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Empirical study of measuring supply chain performance

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Abstract

Purpose – Supply chain (SC) performance measurement – the process of qualifying the efficiency and effectiveness of the SC. The purpose of this paper is to create a SC measurement framework for manufacturing industry, define which data should be measured and verify the measurement framework in the case company's SC.
Design/methodology/approach – There is a review of the current understanding of supply chain management and literature related to SC performance measurement and the study creates a framework for SC measurement. This research is qualitative case study research.
Findings – This study presents the main theoretical framework of SC performance measurement. The key elements for the measurement framework were defined as time, profitability, order book analysis and managerial analysis. The measurement framework is tested by measuring case SC performance.
Research limitations/implications – In the study, a performance measurement framework was created for the needs of manufacturing industry. Suggestions for future research are multiple case study in different manufacturing industry areas and positivistic-based SC performance research.
Practical implications – The measurement framework in this study offers guidelines for measuring the SC in manufacturing industry but the measurement framework could be used in different areas of industry as well.
Originality/value – The SC performance measurement framework is tested and a valid framework for SC performance measurement in manufacturing industry.

Keywords Supply chain, Manufacturing industry, Supply chain performance measurement
Paper type Case study

Introduction

In particular, measuring the supply chain (SC) has been recognized as a problem. The problem occurs when developing a SC in practice. The pressures in rationalizing set by management create a significantly large challenge for supply chain management (SCM). The SC has to be made more streamlined, lead-times have to be decreased, excess processes need to be eliminated and developed as a whole in such a manner that new, more efficient processes can be established. The basis for development work is a survey of the present state and measuring efficacy of the current SC. Tools for this have been scarce. This study provides a resolution to problems in measuring the SC.

Sampson (2000) represents SC as bidirectional in service business since the customer does not merely receive the output but also brings input to the service process. Bidirectionality can be single-level or two-level. On both levels, the customer is involved in the SC in a bidirectional manner: in addition to the customer providing input, customer's input gets additional value from the service process and hereby the customer is able to consume the output. In a single-level bidirectional SC, the service provider's subcontractors are involved in the SC in a unidirectional manner, e.g. as providers of material or facilities. In a two-level bidirectional SC, on the other hand, subcontractors are involved also in the service process (Sampson, 2000).

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An SC is usually regarded as unidirectional in production industry and bidirectional in service industry. In production industry, with regard to production-related inputs and outputs the SC of a product is indeed unidirectional: the flow of products passes from suppliers to customers. Likewise, the flow of payments and feedback passes from customers to suppliers. However, an integrated SC in production industry also encompasses two-way co-operation and information sharing among the parties in the SC (Sampson, 2000).

In SC performance measurement the main purpose is to get information for top management's needs, but also several kinds of SC measures are needed at every management and operational level. SC should be measured because of management interest in measuring how efficient SC is. Usually there are several kinds of interest and several management levels are interested in knowing about SC performance. Measuring is also needed when SCM is going to be developed. Van Hoek identifies the problem of measuring SCM in the research paper titled as "Measuring the unmeasureable - measuring and improving performance in the supply chain management"(Hoek, 1998).

Gunasekaran *et al.* (2004) introduce six metrics for measuring SCM capability and performance. Metrics are based on the following SCM processes: plan, source, make/assemble and delivery/customer (Gunasekaran *et al.*, 2004). Shepherd and Günter (2006) categorize SC performance measures into five SC processes: plan, source, make, deliver and return or customer satisfaction, whether they measure cost, time, quality, flexibility and innovativeness and whether they are quantitative or qualitative measures. Measures can be categorized according to business processes or into strategic, operational and tactical management levels (Shepherd and Gunter, 2006).

Theeranuphattana and Tang (2008) states that the Supply Chain Operations Reference model (SCOR) model is based on five core processes: plan, source, make, deliver and return. The SCOR model advocates hundreds of performance metrics used in conjunction with five performance attributes: reliability, responsiveness, flexibility, cost and asset metrics (Theeranuphattana and Tang, 2008).

Chan (2003) presents SCM performance measurement approach which consists of qualitative and quantitative measures. Quantitative measures are cost and resource utilization and qualitative measures are quality, flexibility, visibility, trust and innovativeness. Chan (2003) and Bhagwat and Sharma (2009) introduce analytic hierarchy process (AHP) for measuring SCM qualitative and quantitative approaches. AHP is a common tool for solving multi-criteria decision-making problems. (Chan, 2003; Bhagwat and Sharma, 2009; Bhagwat and Sharma, 2007).

Typically SC performance measurement research has been carried out via questionnaires and they have not had an action oriented point. Measuring the SC is the basis for developing it. It is possible to evaluate the SC when it can be measured. Likewise, it is possible to evaluate efficiency by following indicators of SC. The research goal can be captured as following.

The goal is to deepen knowledge in SC performance measurement in manufacturing industry.

The research problem is presented as a question.

How to measure SC performance in manufacturing industry?

Research methodology

Eisenhardt (1989) defines case study research as a research strategy that aims at understanding the internal dynamic of an individual case (Eisenhardt, 1989). Case study research is aiming at understanding comprehensive and relevant phenomena of real life. In that case the endeavor is to study the phenomena in their genuine context. Interface between the phenomenon and context is not often clear, which complicates the work of a researcher (Yin, 2009).

Case study research is regarded as a good research method when the research problem can be described with the help of questions how and why. The method is very useful when a researcher cannot control the target. Furthermore, it is useful when the focus is on concurrent events in a real time manner especially when the border between the event and context is not clear. There are three types of case study research: explorative (seeking to find out more about a phenomenon) research, descriptive research and explanatory research. The purpose of explorative research is to obtain information regarding a phenomenon, find new ideas and possible research problems. In explorative research, already existing information is collected and sorted. The aim of descriptive research is to provide as accurate image of an individual, group, situation or phenomenon as possible. In the research the focus is not in clarifying connections between phenomena or factors interpreting behavior, but only in describing a situation. The aim of explanatory research is to explain causal relations between phenomena and testing related hypotheses. (Yin, 2009)

This study is conducted in a challenging environment by studying the measuring of the SC in manufacturing industry. SC is an extremely challenging research subject and the study creates new information by measuring performance of the case SC. The hermeneutic view perceives knowledge as soft, often subjective and experience based as well as insights of a personal nature, whereas the positivist perceives knowledge as hard and real, and considers it possible to transmit knowledge in a tangible form (Burrell and Morgan, 1979). The hermeneutic view is approached in the study in the form of qualitative and quantitative research. Quantitative research refers to a study in which accurate and calculatory (in humanities often statistical) methods are used. Qualitative research is a method of inquiry practised in humanities in addition to quantitative research. The aim of qualitative research is to understand the phenomenon being studied. The point of view of this study is a more qualitative one. In qualitative research, discretionary sampling is normally used. Only a small number of units is selected for the study and they are studied in depth which makes quality of the data important. In this study, qualitative methods are used to collect information regarding the case under study. These methods include observations, interviews, questionnaires and reports (Burrell and Morgan, 1998).

Inductive reasoning, a.k.a. induction is a method of reasoning that starts from an individual group of observations and forms a generalization or a theory regarding it. Deductive reasoning a.k.a. valid reasoning is a method of reasoning in which the true premises are necessarily followed by a true conclusion (Ghauri and Grønhaug, 2005).

Arbnor and Bjerke (1997) presents three main methodological approaches: analytical approach, system approach and action approach. The analytical approach represents clearly explanatory knowledge with the assumption that reality is objective. The action approach represents understanding knowledge with the assumption that reality is socially constructed. The system approach is positioned between positivism and hermeneutics in the assumption that reality is objectively accessible (Arbnor and Bjerke, 1997).

The constructive approach means problem solving in a real-life organizational setting through the construction of a management system (Kasanen *et al.*, 1993; Lukka, 2000; Labro and Tuomela, 2003). According to Kasanen *et al.* (1993), a constructive method is a solution-oriented normative method where target-oriented and innovative step-by-step developments of a solution are combined, and in which empirical testing of the solution is done and utility areas are analyzed (Kasanen *et al.*, 1993).

A hermeneutic view is approached in the study in the form of qualitative and quantitative research. In this study, qualitative methods are used to collect information regarding the case under study. A system approach is a good research method for this study. Furthermore, a constructive approach can be regarded as an important method with regards to the study, since in the study, on the basis of this theory a model with which the SC is measured, is created. These methods include observations, interviews, questionnaires and reports.

This study complies more with the deductive than inductive logic of reasoning. In the study, leading theoretical methods of measurement that represent SC are defined. On basis of these, a theoretic frame of reference is created for measuring the case SC. The indicators and the theory developed are studied, after which the results are interpreted. The study includes both inductive and deductive reasoning (Table I).

SC performance measurement

This chapter presents primary approaches for SC performance measurement. First, the emergence of SCM concept is reviewed. After this, SCM is defined according to the views of various academics. It is possible to measure SC performance in several ways and performance measurement in the SC context has been studied in many perspectives.

SCM

SCM is a management concept of the 2000s. It includes divisions from the management concepts of previous decades. Many definitions for SCM have been presented. SCM has been and is still regarded as a synonym for logistics, supply and SC control. Today the broader definition determined by the Global SC Forum is generally accepted as a norm (Lambert *et al.*, 1998; Cooper *et al.*, 1997):

> Supply Chain Management (SCM) is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders.

SCOR which was defined in the Supply Chain Council (2005), defined a SC as follows:

> The supply chain encompasses every effort involved in producing and delivering a final product, from the supplier's supplier to the customer's customer. Five basic processes– plan, source, make, deliver and return – broadly define these efforts, which include managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer.

Research discipline	Industrial engineering and management (IEM)
Theoretical base	Supply chain management, performance measurement in supply chain
Research paradigm	Hermeneutics
Research strategy and research approaches	Qualitative constructive case study approach
Research methods	Qualitative methods: interviews, data form ERP systems, measurements, observations, questionnaires, documents

Table I. The main methodological choices in this study

Performance measurement in SC context

> When you can measure what you are speaking about, and express it in numbers, you know something about it […] Lord Kelvin, 1824-1907.
>
> You cannot manage what you cannot measure, (Sink and Tuttle, 1989).

There is a set of contributions in the area of SC performance measurement. Chan and Qi (2003a, b) proposed a process-based PMS for mapping and analyzing complex SC networks (Chan, 2003); Van Hoek (2001) emphasizes the importance of performance measurement from the point of view of the third-party logistics alliances in SC (Van Hoek, 2001); Gunasekaran *et al.* (2001) develop performance measures and metrics in a SC environment from a managerial point of view (Gunasekaran *et al.*, 2001). Morgan (2004) offers nine preconditions necessary for effective and dynamic performance measurement within SC's. These preconditions are cheap and reliable identification of units in transition, standard protocols, communication systems that are capable of handling the volume of data, hardware and software, multi-layered control systems, system handshake protocols, routing and re-routing protocols that allow SC cost control, speed and flexibility of delivery response, high velocity electronic cash transfers instigated automatically; and robust systems with inbuilt automatic recovery abilities (Morgan, 2004). Thakkar *et al.* (2007) proposed a balanced scorecard (BSC) framework for a case organization using an integrated approach of interpretive structural modeling and analytic network process (Thakkar *et al.*, 2007; Thakkar *et al.*, 2009). More SC performance approaches are presented in Appendix.

According to the research, SC capability can be measured by using different kinds of approaches:

- a performance measurement matrix (Keegan *et al.*, 1989);
- BSC approaches (Bhagwat and Sharma, 2007; Thakkar *et al.*, 2007; Bigliardi and Bottani, 2010; Chia *et al.*, 2009; Dror, 2008; Xu and Li, 2008; Lawrie and Cobbold, 2004; Brewer and Speh, 2001; Kaplan and Norton, 2001);
- cost and non-cost (Gunasekaran *et al.*, 2001; De Toni and Tonchia, 2001);
- financial and/or non-financial metrics (Lawrie and Cobbold, 2004; Gosselin, 2005; Ittner *et al.*, 2003; Ittner and Larcker, 2003; Lambert and Pohlen, 2001; Neely, 1999; Olsen *et al.*, 2007; Tangen, 2004; Tapinos *et al.*, 2005);
- green SC measurements (Hervani *et al.*, 2005; Shaw *et al.*, 2010);
- input, output and composite measures (Chan, 2003);
- measuring SC in multiple levels (Shepherd and Gunter, 2006; Lin and Li, 2010);
- objective measures and subjective measures (Chan and Chan, 2004);
- performance measurement questionnaire (Dixon, 1990);
- performance prism (Neely *et al.*, 2000);
- quality, cost, delivery and flexibility (Shepherd and Gunter, 2006);
- resources, outputs and flexibility (Beamon, 1999);
- SC collaboration efficiency (Ramanathan *et al.*, 2011); coordination efficiency and configuration (Shepherd and Gunter, 2006);
- SC process-based measuring approach (Shepherd and Gunter, 2006; Chan, 2003);

- Six-sigma approaches (Lin and Li, 2010; Ramaa *et al.*, 2009; Xu, 2008; Wang *et al.*, 2004; Dasgupta, 2003);
- strategic, operational or tactical management approach (Gunasekaran *et al.*, 2001);
- Van Hoek's matrix model (Hoek, 1998); and
- Visibility SC collaboration (Caridi *et al.*, 2010).

SC performance measurement in the case company

As it emerged from the theoretical study, managing the SC has to be measured at various different levels using various approaches. For measuring SC, the barometers have to be tailored case-specifically for each SC. Manufacturing of pre-fabricated products has developed a great deal during the last few decades. Production processes have been automated, SC's have been made more streamlined and production methods have been developed. This, however, is not yet enough – one must be able to improve cost-efficiency from before. Especially in the production plants of the case company one has to be able to respond to the challenges caused by globalization.

Pre-fabricated products of the case company compete with cost-efficient SC, top-rated technology and good quality. To be able to develop the SC, one has to be able to measure its efficacy. The SC of the case company can be measured with the following indicators, taking into consideration the special characteristics of the SC: order book analysis, profitability, time, managerial analysis. This measurement framework was conducted according to the literature review and interviews of this case study (Figure 1).

Order book analysis

Measuring the SC of a production plant has its foundation in order book analysis. According to the survey to literature, order book analysis can be categorized to non-financial metrics (Gosselin, 2005; Lambert and Pohlen, 2001; Lawrie and Cobbold, 2004; Neely, 1999; Olsen *et al.*, 2007; Tangen, 2004; Tapinos *et al.*, 2005; Thakkar *et al.*, 2007), qualitative approach (Beamon, 1999; Chan, 2003a) and non-cost (Gunasekaran *et al.*, 2001; De Toni and Tonchia, 2001). The aim is to gain information regarding the present state of the order book of the production plant. Percentage of delivery to customers of total sales as well as percentage of various deliveries for internal sales from total sales can be regarded as the most central indicators.

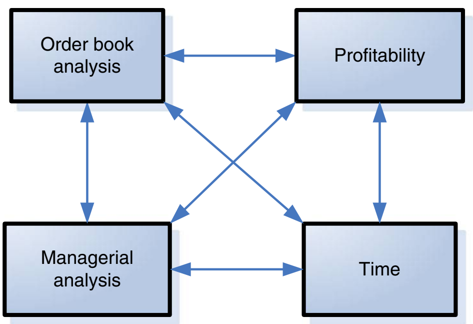

Figure 1. Supply chain performance measurement indicators

Weekly manufacturing amounts suggest the average load of production. With the help of manufacturing figures it is possible to verify seasonal variation and possibly the effect of manufacturing amounts to on time delivery. Delivery amounts should be reviewed as tons. One should analyze weekly and monthly variation of delivery amounts to internal and external customers. Amounts produced are, from the point of view of running the production plant, an essential measurable quantity. In the light of previous amounts produced – together with the sales forecast obtained from sales – it is possible to plan future capacity and future production.

Profitability

It is important for a company manufacturing prefinished products in an engineering works to measure efficacy of the SC from the point of view of cost-efficiency. The profit directed at the order describes cost-efficiency best. On the basis of theoretical review, this indicator is numbered among cost and economic viewpoint indicators (Gosselin, 2005; Gunasekaran *et al.*, 2001; Lambert and Pohlen, 2001; Lawrie and Cobbold, 2004; Neely, 1999; Olsen *et al.*, 2007, Tangen, 2004; Tapinos *et al.*, 2005; Thakkar *et al.*, 2007; De Toni and Tonchia, 2001). The indicator can be generalized as a fundamental indicator for all production companies. The indicator is especially important by the fact that the price of steel varies according to markets and therefore updating the prices for products and continuous follow-up on sale prices for these to meet the actual expenses is extremely important. In the steel service business the sales usually occur on the basis of spot transactions, but additionally the company operating in the field of pre-fabricated plate product business has committed to deliver products to its customers according to long-term contracts. Therefore, re-counting of the products according to changes in production schedules is extremely important.

Time

Lead-time is in many studies considered to be one of the central indicators in manufacturing industry. De Toni and Tonchia (2001) present time-based indicators as non-cost indicators, where time can be measured as internal or external time. Gunasekaran *et al.* (2004) present a great deal of time-based measures. Time is also identified as the next source of competitive advantage (Kessler and Chakrabarti, 1996; Vesey, 1992; Stalk, 1988; Balsmeier and Voisin, 1996; Mehrjerdi, 2009). Also in measuring the SC several scholars recognize lead-time to be a very descriptive indicator. In the case company, lead-time is one of the most important elements that the customer is interested in. Quick times of delivery in the steel service business make the business hectic and therefore lead-time has to be measured in order to be able to decrease it.

Managerial analysis

In measuring the SC one has to review the SC as a whole. Partial optimization has to be avoided because improving one sector is not enough to improve the whole SC. Gunasekaran *et al.* state that several kinds of measures should be used in performance metrics: balanced approach, strategic, tactical and operational levels and financial and non-financial measures. SCM could be measured at a different management or operation level (Gunasekaran *et al.*, 2001, 2004). It is useful to gather managerial analysis from analyses of people involved in the SC as well as analyses of outsiders.

Managerial analysis can be performed on the basis of measured information obtained from the systems, making visual perceptions in production and interviewing professionals involved in the production process. The purpose of managerial analysis is to follow-up the whole SC and obtains information regarding immeasurable issues related to SC. The purpose of observation is also to obtain information regarding efficacy of the SC so that evaluation will not be based merely on measured quantities.

Empirical SC performance measurements

In this chapter the SC is measured with previously established indicators. The indicators consist of four different parts: order book analysis, profitability, time and managerial analysis. In order book analysis, the production plant's completed output and reliability of delivery in different years are reviewed. SC can be also measured from the point of view of profitability. Also the costs of the SC are observed. Time-based measuring of the SC is conducted by measuring the delivery cycle, on time delivery, production time and its subdivision into operational times. It is extremely important to make managerial analyzes where analyses are made on operational, tactical and strategic levels.

Case description

The metal industry has built up around the steel industry. Most typically, Finnish metal industry consists of small and medium sized engineering works as well as of some larger, global companies. The production of large companies in the metal industry in Finland consists of highly refined solutions that aim to produce special additional value to the customer. Products manufactured have to be of especially high quality and efficiency of production has to be at its best. Compared to countries with lower cost levels, the costs of Finnish steel and metal industry are enormous. This fact has forced the companies in the steel and metal industries to invest in efficiency, quality and producing additional value to end customers. When focussing on core business, the production process in metal industry was altered and outsourcing of functions was started from the beginning of the production process. At the beginning of the production process there are usually plate processing functions which include cutting, bending and finishing of standard products manufactured at a steel factory. Instead of supplying a standard product, steelworks can supply steel parts that are manufactured according to diagrams. Customers can implement these parts directly to production process as raw materials.

The most typical manufacturing processes in the metal industry are related to handling and machining steel that is used as raw material. Steelworks manufacture the products according to standard measurements. Engineering works in the metal industry use plenty of steel plate as raw material due to the fact that the parts needed for the product to be manufactured are cut from it.

The case company in the study manufactures steel products and refines steel into solutions. One of the solutions is steel parts tailored to a customer's needs. Steel parts (in other words pre-fabricated products) are manufactured at various units and steel service centers of the case company. Steel service centers are specialized in manufacturing blocks from various steel products for end customers. The case production plant is one of the production units of the case company. It manufactures pre-fabricated products from steel plates. The products are cut plate parts that may have been edged, bevelled, sandblasted and finished. The products are manufactured according to diagrams provided by the client. The production process of pre-fabricated plate parts is extremely hectic and delivery times are usually just a few days.

The case production plant can be described as the steel factory's refinement unit which serves customers by refining steel in a customer-tailored manner. The SC of the case production plant being studied is restricted to the production plant's material flows in such a way that the case SC begins from the material stock of the case production plant. The SC ends when the blocks have been delivered to the end customer or to various production plants of the case company, to internal customers. Internal customers supply the products to end customers after the manufacturing process.

Order book analysis

In 2005, 955 tons was manufactured and in 2006, increasing production as well as rationalization of the production facilities began. Furthermore, in 2006 a new operation control system was implemented in the production plant. In 2006, 8,118 tons of steel parts were manufactured, which means a growth of almost nine times over the previous year. The following year, in 2007, production capacity of the production plant was mobilized more efficiently and benefits of the production control system could be utilized. The amount produced in 2007 was 15,508 tons, which was nearly double 2006 production. In 2008 the amount produced increased to 24,147 tons, which was 1.5 times that of year 2007. The period from 2005 to the end of 2008 was a time of rapid economic growth which was also seen in the growth of sales volumes. In 2009 sales faded as did the order books of customers. Regardless of this the production plant was able to manufacture 27,070 tons of steel parts (Figure 2).

Delivery reliability of the orders

In 2005 delivery reliability averaged out 37.5 percent. In 2006 delivery reliability averaged out at 47.33 percent. There was a very significant improvement in delivery reliability in 2007 when it averaged out at 96.8 percent. After growth in production settled in 2008 and 2009, it has been possible to maintain delivery reliability at a good level. In 2008 delivery reliability was 96.5 percentand in 2009 almost 100 percent. Management of capacity has been made more efficient and co-operation of sales and production has been improved. All the challenges related to launching of production plant have been overcome as growth is steadying and the operations are stabilizing (Figure 3).

Lead-time and profitable analysis in the first measurement

Product A profitability. Profit margin of the order was – 45.9 percent and hence the order was unprofitable. Process time of the order was 134.1 hours. Total lead-time was 23 days and proportion of process time was determined to be 24.3 percent (Table II).

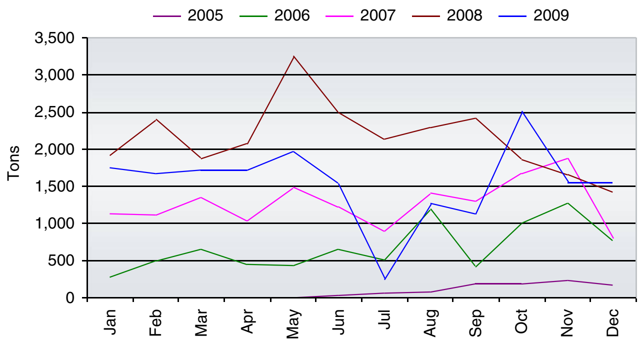

Figure 2.
Output of the case production plant in 2005-2009

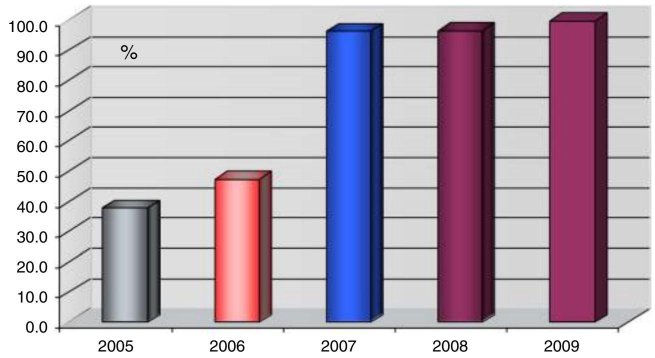

Figure 3. Delivery reliability per year in 2005-2009

Results	Product/ order	Profit margin of the order	Total lead-time (days)	Process time (hrs)/order	Proportion of process time (%)
Total	8	−45.9	23	134.08	24.3

Table II. Cost-efficiency of product A of customer A

Lead-time for product A. Concerning products for Customer A, the problem has been long lead-times. In total, 19 similar orders were manufactured during the period of time. Dispersion in period for the fulfilment for the orders was from nine to 43 days. Average for product lead-times was 27.7 days.

On time delivery for orders of Customer A's Product A varied a great deal. At the beginning of the year all orders were overdue by as much as eight days. On time delivery for the latest orders was 100 percent. Five of the orders were delivered one to six days earlier than the given time of delivery.

Production time a.k.a. process time of the order was 134.8 hours, which makes almost six days. Process time of one stage was 16.85 hours, and to produce the whole order, process time was spent from the period for the fulfilment of the order was 24.3 percent. Lead-time of the SC was 23 days.

Product B profitability. The profit margin of Customer B's order reviewed was 7.76 percent. Process time of the order was 180.12 hours. Total lead-time was 28 days and proportion of process time in the total lead-time was 26.80 percent (Table III).

Product B lead-times. During the period of time in question, the number of orders manufactured was 13. There was great deal of dispersion (from ten to 83 days) in time for fulfillment of an order. Average of periods for fulfilment of an order for Product B was 44.7 days. Proportion of process time in the whole period for fulfilment of an order was very small and there was a great deal of waiting time.

There are clearly challenges with regards to on time delivery of products for Customer B. At the beginning of the year shipments were delivered as much as 25 days

Products/ order	Profit of the order (%)	Total lead-time (days)	Process time (hrs)/ order	Proportion of process time (%)
8	7.76	28.00	180.12	26.80

Table III. Cost efficiency of product B of customer B before the agreed date of delivery. None of the orders was 100 percent delivered on time. Toward the end of the period under review shipments were delivered as much as 35 days late.

The order from Customer B included parts for eight products. The production time a.k.a. process time of the order was 166.62 hours, which is approximately 26.80 percent of the period for fulfilment of an order. The period for fulfilment of an order for the order was 28 days. There were large buffer stocks between the stages of work. Production is controlled in a manner in which after one stage of work is completed, the material is transferred to the next stage of work. Due to this the proportion of process time in the period for fulfilment of an order is small.

Lead-time and profitability analysis in the second measurement

Product A profitability. Second measurements were done only for product A, because of product B production was finished during measurement period. The profit margin of the order was 19 percent, which is – unlike previous year – clearly profitable. Total lead-time was 34 days. Compared to the previous measurement, it increased 11 days. Process time was 115.3 hours per order, which shows clear improvement compared to the previous measurement. This is due to the fact that in the previous measurement there were eight completed products for the order instead of the ten products measured in this measurement. The proportion of process time was 14.1 percent. It decreased almost 13 percentage units due to the total lead-time increasing compared to the previous measurement (Table IV).

Lead-time of product A. Compared to the previous measurement, the number of measurement samples has increased by one order. In periods for the fulfilment of an order, dispersion had increased clearly from 12 days to 78 days, whereas it previously was from nine days to 43 days. The average of periods for the fulfilment of an order for Product A was 46 days, which is nearly 19 days more than in the previous measurement.

On time delivery was studied for the same orders. Dispersion of on time delivery is especially large, from zero days to as much as 24 days late. None of the orders was delivered before the requisite date of delivery. There has been a great improvement in on time delivery compared to the previous measurement. In the latter measurement, there were as many as five orders delivered on time and few orders that were only one day late. During the previous measurement, orders were delivered well beforehand or late. In the latter measurements it was perceived that dispersion of on time delivery has increased.

Process time, product A. The order under review included ten pieces of Product A. Process time of the order was 115.29 hours. It took nearly 20 hours less time to manufacture the order than during the previous measurement. Furthermore, it is worth noting that the results of the first measurement covered productions of ten pieces and the latter productions of eight pieces. In completing the whole order, the proportion of

Table IV. Customer A, cost-efficiency of product A

Pieces/ set	Profit marginal of the order	Total lead-time (days)	Process time (hours)/ order	Proportion of process time (%)
10	19.0	34.0	115.3	14.1

process time in the whole period for the fulfilment of an order was 14.1 percent. Lead-time of the SC was 34 days.

Managerial analysis of SC measurements

SCM was measured at the case production plant during two different periods of time. The aim of two different measurement stages was to obtain information regarding usability of the selected indicators. It proved to be very challenging to carry out the measurements due to the operational environment being highly dynamic. Production volume, changes in the products manufactured as well as updates of the data system created challenges in performing the measurements. Corresponding measurements had not been carried out before, so the methods of measurement as well as the information obtained from the measurements had to be created from scratch. Use of the data systems could not be made in a most efficient manner because no corresponding reports have been created in the systems. The data obtained from the data systems had to be gathered from various sectors.

The results of the measurements reflect the efficiency of the SC of the case production plant very well. The most astonishing result is obtained from comparing the lead-time of the whole SC to production time a.k.a. process time. The proportion of process time in the whole period for the fulfillment of an order is approximately between 10 and 25 percent. The proportion of work stages in production time had also changed between the two different measurements. The proportion of manual work stages in production time had decreased and the proportion of automated work stages had remained more or less the same.

Comparison information regarding Product A in 2006 and 2007 is presented in the table. In 2006, one order included parts for the eight products manufactured by the customer and in 2007 the order contained parts for ten manufactured products. Profitability of the order has turned from loss to profit. Total lead-time has increased from 23 days to 34 days. Process time of order has decreased from 134 hours to 115 hours and hence the process time of plate parts for one product manufactured by the customer has decreased by approximately 30 percent. The proportion of process time has decreased from 24 percent to 14.1 percent, because the total lead-time of the orders under review has increased from 23 days to 34 days (Table V).

In the case production plant's SC process, typical problems presented in literature can be perceived. Load of production has been varying a great deal at the case production plant. Monthly variation is very large. This is due to a short order book and weak practices in customers' forecasting. There is also a great deal of variation in the loading of work stages. To enable stabilizing variations of capacity in production, employees should be more multi-skilled. If there is no work at a given stage of work, an employee could be moved to a post where resources are needed. Loading could be steadied if the bottlenecks of bevelling and finishing would have enough machines and devices. One should pay close attention to these stages of work when loading production. Each hour lost in the backed up stages of work is directly comparable to

Year	Pieces/ set	Profit margin of the order (%)	Total lead-time (days)	Process time (hrs)/order	Process time (hrs)/1 set	Proportion of process time (%)
2006	8	−45.9	23	134.08	16.76	24.3
2007	10	19.0	34	115.289	11.53	14.1

Table V. Comparisons of product A in 2006 and 2007 profit of the company, because the amount of products completed depends on the amount of the products that have gone through the bottlenecks. Bottlenecks could be reduced by increasing machinery to the backed up stages of work and at times moving employees to deal with the backlogs in the bottlenecks.

Conclusions

The indicators consist of four different parts: order book analysis, outcome, time and managerial analysis. The SC was measured with the help of order book analysis. The volume of orders was analyzed and two customer cases were selected. Through these customer cases, cost-efficiency of the SC was measured. With the help of order book analysis it is possible to obtain an overview of the volume of orders, production volumes and on time delivery of the case production plant. It is easy to generalize as an indicator in various SCs. The indicator can be utilized regardless of the branch of industry or production plant in analyzing the SC of manufacturing production.

In measuring the SC, cost-efficiency is defined as the costs of the products to be manufactured on the basis of measured production times as well as machine hour rates. A cost-efficiency indicator was used to measure the costs allocated to the order of the whole SC of the largest customer of the case production plant during two different periods of time. The results obtained when measuring cost-efficiency were reliable and they could be utilized very well.

The SC was measured from the point of view of time during two different periods of time by measuring lead-times and production times of orders as well as the ratio of production times and lead-times. Also on time delivery measurements are related to time. Furthermore, on time delivery was reviewed from two different periods of time. Time lays a foundation also for measuring cost-efficiency, because the basis is measuring costs according to machine hour rates and time spent in different stages of work. According to recognized academic Goldratt, the most essential indicator of the SC is lead-time.

Managerial analysis is an analysis by persons involved in the SC or people monitoring the effectiveness of SCM from outside. In managerial analysis measurement the aim is to draw conclusions regarding the entire SC and avoid partial optimization. The analysis concentrated also on rationalizing capacity management of the production plant.

Framework as a tool for practical SC measurements

In the study, a performance measurement framework was created for the needs of manufacturing industry. This series of indicators is a tool for managers whose work is related to SC development. There has been a demand for indicators for the SC. The foundation of development is recognizing the present state. According to it, goals to required development must be set. The usability of the tool was tested in the measurements in practice. The indicators proved to be very usable for measuring the case SC and the framework could be used for measuring various SCs in manufacturing industry. The tool can be applied to various SCs but it has to be tailored by considering any special features of a chain.

Indicators for SC performance measurement were tested in practice at a typical company that manufactures pre-fabricated products. This very much narrows the chasm between theory and practice. The measurements in practice were conducted by the researcher and managers involved in the SC. The set of indicators established on the basis of theoretical frame of reference was transformed to a practical tool. According to interviews as well as the feedback received, the indicators serve managers at the practical level extremely well when they are managing and developing the SC.

Reliability and validity of the study

Reliability is about demonstrating that the operations of a study – such as the data collection procedures – can be repeated, with the same results, by another researcher, and it thus aims at minimizing errors and bias during the research process (Yin, 2009). Using case study method the same result can be found by another researcher. It is more common to get a more holistic approach for research case by using case study method.

Construct validity could be measured as the use of multiple sources of evidence and was measured in this study by interviewing the specialists at various organizational levels who are involved in the SC. In this study, various data collection methods were used. The methods include interviews, documents, questionnaire, observations and measuring time. Use of multiple investigators was carried out by making specialists participate in conducting measurements and analyzing the data. One of the research quality measures is to establish a chain of evidence between research questions, evidence and conclusion, and respondent review of draft case description. In the study, a theoretical framework of reference for SCM and performance measurement was determined. Furthermore, a series of indicators was established in the case SC. Also practical knowledge of the topic affected establishing indicators. Research follows a research protocol and scientific reasoning.

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Appendix

Author	Framework/performance measures/performance measurement system	Category of measure
Beamon (1999)	Resources, output and flexibility	QN
Holmberg (2000)	Performance model with system perspective, cost, speed and customer service level, agility	C, A, Q
Suwignjo *et al.*(2000)	Quantitative model	QN
Gunasekaran *et al.* (2001)	Strategic, operational and tactical focus	QN, QL
Stephens (2001)	Measures based on process	C,R, QN
De Toni and Tonchia (2001)	Cost and non-cost	C, NF
Hieber (2002)	Supply chain collaboration efficiency; coordination efficiency and configuration	Q, QN
Chan (2003)	Cost, quality, resource utilization, flexibility, visibility, trust and innovativeness	C, Q, QN, F, A
Chan and Qi (2003a, b)	Input, output and composite measures, processes of supply chain	QN, QL
Chunhua *et al.*	Quality, cost, delivery and flexibility perspective performance measures at department, enterprise and supply chain level	C, Q, QN, F, A
Felix *et al.*	Innovative Performance Measurement Method	Q, QN, QL
Stefan Tangen	Financial, time-based measures, non-cost	C, T, NF
Changrui *et al.*	Active performance management system	QN, QL
Archie Lockamy III, Kevin McCormack	SCOR model	QN
David *et al.*	Relationship between productions run lengths and overall supply chain performance	QN, Q
Schonsleben	Quality, cost, delivery and flexibility	Q, C, D, F
Gunasekaran *et al.* (2005)	Framework for measuring costs and performance	C, NF
Li *et al.* (2005)	Strategic supplier partnership, CRM, information sharing, quality, internal lean practices and postponement	QL,QN, Q, C
Liwen Wu and Yutao Song	Finance, business processes, customer, environment, core enterprise ability	C, QN
Fynes *et al.* (2005)	Quality, framework incorporating dimensions of SC relationships and quality performance	Q, QN
Digalwar and Metri	Theoretical framework for the performance measures of World Class Manufacturing	QN, Q, C
MAO Zhaofang *et al.*	Supporting evaluation level(HITS – hu111man, institution, technology, surroundings) and operational evaluation level (TQFS – time, quality, finance and service)	QL, T, Q, C
Li *et al.* (2007)	Supply chain performance measurement approach which evaluates a supply chain from both structural and operational levels	QN, C, Q
Ren (2008)	Supply Chain Performance Measurement Based on SCOR Model	QN

Notes: Q, Quality; C, cost; D, delivery; F, flexibility; A, agility; R, responsiveness; NF, non-financial; QL, qualitative; QN, quantitative

Sources: Chan and Qi (2003a, b), Gunasekaran *et al.* (2001), De Toni and Tonchia (2001), Tangen (2004), Beamon (1999), Ramaa *et al.* (2009), Holmberg (2000), Suwignjo *et al.* (2000), Gunasekaran *et al.* (2005), Gunasekaran and Kobu (2007), Stephens (2001), Hieber (2002), Lockamy and McCormack (2004), Li *et al.* (2005), Fynes *et al.* (2005), Li *et al.* (2007), Ren (2008), Chan and Qi (2003a, b)

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