibility, and capability as demonstrated in [14]. The Fuzzy TOPSIS methodology involves 7 steps outlined below:

Step 5.1: Develop a decision matrix $\widetilde{k_{ij}}$ comparing alternative with different criteria using linguistic variables as shown in Table 2.

Table 2: Fuzzy linguistic variables and expression

Linguistic Variables	Triangular fuzzy numbers
Very Low (VL)	1,1,3
Low (L)	1,3,5
Medium (M)	3,5,7
High (H)	5,7,9
Very High (VH)	7,9,9

Step 5.2: Calculate the normalized decision matrix. This is obtained with the formula below:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i-1}^{n} x_y^2}} n_{ij} = \frac{x_{ij}}{max_i x_{ij}} n_{ij} = \begin{bmatrix} \frac{x_{ij} - min_i x_{ij}}{max_i x_{ij} - min_i x_{ij}} \\ \frac{max_i x_{ij} - x_{ij}}{max_i x_{ij} - min_i x_{ij}} \end{bmatrix} \quad (6)$$

Step 5.3: Calculate and evaluate the weighted normalized decision matrix. The weighted normalized value is calculated by:

$$v = (v_{ij})_{m \times n} \quad (7a)$$

$$v_{ij} = k_{ij} \times w_j \quad (7b)$$

Where, $i = \{1,2,3, \dots, m\}$, $j = \{1,2,3, \dots, n\}$
Step 5.4: Determine the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS)

$$A^+ = \{v_1^+, \dots, v_n^+\} \quad (8a)$$

Where, $V_j^+ = \{\max(v_{ij})\ if\ j \in \boldsymbol{J}; \min(v_{ij})\ if\ j \in \boldsymbol{J'}\}, j = 1 \dots . n,$

$$A^- = \{v_1^-, \dots, v_n^-\} \quad (8b)$$

Where, $V_j^+ = \{\min(v_{ij})\ if\ j \in \boldsymbol{J}; \max(v_{ij})\ if\ j \in \boldsymbol{J'}\}, j = 1 \dots . n,$
Where, $\boldsymbol{J}$ is associated with benefit criteria and $\boldsymbol{J'}$ is associated with cost criteria.
Step 5.5: Obtain the distances D_j^+ and D_j^- for the project alternatives.

$$D_j^+ = \sqrt{\textstyle\sum_{j=1}^{m} (v_{ij} - v_j^+)^2} \quad i = 1, \dots, n \quad (9a)$$

$$D_j^- = \sqrt{\textstyle\sum_{j=1}^{m} (v_{ij} - v_j^-)^2} \quad i = 1, \dots, n \quad (9b)$$

Step 5.6: Calculate the closeness co-efficient of each alternative with respect to the ideal solution:

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-}, \quad i = 1, \dots, m \quad (10)$$

Step 5.7: Rank the alternatives by their closeness coefficients. The bigger the CC_i , the better the alternative A_i . The alternative with the highest closeness coefficient is the best alternative that optimizes resources.

2.2 Data Collection

Data collection is crucial in LSS project selection. This work uses a structured questionnaire for collecting expert opinion on priorities, preferences, and project criteria. This questionnaire was validated by two LSS professionals for completeness, relevance as well as ethical considerations. The case study company for validating the hybrid BWM Fuzzy TOPSIS methodology is a project management company focused on LSS implementation. The company has twenty-seven staff from which three key decision-makers (DM) (the lead project manager, Chief Operating Officer, and a black belt LSS champion) were selected for this work. The questionnaire was administered to each of these DM to evaluate the selection criteria of LSS projects (7 main criteria and 24 sub-criteria) for five LSS projects (labeled as alternatives A1, A2, A3, A4, and A5) that are implemented in the company. These projects include a data warehousing project (A1), a warehouse automation project (A2), an ERP deployment project (A3), a battery-life improvement project (A4) and an Improvement of Overall Equipment Efficiency (OEE) project (A5). The criteria are summarized in the Table 2 below.

Table 2: Description of all criteria

Main Criteria	Sub-Criteria
Management Commitment & Involvement (MIC)	Top level Management Commitment (SC1) Employee Participation (SC2) Employee motivation and cooperation (SC3)
Operational Feasibility (OF)	Technical Feasibility (SC4) Resources and Information Availability (SC5) Project Duration (SC6) Pull Production and Streamlined Process (SC7) Cycle time reduction (SC8)
Learning & Growth Potential (LGP)	Education and Training (SC9) Information Sharing Transparency (SC10) Improved capability (SC11)
Financial Impact and Status (FIS)	Return on investment (SC12) Project budget (SC13) Financial Risk (SC14) Project Cost Reduction (SC15)
Business Management (BM)	Critical to Quality Project (SC16) Flexible Workforce (SC17) Process Improvement (SC18)
Customer Impact (CI)	Customer Satisfaction (SC19) Business Opportunities (SC20) Customer Complaints (SC21)
Environmental Impact (EI)	Energy Management (SC22) Materials Management (SC23) Waste Management (SC24)

3.0 RESULTS

The weights for LSS project selection criteria and performance impacts were determined through expert inputs via distributed questionnaires among four decision-makers. Utilizing the BWM, criteria and sub-criteria weights were calculated.

3.1 Weighing of Criteria with Best Worst Method

The criterion weight is determined by assessing pairwise comparisons based on a 1-9 scale after identifying the best and worst criteria. This is implemented in Microsoft Excel 2016 (with optimal weights and consistency ratios presented in tables 3a-h for the sub-criteria.

Table 3a: Best worst method for customer impact

Criteria	SC 19	SC 20	SC 21
Best to Others: Customer Satisfaction	8	8	7
Others to the Worst: Business Opportunities	1	1	2
Weights	0.43	0.36	0.21
Input-Based CR	0.10714286		
Associated Threshold	0.1309		

Table 3b: Best worst method for environmental impact

Criteria	SC 22	SC 23	SC 24
Best to others: Waste	6	7	9
Others to worst: Energy	3	1	2
Weights	0.43	0.37	0.2
Input-Based CR	0.125		
Associated Threshold	0.1359		

Table 3c: Best-worst method for learning and growth potential

Criteria	SC 9	SC 10	SC 11
Best to others: Education	9	7	8
Others to worst: Improved	2	2	2
Weights	0.79	0.19	0.02
Input-Based CR	0.125		
Associated Threshold	0.1359		

Table 3d: Best worst method for business management

Criteria	SC 18	SC 17	SC 16
Best to others: Process	9	8	8
Others to worst: Flexible	2	2	2
Weights	0.39	0.16	0.45
Input-Based CR	0.125		
Associated Threshold	0.1359		

Table 3e: Best worst method for management commitment and involvement

Criteria	SC 1	SC 2	SC 3
Best to others: Top level Commitment	9	6	7
Others to worst: Employee Participation	2	3	2
Weights	0.64	0.29	0.07
Input-Based CR	0.125		
Associated Threshold	0.1359		

Table 3f: Best worst method for financial impact and status

Criteria	SC 12	SC 13	SC 14	SC 15
Best to others: Project budget	7	8	8	7
Others to worst: Financial Risk	2	1	2	3
Weights	0.26	0.54	0.2	0.04
Input-Based CR	0.23214286			
Associated Threshold	0.2521			

Table 3g: Best worst method for operational feasibility

Criteria	SC 4	SC 5	SC 6	SC 7	SC 8
Best to others: Project duration	7	6	9	7	6
Others to worst: Financial	3	3	3	3	3
Weights	0.51	0.19	0.19	0.06	0.05
Input-Based CR	0.16666667				
Associated Threshold	0.3062				

Table 3h: Best worst method for major criteria

Criteria	MIC	OF	LGP	FIS	BM	CI	EI
Best to others: Project	9	6	8	7	6	7	6

Others to worst: Pull	2	2	2	2	2	2	2
Weights	0.83	0.61	0.69	0.63	0.59	0.71	0.55
Input-Based CR	0.20833333						
Associated Threshold	0.3517						

The combined weights of the main criteria and their global weights is given in Table 4 as follows.

Table 4: Weight of both main criteria and sub criteria and their global weights

Main Criteria	Sub-Criteria	Sub criteria weight	Main criteria weight	Global Weight
MIC	SC1	0.64	0.83	0.5312
	SC2	0.29		0.2407
	SC3	0.07		0.0581
OF	SC4	0.51	0.61	0.3111
	SC5	0.19		0.1159
	SC6	0.19		0.1159
	SC7	0.06		0.0366
	SC8	0.05		0.0305
LGP	SC9	0.79	0.69	0.5451
	SC10	0.19		0.1311
	SC11	0.02		0.0138
FIS	SC12	0.26	0.63	0.1638
	SC13	0.54		0.3402
	SC14	0.2		0.126
	SC15	0.04		0.0252
BM	SC16	0.39	0.59	0.2301
	SC17	0.16		0.0944
	SC18	0.45		0.2655
CI	SC19	0.43	0.71	0.3053
	SC20	0.36		0.2556
	SC21	0.21		0.1491
EI	SC22	0.43	0.55	0.2365
	SC23	0.37		0.2035
	SC24	0.2		0.11

3.2 Ranking of Alternatives with Fuzzy TOPSIS

The decision makers rated the importance of criteria for each alternative project. Their responses were collated and analyzed on a .xlsx spreadsheet. By combining the normalized combined decision matrix and the weights of the criteria as obtained from equation (6), the weighted decision matrix is obtained. The FPIS and FNIS are obtained from the weighted normalized decision matrix. Tables 5a and 5b represent the positive and negative ideal solutions respectively.

Table 5a: Positive ideal solution (A+) of each sub-criteria

SC1	0.2037	0.3486	0.403	**SC13**	0.0855	0.2126	0.2747
SC2	0.0945	0.1493	0.1994	**SC14**	0.0321	0.0773	0.1044
SC3	0.0146	0.036	0.0469	**SC15**	0.0066	0.0151	0.0206
SC4	0.0812	0.1909	0.2578	**SC16**	0.0586	0.1407	0.1858
SC5	0.0306	0.0693	0.0924	**SC17**	0.024	0.0597	0.0772
SC6	0.0295	0.0709	0.096	**SC18**	0.0684	0.1576	0.22
SC7	0.0093	0.0232	0.0292	**SC19**	0.0738	0.1968	0.2481
SC8	0.0079	0.0182	0.0253	**SC20**	0.0969	0.1662	0.2087
SC9	0.1422	0.3514	0.4344	**SC21**	0.0375	0.0925	0.1204
SC10	0.0497	0.0852	0.1072	**SC22**	0.0617	0.1452	0.1959
SC11	0.0053	0.0091	0.0113	**SC23**	0.0537	0.1216	0.1622
SC12	0.0628	0.1016	0.1357	**SC24**	0.028	0.0673	0.0911

Table 5b: Negative ideal solution (A-) of each sub-criteria

SC1	0.0446	0.319	0.3667	**SC13**	0.0293	0.1984	0.2532
SC2	0.0222	0.1329	0.1661	**SC14**	0.0113	0.0696	0.0944
SC3	0.0051	0.0339	0.0432	**SC15**	0.0022	0.0142	0.0192
SC4	0.0279	0.1718	0.233	**SC16**	0.0201	0.1342	0.1734
SC5	0.0103	0.0638	0.0885	**SC17**	0.0084	0.0536	0.0694
SC6	0.0101	0.064	0.0874	**SC18**	0.0238	0.1466	0.2027
SC7	0.0032	0.0217	0.0269	**SC19**	0.0267	0.1757	0.2214
SC8	0.0027	0.0168	0.0233	**SC20**	0.0209	0.1461	0.1744
SC9	0.0476	0.3081	0.3953	**SC21**	0.0132	0.0869	0.111
SC10	0.0107	0.0745	0.0894	**SC22**	0.0212	0.1306	0.1771
SC11	0.0012	0.0078	0.0095	**SC23**	0.018	0.112	0.1553
SC12	0.0151	0.0905	0.1131	**SC24**	0.0096	0.0608	0.0829

By using the Tables 5a and 5b, the distance from the ideal solutions (fuzzy positive and negative ideal solutions) are determined. FPIS and FNIS are summarized in Tables 6a and 6b. The total distances for each criterion across alternatives are calculated. For instance, for Alternative 1, FPIS is 0.4107, while distances from positive ideal solutions (A+) for Alternatives 2, 3, 4, and 5 are 0.4531, 0.2250, 0.3326, and 0.6992 respectively. Similarly, Table 6b outlines the Fuzzy Negative Ideal Solution (FNIS) for each of the five alternatives.

Table 6a: Fuzzy positive ideal solution (FPIS)

	A1	**A2**	**A3**	**A4**	**A5**		**A1**	**A2**	**A3**	**A4**	**A5**
SC1	0.0463	0.0919	0.0248	0.0437	0.0436	**SC13**	0.0331	0.0125	0.0111	0.0111	0.0328
SC2	0.0191	0.0428	0.0233	0.0223	0.0175	**SC14**	0.0126	0.0050	0.0125	0.0058	0.0123
SC3	0.0018	0.0056	0.0022	0.0018	0.0056	**SC15**	0.0025	0.0008	0.0008	0.0008	0.0026
SC4	0.0323	0.0315	0.0123	0.0145	0.0121	**SC16**	0.0222	0.0063	0.0072	0.0224	0.0223
SC5	0.0024	0.0117	0.0024	0.0025	0.0032	**SC17**	0.0096	0.0037	0.0045	0.0093	0.0036
SC6	0.0049	0.0113	0.0045	0.0116	0.0116	**SC18**	0.0260	0.0099	0.0088	0.0262	0.0259
SC7	0.0013	0.0012	0.0012	0.0036	0.0036	**SC19**	0.0293	0.0284	0.0154	0.0154	0.0282
SC8	0.0010	0.0030	0.0012	0.0031	0.0031	**SC20**	0.0441	0.0226	0.0201	0.0445	0.0454
SC9	0.0557	0.0562	0.0234	0.0254	0.3329	**SC21**	0.0048	0.0143	0.0054	0.0048	0.0142
SC10	0.0104	0.0233	0.0116	0.0228	0.0227	**SC22**	0.0245	0.0239	0.0094	0.0109	0.0091
SC11	0.0024	0.0011	0.0014	0.0013	0.0024	**SC23**	0.0042	0.0206	0.0042	0.0042	0.0056
SC12	0.0151	0.0151	0.0131	0.0144	0.0282	**SC24**	0.0048	0.0107	0.0043	0.0109	0.0109
d+	**0.4107**	**0.4531**	**0.2250**	**0.3326**	**0.6992**						

Table 6b: Fuzzy negative ideal solution (FNIS)

	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
SC1	0.05105	0.025	0.0919	0.0549	0.0559	**SC13**	0.0103	0.0326	0.0328	0.0328	0.0124
SC2	0.04136	0.0192	0.0248	0.0251	0.0421	**SC14**	0.0058	0.0124	0.0058	0.0125	0.0048
SC3	0.00555	0.0021	0.0055	0.0056	0.0018	**SC15**	0.0008	0.0026	0.0025	0.0026	0.0007
SC4	0.01432	0.0119	0.0307	0.0308	0.0314	**SC16**	0.0061	0.0223	0.0220	0.0057	0.0072
SC5	0.01145	0.0039	0.0118	0.0116	0.0119	**SC17**	0.0045	0.0092	0.0092	0.0037	0.0092
SC6	0.01158	0.0041	0.0116	0.0045	0.005	**SC18**	0.0083	0.0261	0.0262	0.0099	0.0087
SC7	0.00346	0.0036	0.0036	0.0013	0.0012	**SC19**	0.0154	0.0132	0.0298	0.0298	0.0125
SC8	0.00305	0.001	0.0031	0.0012	0.001	**SC20**	0.0157	0.0271	0.0446	0.0158	0.0198
SC9	0.05466	0.0241	0.0248	0.0547	0.0575	**SC21**	0.0142	0.0054	0.0142	0.0142	0.0047
SC10	0.02293	0.0102	0.0141	0.0083	0.0103	**SC22**	0.0109	0.0091	0.0233	0.0234	0.0239
SC11	0.00104	0.0024	0.0015	0.0015	0.0009	**SC23**	0.0202	0.0068	0.0205	0.0205	0.0209
SC12	0.01684	0.0168	0.0282	0.0171	0.013	**SC24**	0.0109	0.0039	0.0110	0.0043	0.0047
d-	**0.36027**	**0.2953**	**0.4927**	**0.3917**	**0.3617**						

Now, the distances from negative ideal solutions are 0.36027, 0.2953, 0.49265809, 0.391666515, and 0.3617 for alternatives 1, 2, 3, 4 and 5 respectively. Then, the closeness coefficient for each alternative is calculated using equation (10) and summarized in Table 7 below.

Table 7: Calculation of closeness coefficient

	d+	d-	CCi
A1	0.410664	0.36	0.46731
A2	0.453066	0.295	0.39455
A3	0.224969	0.493	0.68651
A4	0.33261	0.392	0.54077
A5	0.699147	0.362	0.34093

In Figure 2, d+ is highest for Alternative 5, followed by Alternative 2. Alternative 1, 4, and 3 are close. Conversely, d- is highest for alternative 3 and lowest for Alternative 2.

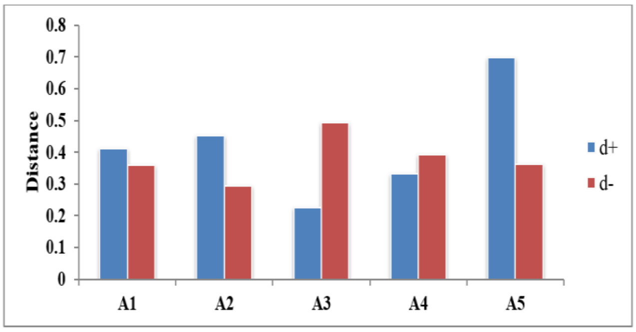

Figure 2: Histogram of d+ and d-

Table 8 ranks alternatives based on closeness coefficient. Alternative 3 leads (0.68651), followed by Alternative 2 (0.54077). Others: Alternative 1 (0.46731), Alternative 4 (0.39455), and Alternative 5 (0.34093). ERP deployment project tops criteria ranking. The histogram of the CCi is shown in Figure 3.

Table 8: The rank of each alternative

Alternatives		CCi	Rank
A1	Data Warehousing Project	0.46731	3
A2	Warehouse Automation Project	0.39455	4
A3	ERP Deployment Project	0.68651	*1*
A4	Battery life improvement	0.54077	2
A5	Improvement of OEE	0.34093	5

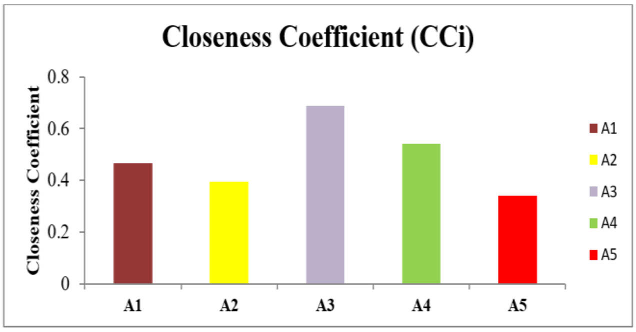

Figure 3: Closeness coefficient of the 5 alternatives

4.0 SUMMARY AND CONCLUSION

This study employed the Best Worst Method (BWM) and Fuzzy VIKOR methodology to select the most suitable project alternative, aiming to enhance accuracy and efficiency in project selection for business adapting to global changes. Five LSS project alternatives were evaluated against 24 criteria by industry-experienced decision makers. BWM helped to find the criteria weights and fuzzy TOPSIS to select alternatives while accommodating uncertainty and subjectivity of decision-makers. A decision matrix with linguistic variables was developed and normalized to compute closeness coefficients, facilitating alternatives ranking. The analysis of results using BWM and fuzzy TOPSIS techniques indicates project alternative 3 (ERP Deployment Project) as the top choice with a closeness coefficient of 0.68651, followed by project alternative 2 (Warehouse Automation Project) at 0.54077. Projects 1, 4, and 5 follow closely.

This work has contributed to knowledge by combining two MCDM methodologies (best worst method and fuzzy TOPSIS) to solve a project selection problem. The best worst method is useful in assessing criteria weights while fuzzy TOPSIS helps to tackle comparative bias in selection and ranking problems. Future research can combine other multi-criterion decision making approaches to focus on selecting optimal LSS projects to achieve sustainability while also adapting methodologies to evolving industry dynamics and expanding criteria to ensure continued relevance. This work is also relevant in other disciplines where selection and ranking problems exists. Methods that enrich the assignment of criteria weights should be emphasized while the subjectivity of decision-makers can also be addressed differently.

5.0 DECLARATION OF INTEREST

The authors declare that this research was carried out without any financial or commercial relationship that can be considered as a potential conflict of interest. No grant was received for this work.

REFERENCES

[1] Anthony, J., Snee, R., and Hoerl, R. "Lean Six Sigma: yesterday, today and tomorrow", *International Journal of Quality & Reliability Management*, 34(7), 2017; 1073-1093.

[2] Bašić, H., Gavranović, H., and Ćuprija, E. "Implementation of Lean Six Sigma in Industry 4.0", 2022, p. 145. https://doi.org/10.5644/PI2022.202.27.

[3] Bazrkar, A., and Iranzadeh, S. "Prioritization of Lean Six Sigma improvement projects using data envelopment analysis cross efficiency model", Quality - Access to Success, 18, 2017a ; 72–76.

[4] Birgün, S., and Cihan, E. "Supplier selection process using ELECTRE method", 2010; 634–639. https://doi.org/10.1109/ISKE.2010.5680767.

[5] Ghodasara, P., Yadav, G., Seth, D., and Desai, T. N. "A Hybrid Fuzzy AHP-ELECTRE approach to rank Lean Six Sigma solutions: Case experience of a manufacturing organization", *Proceedings of ICIE*, 2017; 1159-1167.

[6] Ghorabaee, K, Amiri, M, Zavadskas, M, E. K., and Antucheviciene, J. "Supplier evaluation and selection in fuzzy environments: A review of MADM approaches", *Economic Research-Ekonomska Istraživanja*, 30(1), 2017; 1073–1118.

[7] Gijo, E. V., Palod, R., and Anthony, J. "Lean Six Sigma approach in an Indian auto ancillary conglomerate: A case study", *Production Planning & Control*, 29(9), 2018; 761–772. https://doi.org/10.1080/09537287.2018.1469801

[8] Govindan, K., and Jepsen, M. B. "ELECTRE: A comprehensive literature review on methodologies and applications", *European Journal of Operational Research*, 250(1), 2016; 1-29.

[9] Kaswan, M. S., Rathi, R., Singh, M., Garza-Reyes, J. A., and Anthony, J. "Exploration and prioritization of just in time enablers for sustainable health care: an integrated GRA-Fuzzy TOPSIS application", *World Journal of Engineering*, 19(3), 2022; 402-417.

[10] Liang, F., Brunelli, M., and Rezaei, J. "Consistency issues in the best worst method: Measurements and thresholds", *Omega*, 2020, 96, 102175.

[11] Munemune, E. A., and Erameh, A. A. "Determination of the Stability of a Potable Water Production Line Using Lean Six Sigma Method: A Case Study of XYZ Water Factory", *Nigerian Journal of Technology*, 41(2), 2022, 247–255.

[12] Mi, X., Tang, M., Liao, H., Shen, W., and Lev, B. "The state-of-the-art survey on integrations and applications of the best worst method in decision making: Why, what, what for and what's next?", *Omega*, 2019, 87, 205–225. https://doi.org/10.1016/j.omega.2019.01.009.

[13] Mohammed, H. J. "The optimal project selection in portfolio management using fuzzy multi-criteria decision- making methodology", *Journal of Sustainable Finance and Investment*, 2021, https://doi.org/10.1080/20430795.2021.1886551.

[14] Odeyinka, O. F., Okandeji, A. A., and Sogbesan, A. A. "A fuzzy TOPSIS model for selecting raw material suppliers in a manufacturing company", *Nigerian Journal of Technology*, 41(4), 2022, 797–804. https://doi.org/10.4314/njt.v41i4.17.

[15] Odeyinka, O., Joseph, A., and Adeleke, A. "An Assessment of the Implementation of Lean Concept in Nigerian Manufacturing Companies", *International Journal of Advanced Engineering and Management Research*, 3, 2018.

[16] Ogunwolu, F. O., Odeyinka, O. F., and Oluwaji, O. A. "A Review of Lean Manufacturing, Six Sigma and Lean Six Sigma", *Pacific Journal of Science and Technology*. 22(1), 2021; 77-90.

[17] Opricovic, S., and Tzeng, G. H. "Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS", *European journal of operational research*, 156(2), 2004; 445-455.

[18] Rathi, R., and Khanduja, D. "Identification and prioritization lean six sigma barriers in

MSMEs", *In Journal of Physics: Conference Series*, (Vol. 1240, No. 1, 2019; p. 012062). IOP Publishing.

[19] Rezaei, J. "Best-worst multi-criteria decision-making method", Omega, 53, 2015; 49-57.

[20] Shukla, V., Swarnakar, V., and Singh, A. R. "Prioritization of Lean Six Sigma project selection criteria using Best Worst Method", *Materials Today: Proceedings*, *47*, 2021; 5749–5754. https://doi.org/10.1016/j.matpr.2021.04.038

[21] Singh, K., Swarnakar, V., and Singh, A. R. "Lean Six Sigma project selection using Best Worst Method", *Materials Today: Proceedings*, *47*, 2021; 5766–5770. https://doi.org/10.1016/j.matpr.2021.04.094

[22] Singh, M., Rathi, R., Anthony, J., and Garza-Reyes, J. A. "Lean Six Sigma Project Selection in a Manufacturing Environment Using Hybrid Methodology Based on Intuitionistic Fuzzy MADM Approach", *IEEE Transactions on Engineering Management*, 70(2), 2023; 590–604. https://doi.org/10.1109/TEM.2021.3049877.

[23] Sunder M., V., Ganesh, L. S., and Marathe, R. R. "Lean Six Sigma in consumer banking – an empirical inquiry", *International Journal of Quality and Reliability Management*, 36(8), 2019; 1345–1369. https://doi.org/10.1108/IJQRM-01-2019-0012.

[24] Swarnakar, V., Singh, A. R., Anthony, J., Tiwari, A., and Garza-Reyes, J. A. "Sustainable Lean Six Sigma project selection in manufacturing environments using best-worst method", *Total Quality Management and Business Excellence*, 2022; 1–25. https://doi.org/10.1080/14783363.2022.2139675.

[25] Tabatabaei, M. H., Firouzabadi, S. M. A. K., Amiri, M., and Ghahremanloo, M. "A combination of the fuzzy best-worst and Vikor methods for prioritisation the Lean Six Sigma improvement projects", *International Journal of Business Continuity and Risk Management*, 10(4), 2020; 267-277.

[26] Trakulsunti, Y., Anthony, J., and Douglas, J. A. "Lean Six Sigma implementation and sustainability roadmap for reducing medication errors in hospitals", *The TQM Journal*, 33(1), 2020; 33–55. https://doi.org/10.1108/TQM-03-2020-0063.

[27] Valmohammadi, C., Faezy Razi, F., and Einy, F. "Six Sigma Project Selection Using the Hybrid Approach FAHP-FTOPSIS and Grey Relational Analysis Model", *IEEE Engineering Management Review*, 49(2), 2021; 134–146. https://doi.org/10.1109/EMR.2021.3071368.

[28] Vinodh, S., and Swarnakar, V. "Lean Six Sigma project selection using hybrid approach based on fuzzy DEMATEL–ANP–TOPSIS", *Intern-ational Journal of Lean Six Sigma*, 6(4), 2015; 313-338.

[29] Yadav, G., and Desai, T. N. "Analyzing lean six sigma enablers: a hybrid ISM-fuzzy MICMAC approach", *The TQM Journal*, 29(3), 2017; 488-511.

[30] Zavadskas, E. K., Turskis, Z., and Kildienė, S. "State of art surveys of overviews on MCDM/MADM methods", *Technological and economic development of economy*, 20(1), 2014; 165-179.

[31] Aytekin, A., Okoth, B. O., Korucuk, S., Mishra, A. R., Memiş, S., Karamaşa, Ç., and Tirkolaee, E. B. "Critical success factors of lean six sigma to select the most ideal critical business process using q-ROF CRITIC-ARAS technique: Case study of food business", *Expert Systems with Applications*, *224*, 2023; 120057. https://doi.org/10.1016/j.eswa.2023.120057

[32] Can, G. F., Toktaş, P., and Pakdil, F. "Six Sigma Project Prioritization and Selection Using AHP–CODAS Integration: A Case Study in Healthcare Industry", *IEEE Transactions on Engineering Management*, *70*(10), 2023; 3587–3600. https://doi.org/10.1109/TEM.2021.3100 795

[33] Goker, N., and Dursun, M. "An Intuitionistic Fuzzy Decision Support for Agile Project Selection Problem", *International Journal of Applied Mathematics, Computational Science and Systems Engineering*, *5*, 2023; 145–149. https://doi.org/10.37394/232026.2023.5.13

[34] Ibrahim, A., and Kumar, G. "Selection of Industry 4.0 technologies for Lean Six Sigma integration using fuzzy DEMATEL approach", *International Journal of Lean Six Sigma*, *ahead – of - print* (ahead-of-print), 2024; https://doi.org/10.1108/IJLSS-05-2023-0090

[35] Prakash, R. A., and Edalati, A. "Develop a Process for the Selection of New Continuous Improvement Projects: A case study of the prioritization of Lean Six-Sigmain the quality management team in an assembly industry through the AHP method", 2023; https://urn.kb.se/resolve?urn=urn:nbn:se:mdh:diva-63038

[36] Sheykhzadeh, M., Ghasemi, R., Vandchali, H. R., Sepehri, A., and Torabi, S. A. "A hybrid decision-making framework for a supplier selection problem based on lean, agile,

resilience, and green criteria: A case study of a pharmaceutical industry", *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-023-04135-7

[37] Singh, M., Rathi, R., Antony, J., and Garza-Reyes, J. A. "A toolset for complex decision-making in analyze phase of Lean Six Sigma project: A case validation", *International Journal of Lean Six Sigma*, *14*(1), 2022; 139–157. https://doi.org/10.1108/IJLSS-11-2020-0200

[38] Skalli, D., Cherrafi, A., Charkaoui, A., Chiarini, A., Elbaz, J., and Hamani, N. "Select a winning Lean Six Sigma 4.0 project: Best Worst Method based decision making approach", *Total Quality Management and Business Excellence*, *35*(5–6), 2024; 503–528. https://doi.org/10.1080/14783363.2024.2315427

[39] Sahu, A. K., Sharma, M., Raut, R. D., Sahu, A. K., Sahu, N. K., Antony, J., and Tortorella, G. L. "Decision-making framework for supplier selection using an integrated MCDM approach in a lean – agile – resilient - green environment: Evidence from Indian automotive sector", *The TQM Journal*, *35*(4), 2022; 964–1006. https://doi.org/10.1108/TQM-12-2021-0372