Quality Measurement in the Supply Chain

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ABSTRACT

Supply Chain Management is the integration of business processes along the value chain, from suppliers to end customer. Performance measurement of these processes has so far received little attention from researchers and practitioners. This paper reports the results from a study of a discrete products supply chain and measures its performance. In particular, a case study was conducted on a wood product supply chain, with a focus on quality performance measurements. The research question was whether current practices were consistent with end customer satisfaction and if improvements were possible. Interviews with quality management personnel and on-site evaluations were conducted at all stages of the supply chain, and a new visualization tool was developed. Quantitative and qualitative analysis tools were used to evaluate current practices. Opportunities for improvement were found in external integration and information sharing between supply chain partners. Also, a need for true measures of supply chain performance measures was identified. A 5-step process to develop such metrics is proposed, and an application example is provided. The proposed supply chain performance measurement system uses Six Sigma measures and facilitates collaboration between supply chain partners and provides information that allows focusing on improvement projects more efficiently.

1. INTRODUCTION

Supply Chain Management (SMC) can be defined as "*the strategic coordination of business processes within an organization and across businesses within the supply chain, with the objective of improving performance of individual organizations and of the entire supply chain*" [1, 2]. SCM practices have been found to be associated with superior product quality, delivery reliability, process flexibility, cost leadership, and higher levels of conformance quality [3, 4]. Competition no longer occurs between individual companies but between supply chains, and the long-term success of a firm will depend in part on its ability to successfully integrate its customers and suppliers [5].

In a similar way, performance measurement and process improvement have become primary concerns for organizations of all kinds, from governments to global corporations because of increasing global and domestic competition, continuous improvement initiatives, national and international quality awards, changing demand, and developments in information technology [6]. Many firms have engaged in "*continuous improvement*" programs. It is not uncommon to find companies to have personnel whose sole purpose is to identify and implement improvement activities ("*continuous improvement coordinators*"). Two specific approaches for organizational and supply chain improvement, Six-Sigma and Lean Manufacturing, have received considerable attention [7, 8]. Six-Sigma was introduced by Motorola in the early 1980s [9] as an improvement methodology that focuses on the reduction of variation through the extensive use of data and statistical tools as well as the use of standardized processes for problem solving (e.g., the Define, Measure, Analyze, Implement, and Control, or DMAIC cycle). The ultimate goal of Six-Sigma is to have a process that produces only 3.4 defects per million opportunities. Lean Manufacturing (LM), which has its origins in the Toyota Production System (TPS), focuses on the elimination of waste, i.e., activities that do not add value to the product or service from the customer's viewpoint. LM also focuses on increasing process flexibility to generate the greatest possible value in the eyes of the customer [10]. Numerous companies use a combination of Six-Sigma and LM, known as Lean Six-Sigma, because it is believed that LM alone cannot bring statistical control and Six-Sigma cannot improve processes in a radical manner [11]. Sixty percent of respondents to a 2006 survey among U.S. manufacturers cited Six-Sigma, Lean Manufacturing, and Lean Six-Sigma as their primary improvement method [12]. Numerous articles and books have proposed using Six-Sigma and Lean Manufacturing to improve supply chain performance [13-22], but very few focus on quality [16, 48]. Levels of use

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and sophistication of supply chain management and performance measurement practices vary widely in the wood products industry, but arguably this industry has historically lagged behind in adopting such innovations compared to automotive and electronics industry [23]. The focus is still on conformance to standards, even if these standards do not necessarily reflect customers' expectations and/or actually hinder improvements. The wood products industry often lacks attention to non-physical dimensions of quality, such as responsiveness; and has a commodity mentality towards the operations [23].

The objective of this research was to increase the understanding of quality performance measurement practices in a wood products supply chain and identify opportunities for improvement. The study focused on the potential of combining SCM principles and effective quality performance measurement practices as an approach to improve the competitive position of wood products manufacturers.

2. METHODS

To accomplish the study's objectives, an in-depth case study was conducted in an integrated wood products supply chain. The supply chain comprises suppliers of raw materials (lumber), components manufacturers, assembly plant, retailers, and building contractors. The first step was to map the value stream, following the process suggested by Jones and Womack, this is selecting a representative product or product component and "walking" the supply chain from end customer to first supplier [24]. Data collection tools included a set of semi-structured questionnaires, checklists, and graphic tools. An in-depth understanding of current quality measurement practices was sought. Thirty visits and interviews were conducted. Positions of the interviewees included continuous improvement coordinator, logistics manager, material manager, quality control manager, rough-mill supervisor, sawmill manager, lumber purchasing, project coordinator, quality assurance, office manager, and branch manager. After the data collection phase was completed, current quality measurement practices in the supply chain were compared with best practices according to what is reported in the literature. A new graphic tool was developed for this analysis. Linear regression analysis was used to find correlations between major quality indicators throughout the supply chain. Finally, a quality performance measurement systems was developed using Six-Sigma measures of performance.

3. RESULTS AND DISCUSSION

Figure 1 shows the current state value stream map, essential in understanding the flows of materials and information in any supply chain [25, 26]. The purpose of a value stream map is to identify wasteful activities, and from there formulate opportunities for improvement. In this particular example, the total time required for a product to reach the customer from the raw material being harversted is 125 days, but the total value-adding time is only 29 days (results from adding values in parentheses, which show the value-adding time at each step of the supply chain), meaning that 76 percent of the time materials are sitting in inventory or are being moved, e.g., 76 percent of the time is wasted, since during this time no value is added to the product from the customer's perspective. If drying (i.e., the necessary step of reducing wood's moisture) is not considered as value-added activity, value-adding time amounts to only 1.2 percent of total time (125 days). Value stream mapping also helps to visualize other process information such as inventories or movement of materials, as shown in Figure 1.

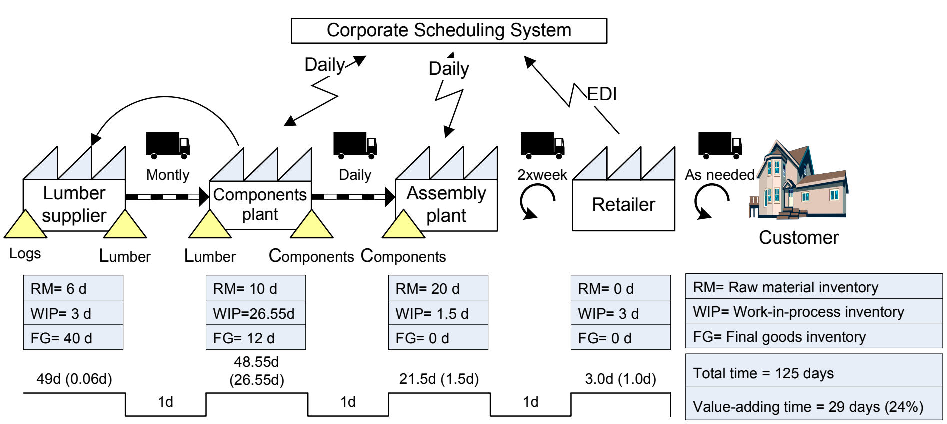

Figure 1. Extended value stream of the integrated wood products supply chain studied.

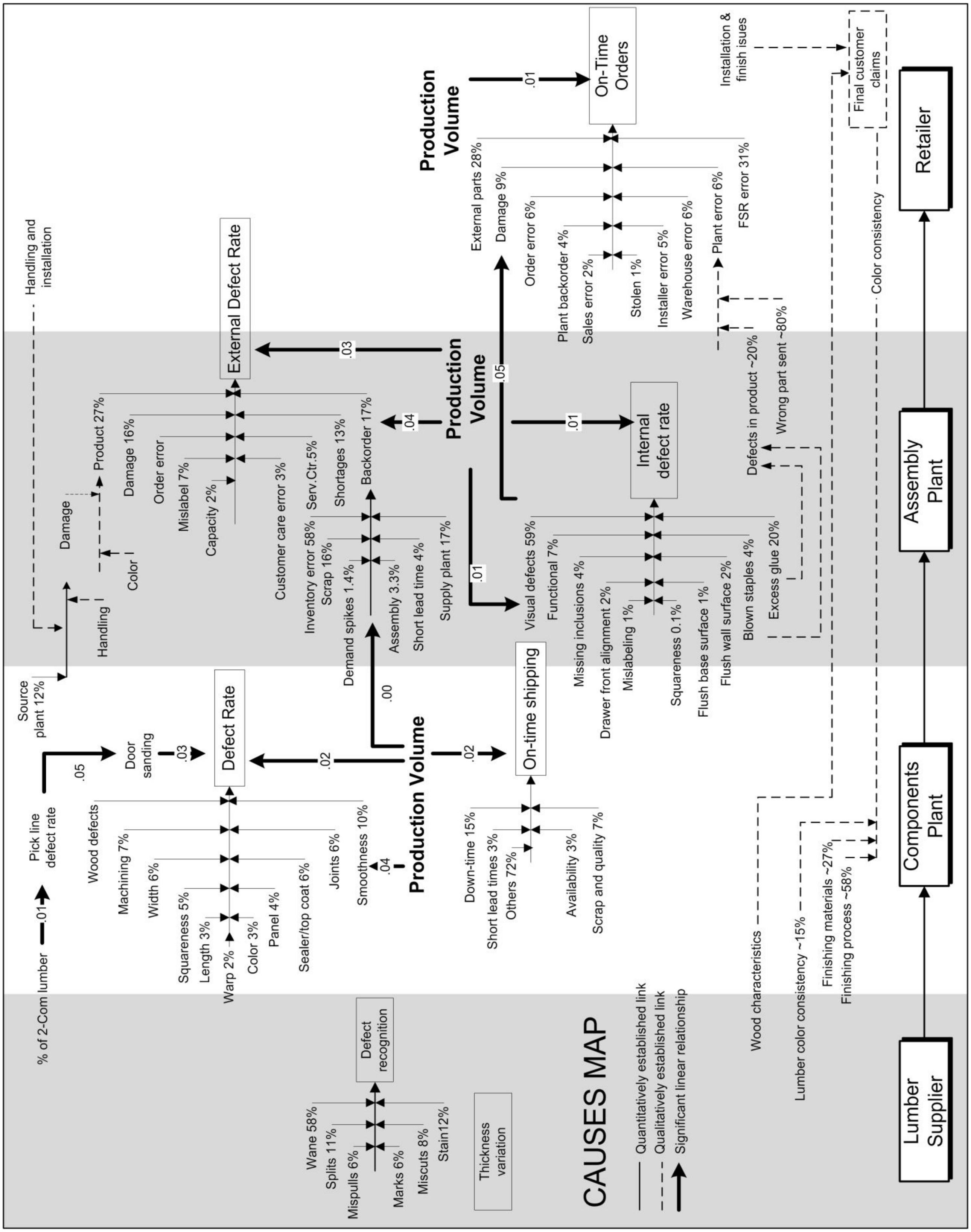

Figure 2. Supply Chain Causes Map (p-values are shown for regression analysis).

After developing a value stream map and understanding the Supply Chain (SC) structure as well as the flows of materials and information, the data collection focused on learning about the current quality measurement practices. Quality measurement practices used were highly variable throughout the supply chain, ranging from no formal quality measurement system to an internet-based database dedicated to quality reporting, to a systematic quality control and improvement procedures using Six-Sigma improvement methodologies. A graphic representation tool was developed to analyze the quality measures used in this particular supply chain. Figure 2 summarizes the major quality indicators in use throughout the integrated wood products supply chain at the time of the study (shown in boxes), their components or causes (the defect categories leading to the major quality indicators), and the contribution of each component to the total defect rate (shown as percentages). Regression analysis was performed between quality indicators at different positions in the supply chain, with the purpose of investigating how quality at any point in the supply chain affected downstream quality. The statistically significant correlations thus found are represented by bold lines in Figure 2. In most cases, there was a significant correlation between production volume and defect rate, which suggested a need for production-level strategies. This graphic tool creates a higher level view of the quality measurement practices in this supply chain and allows analyzing the relationships between practices at different points in the supply chain.

A comparison of the integrated wood products current supply chain management practices with best practices was used to identify opportunities for improvement. Three major aspects were analyzed: internal and external integration, supplier quality management, and alignment of current measures of performance with customer needs. Major findings are summarized in the following sections.

3.1 INTEGRATION

Integration is "*the coordinated management of business processes and functions inside the organization, through a common set of principles, strategies, policies, and performance metrics*" [27, 28], and is a frequent theme in SCM. There is evidence of a positive association between internal integration (within the organization), external integration (with external SC entities), and supply chain performance [28-33]. The data collected for this study revealed a high level of internal integration, evidenced by (a) a company-wide continuous improvement effort, with common tools and methods, and goals set at the corporate level, (b) a "corporate dashboard," which listed critical performance information and was visible to the entire organization, and (c) a practice of evaluating managers based on performance information.

However, internal integration does not guarantee supply chain performance. For this, external integration with suppliers and customers is necessary [28, 30, 34]. External integration can be evaluated based on characteristics of a joint quality management effort: for example, growing confidence in supplier's quality, reduction in inspection of incoming materials, greater responsibility for suppliers in assuring quality, and no double handling with reduced need for storage [35]. For the case study, this is the area with the most need of improvement in the supply chain of study. Some opportunities for improvement are (a) disconnects were identified between the components plant and its lumber suppliers, as these suppliers were not integrated in the quality management system of the company (since large amounts of inventories are held at every step of the supply chain, Figure 1, scheduling and quality inefficiencies were masked); (b) the flow of quality information was limited to immediate supply chain partners (integration in the flow of information facilitates integration by reducing transaction costs, comprised of coordination costs and transaction risks [36]); and (c) the corporate dashboard did not provide feedback about the relative contribution of individual components on the supply chain's performance and external suppliers were not included in the reporting system (research has shown that effective measurement systems span the entire supply chain [37]).

3.2 SUPPLER QUALITY MANAGEMENT

According to SCM research, the three main components of strategic management of suppliers are: supplier relationship, supplier evaluation, and supplier development [38]. Research also supports the development of collaborative rather than traditional, often adversarial, relationships with suppliers and customers. The focal facility in this study had long-term and close relationships with its lumber suppliers, and conflicts were solved directly and in an expedient fashion. However, the flow of information about quality issues with lumber suppliers was mostly unidirectional, in the form of orders and purchase specifications. There was no supplier participation in the development of these specifications. Also, there was not a formal supplier evaluation program, which has been linked to higher financial and market performance levels [38-41]. Supplier evaluation was based mostly on rejection of "out of specification" orders (orders having a higher than specified amount of low-quality material were rejected); this practice does not consider the potential processing problems of having high variability in quality of incoming materials [39]. Lastly, supplier development can be defined as a systematic effort to create and maintain competent suppliers [42]. This can range from conformance-based selection to close collaboration with suppliers to enhance their process capability [43]. Examples of supplier development activities are: recognizing supplier with certifications or awards, providing technical assistance, and enhancing communication with suppliers [44]. The focal company did not have a supplier development program at the time of the study.

3.3 Alignment with Customer Needs

In a Supply Chain Management context, quality management needs to be aligned with the customers' requirements to contribute to the success of supply chain. In this study, two specific examples illustrate a need for improvement in this aspect. Raw material purchases (lumber) are focused on maximizing yield and not necessarily final product quality. This was evident looking at the purchase specifications, which did not include "color" as one critical quality attribute, although from interviews at downstream processes it was found that color consistency is probably the most common cause for complains at the end-customer level. Audits were conducted to control color consistency between product components at the components and assembly plants, but this evaluation was more likely to detect finishing process or materials variances, rather than lumber color consistency issues.

3.4 Performance Measurement System

Although the focal company had implemented a corporate performance reporting system in which the focal facility fully participated, it was internally focused; metrics reported only performance of individual facilities operated by the company, and did not reflect the relative contribution of each plant to the overall performance, necessary for an effective supply chain (SC) performance measurement system [45]. Also, external suppliers were not included in this performance measurement system, which did not allow the capture of performance across the entire SC [25]. Although the metrics used internally were instrumental in identifying and correcting defects at each establishment, they did not facilitate the rapid identification of causes when these originated farther upstream the SC. Lastly, it was found that quality performance information was shared only with the immediate SC partners. The need for SC performance measurement was explained by Lambert [25] as the need to (1) expand the line of sight from a single entity to the overall SC network, (2) align strategy and activities in the SC, (3) achieve differentiation to gain competitive advantage, and (4) encourage cooperative behavior between SC members. SC measures of performance span the entire SC and should reflect quality across all entities and the contributions of each component to the overall performance.

Considering the aforementioned findings, a system to develop a supply chain performance measurement system was proposed. The development process is illustrated in Figure 3, and was based on methodologies suggested in [46], [25], and [16]. The supply chain structure and the materials and information flows are identified as a starting point (Figure 1), followed by deciding which performance areas the supply chain must excel at to achieve customer satisfaction. Not all entities in the supply chain are relevant for all the key performance areas (e.g., transportation providers may not be relevant for physical quality but very important for time performance), thus in a third step, the relevant SC entities are identified. In a fourth step, supply chain measures of performance are defined. Lastly, the measures are implemented and evaluated for improvement. The remaining of this paper describes the measures of performance suggested for the supply chain of study.

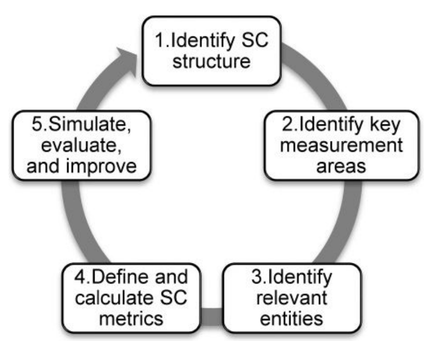

Figure 3. Supply chain quality measurement development process [47].

For supply chain measures of performance, metrics used in a six sigma environment were suggested. A major advantage of six sigma measures is that they allow making comparisons between processes different in nature and complexity on the same scale [16]. These comparisons are critical when evaluating the performance and alignment of businesses in their SC environment. Defects per opportunity, for example, allow comparisons between processes of different levels of complexity, by considering the number of opportunities for a defect in each product unit (there are many more opportunities for a defect in an assembled product than in one component, for example). Rolled throughput yield (RTY) is especially valuable in situations where different types of products and/or services are compared [48]. A major advantage of RTY is that it considers the contributing losses at all steps in the transformation process, not only the final result. RTY facilitates the process of selecting those improvement projects that will have the most impact in overall quality improvement and cost reduction. Table 1 summarizes the measures of performance used, including their calculation.

Table 1. Selected supply chain performance measures suggested for the case study.

(1) Defect rate per opportunity	$\text{DPO}=\frac{d}{p\times n}$	d = number of defects observed p = opportunities for defects in a product unit* n = product sample size
(2) Defect rate per million opportunities	$\text{DPMO}=\text{DPO}\times 1{,}000{,}000$	DPO = observed defects per opportunity
(3) First-time yield**	$\text{FTY}=\frac{\text{output-rework}}{\text{input}}\approx e^{-\text{DPO}}$	output = defect-free units from the operation input = units entering the operation for processing rework = number of reprocessed units
(4) Rolled throughput yield (operations in series)	$\text{RTY}=\prod_{i=1}^{n}\text{FTY}_i$	FTY_i = first-time yield of the i^{th} operation n = number of operations
(5) Sigma score***	$\text{Z-Score}=\frac{\lvert SL-\bar{x}\rvert}{\sigma}$	SL= specification limit x = process mean σ = process standard deviation
(6) Throughput yield (operations in parallel)	$\text{RTY}=\sum_{i=1}^{n}(Y_i\times p_i)$	Y_i= rolled throughput yield at the i^{th} operation n = number of parallel, interchangeable, operations p= share of the i^{th} operation on total
(7) On-time shipment	$\text{OT}=\frac{OS}{N}$	OS=orders shipped complete and on/before due date N = total orders

* Opportunities for a defect are determined with the customer needs in mind. For example, a pre-finished door may have 8 attributes that are critical for customer satisfaction (e.g., finishing, color, width, length, wood characteristics, smoothness, joint quality, and squareness). These attributes can be considered opportunities for defects.

** For large samples and low defect rates, FTY can be approximated as e^{-DPO}

*** Z-score for each SC component is calculated using the inverse normal distribution, and look for the value that corresponds with FTY [$Z-\text{score}=N^{-1}(\text{RTY})$]. A long term Z-score is calculated adding 1.5 to the short term Z-score, to consider shifts in the process over a long period. In this study, this "sigma drift" was not considered. The overall supply chain Z-score is calculated transforming the RTY to DPO [DPO = - ln(RTY)] and then reading the corresponding value in a Normal distribution table.

The measures of performance proposed for the supply chain (SC) under scrutiny were validated using historical data. A sample calculation is shown in Figure 4. The left chart shows defect rate and sigma score for a specific period and the right chart shows RTY behavior over time. Defect rate is measured as the ratio between the number of observed defects and the opportunities for a defect (usually expressed on a per-million basis), and sigma score reflects the number of standard deviations that can fit between the average of the process and the specification limit; thus a higher sigma means a more capable process. Notice how these measures reflect the relative contributions of each step in the supply chain to overall performance, which helps to prioritize improvement efforts. RTY measures the likelihood of a product (physical or service) to undergo a process with no defects and is highly correlated with scrap, rework, warranty, and customer satisfaction [48]. Figure 4 allows making lineal comparisons for process performance during the year. Notice for example, that RTY decreases in January and October, reflecting periods of higher-than-usual activity; which could suggest that efforts to level the production pace and measures for temporarily increase capacity could yield significant improvements in quality performance.

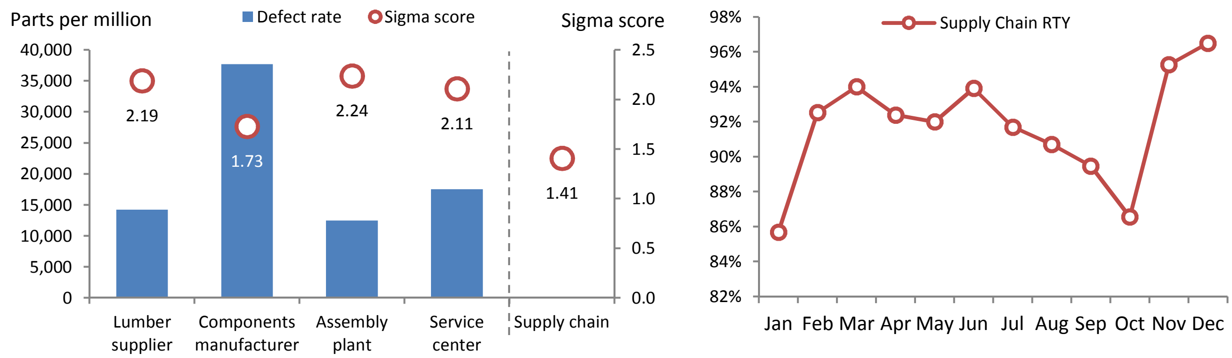

Figure 4. Supply chain measures of performance. Left: defect rate and sigma score, right: rolled throughput yield (RTY).

4. Summary

An in-depth case study was conducted in a wood products supply chain (SC), to gain an understanding of quality measurement practices and to identify opportunities for improvement. A need for performance measures with a SC perspective was identified. To address this need, a process for developing a supply chain performance measurement system was suggested. A set of six sigma performance measures was proposed and then validated with historical data. Companies can benefit using the process described in this paper by developing a performance measurement system that helps them to align strategies and activities in the value stream. Such a system also encourages cooperation between SC partners by improving transparency and providing a common language, and facilitating differentiation between supply chains. A performance measurement system can significantly contribute to the competitive advantage of the firm and SC.

Note: Part of the information contained in this publication has been published in Forest Products Journal [5, 47].

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