ABSTRACT

Increasing global competitiveness has forced manufacturing organizations to produce high-quality products quickly and at competitive prices which can only be achieved thorough continuous improvements techniques. In this paper, we propose a fuzzy based performance evaluation method for lean supply chain. To understand the overall performance of cost competitive supply chain, we investigate the alignment of market strategy and position of the supply chain. Competitive strategies can be achieved by using a different weight calculation for different supply chain situations. By identifying optimal performance metrics and applying performance evaluation methods, managers can predict the overall supply chain performance under lean strategy.

Keywords: Supply chain metrics, Lean supply chain, Fuzzy based evaluation method.

INTRODUCTION

In the era of globalisation, supply chains are being treated as extended enterprises linking firms in different locations and enabling partners to gain competitive advantage. In recent years, firms have realised the potential of effective supply chain management (SCM) in the management of day-to-day operations. However, many firms fail to develop effective performance measures and the metrics needed to achieve integrated SCM. Measuring supply chain performance can facilitate a better understanding of supply chain activity, positively influence supply chain players’ behaviour and improve its overall performance [1]. In order to achieve the supply chain goal of fulfilling customer orders more quickly and efficiently than competitors, a supply chain needs to engage in continuous improvement processes and competitive strategies. So, to understand how supply chains compete, it is necessary to understand the overall performance of the supply chain.

Another important characteristic regarding supply chain measures is the strategic fit between competitive performance and supply chain strategy. Soni and Kodali [2] found that the choice of competitive supply chain strategy impacted business and supply chain performance and they claimed that the strategic fit considering the degree of alignment between competitive situation, strategy, organisational culture and leadership can enhance business performance. As such, to achieve effective performance measures the competitive performance of a supply chain must be aligned with the market strategy and position of supply chain actors.
Lean philosophy is one of many initiatives that businesses around the world have been adopting in order to remain competitive in the increasingly global market [3-4]. The core thrust of a lean supply chain is to create a streamlined, highly efficient system that produces finished products at the pace customers demand with little or no waste [5]. Lean is applicable in many supply chains, particularly those seeking to improve performance by reducing waste. For example, cost competitive supply chains can benefit from utilising lean to remove waste and reduce costs.

Given the inherent complexity of supply chain measures, market competitiveness and supply chain strategy, a measurement method to deal with these complexities is critical. Gunasekaran and Kobu [6] stated that conventional measures (such as: profit, percentage of products delivered on time etc.) had the drawbacks of tending to measure financial metrics, and failed to include intangible and lagging indicators. In this case, fuzzy is an appropriate modelling method to deal with intangible and qualitative measures which uses fuzzy set theory and linguistic values and has been applied widely in various areas of SCM. In literature, several studies (e.g., [7-8]) have reported findings regarding supply chain performance measurement using fuzzy set theory, fuzzy logic and multiple linguistic terms with combinations of other methods. Fuzzy modelling also allows a significant number of performance metrics to be considered across multiple elements and processes of a supply chain. As such, a complete framework for performance measures and a fuzzy based performance evaluation method for overall supply chain measurement is essential to address these challenges.

In spite of the vast research published on supply chain measures, the concept of performance metrics and measures is still underdeveloped for two reasons: a) a lack of strategic alignment between competitive strategy and performance metrics while measuring cost competitive supply chain performance [9-11] and (b) deficiencies in considering uncertainty and linguistic terms in performance evaluation methods, especially for lean supply chain. Therefore, the research problem addressed in this paper is the need to develop the linkages between supply chain performance measures with competitive strategy, implementation of lean tools, market position and an evaluation method to assess lean attributes and competitive supply chain strategies.

LITERATURE REVIEW

Performance measurement and metrics in SCM

Neely et al. (1995) define performance measurement as the process of quantifying the effectiveness and efficiency of action where measurement is the process of quantification and action leads to performance [11]. Performance measurement systems (PMS) are described as the overall set of metrics used to quantify both the efficiency and effectiveness of action [10]. Beamon [12] identified four characteristics for an effective performance measurement system: inclusiveness, universality, measurability and consistency. The purpose of measuring organisational performance is to (a) identify success; (b) identify whether customer needs are met; (c) help the organisation to understand its processes and to confirm what they know or reveal what they do not know; (d) identify where problems, bottlenecks, waste, etc. exist and where improvements are necessary; (e) ensure decisions are based on facts and not on supposition, emotion, faith or intuition; and (f) show if planned improvements actually happened [6]. A PMS consists of a number of individual performance measures or metrics. The main challenge is to identify the key performance measures for value-adding areas of an
organisation and then the factors that will affect the core business processes that create value. Despite the extensive literatures, research has yet to address a number of important limitations:

1. Lack of strategic focus (the measurement system is not well aligned with strategic goals, organisation culture or reward systems) [13-14].
2. Lack of systematic approach to prioritise measures and metrics [15-16].
3. How to maintain PMS over time so they remain aligned with dynamic environments and changing strategies? [11][14].

Supply chain performance relates to competitive strategies since competitiveness in the supply chain must be linked to organisational goals. Whereas, Hanson et al. [17] viewed PMS as a process with dual functions: communicating strategies and controlling performance. A company’s competitive strategy defines, relative to its competitors, the set of customer needs that it seeks to satisfy through its products and services [2]. So, a competitive strategy is the basis for defining business goals. Competitive strategies can be categorised into: cost, quality, delivery and flexibility [2] [18]. These competitive strategies need to be aligned with the supply chain performance measurement system to fulfil organisational goals. To understand therefore how competitive a supply chain is, it is necessary to understand the overall performance of the supply chain.

In recent times researchers such as Gunasekaran et al. [9] and Neely et al. [10] have attempted to respond to these arguments by designing systemic and balanced performance measurement systems or a flexibility measurement approach [12]. Perhaps the most well accepted of these is the supply chain operations reference (SCOR) model. This was developed by the Supply Chain Council in 1997 and has been described as a “systematic approach for identifying, evaluating and monitoring supply chain performance” [11]. SCOR combines elements of business process engineering, benchmarking and leading practices into a single framework. Utilizing SCOR, SCM is defined as a set of integrated processes: Plan, Source, Make, Deliver, and Return—from the supplier’s supplier to the customer’s customer, and all are aligned with a company’s operational strategy, material, work and information flows (see Figure 1).

Figure 1 Supply chain operation reference model [37].

Despite all the attempts regarding PMS using SCOR frameworks for SCM, research is yet to address a critical issue to unravel the:

“Lack of integration in between performance measurement systems with human resource management (HRM) and modern manufacturing practices such as total
The necessity for competitive performance of a supply chain and the alignment with market strategy are argued here. The above discussions lead to a suggestion that a current study is needed to establish a framework of metrics and performance measures which can be integrated with competitive strategies as well as modern manufacturing practices. So, the effects of modern improvement practices on performance metrics need to be addressed to incorporate the synchronisation with a company’s strategic objectives and PMS. Cost competitive supply chains such as lean supply chains and other improvement techniques are discussed in the next section and linked to synchronisation.

**Lean supply chain, improvement tools and techniques**

In an increasingly competitive global environment, businesses have introduced approaches such as total quality management (TQM), Just in Time (JIT), business process reengineering (BPR) and SCM to enhance their performance and gain competitive advantage [2]. Researchers believe that tools for measuring an organisation’s need and ability to develop an agile business strategy within the context of a virtual organisation are important. The term “Lean” means a series of activities or solutions to eliminate waste, reduce Non-Value Added (NVA) operations, and improve the Value Added (VA) process. A lean supply chain means the identification of all types of waste in the value stream of a supply chain and taking steps to eliminate them and minimise lead times [19-20].

The concept of lean has had significant positive impacts on productivity in various industries. The SCOR model is a process reference model and can be used with standard metrics to measure process performance and management practices that produce best-in-class performance. In this research SCOR is the base model used to identify the optimal metrics to evaluate supply chain leanness and, for this reason, the effects of different lean tools and techniques over five basic processes of the SCOR model are listed in Figure 2.

<table>
<thead>
<tr>
<th>Plan</th>
<th>Source</th>
<th>Make</th>
<th>Delivery</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VSM&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td>FMS&lt;sup&gt;a&lt;/sup&gt;, CIM&lt;sup&gt;c&lt;/sup&gt;, SMED&lt;sup&gt;a,c,f&lt;/sup&gt;, RFID, GT&lt;sup&gt;a&lt;/sup&gt;, CM&lt;sup&gt;a,d&lt;/sup&gt;</td>
<td></td>
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<td></td>
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<td>EOQ&lt;sup&gt;c,d&lt;/sup&gt;, TQM&lt;sup&gt;d,e,h&lt;/sup&gt;, Pull system&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>MRP&lt;sup&gt;a&lt;/sup&gt;, MRP-II, BOM&lt;sup&gt;a&lt;/sup&gt;, MTM&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>JIT&lt;sup&gt;a,d,f,g,h&lt;/sup&gt;, JIT-2&lt;sup&gt;a&lt;/sup&gt;, Kaizen, ERP&lt;sup&gt;a&lt;/sup&gt;, EDI&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

VSM — Value stream mapping; MRP — Material requirement planning; BOM — Bill of material; MTM — Method time measurement; FMS — Flexible manufacturing planning; CIM — Computer integrated Manufacturing; SMED — Single minute exchange of die; RFID — Radio frequency integrated device; GT — Group technology; CM - Cellular manufacturing; TQM — Total quality management; JIT — Just in time; JIT-2 — Supplier-customer relationship; MRP-II — Manufacturing resource planning; EDI — Electronic data interchange; EOQ — Economic order quantity; TPM — Total productive maintenance; HRM — Human resource management.

a- Gunasekaran et al. [22]; b- Kuhllang et al. (2011); c- Ramasamy [23]; d- Fullerton and Wempe [24]; e- Eroglu and Hofer [25]; f- Wan [26]; g- Kojima and Kaplinsky [27]; h- Shah and Ward [5]

*Figure 2* Effects of different lean supply chain tools and techniques over SCOR model.
In Figure 2, we outline the effects of various lean tools over different supply chain tiers with corresponding author references. Most of the authors tried to discover the possible effects of lean tools over SCOR processes. For example, Kuhlang et al. [21] mentioned that Value Stream Mapping (VSM) had an effect on the plan stage by increasing productivity and reducing lead times. Similarly, other lean tools and their effects over different SCOR processes are shown in Figure 2 and analysed later since the analysis of the effects of lean tools over performance metrics is noteworthy to design the optimal metrics for lean supply chain study. It therefore becomes apparent that the benefits of lean tools can be measured using supply chain performance metrics and can also be used based on different supply chain strategies. Lean is applicable in many supply chains, particularly those seeking to improve performance by reducing waste. For example, cost competitive supply chains can benefit from utilising lean to remove waste and reduce costs. The lean supply chain can mitigate the lack of co-ordination between performance measures and lean tools and techniques.

From literature, it is evident that overall supply chain performance is dependent on number of supply chain contexts, contents and processes. The relation between these major factors and supply chain performance is proposed in Figure 3.

![Figure 3 Theoretical framework of the research](image)

The above discussion suggests for further examination of relations between competitive strategies, lean tools and techniques, market positions and supply chain performance (SCP). To identify the relations, it is thus important to investigate the following hypotheses for cost competitive supply chain:

1. **Hypothesis 1**: Implementation of lean tools and techniques influence SCP.
2. **Hypothesis 2**: A supply chain’s choice of competitive strategy influences SCP.
3. **Hypothesis 3**: Market position positively affects SCP.

Performance metrics have both quantitative and qualitative measures. Qualitative metrics have linguistic behaviours and also include non-financial measures. Fuzzy is an appropriate method when uncertainty is present and it allows modelling of a significant number of performance metrics across multiple elements and processes of a supply chain. The effects of lean tools and techniques over these metrics have been discussed previously and will be quantified in the next section using fuzzy based performance evaluation method. The competitive strategies for different product and process based supply chains will also be used by applying different relative weights for performance categories. So the combined effect of
different lean tools and competitive strategies over a supply chain’s performance will be evaluated by the proposed performance measurement method.

**PROPOSED PERFORMANCE EVALUATION METHOD**

**Select supply chain optimal metrics**

For effective performance evaluation, measurement goals must represent organisational goals and the metrics selected should reflect a balance between financial and non-financial measures that can be related to strategic, tactical and operational levels of decision making and control [9]. It is important to reduce many of the established performance metrics to a relatively low number that are more effective for performance evaluation.

<table>
<thead>
<tr>
<th>1. Purchase order cycle</th>
<th>1. Production time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Profit/piece ($)</td>
<td>time (days) / piece (mins)</td>
</tr>
<tr>
<td>2. Cost of goods</td>
<td>2. Suppliers defect</td>
</tr>
<tr>
<td>sold/piece ($)</td>
<td>free delivery (%) / piece ($)</td>
</tr>
<tr>
<td>1. Price/piece ($)</td>
<td>1. Total logistic cost ($) satisfaction</td>
</tr>
</tbody>
</table>

---

**Non lean metrics (Italic)**

**Lean metrics (Normal)**

Figure 4 Optimal metrics for cost competitive supply chain performance evaluation.

We propose a list of optimal metrics (see Figure 4) to evaluate the performance of cost competitive supply chain and all the metrics are selected based on existing research (e.g., [11][22]). Shepherd and Günter [11] provided a taxonomy of performance measures (in terms of cost, time, quality, flexibility and innovativeness) using the five SCOR processes. Gunasekaran et al. [9] used the same processes and developed supply chain measures at strategic, tactical and operational levels of framework. In this research, the metrics are grouped according to different processes of SCOR model to calculate individual performances at the process level as well as overall supply chain performance.

The proposed optimal metrics have both crisp and linguistic values. Since, fuzzy allows modelling of a significant number of performance metrics across multiple elements and processes of a supply chain, we initially convert the quantitative metric values into triangular fuzzy numbers and linguistic terms are used for qualitative metrics. Converting both the metric values into fuzzy numbers, then the fuzzy TOPSIS is used to evaluate the performance.
of whole supply chain by considering the distance of non-lean and lean supply chain situations from positive and negative ideal solutions. The details of fuzzy set theory, triangular fuzzy number generation and fuzzy TOPSIS method will be discussed in the following sections.

**Fuzzy set theory**

Fuzzy set theory was first proposed by Zadeh [28] and was first used in control by Mamdani [29]. Fuzzy set theory is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings. Formally, the process by which individuals from a universal set $X$ are determined to be either members or non-members of a crisp set can be defined by a characteristic or discrimination function. For a given crisp set $A$, this function assigns a value $\mu_A(x)$ to every $x \in X$ such that,

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

Where $X$ refers to the universal set defined in a specific problem, and $[0, 1]$ denotes the interval of real numbers from 0 to 1, inclusively.

![Triangular fuzzy number, A](image)

**Convert metric values into triangular fuzzy number**

In this step, we need to convert all the metric values into triangular fuzzy numbers. Initially, different values for each of the metric are to be collected for before and after lean implementation. Let assume, $i = 1, 2, \ldots, m$ are different supply chain situations (before and after lean implementation); $j = 1, 2, \ldots, n$ are different supply chain performance categories and $k = 1, 2, \ldots, t$ are different optimal metrics which means, $I = (i_1, i_2, \ldots, i_m)$; $J = (j_1, j_2, \ldots, j_n)$; $K = \{k_1, k_2, \ldots, k_t\}$. Now assume, $x_{imjn}k_{i1}, x_{imjn}k_{i2}, \ldots, x_{imjn}k_{id'}$, are different values of $d$ number of units (per week) for metric $k_t$ under situation $i_m$ and category $j_n$. Here $k_t = $ process cycle time, $j_n = $ time, $i_m = $ after lean implementation. In the next two subsections, the quantitative and qualitative triangular fuzzy number conversion from performance metrics values will be discussed. The overall conversion algorithm [30] from metric values to triangular fuzzy numbers is discussed below and sketched in Figure 6.

**Triangular fuzzy number for quantitative metric values**

The values of quantitative metrics need to be collected from supplier, manufacturer, distributer as well as customers. Since we assumed, $x_{imjn}k_{i1}, x_{imjn}k_{i2}, \ldots, x_{imjn}k_{i'd'}$, are different values of $d'$ number of units for metric $k_{i't}$ under situation $i_m$ and criteria $j_n$, these values are converted into quantitative fuzzy linguistic number and membership values applying the following model algorithm:
Triangular fuzzy number for qualitative metric values

For qualitative metrics, we use multiple triangular fuzzy linguistic terms and corresponding triangular fuzzy numbers. Here the linguistic terms are defined by two unit interval of linear triangular membership functions by fuzzy set \((a_{lm/hr}, b_{lm/hr}, c_{lm/hr})\) as listed in Table 1, where \(a_{lm/hr}, b_{lm/hr}, c_{lm/hr}\) represent three point of triangular fuzzy number against corresponding linguistic terms for qualitative metrics.

**Figure 6** Model algorithms to determine the triangular fuzzy number from metric values.

**Figure 7** Triangular fuzzy numbers for corresponding linguistic terms.
Table 1 Linguistic terms and corresponding triangular numbers for qualitative metrics

<table>
<thead>
<tr>
<th>Linguistic Terms</th>
<th>Triangular Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low (VL)</td>
<td>(1, 1, 3)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(1, 3, 5)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(3, 5, 7)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(5, 7, 9)</td>
</tr>
<tr>
<td>Very High (VH)</td>
<td>(7, 9, 9)</td>
</tr>
</tbody>
</table>

The generated triangular fuzzy numbers will be used in Fuzzy TOPSIS method to evaluate the performance of different supply chain situations by measuring their distances from positive and negative ideal solutions.

**Fuzzy TOPSIS**

TOPSIS is a multi criteria decision making (MCDM) method to identify solutions from a finite set of alternatives [31]. The logic of fuzzy TOPSIS is proposed by Hwang and Yoon [32] to define the positive ideal solution and negative ideal solution. The positive ideal solution is the solution that maximizes the benefit metrics and minimizes the cost metrics, whereas the negative ideal solution is the solution that maximizes the cost metrics and minimizes the benefit metrics. The best alternative is the one which has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The step-by-step fuzzy TOPSIS method to identify best solution is developed which is based on the works of several researchers [31] [33-36] and discussed below:

**Normalize triangular fuzzy number**

Beside quantitative and qualitative metrics, there are also two important type of metrics, called, benefit and cost metrics. Benefit means the more the better where cost means the less the better. If the metrics are not normalized, they cannot be compared to each other to find out the supply chain performance. The corresponding normalization methods are as follows:

\[ N_{im,jn,ktr} = \left( \frac{a_{im,jn,ktr}}{c_{tr}^{max}}, \frac{b_{im,jn,ktr}}{c_{tr}^{max}}, \frac{c_{im,jn,ktr}}{c_{tr}^{max}} \right) \quad \text{and} \quad c_{tr}^{max} = \max(c_{im,jn,ktr}) \]  

(benefit metrics) (1)

\[ N_{im,jn,ktr} = \left( \frac{c_{tr}^{min}}{c_{tr}^{min}}, \frac{c_{tr}^{min}}{c_{tr}^{min}}, \frac{c_{tr}^{min}}{c_{tr}^{min}} \right) \quad \text{and} \quad c_{tr}^{min} = \min(a_{im,jn,ktr}) \]  

(cost metrics) (2)

**Prioritize competitive strategy over metric category**

Considering different competitive strategy and company objective towards better customer service, we use relative importance to performance categories. For this reason, we take the relative weight vector for performance category \( x_{im,jn} \) which is defined as,

\[ w_{im,jn,u} = w_{im,j1} + w_{im,j2} + w_{im,j3} + w_{im,j4} + \cdots + w_{im,jn} \]  

(3)

Where, \( u \) = number of weight vector for metric category, and \( \sum_{u=1}^{n} w_u = 1 \), where, \( w_u \epsilon [0,1] \)
Compute weighted normalized fuzzy value

The weighted normalized fuzzy value \( V_{im,n,k_t,v} \) for optimal metrics is computed by multiplying the competitive priority weights \( (W_{im,n,u}) \) of metric category with the normalized triangular fuzzy numbers \( (N_{im,n,k_t,v}) \) as,

\[
V_{im,n,k_t,v} = N_{im,n,k_t,v} \times W_{im,n,u} = (a_{im,n,k_t,v}, b_{im,n,k_t,v}, c_{im,n,k_t,v})
\]

Where, \( v = \) number of weighted fuzzy numbers

Identify fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

Since, the weighted normalized fuzzy value \( (V_{im,n,k_t,v}) \) is calculated, now the FPIS and FNIS can be computed by following equations,

\[
S_{k_t}^+(FPIS) = \max (c_{im,n,k_t,v}) \quad \text{(5)}
\]

\[
S_{k_t}^-(FNIS) = \min (a_{im,n,k_t,v}) \quad \text{(6)}
\]

Where, \( S_{k_t}^+, S_{k_t}^- \) are FPIS and FNIS for performance metrics \( k_t \)

Calculate the distance of non-lean and lean supply chain situations from FPIS and FNIS

The distance \( (D_{k_t}^+, D_{k_t}^-) \) of supply chain situations (before and after lean implementation) from FPIS and FNIS is calculated as,

\[
D_{k_t}^+ = \sqrt{\frac{1}{3} [(a_{im,n,k_t,v} - S_{k_t}^+)^2 + (b_{im,n,k_t,v} - S_{k_t}^+)^2 + (c_{im,n,k_t,v} - S_{k_t}^+)^2]}
\]

\[
D_{k_t}^- = \sqrt{\frac{1}{3} [(a_{im,n,k_t,v} - S_{k_t}^-)^2 + (b_{im,n,k_t,v} - S_{k_t}^-)^2 + (c_{im,n,k_t,v} - S_{k_t}^-)^2]}
\]

Where, \( D_{k_t}^+, D_{k_t}^- \) are the distance measurements of supply chain situations from FPIS and FNIS for performance metrics \( k_t \)

Compute the closeness coefficients for each supply chain situation

The closeness coefficient \( (CC_{im}) \) represents the distances of supply chain situations to the fuzzy positive ideal solutions \( (S_{k_t}^+) \) and fuzzy negative ideal solutions \( (S_{k_t}^-) \) simultaneously. The value of \( CC_{im} \) for each supply chain situations is computed as,

\[
CC_{im} = \frac{D_{k_t}^-}{D_{k_t}^+ + D_{k_t}^-}
\]
Calculate the performance of non-lean and lean supply chain

Since, closeness coefficient determines the distance of each supply chain situation between FPIS and FNIS, it represents the value of close to FPIS and farthest to FNIS. So, the performance value for supply chain situation (before and after lean implementation) can be evaluated by,

\[ P_{lm} = CC_{lm} \times 100\% \]  

(10)

A CASE EXAMPLE

We have selected for our case study SIGMA\(^1\) clothing (woven) manufacturing company to evaluate supply chain performance as this supply chain implemented lean tools and techniques. The organization was also selected as a convenience sample as management was willing to provide relevant data. We took woven pant named “Motion Pant” as supply chain study. In this supply chain, there are three piers of chain- buyer, manufacturer and suppliers. Except fabric “Cordura” supplies (a special fabric), other accessories (button, zipper) are stored in house by the manufacturers. We conducted this case study investigating buyer, manufacturer and “Cordura” fabric supplier as the sample supply chain for “Motion Pant”. After product development, the average production time to produce one pant is anticipated as 102 minutes with $23.5 production cost. The order amount was 10,00000 pieces and started to feed in 6 production lines from mid of January, 2011. We selected this supply chain to evaluate lean performance. As we mentioned earlier, cost competitive or lean supply chain had four major performance categories- cost, time, quality and flexibility where most of the metrics were cost related.

<table>
<thead>
<tr>
<th>Performance Categories</th>
<th>Metric Id (xᵢₙ)</th>
<th>Performance Metrics (Units)</th>
<th>Metric Type</th>
<th>Data source/ departments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>x₁₁</td>
<td>Profit/ piece ($)</td>
<td>Quantitative/Benefit</td>
<td>Finance and commercial</td>
</tr>
<tr>
<td></td>
<td>x₁₂</td>
<td>Production efficiency/ line/day (%)</td>
<td>Quantitative/Benefit</td>
<td>Industrial Engineering</td>
</tr>
<tr>
<td></td>
<td>x₁₃</td>
<td>Effectiveness of master production schedule/ line/day (%)</td>
<td>Quantitative/Benefit</td>
<td>Industrial Engineering</td>
</tr>
<tr>
<td></td>
<td>x₁₄</td>
<td>cost of goods sold/ piece ($)</td>
<td>Quantitative/ Cost</td>
<td>Finance and commercial</td>
</tr>
<tr>
<td></td>
<td>x₁₅</td>
<td>Manufacturing cost/ piece ($)</td>
<td>Quantitative/ Cost</td>
<td>Finance and commercial</td>
</tr>
<tr>
<td></td>
<td>x₁₆</td>
<td>Overhead cost/ Piece ($)</td>
<td>Quantitative/ Cost</td>
<td>Finance and commercial</td>
</tr>
<tr>
<td></td>
<td>x₁₇</td>
<td>Total logistic cost/ 21900 pieces ($)</td>
<td>Quantitative/ Cost</td>
<td>Logistics and supply chain</td>
</tr>
<tr>
<td></td>
<td>x₁₈</td>
<td>Price/ piece ($)</td>
<td>Quantitative/ Cost</td>
<td>Merchandising</td>
</tr>
<tr>
<td></td>
<td>x₁₉</td>
<td>Mutual assistance in problem solving ($)</td>
<td>Qualitative/ Cost</td>
<td>Industrial Engineering</td>
</tr>
<tr>
<td>Time</td>
<td>x₂₁</td>
<td>Total cycle time/21900 pieces (days)</td>
<td>Quantitative/ Cost</td>
<td>Industrial Engineering</td>
</tr>
<tr>
<td></td>
<td>x₂₂</td>
<td>Purchase order cycle time (days)</td>
<td>Quantitative/ Cost</td>
<td>Sales</td>
</tr>
<tr>
<td></td>
<td>x₂₃</td>
<td>Production time/ piece (Minutes)</td>
<td>Quantitative/ Cost</td>
<td>Industrial Engineering</td>
</tr>
<tr>
<td></td>
<td>x₂₄</td>
<td>Delivery lead time/ 21900 pieces (days)</td>
<td>Quantitative/ Cost</td>
<td>Logistics and supply chain</td>
</tr>
<tr>
<td>Quality</td>
<td>x₃₁</td>
<td>Customer satisfaction</td>
<td>Qualitative/Benefit</td>
<td>Merchandising</td>
</tr>
<tr>
<td></td>
<td>x₃₂</td>
<td>Buyer- Suppliers relationship level</td>
<td>Qualitative/Benefit</td>
<td>Sales</td>
</tr>
<tr>
<td></td>
<td>x₃₃</td>
<td>Quality of delivered Goods (%)</td>
<td>Quantitative/Benefit</td>
<td>Merchandising</td>
</tr>
<tr>
<td></td>
<td>x₃₄</td>
<td>Accuracy of forecasting techniques</td>
<td>Qualitative/Benefit</td>
<td>Planning and control</td>
</tr>
<tr>
<td>Flexibility</td>
<td>x₄₁</td>
<td>Suppliers defect free delivery (%)</td>
<td>Quantitative/Benefit</td>
<td>Sales</td>
</tr>
<tr>
<td></td>
<td>x₄₂</td>
<td>Ability to response demand</td>
<td>Qualitative/Benefit</td>
<td>Finishing and quality</td>
</tr>
</tbody>
</table>

\(^1\) For reasons of confidentiality, the name of the manufacturer cannot be disclosed. SIGMA is a pseudonym.
We selected nineteen performance metrics (see Figure 4) out of four performance categories and nine of them were cost measures. All the metrics have shown in Table 2. The second column shows metric id where, n=1 to 4 and t=1 to 19. Metrics can be of two types. One is whether it can be measured by number (quantitative) or linguistic terms (qualitative); another is the direction of improvement. Benefit metrics mean the more the better and cost metrics mean the less the better. All the types of performance metrics are mentioned in fifth column in Table 2. The last column in Table 2 shows the sources of all data presented used in this research.

We collected and calculated different values for performance metrics in two supply chain situations- before and after lean implementations. So, in our proposed model, i=1 to 2. Initially, no lean tools and improvement techniques were applied but interestingly there were improvements in quantitative metric values. But, at the beginning of April- 2011 (6-8 columns in Table 3), the metric values remained same without any significant improvements.

| Table 3 Performance metrics values in two supply chain situations- before and after lean implementation |
|----------------------------------|----------------------------------|----------------------------------|
| Metric Values                    | Before Lean implementation (i=1) | After Lean implementation (i=2) |
| Efficiency (%)                  | 41 | 48 | 58 | 77 | 82 | 65 | 60 | 70 | 66 | 77 | 81 | 83 | 88 | 66 |
| Cost of goods sold ($)           | 19.552 | 19.55 | 19.536 | 19.5 | 19.418 | 19.422 | 19.419 | 72.81 | 67.57 | 77.03 | 72.94 | 76.98 | 76.61 | 72.11 |
| Off cost ($)                    | 0.204 | 0.2093 | 0.2034 | 0.2022 | 0.1994 | 0.1995 | 0.1994 | 0.1956 | 0.2407 | 0.24 | 0.2385 | 0.19 | 0.1892 | 0.188 |
| Logistic cost ($)               | 20586 | 20584 | 20569 | 20530 | 20444 | 20448 | 20446 | 20328 | 20326 | 20218 | 20181 | 20156 | 2032 | 20104 |
| Price ($)                       | 23.3 | 23.497 | 23.491 | 23.437 | 23.339 | 23.343 | 23.34 | 23.206 | 23.101 | 23.08 | 23.038 | 23.01 | 22.982 | 22.95 |
| Mutual assistance               | Very low (1, 1.3) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Very low (1, 1.3) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) |
| Total Cycle time (days)         | 225.66 | 223.32 | 220.28 | 220.44 | 219.54 | 219.61 | 218.96 | 199.93 | 204.35 | 192.4 | 198.98 | 198.4 | 191.19 | 190.42 |
| Purchase order time (days)      | 75 | 74.6 | 74.3 | 73.8 | 74.1 | 74.7 | 73.2 | 74.3 | 73.7 | 74.5 | 75.2 | 74.8 | 73.2 | 73.1 |
| Production time (minutes)       | 102 | 101.98 | 101.73 | 101.1 | 99.7 | 99.76 | 99.72 | 97.8 | 96.3 | 96 | 95.4 | 95 | 94.6 | 94 |
| Delivery lead time (days)       | 97.66 | 96.5 | 95.62 | 95.8 | 94.2 | 94.31 | 94.23 | 88.63 | 87.43 | 83.2 | 84.11 | 83.3 | 79.29 | 81.72 |
| Buyer- manufacturer relation    | Very low (1, 1.3) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Very low (1, 1.3) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) | Medium (3, 5, 7) |
| Quality of delivered goods      | 89 | 92 | 91 | 95 | 93 | 91 | 92 | 94 | 88 | 93 | 96 | 92 | 93 | 92 |
| Supplier defect free delivery   | 95 | 98 | 92 | 93 | 99 | 91 | 92 | 94 | 91 | 95 | 97 | 91 | 93 | 94 |

After that, we examined the whole supply chain and applied different lean tools to improve the values of performance metrics as well as the performance of supply chain. Weekly values for different quantitative metrics are presented in Table 3. Since, we examined two supply chain situations; here the values are also measured in two different situations. The values for quantitative metrics are converted into triangular fuzzy numbers (TFN) using the algorithms showed in Figure 6. Similarly, all the qualitative values are also collected and converted into TFN using the values mentioned in Table 1. Finally, following the equations from (1) to (10), the overall performance for lean and non-lean supply chain have been calculated as 50.81% and 48.4%.

DISCUSSION & CONCLUSION

Since, a supply chain is an integrated process wherein raw materials are supplied, products are manufactured, and then delivered to customers (via distribution, retail, or both), the
complexity of the supply chain arises from the number of echelons in the chain and the number of facilities in each echelon [12]. Considering this complexity of a typical supply chain, selecting appropriate performance metrics and performance measurement model for supply chain analysis is particularly critical. Initially the linkage between SCOR framework and effects of different lean tools has been established. Fuzzy TOPSIS method is used to evaluate the performance of supply chain and results show that performance for lean supply chain is better than without lean. The results also show that, the effects of lean tools and techniques have positive influence over supply chain performance. Similarly, supply chain performance has positive effects on competitive strategy. By improving competitive strategies throughout the entire supply chain, managers can improve the overall supply chain performance. Moreover, managers can evaluate and predict the performance for lean supply chain. Importantly this provides a method for measuring overall supply chain performance rather than measuring the performance of individual business units. By understanding the impact of an initiative such as lean on the overall performance of the supply chain managers are able to make better informed decisions. Also but measuring total supply chain performance managers are able to demonstrate to multiple supply chain members the performance benefits of introducing improvements programs such as lean. By demonstrating the overall benefit of such programs it can improve the adoption of improvement programs. Fuzzy also be used to indicate which areas such as cost or quality will benefit from lean so emphasizing more on cost and quality metrics as market qualifiers for the supply chain.

REFERENCES


