Ranking the Critical Failure Factors to Lean Six Sigma Implementation in Dairy Processing Industry: A Bayesian BWM Approach

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Abstract

Lean Six Sigma (LSS) is a data-driven process improvement approach for waste minimization, cost-effective processing, and increasing overall performance. This study proposes a Bayesian Best Worst Method (BBWM) approach to rank critical failure factors inhibiting the implementation of Lean Six Sigma in the dairy processing industry. BBWM is an advanced Multi-Criteria Decision-Making Method (MCDM) that incorporates the subjective judgment of decision-makers to reduce the uncertainty and complexity of the decision-making process. The study is based on the Bangladeshi dairy processing industry. Four main criteria are found through an extensive literature review and experts' opinions. These four main criteria have been ranked using BBWM. Each major criteria are divided into sub-criteria which are also ranked using the same approach. This study will be helpful for further analysis of LSS applications in the dairy processing industry.

Keywords
Lean Six Sigma, Multi Criteria Decision Method, Bayesian Best Worst Method, Critical factor analysis, Dairy Processing Industry.

1. Introduction
The incorporation of approaches that optimize productivity and reduce waste has become critical in the dynamic realm of industrial operations. Lean Six Sigma (LSS) is a leader in this field, providing a strong data-driven methodology for process optimization. Increasing bottom-line performance is LSS's principal goal. Two commonly used continuous improvement tools in businesses today are lean management and Six Sigma techniques (Alfaro et al. 2020). The use of Lean Six Sigma (LSS) has the potential to transform operational procedures, especially in sectors like dairy processing where accuracy, economy, and overall performance are critical. However, several crucial failure reasons frequently obstruct the smooth use of Lean Six Sigma concepts, making it difficult to realize this potential.

This research investigates the challenges of implementing Lean Six Sigma in Bangladesh's dairy processing industry, a crucial sector for the nation's economy. No study has been found where the critical factors inhibiting the implementation of LSS in the dairy processing industry have been ranked and no generic study has been found on critical factors for implementing LSS in Bangladeshi dairy industries. So, it aims to identify and rank the unique factors preventing the successful integration of Lean Six Sigma in the dairy processing sector using the Bayesian Best Worst Method (BBWM) as a Multi-Criteria Decision-Making technique to assess and prioritize significant failure reasons in the dairy processing sector in Bangladesh. This method of multi-criteria decision-making (MCDM) is based on pairwise comparisons and aggregates the preferences of several experts or decision-makers using a probabilistic framework. BBWM reduces ambiguities and intricacies in decision-making procedures, providing a practical understanding of the unique difficulties faced by the sector. Four key criteria influencing the effectiveness of Lean Six Sigma deployment have been found after a thorough assessment of the literature and inputs from industry professionals. Moreover, acknowledging the complex characteristics of these criteria, the study explores their sub-criteria, utilizing the BBWM technique to determine the proportional significance of each using the Bayesian Best Worst Methodology and investigates the main failure causes preventing Lean Six Sigma adoption in Bangladesh's dairy processing sector. It provides valuable insights for practitioners and policymakers, laying the groundwork for further studies and interventions to maximize the full potential of Lean Six Sigma in the industry.

1.1 Objectives

Finding and grouping important failure factors related to the application of Lean Six Sigma (LSS) in the dairy processing sector is the main goal of this study. These elements will be divided into major and sub-criteria, creating an all-encompassing framework for examination. The Bayesian Best Worst Method (BBWM), a Multi-Criteria Decision Making (MCDM) technique, will then be utilized to rank and prioritize these factors methodically. In the context of Bangladesh's dairy processing industry, the research hopes to provide a nuanced understanding of the obstacles to the successful implementation of LSS through this process.

2. Literature Review

Lean, also referred to as "Lean Manufacturing" or "Lean Production" (Holweg 2007), is mostly preferred in manufacturing firms to reduce overall defects and improve the process by the reduction of waste. Waste reduction (Drohomeretski et al. 2014) and nonconformity elimination from activity (Holweg 2007) are the major focus of lean. Six Sigma finds and removes errors, flaws, or failures that could affect processes by concentrating on the crucial quality aspects of products that matter to customers (Garza-Reyes et al. 2014). Using Six Sigma methodologies, a quantitative analysis of structured continuous programs and lean manufacturing in the Canadian food industry was carried out (Scott et al. 2009). The DMAIC methodology was employed by researchers to apply the Six Sigma framework and attain the optimal acidity rate in yogurt within the Iranian dairy industry (Hakimi et al. 2018). The packaging of sweetened condensed milk sachets in Indonesia was examined for defects using the Six Sigma methodology (Rawendra and Puspita 2020). It has also been researched how to apply lean manufacturing and maintenance management strategies in the dairy industry to increase productivity and decrease breakdown losses (Arslankaya and Atay 2015).

After performing an extensive investigation of relevant articles using Google Scholar, we found twenty relevant CFFs for LSS implementation in the dairy industry. With the help of industry experts, we finalize the CFFs. The findings are summarized in Table 1.

Table 1. List of CFFs for LSS implementation in the dairy industry

Sub-Criteria	How does it affect	Sources
Poor Organization capability	Low productivity and efficiency, a sluggish reaction to market changes, poor decision-making skills, a lack of creativity, an inability to adapt to new technology, and altering client expectations are just a few ways this might show themselves.	(Gupta et al. 2023), (Chakravorty 2009)
Replicating another organization's LSS strategy	If a corporation adopts a strategy without first ensuring that it is compatible with its culture and aims, it may suffer the repercussions of doing so.	(Bhasin 2012a), (Bhasin 2012b)
Weak infrastructure	Weak infrastructure can hinder economic growth and development, leading to negative impacts on productivity, competitiveness, and overall well-being of a society.	Experts' opinion
Resistance to cultural change	LSS demands a culture shift toward ongoing development and a concentration on fact-based judgment. For workers accustomed to operating in a more conventional, reactive setting, this can be difficult.	(Antony et al. 2012), (Bhasin 2012a)

Misalignment between organizational goals, project aim and customer demand	It creates confusion and lack of focus on improvement areas. As a result, projects may not have the necessary support and resources, making it difficult to achieve desired outcomes.	(Ho et al. 2008)
Weak Linking to supplier	It results in Poor quality of inputs, delays in supply chain, difficulties in data collection etc.	(Bamber and Dale 2000)
Lack of training and education	Employees may lack the skills and equipment required for data collection and analysis, an essential element of LSS. The capacity of management and leadership to successfully lead the adoption of LSS can also be impacted by a lack of knowledge.	(Chakravorty 2009), (Gupta et al. 2023)
Lack of resources	It may create low morale and resistance from employees, the organization might not be able to handle all instances of waste and inefficiency, which would produce erratic outcomes and limited benefits.	(Burcher et al. 2010), (Pinto et al. 2008)
Lack of top management attitude, commitment and involvement	The company might not set aside enough funds and employees to ensure that LSS is implemented successfully. This may reduce the initiative's potential advantages by limiting its breadth and effect.	(Bhasin 2012a), (Bhasin 2012b)
A weak link between the CI projects and the strategic objectives of the organization	A lack of focus, uneven results, and little advantages may emerge from a lack of clear alignment between the initiatives and the organization's strategic goals.	(Antony et al. 2012)
Wastage due to leakages (milk, water etc.) at shop-floor	This has the potential of becoming a big problem in raising production.	(Singh et al. 2013), (Bhanpurkar et al. 2012)
Milk Pasteurization Problem	Milk pasteurization temperature should be in control to make quality final product.	Experts' opinion
Lack of automation and outdated technology	Handling dairy products manually might cause hygiene issue, more production time, less production.	(Mor et al. 2018)
Unbalanced production line	The inefficiencies brought on by an unbalanced production line, such as overworked employees or idle equipment, can increase lead times, lower throughput, and lower overall production efficiency.	(Shaaban et al. 2013), (Hudson et al. 2015)
More waiting time at milk packaging line	Waiting time can result in lost production time, increased lead times, and decreased overall production efficiency.	(Mor et al. 2018)

Traceability of machinery breakdown	Increases production downtime, more maintanence time.	(Burcher et al. 2010)
Unavailability of data and lack of application of statistical theory	It causes lack of identification and measurement of process performance, inefficiencies and needs.	(Thomas et al. 2009)
Inefficient quality information and analysis	It may result in huge disaster for the organization in a data-driven world.	(Yadav and Desai 2017)
Wrong selection of LSS tools	It hinders the identification of root cause problem.	(Antony 2006), (Antony et al. 2005)
Lack of technological resources	Lack of proper hardware and software support can cause various types of problem in tracking continuous improvement projects.	(Aboelmaged 2011), (Antony 2008)

3. Methods

3.1 Bayesian Best Worst Method (BBWM)

Bayesian Best-Worst Method is a development of the Best-Worst Method where the method is viewed from a probabilistic angle and the decisions of the group of decision-makers are weighted using the Bayesian hierarchical model. Further, a confidence level is assigned to measure the extent of preference of one criterion over another. The ranking scheme is called credal ranking which is viewed using a weighted directed graph. The key steps of the Bayesian Best Worst Method are:

Step 1: The decision-makers (k) are given with some criteria, $C = \{C_1, C_2, C_3, \ldots, C_n\}$ to conduct with.

Step 2: The decision makers select the best (C_B) criteria from C and perform a pair-wise comparison between C_B and the other members of C and determine the preference of the best criterion to the others criteria as 1-9, where 1 denotes equally important and 9 significantly more important. The pair-wise comparison yielded the "Best-to-Others" vector of $AB = \{a_{B1}^k, a_{B2}^k, \ldots, a_{Bn}^k\}$, where k= 1, 2, 3, …, N, in which a_{Bj} implies the preference of the best criteria over $C_j \epsilon C$.

Step 3: The decision makers select the worst (C_w) from C The decision makers perform pair-wise comparisons between C_W and the other members of **C** and determines the preference of the other criteria to the worst criterion as 1-9. The pair-wise comparison yielded the "Others-to-Worst" vector of $A_w^k = \{a_{w1}^k, a_{w2}^k, \ldots, a_{wn}^k\}T$ where k= 1, 2, 3, …, N, in which a_{Wj} implies the preference of $C_j \epsilon C$ over the worst criteria.

Step 4: The final step is to aggregate the weight. The aggregated weights ($w^{agg} = w_1^{agg}, w_2^{agg}, \ldots \ldots, w_n^{agg}$) of all k experts, where $w_j \geq 0, \ \sum_{j=1}^{n} w_j = 1$ and the weight for each expert are calculated using the following probabilistic technique of Bayesian BWM.

$$A_B^k \mid w^k \sim \text{multinomial } (1/w^k), \forall k = 1, \ldots, k$$
$$A_W^k \mid w^k \sim \text{multinomial}(w^k), \forall k = 1, \ldots, k$$
$$w^k \mid w^{agg} \sim Dir(\gamma \times w^{agg}), \forall k = 1, \ldots, k$$
$$\gamma \sim gamma(0.1, 0.1)$$
$$w^{agg} \sim Dir(1)$$

To compute the solution, the use of Markov Chain Monte Carlo sampling is introduced. The probability characteristics of weight vector, ($w^* = w^*_1, w^*_2, \dots \dots, w^*_n$) where $\sum_{j=1}^{m} w_j = 1$, and $w_j \geq 0$. The weighting of each related criterion (c_j) is viewed as a stochastic random event.

3.2 Credal Ranking

The probability distributions of the aggregated weight (w*) are used to generate S samples once the problem has been solved by employing the Bayesian BWM. The significance of each criterion and the degree to which one criterion is selected over another focusing on the opinions of all experts can be determined depending on the aggregated weight. We must conclude a Bayesian perspective to calculate this extent. Based on the aggregated preferences w*, the following formulations and calculations would offer such probabilistic perception.

Definition 1: The formulation of a credal ordering (O) for two criteria, c_i and c_j, is as follows:

$$O = (c_i, c_j, R, d)$$

Where,
R is indeed the relationship (for example, > or ≥ among the performance measures c_i and c_j. $d \in [0,1]$ represents the relation's degree of confidence.
Definition 2: The credal ranking is a list of credal orderings that contains all pairs (c_i, c_j) for all $c_i, c_j \in C$, upon a given set of criteria $(C = C_1, C_2, \dots \dots \dots, C_m)$. Now, for every set of criteria c_i and c_j, we just require calculating the credal ordering degree. To achieve this, we utilize the S samples from JAGS and calculate the degree in the manner specified below:

$$P(c_i > c_j) = \frac{1}{S}\sum_{s=1}^{S} I(W_i^{*s} > W_j^{*s})$$

The credal ordering has a confidence score which provides the decision makers with more information to improve their decision. A new Bayesian test is devised to find each credal ordering confidence based on the prediction of the posterior distribution of w^{*s}. The weights of posterior distribution help to measure the credal ordering confidence of the relations between the factors, and the credal ranking confidence is computed based on the Dirichlet distribution of w^{*s}. However, other ranking methods consider two intervals or numbers and try to determine which is significantly superior. We may compare different criteria probabilistically based on this calculation. The credal ranking of a collection of criteria is visualized in this section that precedes utilizing a weighted graph structure. This makes the comprehension of all the necessary details about the probabilistic comparison easier.

4. Data Collection

This study employed a Bayesian BWM framework to analyze the identified key CFFs to implement LSS. This study collected experts' feedback in three distinct phases. The first phase was feedback collection which was done through interviews and emails. A total of 10 experts were asked with a survey questionnaire to validate, finalize, and cluster the key CFFs for further analysis. The experts are either related to the dairy industry or LSS or both. The selection criteria also involve at least five years of experience in the relevant field. The experts' profile is summarized in the Table 2.

Table 2. A brief overview of the participating experts' profile

Total Experts	No.	Expertise Area	Experience
10	1	Operations & LSS Expert	Above 15 years
	2	Operations & LSS Expert	Above 15 years
	3	Manager	Above 15 years
	4	Deputy Manager	Above 10 years
	5	Regional Manager	Above 10 Years
	6	Production Manager	Above 8 years
	7	Quality Officer	Above 8 years
	8	Dairy Professional	Above 6 years
	9	Dairy Professional	Above 6 years

	10	Production & LSS Expert	Above 5 years

After the identification of the CFFs, the CFFs were grouped into four major clusters with the guidance of the experts-Organizational Barrier (C1), Strategic Barrier (C2), Shop Floor Barrier (C3), Technology-based Barrier (C4). The for major clusters and their respective CFFs are presented in the **Table 3**.

Table 3. List of clusters

Criteria (Code)	Sub-Criteria **(Code)**
Organizational Barrier (C1)	Poor Organization capability **(C11)**
	Replicating another organization's LSS strategy **(C12)**
	Weak infrastructure **(C13)**
	Resistance to cultural change **(C14)**
	Misalignment between organizational goals, project aim and customer demand **(C15)**
Strategic Barrier (C2)	Weak Linking to supplier **(C21)**
	Lack of training and education **(C22)**
	Lack of resources **(C23)**
	Lack of top management attitude, commitment and involvement **(C24)**
	A weak link between the CI projects and the strategic objectives of the organization **(C25)**
Shop Floor Barrier (C3)	Wastage due to leakages (milk, water etc.) at shop-floor **(C31)**
	Milk Pasteurization Problem **(C32)**
	Lack of automation and outdated technology **(C33)**
	Unbalanced production line **(C34)**
	More waiting time at milk packaging line **(C35)**
Technology-based Barrier (C4)	Traceability of machinery breakdown **(C41)**
	Unavailability of data and lack of application of statistical theory **(C42)**
	Inefficient quality information and analysis **(C43)**
	Wrong selection of LSS tools **(C44)**
	Lack of technological resources **(C45)**

5. Results and Discussion

The Bayesian BWM enables us to rank criterions of this research by providing average weight and graph. Each line $X \xrightarrow{d} Y$ indicates X is more significant than Y along with a confidence level of d. The graph represents the credal ranking and each line represents credal order. The Bayesian BWM enables us to rank the four major criteria of this research by providing average weight and graph. The graph represents the credal ranking and each line represents credal order.

5.1 Numerical Results

The four criteria shown here are Organizational Barrier **(C1)**, Strategic Barrier **(C2)**, Shop Floor Barrier **(C3)**, Technology Based Barrier **(C4)**. The aggregated weight and ranking is shown on Table 4.

Table 4. Aggregated weight of Major Criteria

Organizational Barrier **(C1)**	Strategic Barrier **(C2)**	Shop Floor Barrier **(C3)**	Technological Barrier **(C4)**
0.1320	0.4397	0.1863	0.2420
Rank-4	Rank-1	Rank-3	Rank-2

The first major criteria, "Organizational Barrier", is divided into 5 sub-criteria named Poor Organization capability **(C11)**, Replicating another organization's LSS strategy **(C12)**, Weak infrastructure **(C13)**, Resistance to cultural change **(C14)**, Misalignment between organizational goals, project aim and customer demand **(C15).** The aggregated weight and ranking is shown on Table 5.

Table 5. Aggregated weight of Sub-Criteria of Organizational Barrier (First Major Criteria)

Poor Organization capability **(C11)**	Replicating another organization's LSS strategy **(C12)**	weak infrastructure**(C13)**	Resistance to cultural change **(C14)**	Misalignment between organizational goals, project aim and customer demand **(C15)**
0.1952	0.1513	0.3887	0.1398	0.1250
Rank-2	Rank-3	Rank-1	Rank-4	Rank-5

The second major criteria, "Strategic Barrier", is divided into 5 sub-criteria named Weak Linking to supplier **(C21)**, Lack of training and education **(C22)**, Lack of resources **(C23)**, Lack of top management attitude, commitment and involvement **(C24)**, and A weak link between the CI projects and the strategic objectives of the organization **(C25)**. The aggregated weight and ranking is shown on Table 6.

Table 6. Aggregated weight of Sub-Criteria of Strategic Barrier

Weak Linking to supplier **(C21)**	Lack of training and education **(C22)**	Lack of resources **(C23)**	Lack of top management attitude, commitment and involvement **(C24)**	A weak link between the CI projects and the strategic objectives of the organization **(C25)**
0.2626	0.1369	0.2825	0.2141	0.1038
Rank-2	Rank-4	Rank-1	Rank-3	Rank-5

The third major criteria, "Shop Floor Barrier", is divided into 5 sub-criteria named Wastage due to leakages (milk, water etc.) at shop-floor **(C31)**, Milk Pasteurization Problem **(C32)**, Lack of automation and outdated technology **(C33)**, Unbalanced production line **(C34)**, and More waiting time at milk packaging line **(C35).** The aggregated weight and ranking is shown on Table 7.

Table 7. Aggregated weight of Sub-Criteria of Shop Floor Barrier

Wastage due to leakages (milk, water etc.) at shop-floor **(C31)**	Milk Pasteurization Problem **(C32)**	Lack of automation and outdated technology **(C33)**	Unbalanced production line **(C34)**	More waiting time at milk packaging line **(C35)**
0.3153	0.1369	0.3346	0.1153	0.0979
Rank-2	Rank-3	Rank-1	Rank-4	Rank-5

The fourth criteria, "Technological Barrier", is divided into 5 sub-criteria named Traceability of machinery breakdown **(C41)**, Unavailability of data and lack of application of statistical theory **(C42)**, Inefficient quality information and analysis **(C43)**, Wrong selection of LSS tools **(C44)**, and Lack of technological resources **(C45).** The aggregated weight and ranking is shown on Table 8.

Table 8. Aggregated weight of Sub-Criteria of Technological Barrier

Traceability of machinery breakdown **(C41)**	Unavailability of data and lack of application of statistical theory **(C42)**	Inefficient quality information and analysis **(C43)**	Wrong selection of LSS tools **(C44)**	Lack of technological resources **(C45)**
0.2284	0.1531	0.1207	0.1805	0.3173
Rank-2	Rank-4	Rank-5	Rank-3	Rank-1

All the 20 sub-criterions can be arranged in a single table and done a global ranking among them. The global ranking is shown in Table 9.

Table 9. Global Ranking of all Sub-Criteria

Sub-Criteria (Descending Order)	**Weight**
(C23) Lack of resources	0.1242
(C21) Weak Linking to supplier	0.1155
(C24) Lack of top management attitude, commitment and involvement	0.0941
(C45) Lack of technological resources	0.0768
(C33) Lack of automation and outdated technology	0.0623
(C22) Lack of training and education	0.0602
(C31) Wastage due to leakages (milk, water etc.) at shop-floor	0.0587
(C41) Traceability of machinery breakdown	0.0553
(C13) weak infrastructure	0.0513
(C25) A weak link between the CI projects and the strategic objectives of the organization	0.0456
(C44) Wrong selection of LSS tools	0.0437
(C42) Unavailability of data and lack of application of statistical theory	0.0371
(C43) Inefficient quality information and analysis	0.0292
(C11) Poor Organization capability	0.0258
(C32) Milk Pasteurization Problem	0.0255
(C34) Unbalanced production line	0.0215
(C12) Replicating another organization’s LSS strategy	0.0200
(C14) Resistance to cultural change	0.0185
(C35) More waiting time at milk packaging line	0.0182

(C15) Misalignment between organizational goals, project aim and customer demand	0.0165

5.2 Graphical Results

Figure 1 shows the credal ranking between major criteria, Figure 2 shows the ranking between the sub-criteria of first major criteria, Figure 3 shows the ranking between the sub-criteria of second major criteria, Figure 4 shows the ranking between the sub-criteria of third major criteria, Figure 5 shows the ranking between the sub-criteria of fourth major criteria. The graphs are figured using MATLAB. The confidence interval is shown in the graph along with the ranking.

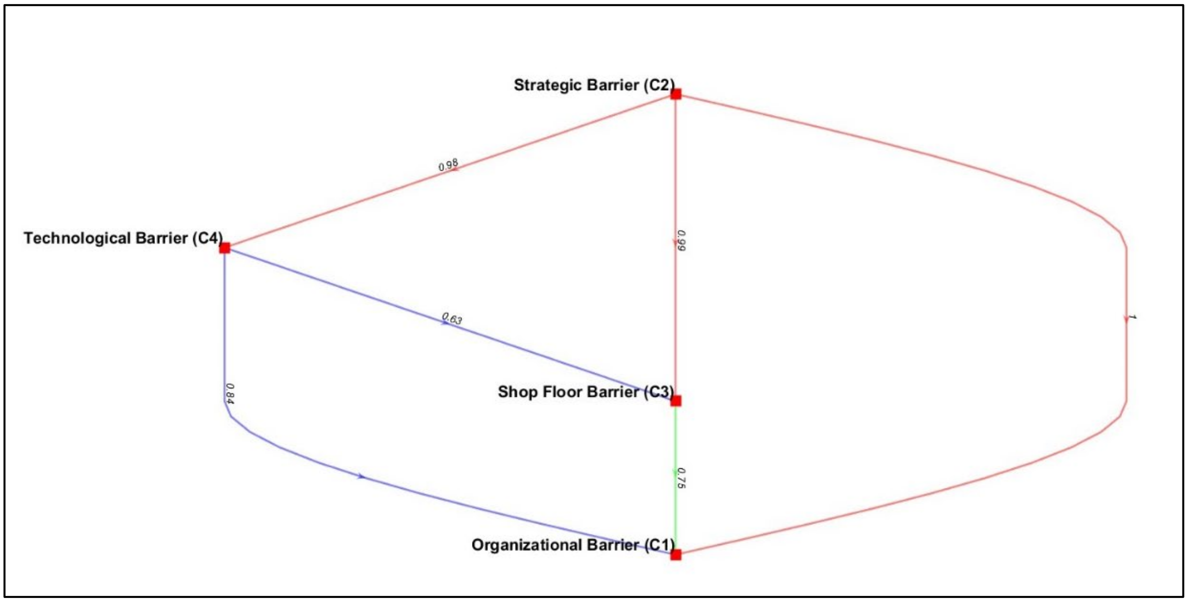

Figure 1. Ranking of Major Criteria

The Figure 2 shows, weak infrastructure**(C13)** is the most CFF among organizational factors followed by Poor Organization capability **(C11)**, Replicating another organization's LSS strategy **(C12)**, Resistance to cultural change **(C14)**, and Misalignment between organizational goals, project aim and customer demand **(C15).**

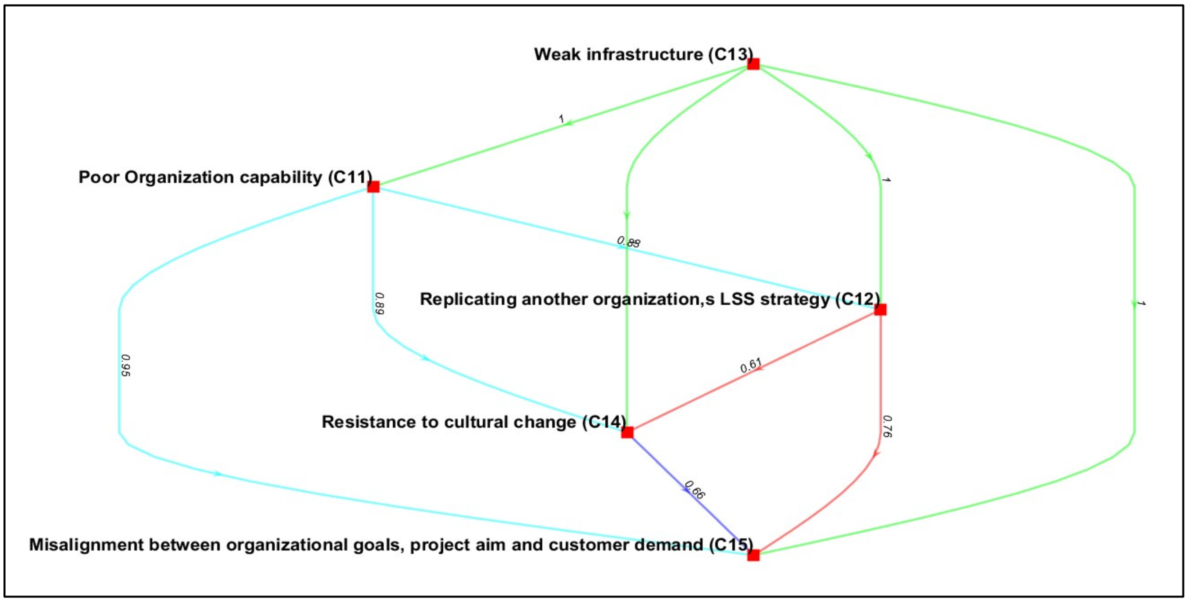

Figure 2. Ranking of Sub Criteria of Organizational Barrier (C1)

The Figure 3 shows, Lack of resources **(C23)** is the most CFF followed by Weak Linking to supplier **(C21)**, Lack of top management attitude, commitment and involvement **(C24)**, Lack of training and education **(C22)**, and A weak link between the CI projects and the strategic objectives of the organization **(C25)**.

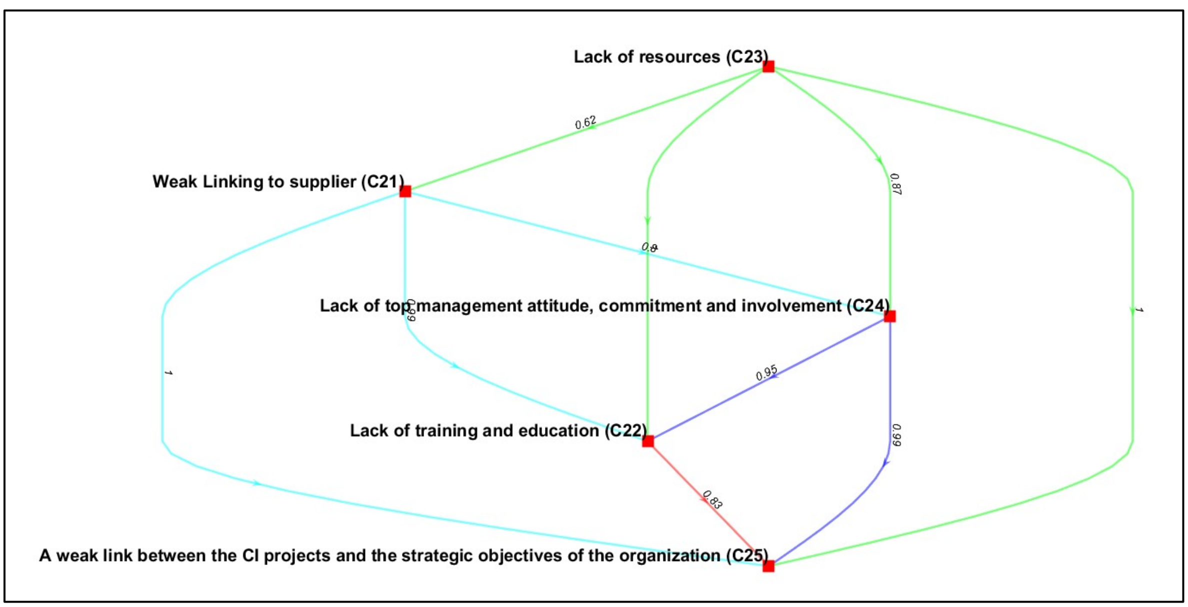

Figure 3. Ranking Sub-Criteria of Strategic Criteria (C2)

The Figure 4 shows, Lack of automation and outdated technology **(C33)** is the most CFF followed by Wastage due to leakages (milk, water etc.) at shop-floor **(C31)**, Milk Pasteurization Problem **(C32)**, Unbalanced production line **(C34)**, and More waiting time at milk packaging line **(C35)**.

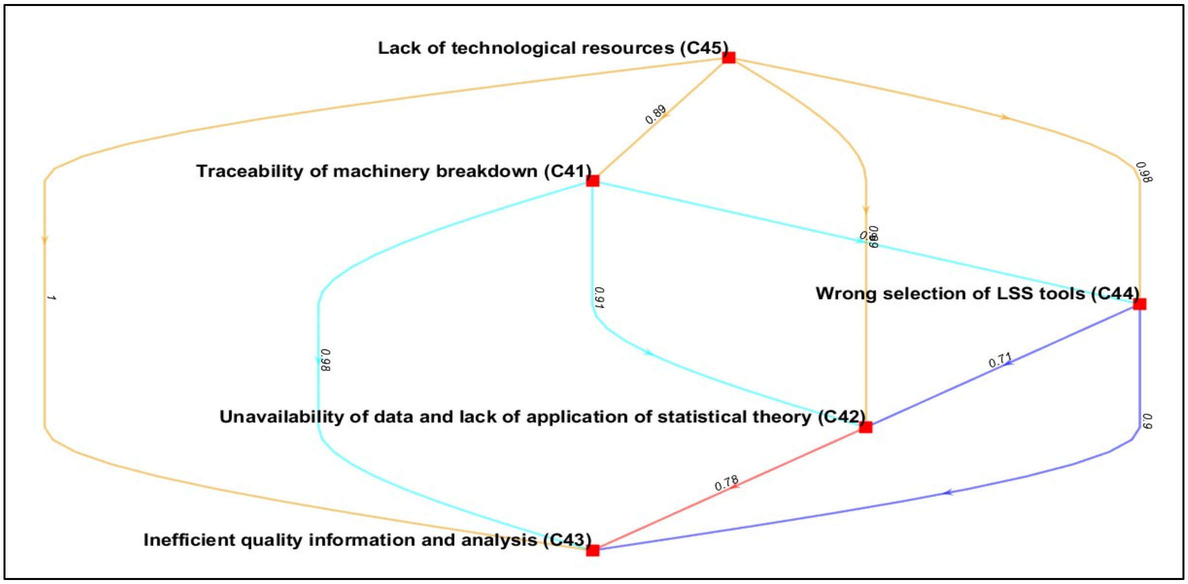

Figure 4. Ranking Sub-Criteria of Shop Floor Criteria (C3)

The Figure 5 shows, Lack of technological resources **(C45)** is the most CFF followed by Traceability of machinery breakdown **(C41)**, Wrong selection of LSS tools **(C44)**, Unavailability of data and lack of application of statistical theory **(C42)**, and Inefficient quality information and analysis **(C43)**.

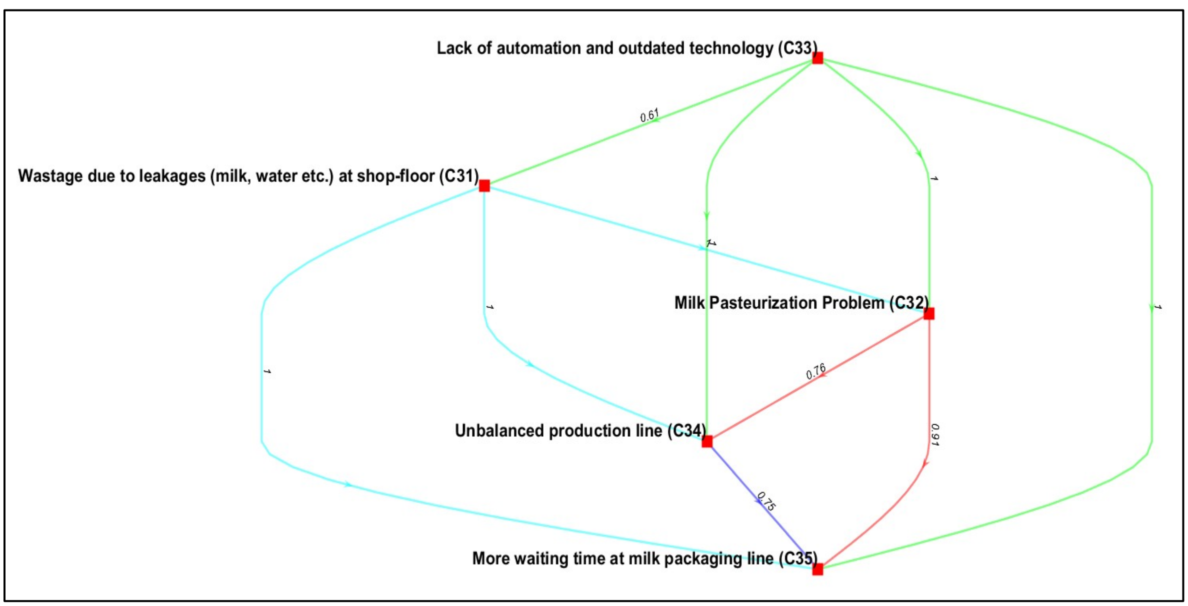

Figure 5. Ranking Sub-Criteria of Technological Barrier (C4)

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6. Conclusion

The research findings highlighted the critical failure factors that hinder the successful implementation of LSS in the dairy industry of Bangladesh. These factors encompassed various dimensions such as management support, employee engagement, training and education, cultural factors, communication, and technology adoption. The

Bayesian BWM approach allowed for the integration of expert judgments and the consideration of multiple criteria, leading to a comprehensive assessment and ranking of the critical failure factors. The identified factors serve as crucial reference points for organizations in the dairy industry, providing guidance on areas that require attention and improvement to enhance LSS implementation outcomes.

However, it is important to acknowledge the limitations of the study. The findings may not be fully generalizable due to the small sample or potential biases in the selection process. Another limitation is associated with the data collection method employed in the study. Surveys or interviews may introduce biases, self-reporting errors, or interpretation variations, impacting the reliability and validity of the findings. The subjectivity in the ranking process of critical failure factors, influenced by individual perspectives and biases, is another limitation that may affect the robustness of the results. Additionally, the study's focus on a specific set of factors may limit the comprehensiveness of the findings, as there could be additional factors not included in the research.
The outcomes of future research efforts can contribute to enhancing the understanding of LSS implementation in various contexts, provide insights into effective decision-making methods, and support organizations in optimizing their implementation strategies.

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