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PERFORMANCE EVALUATION OF LEAN IMPLEMENTATION IN SUPPLY CHAIN USING FUZZY-BASED APPROACH

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Abstract

The supply chain comprises a series of interconnected processes and the number of echelons and facilities within each echelon contribute to the supply chain's complexity. Even though businesses have changed their supply chains to integrated supply- chains, they still require a tool that will display the supply chain's overall performance, and this crucial tool is a supply chain performance measurement system (SCPMS). Measurement of Performance refers to a collection of measures used to manage scheduled tasks and resource allocation to achieve predefined objectives. This paper models complicated manufacturing supply chain processes using fuzzy logic, analyzing the outcomes through a case study. Based on the SCOR framework, a lean Supply Chain model is created, including both lean and non-lean metrics as necessary. The performance of both non-Lean and Lean supply chain scenarios has been assessed, After the apposite metrics values are converted into triangular fuzzy numbers (TFNs), overall performance is measured using the Fuzzy Topsis. Results indicate that the application of lean technologies has a major impact on overall performance enhancements of supply-chain.

Keywords: Performance metrics, SCOR, TFN, Fuzzy Topsis, performance evaluation.

1. INTRODUCTION

In order to gain competitive advantages, emerging advancements in manufacturing, technology, and customer demand necessitate fast product invention, more flexible manufacturing, waste elimination, increased process control, effective worker utilization, and international expansion [1]. However, as global markets develop, it is becoming more difficult to achieve the goal because of factors such as capacity variance, global competition, resource limits, and shifting market dynamics [2]. Many big companies worldwide have been attempting to use the lean concept as a means of optimizing resources and streamlining the production process [3]. Producers can reduce waste and non-value-added (NVA) activities by implementing several lean practices and lean concepts [4]. Complex interdependencies must be addressed by supply-chain (SC), ultimately leading to the creation of an "extended enterprise" that extends well beyond the walls of the factory such as suppliers, sub-tiers, and distribution networks [5]. Fuzzy logic (FL) provides plenty of resources for evaluation purposes. Efforts to evaluate the performance of SC have been made in many industries. The Fuzzy Topsis (FTOPSIS) is utilized to maintain consistency in the assessment of the results. [6]. The study generated a conceptual model for evaluating leanness that is applicable to manufacturing supply chains. This paper is structured as follows. The paper is organized into six sections, beginning with the introduction. A theoretical framework is addressed in the second section. The approach and framework for assessing the performance of a lean Supply Chain (LSC) are then covered in the third section. The methodology's effectiveness is illustrated through a case study for the effective performance evaluation method in the fourth section, The fifth portion contains the results and conclusion. The limitations and future directions of the research are finally covered in the sixth section.

2. THEORETICAL FRAMEWORK

2.1 Lean Supply Chain Management: The intent of a supply chain is to generate value and then transfer that value to the customers [7-8]. By utilizing information technology, companies were able to regulate the flow and influence several dimensions of the SC [9]. As the competition increasingly more fierce, companies began investigating lean concepts [10-11]. The lean approach strives for the most efficient use of the resources at hand [12]. Implementing lean produced better first-pass correct production, decreased lead times, decreased inventory needs, and decreased space requirements [13-14]. LSCM refers to adapting lean concepts and procedures to be employed across the whole SC [15]. According to LSCM, the whole SC from the raw material to the end customer is unified [16]. Lean SC improves customer satisfaction by lowering costs, delivering consistent quality, cutting lead times, and lowering inventory levels [17]. The LSC is facilitated by a number of key enablers [18].

2.2 Performance Metrics: The significance of performance measures and indicators for an organization's triumph is in their ability to facilitate goal-setting, performance assessment, and future planning [19]. In order to find areas where major changes, can be made, performance assessment is helpful in assessing present performance [20]. While financial performance metrics have been the focus of some managers and researchers, operational measures have been the focus of others [21-22]. Decisions at the tactical, operational, and strategic levels are influenced by performance-measuring metrics [23]. Measuring goals must take into account the whole SC goals as well as the metrics to be employed in order for SCM to work efficiently [24]. SC measures must be devised for the operational and strategic levels of the framework [25]. The metrics chosen ought to demonstrate an equilibrium between monetary and non-monetary measurements that might be linked to the strategic and operational phases of management [13].

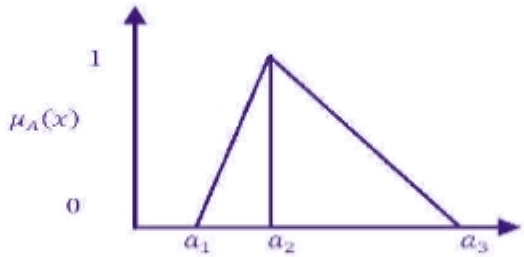
2.3 Performance Evaluation: In the context of SC, PMS can be categorized for identifying key performance measures (KPM) and choosing the best PMS [26]. To identify the performance metrics a framework is needed [27]. It has been discovered that a hybrid strategy combining System Dynamics (SD), Game theory, and BSC is appropriate for assessing the performance of the automotive sector [28]. In addition to non-financial variables, the BSC consists of conventional financial measures that reflect an organization's historical performance [29]. It is possible to combine the characteristics of the BSC and SCOR models to create a PMS specifically for SMEs in India [30]. For evaluating a SC's performance at different levels of hierarchy, models with a hierarchical base are relevant [31]. performance measures can be categorized as time measures, quality measures, cost measures, and flexibility measures [32]. The SC measure components, measurement process, balanced scorecard context, measure landscape, and decision hierarchy level are used to categorize various performance metrics [33].

2.4 Fuzzy Logic: Utilizing fuzzy set theory in assessment systems can enhance the outcomes of assessments. A non-linear system that converts a data input vector into a scalar output is a fuzzy logic system (FLS) [34]. A precise logic of imprecision and approximation is known as FL [35]. For sustainable supplier selection in the supply chain, a new model with a triangular fuzzy approach is employed [36]. Four typical forms of fuzzy are as follows: single fuzzy, trapezoidal fuzzy, triangular fuzzy, and Gaussian fuzzy [37]. Studies using fuzzy set models are descriptive in nature and frequently entail a particular defuzzification procedure [38]. FL has emerged to be a successful multicriteria decision-making (MCDM) technique [39]. To determine leanness, multi-grade FL may be applied [40]. The members of a crisp set are selected from a universal set X and classified as either members or non-members. i.e. In a specified crisp set A, the function allocates a value μA(x) to each x∈X

$$\mu_A(x) = \begin{cases} 1 \text{ if } x \in A \\ 0 \text{ if } x \notin A \end{cases}$$

here [0, l] indicates the real numbers interval ranging from 0-1, inclusive, and X is the universal set described in a particular problem.

Figure1. TFN, A



2.5 Fuzzy Topsis Method: "TOPSIS", or "Technique for Order Performance by Similarity to Ideal Solution", is an MCDM approach centered on criteria and alternatives [41]. An approach for selecting solutions from a limited number of options is termed multicriteria decision-making, or TOPSIS [42]. The optimal solution is the one that is the most distant from the negative ideal solution and most near to the positive ideal solution [43]. A sustainable SC network design model is created using the BWM and TOPSIS methodologies [44]. FTOPSIS is the merger of FL and TOPSIS. The FTOPSIS approach ranks the alternatives based on the specified criteria by using multiple-criteria analysis [45]. The FTOPSIS approach is utilized to rank providers in uncertain situations [46]. The problem of supplier selection with ambiguous and subjective preferences is solved using the FTOPSIS approach [47]. Hybrid neuro-fuzzy approach used for Six different forms of worldwide logistics [48]. The most efficient operating and strategic guiding principles for an effective SCM are determined using FTOPSIS in conjunction with simulation [49]. The FTOPSIS is used to determine the potential risks in the SC [50]. The FTOPSIS approach is used to identify and suggest solutions for the obstacles [51]. It is crucial to transfigure numerical values into fuzzy numbers and subsequently defuzzify those numbers to crisp values in the FTOPSIS method [52].

3. METHODOLOGY

The technique is used to evaluate how the independent SC practices measure affected the dependent SC performance measure. This study has suggested a set of ideal measures that are based on the five SCOR practices. SCOR architectures incorporate both lean and non-lean metrics to enable the measurement of LSC performance both prior to and following lean deployment. The values of metrics are primarily converted into triangular fuzzy numbers (TFNs). The performance of the entire SC is then assessed using the FTOPSIS technique. The steps of the methodology are as follows:

Initially, two SC conditions prior to and after the application of lean were used to collect distinct results for each metric. Let J= 1,2, ………n are different SC performance categories, I= 1,2, ………m are SC conditions (lean and non-lean); and K= 1,2, …………….t are optimal metrics which means, J= ($j_1, j_2, \dots j_n$), I= ($i_1, i_2, \ldots . i_m$), and K= ($k_1, k_2, \ldots, k_t$). Now assume, $Zi_mj_nk_t1$, $Zi_mj_nk_t2$, and $Zi_mj_nk_td$ are the number of units (weekly basis) for metric k_t, in J_n category and, condition I_m.

3.1 Triangular fuzzy number

Table 1. Linguistic phrases and equivalent TFNs

Linguistic Phrases	TFNs ($a_{imjnkt}, b_{imjnkt}, c_{imjnkt}$)
Very High (VH)	(7, 9, 9)
High (H)	(5, 7, 9)
Medium (M)	(3, 5, 7)
Very Low (VL)	(1, 1, 3)
Low (L)	(1, 3, 5)

As stated in Table 1, which represents three points of TFNs for equivalent linguistic expressions.

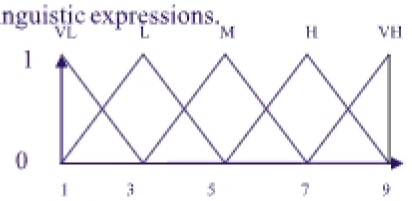


Figure 2 TFN for equivalent linguistic phrases

3.2 Normalize triangular fuzzy number (NTFN): Cost and Profit metrics are two more significant categories of metrics. Whereas cost indicates that less is better, benefit indicates that more is better. The following are the normalization procedures:

$$N_{i_m j_n k_t r} = \left(\frac{a_{i_m j_n k_t r}}{c_r^{max}}, \frac{b_{i_m j_n k_t r}}{c_r^{max}}, \frac{c_{i_m j_n k_t r}}{c_r^{max}}\right) \text{ Where } c_r^{max} = max(c_{i_m j_n k_t r}) \quad \text{(profit metrics) (1)}$$

$$N_{i_m j_n k_t r} = \left(\frac{c_r^{min}}{c_{i_m j_n k_t r}}, \frac{c_r^{min}}{b_{i_m j_n k_t r}}, \frac{c_r^{min}}{a_{i_m j_n k_t r}}\right) \text{Where } c_r^{min} = min(a_{i_m j_n k_t r}) \quad \text{(cost metrics) (2)}$$

3.3 Compute weighted normalized fuzzy value: The NTFNs ($N_{i_m j_n k_t r}$) are multiplied with the competing priority weights ($Wimjnu$) of the metric category to provide the weighted normalized fuzzy value $Vimjnktv$.

$Vi_mj_nk_tv = Ni_mj_nk_t r * Wi_mj_nk_t u = (a'i_mj_nk_t\, v,\ b'i_mj_nk_t\, v,\ c'i_mj_nk_t\, v)$………………………………………… (3)

v= number of weighted fuzzy numbers and u= number of weight vectors for the category of metric

3.4 Identify Fuzzy Positive Ideal Solution and Fuzzy Negative Ideal Solution:

FPIS= S_{kt}^{+} = Max ($c'i_mj_nk_tv$)………………………… (4)

FNIS= S_{kt}^{-} = Min($a'i_mj_nk_tv$)…………………………… (5)

3.5 Calculate the distance from Fuzzy Positive Ideal Solution and from Fuzzy Negative Ideal Solution: The distance (D^{+}_{kt}, $D^{-}_{k_t}$) of SC circumstances (Non-LSC and LSC) from FPIS and FNIS for performance metrics k_t is computed as,

$$= \sqrt{\frac{1}{3}\left[\left(a'_{i_m j_n k_t v} - S^{+}_{k_t}\right)^2 + \left(b'_{i_m j_n k_t v} - S^{+}_{k_t}\right)^2 + \left(c'_{i_m j_n k_t v} - S^{+}_{k_t}\right)^2\right]} \quad (6)$$

$$= \sqrt{\frac{1}{3}\left[\left(a'_{i_m j_n k_t v} - S^{-}_{k_t}\right)^2 + \left(b'_{i_m j_n k_t v} - S^{-}_{k_t}\right)^2 + \left(c'_{i_m j_n k_t v} - S^{-}_{k_t}\right)^2\right]} \quad (7)$$

3.6 Calculate the closeness coefficients: The closeness coefficient value is calculated as follows for both SC conditions: $CC_{im} = D^{-}_{kt}/(D^{-}_{kt}+D^{+}_{kt})$ …………………………….. (8)

3.7 Compute the LSC and non-LSC performance: Evaluation of the SC performance can be obtained by $P_{im} = CC_{im} * 100$ ……………………………………………………………… (9)

4. A CASE EXAMPLE

To evaluate SC performance a study of a case example of a manufacturing company "MFG" is selected as various lean practices are implemented in the SC of the company. As the management of the organization was willing to provide relevant data, this organization was selected as a convenience sample for the case study. For the SC study, a manufactured product named job shop bracket is chosen, and investigated the parameters of the sample SC. Cost, time, flexibility, and quality were the four main performance criteria in a cost-competitive supply chain, with the majority of the metrics being tied to costs.

Table 2. Supply chain metrics and categories

Performance Categories	Measures id ($Z_{i\,m\,j\,n\,k't}$)	Performance Measures	Source of data
Cost	Z_{i01}	Cost of goods sold/Piece (Rs.)	Finance/Cost accounting
	Z_{i02}	Manufacturing cost/piece (Rs.)	Finance/Cost account
	Z_{i03}	Total logistic cost (Rs.)	Logistics
	Z_{i04}	Price/piece (Rs.)	Marketing
	Z_{i05}	Production efficiency/ week (%)	Production
	Z_{i06}	Profit/ piece (Rs.)	Finance
Time	Z_{i07}	Purchase order cycle time (days)	Purchase
	Z_{i08}	Production time/piece (Minutes)	Production
	Z_{i09}	Delivery lead time (days)	Logistics
	Z_{i10}	Total cycle time (days)	Production
Flexibility	Z_{i11}	Suppliers defect free delivery (%)	Procurement
Quality	Z_{i12}	Quality of delivered Goods (%)	Quality assurance

"Manufacturer's name cannot be unveiled for reasons of confidentiality,. "MFG" is a pseudonym."Among the four performance categories, we chose twelve metrics for measurement. Table 2 displays all metrics. The sources and departments of data used in this study are displayed in Table 2's final column. Where n=1... 4 and t=1.....12 are the metric id values displayed in the second column. The algorithms depicted in Figure 3 are used to convert the data for quantitative measurements into triangular fuzzy numbers (TFN).

Figure 3. Procedures to convert the metric values into TFNs

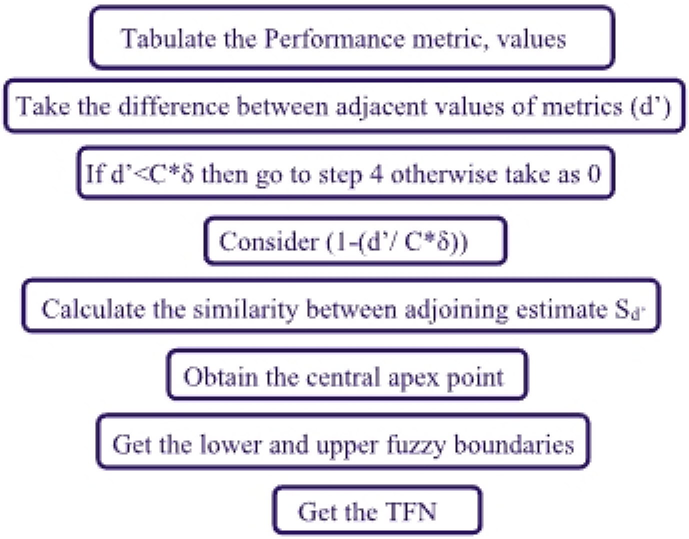


Table 3. Metric values prior to Lean Implementation

Performance metrics	Prior to Lean implementation (i=1)						
	May-24				June-24		
	W1	W2	W3	W4	W1	W2	W3
Z_{i01}	18.995	18.89	18.675	18.605	18.515	18.535	18.6
Z_{i02}	19.564	19.587	19.627	19.849	19.767	19.797	19.889
Z_{i03}	10340	10339	10331	10312	10319	10271	10270
Z_{i04}	22.9	22.784	22.632	22.581	22.482	22.495	22.483
Z_{i05}	42.67	49.75	59.7	58.65	63.5	66.67	64
Z_{i06}	17.88	17.996	18.0	18.199	18.298	18.285	18.297
Z_{i07}	37.67	37.47	37.31	37.06	37.21	37.52	36.76
Z_{i08}	53	52.85	52.62	52.09	50.52	50.67	99.72
Z_{i09}	49.05	48.47	48.02	48.11	47.31	47.37	47.33
Z_{i10}	113.34	112.16	110.64	110.72	110.27	110.3	109.96
Z_{i11}	94.89	97.99	91.68	92.87	98.9	90.88	91.83
Z_{i12}	88.95	91.89	90.88	94.97	92.89	90.92	91.88

Table 4. Metric Values Following Lean Implementation

Performance Metrics	Following Lean implementation (i=2)						
	Nov-24				Dec-24		
	W1	W2	W3	W4	W1	W2	W3
Z_{i01}	18.745	18.562	18.51	18.105	18.187	17.97	17.567
Z_{i02}	19.343	19.282	19.1	19.088	18.99	18.854	18.645
Z_{i03}	10210	10164	10155	10137	10124	10112	10098
Z_{i04}	22.612	22.507	22.4	22.357	22.136	21.892	21.753
Z_{i05}	71.35	67.56	76.23	84.67	87.77	81.34	83.84
Z_{i06}	18.168	18.273	18.38	18.423	18.644	18.888	19.027
Z_{i07}	37.31	37.01	37.42	37.77	37.57	36.67	36.71
Z_{i08}	49.45	48.12	47.85	47.11	46.92	46.84	94
Z_{i09}	43.34	43.91	41.78	42.24	41.84	39.82	41.04
Z_{i10}	100.42	102.64	96.63	99.94	99.65	96.03	95.64
Z_{i11}	93.98	90.86	94.9	96.88	90.92	92.95	93.97
Z_{i12}	93.9	88.34	92.98	95.88	93.23	94	93.5

Distinct values for the performance measures computed in the two scenarios of SC i.e. prior to and following lean executions and they are represented in the intended models by i=1 and i=2. Weekly values for different quantitative metrics before lean adoption are presented in Table 3, while Table 4 displays the same values following lean implementation. The metric values stayed the same at first with no appreciable increases without implementing lean practices. Hereafter the whole supply chain was examined and different lean practices were applied to improve the values of performance metrics as well as the overall performance of the supply chain. The values for quantitative metrics are converted into triangular fuzzy numbers (TFN) using the algorithms shown in Figure 3. Finally, following the equations from (1) to (9), the closeness coefficient and the overall performance have been calculated for both non-lean and lean supply chains.

5. RESULTS AND CONCLUSION

Following the application of lean methodology, the quality of delivered goods increased from 88.95% to 93.9%. The percentage of production efficiency per week (%) increased from 42.67% to 71.35% following the application of lean principles. profit for each unit increased to Rs. 18.17 upon lean implementation from Rs. 17.88 prior to it. Comparably, the entire cycle time of the SC was shortened from 113.33 days to 100.42 days. The evaluation revealed that the organization under the case study lacked lean practices. By employing equations (8) and (9), the two supply chains' closeness coefficients came as 0.488 and 0.5292 respective performances are computed as follows: 48.80% for the non-LSC and 52.92% for the LSC. Measures indicate that an LSC performs better than a non-LSC counterpart. it was found that the lean practices had a statistically momentous impact on the SC performance. The findings indicate enhanced performance in competitive scenarios involving cost, time, flexibility, and quality. The employed methodology allowed for a realistic examination. A set of performance measures is one of the main contributions of this research. Instead of evaluating the performance of individual business units, the proposed method offers a way to evaluate the overall performance of the SC. The proposed model can be utilized as an evaluation instrument to determine the gap between the current state of leanness and the intended leanness state, enabling the industrial sectors to identify areas for improvement. The SCM decision support systems' potential can be reinforced with its enforcement. When analyzing problems of dynamic improvement, the framework and assessment approach might be a helpful modeling tool. This can offer valuable insights for officials to enhance SC efficiency and fulfill their goals.

6. LIMITATIONS AND FUTURE RESEARCH

The proposed study concentrated on a particular manufacturing industry. For the purpose of strengthening the conclusions, multi-case studies can be the focus of future research. For the purpose of more accurately assessing the level of integration between the downstream components and upstream components in the wider SC, the study may additionally incorporate a significant amount of data from suppliers and buyers. This study's sampling frame was derived from manufacturing organizations. For more reliable results, future studies can use more performance measurements in different sectors of industry. Managers and engineers can use software to code the fuzzy number generation from metric values for faster calculations. Which can lead to faster decisions and a quick picture of SC performance. This strategy not only helps industries adapt to changes much more rapidly, but it also makes it possible for academics and researchers to keep conducting their further work. It might be beneficial for subsequent research to look at it more in multiple contexts.

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