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Ilkka Sillanpää

SUPPLY CHAIN PERFORMANCE MEASUREMENT IN THE MANU-FACTURING INDUSTRY

A SINGLE CASE STUDY RESEARCH TO DEVELOP A SUPPLY CHAIN PERFORMANCE MEASUREMENT FRAMEWORK

*UNIVERSITY OF OULU,
FACULTY OF TECHNOLOGY,
DEPARTMENT OF INDUSTRIAL ENGINEERING AND MANAGEMENT*

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SUPPLY CHAIN PERFORMANCE MEASUREMENT IN THE MANUFACTURING INDUSTRY

A single case study research to develop a supply chain performance measurement framework

Academic dissertation to be presented with the assent of the Faculty of Technology of the University of Oulu for public defence in OP-sali (Auditorium L10), Linnanmaa, on 15 January 2011, at 12 noon

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Abstract

Supply chain performance measurement – the process of qualifying the efficiency and effectiveness of the supply chain. The aim of this study is to create a supply chain measurement framework for manufacturing industry, define what data should be measured and verify the measurement framework in the case company's supply chain. The research approach is hermeneutic and the research was a qualitative, constructive single case study research. The case company operates in the steel industry and provides prefabricated products for customers. The case supply chain was defined to be one supply chain in a plant where prefabricated products are produced.

There is a review of the current understanding of supply chain management and literature related to supply chain performance measurement and the study creates a framework for supply chain measurement. This study presents the main theory framework of supply chain 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 supply chain performance. The measurement framework is a valid framework for supply chain performance measurement in manufacturing industry.

It is stated that supply chain performance measurement is extremely important in developing supply chain. The measurement framework in this study offers guidelines for measuring the supply chain in manufacturing industry but the measurement framework could be used in different areas of industry as well.

Keywords: manufacturing industry, supply chain management, supply chain performance measurement

Acknowledgements

I started my mechanical engineering studies in the Department of Mechanical Engineering in University of Oulu in September 2001. I had taken my matriculation exam the previous spring and applied to University of Oulu. It was the start of a new and extremely interesting period in my life. I was engrossed by student life and its activities with various events during my first year at the university. After my first year I did my military service and returned home in June 2003 as a reservist second lieutenant. That year was especially motivating for my studies. In 2006, I graduated as M.Sc. in Technology. After graduating, I still felt myself thirsty for knowledge and my feelings were conflicting. I had studied mechanical engineering as well as industrial engineering and management but nevertheless it felt as if I did not know anything. At that time I decided to continue with my studies so that someday I could feel that I had mastered one field well.

Professor Pekka Kess inspired me to continue with my studies at the department of Industrial Engineering and Management. The topic for my doctoral studies was already clear at the time. I had completed a diploma thesis on supply chain management. It had increased my interest in the topic and I therefore wanted to continue to further study in this area. After graduating I directly entered working life. Then, as a 23-year-old recently-graduated engineer I knew that combining doctoral studies and working life was going to be extremely challenging. So I set myself a goal to complete my doctoral thesis before I turned 50. When I decided to begin my doctoral studies I had no idea what I was getting myself into. Since then, I marvel at being so open-minded about this extremely large job. If I had any idea about the number of hours I was going to spend doing this, I would certainly have thought twice about doctoral studies.

My studies started very slowly. I did the first courses only after a couple of years of starting the studies. Before that I was doing research whenever my schedule allowed it. My first complete shock took place when my tutor, Professor Kess, only incidentally alluded to the fact that the study was to be written in English. Afterwards, with the pain already behind me, I am reminded of the saying: ”what doesn’t kill you makes you stronger”. As a side effect, I gained some supplementary education in English language when writing the thesis.

First of all, I would like to give my special thanks to my tutor, Professor Pekka Kess, who has been the best mentor of all. Furthermore, he has been open-minded and, above all, down-to-earth when sparring with me in my studies. I would also like to thank the Pre-examiners Professor Timo Pirttilä from the Lappeenranta University of Technology and Dr Kris Law from The Hong Kong Polytechnic University. As one significant interest group, I want to thank all of my colleagues and my employer who have been contributing my study. Furthermore, I want to thank Tiina Talvitie and Alan Pembshaw for language consulting and for guiding me in how to write research text in English. Last, but not least, I also want to thank all of my close friends and family for the support that you have given me during this project.

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Abbreviations

ABM	Activity Based Management
AHP	Analytic Hierarchy Process
ATO	Assemble To Order
BPR	Business Process Reengineering
BSC	Balanced ScoreCard
DTO	Design To Order
IEM	Industrial Engineering and Management
JIT	Just In Time
LT	Lean Thinking
MTO	Manufacture To Order
MTS	Manufacture To Stock
OPP	Order Penetration Point
SC	Supply Chain
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference model
TOC	Theory Of constraints
TQC	Total Quality Control
TQM	Total Quality Management
VMI	Vendor Managed Inventory
VOP	Value Offering Point

Contents

1 Introduction

This chapter is an introduction to reviewing problems in the field of production. The basis of the research, the research problem as well as the researcher's rapport with the study are being reviewed. In the chapter, the case aggregate studied is described and defined. Furthermore, research goals are stated. Scientific paradigms and research methods chosen are reviewed. Finally, the structure of the dissertation is described.

1.1 Background

Niiniluoto defines science as the systematic pursuit of new knowledge, covering general truths and regularities of nature, humans and society. Science can be divided into basic sciences and applied sciences. Basic sciences include such fields as physics, chemistry and biology. Such sciences as engineering sciences, agricultural and forestry sciences are applied sciences. (Niiniluoto 1997) Industrial Engineering and Management (IEM) is positioned as an applied science. IEM is a science that combines economics and technical sciences. The goal is to produce additional value for business as well as to develop production processes. One major research subject of IEM is industrial economics. Research in industrial economics focuses on planning, developing and managing production systems. Supply chain management (SCM) and the subject of this study, measuring supply chain management, are placed in the field of research in industrial economics.

This study has been conducted for the Department of Industrial Engineering and Management within the Faculty of Technology at the University of Oulu. Measuring the supply chain (SC) of a certain production plant in the steel industry seen to be a research problem. The problem often occurs in the manufacturing industry. In this environment the problem has hardly been studied at all. The field of research is new and the findings from the study will be filling the void in measuring the SC in manufacturing industry.

The problem became concrete in 2006, when the researcher completed a diploma thesis regarding SCM in a case company. Research for the diploma thesis provided a chance to study SCM and to measure SC performance. After qualifying as Master of Science in Technology, the researcher's responsibilities have included middle management functions in SCM in a consolidated corporation in the steel industry. Along with these tasks the researcher's understanding of managing the SC of an international consolidated corporation has increased. However, at the same time, several research problems have arisen. In particular, measuring the 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 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.

1.2 Case description

With regards to the size and population of Finland, the steel and metal industry is a significant field in Finnish society. The steel industry directly employs tens of thousands of employees. Furthermore, the steel industry employs through its networks a significant number of employees indirectly. In proportion to the size of the country, revenue from the steel and metal industry is significant. The steel industry has established itself in Finland very firmly with support from the state. After the Second World War, during the era of reconstruction, the state established the steel industry very systematically. Afterwards, stockholdings of the state in the established companies has decreased and companies have been quoted on the stock market.

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. Due to competing markets and moderate costs, Finnish steel and metal industry has, during the decades, developed a network. In the network assignments have been distributed among companies according to how specialized the manufacturers are in manufacturing certain products. Specializing in core business as well as eliminating non-core functions have been the measures taken to maintain competitiveness. Non-core functions have been outsourced and bought from such companies that are specialized in producing given products or services as their core business. When focusing 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.

Due to the pressure on costs in the steel and metal industries, the significance of SCM has been emphasized more and more. Furthermore, networking has increased the need for SCM. A company in the steel or metal industry that manufactures end products has to be able to control the entire SC in the most efficient way to maintain competitiveness. There were important changes in the culture of networking especially from the beginning of the 1990's, when even core business functions were outsourced in the IT sector. Culture changed and it was more and more adopted also in the steel and metal industries.

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 is Rautaruukki Oyj. Rautaruukki 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 supply chain 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 supply chain 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.

1.3 Research problem

SCM has been studied a great deal in the industrial economics field of research. Researchers of SCM as well as the public have been interested in the published studies related to improving cost efficiency, optimizing the whole SC, production control, stock management, agility, lean SCM and SC integration. There are only a few studies of performance measurement in supply chain management in this field of research.

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 presents framework with the metrics of SC performance. The framework consists of a table where in the left column there are four SC activities / processes: plan, source, make/assembly and deliver. On the top of the table there are strategic, tactical and operational management perspectives. (Gunasekaran *et al.* 2001)

Gunasekaran *et al.* (2001) state that there should be several kinds of measures used in performance metrics: balanced approach, strategic, tactical and operational levels and financial as well as non-financial measures. SCM could be measured at various management or operation levels. Strategic level measures influence top management decisions and also very often reflects investigation of broad based policies and level of adherence to organisational goals. The tactical level deals with resource allocation and measuring performance against targets to be met in order to achieve results specified at the strategic level. At the Operational level, metrics are relevant for day to day business. The main metrics are time related and non-financial metrics. (Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2004)

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 & Gunter 2006)

De Toni and Tonchia (2001) present several indicators of internal and external time measurement. These time measures presented are called time performance. Time-based indicators were used in the research and the results in order of superiority are: Time-to-market, distribution lead-times, delivery reliability, supplying lead-times, supplier delivery reliability, manufacturing lead-times, standard run times, actual run times, wait times, set-up times, move times, inventory turnover, order carrying-out times and flexibility. Time performances are divided into external and internal times. Internal times can be split into run and set-up times on the one hand and wait and move times on the other. Externally-perceived time performances can be divided in three parts: system times (including supplying, manufacturing and distribution lead-times), delivery speed and delivery reliability (both from suppliers and to customers) and time-to-market (or time required to develop a new product). (Toni & Tonchia 2001)

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 (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. (Bhagwat & Sharma 2007b, Chan 2003a). Chan and Qi (2003) present an innovative performance measurement method. The aim is to build up a measurement team whose members should be from different organizations. SCM should be measured beyond the organizational boundaries rather than focusing on one organization only. SCM can be categorized into six general processes which are linked together: supplier, inbound logistics, manufacturing, outbound logistics, marketing and sales and end customers. Each main process can be decomposed into sub-processes and performance is measured in a process based manner. (Chan & Qi 2003b)

Process based approaches are cost, time, capacity, capability, productivity, utilization, and outcome. Cost is the financial expense for carrying out one event or activity. It is always one of the indispensable aspects in assessing the performance of the business activities and processes. Time is an important resource in modern business environments. Capacity is the ability of one specific activity to fulfil a task or perform a required function. Capability is a talent or ability of one activity to be used. In capability measures there are effectiveness, reliability, availability, and flexibility measures. Productivity is the rate at which a specific event or activity adds value at the cost of resources. Utilization stands for the utilizing rate of the resources to carry out one specific activity. Outcome is the results of or value added to one specific activity and event. (Chan & Qi 2003a)

Theeranuphattana (2008) states that the 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 & Tang 2008)

Kaplan and Norton (1992) present a balanced scorecard (BSC) model for evaluating corporate performance in four types of approaches: the financial, the internal business process, the customer as well as learning and growth. The name of this concept comes from keeping score of a set of items that maintain a balance between short term and long term objectives, between financial and non-financial measures, and between internal and external performance perspectives. BSC's have two main approaches: customer perspective, which is value-adding view and financial perspective, which is the shareholders' view. The approach mission of the customer perspectives is to achieve vision by delivering value to customers. It is also an internal perspective (process-based view) and its aim is to promote efficiency and effectiveness in the business process. The mission of financial perspective is to succeed financially, by delivering value to the shareholders and to achieve the vision, by sustaining innovation and change capabilities, through continuous improvement and preparation for future challenges. This approach has also a learning as well as a growth perspective in the future view. (Bhagwat & Sharma 2007b, Kaplan & Norton 1993, Kaplan & Norton 1996, Kaplan & Norton 1992, Kaplan 1996, Neely *et al.* 1995)

Few dissertations or equivalent studies related to SCM have been conducted in the case area. It is also remarkable that no dissertation dealing with this case problem has been published. Salo (2006) studied business relationship digitalisation in steel industry (Salo 2006). Iskanius (2006) has been modelling information flows in project-based deliveries from the perspective of agility in the SC (Iskanius 2006). Helaakoski (2007) has studied technology in information sharing and networking (Helaakoski 2007). Uusipaavalniemi (2009) presents a framework for analysing and developing information integration within the steel industry service SC (Uusipaavalniemi 2009). In addition, few dissertations have been written in the field of SCM regarding other branches of industry. Collin (2002) studies how to select the right SC for a customer in project-oriented business in the mobile communication infrastructure industry (Collin 2002). Lehtinen (2001) focuses on the factors affecting the evolution of subcontracting in SC decisions in the metal and electronics industries between 1980 and 2000 (Lehtinen 2001). Heikkilä (2000) and Kaski (2002) have developed Demand Chain Management in the cellular networks industry (Heikkilä 2000, Kaski 2002). Lehtonen (1999) focuses on SCM in process industry (Lehtonen 1999). Kämäräinen (2004), Punakivi (2003) and Yrjölä (2003) study SCM in the e-grocery industry (Kämäräinen 2004, Punakivi 2003, Yrjölä 2003). Holma (2006) studies SCM in the saw-mill industry (Holma 2006). Huiskonen (2006) presents several SC integration studies (Huiskonen 2004.). SmåRos (2005) studies research information sharing and forecasting (Småros 2005). Research areas of Appleqvist (2005) are operations strategy and demand chain management (Appelqvist 2005). Dissertation topic of Breite (2003) is Managing Supply and Value Chains in a Dynamic Business Environment (Breite 2003). Helo (2001) has focused on how to manage agility in electronics industry (Helo 2001.).

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 supply chain performance measurement in manufacturing industry.

The research problem is presented as a question:

(R1) How to measure supply chain performance in manufacturing industry?

Research tasks to answer the question are:

(RT1) How can the performance of the supply chain be measured?

(RT2) With which indicators can the performance of the supply chain in the manufacturing industry be measured?

(RT3) How do the indicators selected represent the supply chain?

The purpose of the first research task (RT1) is to become acquainted with the literature as well as the latest studies regarding SCM and supply chain management performance measurement. With the help of the second research task (RT2), indicators for the SC of the manufacturing industry are developed. The aim of the third research task (RT3) is to find out how the indicators developed represent the SC of the case company and how suitable they are to measuring it.

1.4 Scientific paradigms

Modern world view or all-round education does not include only knowing the most significant output of science, but also an understanding of the processes and methods of research with which this output has been achieved. This requirement does not only apply to scientists but also to all of those who are to utilize the results of the studies. It can be therefore defined that philosophy of science stands for applying philosophical method to science, research and to its results. (Niiniluoto 1997)

In philosophy, the aim is to raise problems in order to challenge or problematize various models, established ways of thinking and premises that are taken for granted. Another aim in philosophy is considered to be explication (a.k.a. making clear) of incoherent, ambiguous or implicitly assimilated views. Thirdly, argumentation is highlighted. In other words, views assimilated as a result of explication are evaluated for validity by searching for justifications or counterexamples for them. (Niiniluoto 1997)

Burrel *et al.* (1998) as well as Järvinen *et al.* (2004) highlight philosophical paradigms of science and through them draw attention to ontology, epistemology, methodology and the idea of man (Burrell & Morgan 1998, Järvinen & Järvinen 2004). Ontology studies hypotheses concerning the phenomenon under review (Järvinen & Järvinen 2004). Ontology pursues ”What exists?” Reality can be reviewed in a nominalistic manner or in a realistic manner. In a nominalistic system, the existence of only one kind of individual is required whereas in a realistic system firmer commitments can be made, say, in addition to individual animals, species of animals consisting of these individual animals can be assumed. Epistemology is a theory of information, a doctrine of concept of information. According to the classic definition of information, information is well-justified true belief. When realistic information theories are concerned, the existence of focus of information is expected to be independent of aware subject, a.k.a. the focus of information is”reality” (Niiniluoto 1997). Epistemology concerns the nature of scientific knowledge that is produced from a phenomenon by means of research. Methodology studies research methods (Burrell & Morgan 1979, Järvinen & Järvinen 2004, Niiniluoto 1997).

Science signifies, on the one hand, the systematic entirety of information regarding nature, human and society. On the other hand it signifies purposeful and systematic pursuit of this kind of information. According to Niiniluoto (1997), the theory consists of a number of laws that structure the empirical regularities regarding an area of phenomena. A theory should have both explanatory and predictive power: it explains previously observed regularities and predicts validity of the new ones. (Niiniluoto 1997)

According to Niiniluoto (1997), philosophy of science refers to applying philosophical method to science, research and to its results. Philosophy of science builds itself around three basic functions: problematizing routines of thinking and premises that are taken for granted, explication a.k.a. clarifying of incoherent, ambiguous or implicitly adopted views and, third, evaluating views resulting from argumentation a.k.a. explication by justifying or searching for counter examples. (Niiniluoto 1997)

1.5 Case study research

Case study research is one of the most widely used methods in industrial economics. Although the method is commonly used in industrial economics, case study research can be regarded as a highly challenging method of research. With the help of the method it is possible to explain complex social events, like organizational processes and problems of an industry. Case study research is used widely in various sciences because the functionality of its methodology is not restricted to only certain sciences. (Yin 2009) Orientation to practice, democracy, striving towards change as well as subjects’ participation in the research process are characteristics of functional research (Kuula 2001).

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 endeavour 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 behaviour, but only in describing a situation. The aim of explanatory research is to explain causal relations between phenomena and testing related hypotheses. (Yin 2009)

Action research can even be regarded as an undisciplined approach since in action research it is possible, without limits, to use all possible methods that participants find suitable at a time (Kuula 2001). Since action research, nevertheless, has to be defined as a separate type of research, it can be regarded as belonging to qualitative methods. Case study research is used in various fields. The cases studied may be, among others, organizations, incidents, individuals and lines of business. Case study research can be, by its nature, descriptive, deductive (a.k.a. testing a theory) or inductive (creating a theory). (Järvinen & Järvinen 2004)

Case study research is begun by preparing a research plan. A research plan consists of five different divisions: research problem, argument, subject of the analysis, logic and criteria. Research problem, with regards to case study research, is well formed when it answers to questions *how* and *why*. With help of the argument, the study can be directed exactly to the fact which the research questions must provide an answer to. The focus of the analysis discusses the subject being studied: the case. Logic pools the data of case study research. With regards to logic, it is possible to review the current, existing models or to create a connection between empirical data and the argument. Criteria represent the criteria used for analyzing the data. In addition to authoring a research plan, a frame of reference that discusses the topic has to be created. (Yin 2009)

Case research method may include one case or several cases to be studied. Studying an individual case is an appropriate method when the theory is tested using a given case, when a unique or typical case is studied, when such case that has previously been impossible to study is studied or when a long-term case is studied. An individual case may contain several focuses to be studied. What is regarded as an advantage of individual case is the fact that the method is suitable for studying unique and long-term focuses. Furthermore, an individual case study can be carried out in short time with small amount of resources. What is challenging is the fact that since the study concerns only one case, there is only a small amount of adequate research material. Due to this, the focus of the study requires a very thorough justification for selecting a specific case. (Yin 2009) According to Järvinen (2004), case study research has been criticized for the fact that it is not possible to make generalizations on the basis of a single case study. However, results of a case study can be generalized if similar cases with similar type of characteristics are compared in the same contexts. (Järvinen & Järvinen 2004) Problems in generalization occur mostly when studying an individual case (Yin 2009).

In case study research, the data can be collected using various means. Six most used and most important means to obtain data for a case study are the following: documents, archives, interviews, direct observations, participatory observations and items / devices (Yin 2009). In case study research, the researcher has an opportunity to change or even add data collection methods during the study (Eisenhardt 1989). Using various sources of information prepares the way for a more convincing and accurate final result of a study. One of the strengths of case study research is indeed the fact that various sources of information can be used in the same study. To increase the reliability of a study the researcher has to be able to formulate a chain of evidence. (Yin 2009)

Questionnaires, interviews, observation and usage of material from archives are methods used for collecting data. The data to be collected can therefore be quantitative, qualitative or both. The purpose of a study protocol is to improve reliability of the study and direct the research process. The plan to be prepared for a case study includes the following sections: overview of the project, instructions for fieldwork, central questions and instruction for writing the research report.

Through these sections it is possible to discover problems that are specified in separate paragraphs. (Järvinen & Järvinen 2004)

There are three commonly used strategies for analyzing data: theoretical presentations, competing presentations and creating a description of the case. The most popular strategy in analyzing data is to trace the theoretical statements that altogether led to studying the case. The underlying goals as well as planning and implementation of the whole study are often largely based on statements and questions from existing theories. The goal of the second analytic strategy is to define and test competitive explanations. The third popular analytic strategy is to create a descriptive outline, a frame for the study. The case and its analysis are built around this outline. Regardless of the strategy, the data is analyzed with help of an analytic technique. Analytic techniques include pattern matching, explanation building, time series analysis, logical model and cross-case synthesis. (Yin 2009)

Problems in case study research are related to theory formulation, generalization of the results, deficiencies in scientific discipline, data collection methods and reliability of the results. Theory can remain too insufficient if the researcher does not know his or her field of research well enough or if he or she is prejudiced against items. On the other hand, a theory can also easily become too complicated. Findings of an individual case cannot always be generalized as scientific laws. Furthermore, researcher has an opportunity to screen his or her data during the study which questions scientific discipline. There is a great deal of social interaction related to data collection methods. It may affect the opinions of the study subjects as well as researcher's biases towards the study subjects. (Yin 2009)

1.6 Research approach for this study

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 & 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 & 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 & Grønhaug 2005)

Arbnor (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 & 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, Labro & Tuomela 2003, Lukka 2000) According to Kasanen (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 analysed. (Kasanen *et al.* 1993)

The constructive approach refers to a problem-solving approach for producing innovative constructs intended to solve problems through constructing a model and making a contribution to the theory of science in which it is applied. Constructs tend to create a new reality by producing solutions to explicit managerial problems. The constructive approach produces innovative constructs. According to Kasanen (1993) constructs can vary from simple models, plans, and diagrams, to complex management systems, to manifestos of new ways of approaching and carrying out activities in organizations. Constructive research project has to produce a new solution to the problem in question; otherwise there is no point in going on with the research. (Kasanen *et al.* 1993)

Accrding to Kasanen (1993) it is a characteristic of constructive research that the researcher's empirical approach is explicit and strong. A constructive study is thus experimental. Development and implementation of the new construct should be regarded as a test instrument. The constructive research approach is based on the belief that by a profound analysis of what works in practice it is possible to make a significant contribution. According to Kasanen (1993), in constructive research, the empirical work is typically quite strongly geared towards achieving this part of the potential contribution. In addition to the attempt to design new constructs and test their functioning, a constructive research project is an arena for both applying and developing the existing theoretical knowledge about the structural features and process emerging from the case. (Kasanen *et al.* 1993)

According to Kasanen *et al.* (1993), Lukka (2000), Labro and Tuomela (2003), there are seven crucial steps in the constructive research approach (Kasanen *et al.* 1993, Labro & Tuomela 2003, Lukka 2000):

- to find a practically relevant problem, which also has research potential
- to examine the potential for long-term research co-operation with the target organisation
- to obtain a general and comprehensive understanding of the topic
- to innovate and construct a theoretically grounded solution idea
- to implement the solution and test whether it works in practice
- to examine the scope of the solution's applicability
- to show the theoretical connections and the research contribution of the solution.

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.

The study is carried out as a case study research. The study includes one case which is delimited to measuring a given SC. The research question has been defined according to case study research to answer especially the question *how*. (Yin 2009) The research problem is presented as a question: (R1) How to measure SC performance in manufacturing industry? Research tasks to answer the question are: (RT1) How can the performance of the supply chain be measured? (RT2) With which indicators the performance of the supply chain in the manufacturing industry can be measured? (RT3) How do the indicators selected represent the supply chain? The study is a very practical one and the case study research method suits excellently for carrying it out.

Table 1. The main methodological choices in this study.

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

1.7 Research design of the study

Research design is the logic that links the data to be collected and conclusions. After a relevant research problem was found, the first research process was the literature research of the SCM and SC performance measurement. Literature research was made in order to increase the knowledge regarding SC and performance measurement. The research problem was formed from the real-life challenges and based on this the research question as well as the tasks related to the study were developed. Furthermore, the plan for answering the research questions was made. The research questions and the plan for answering those are presented as following:

(R1) How to measure supply chain performance in manufacturing industry?

(RT1) How can the performance of the supply chain be measured?

– Definition of SCM and SC performance measurement
– Literature research
– Main theories in SCM and SC performance measurement to be presented

(RT2) With which indicators the performance of the supply chain in the manufacturing industry can be measured?

– Case SC presentation and process chart models
– Developing measurement indicators / framework according to literature review and case SC

(RT3) How do the indicators selected represent the supply chain?

– Measuring case SC according to developed measurement framework and measurement indicator
– Analysing measurement framework
– Verifying that measurement framework is usable for the case SC

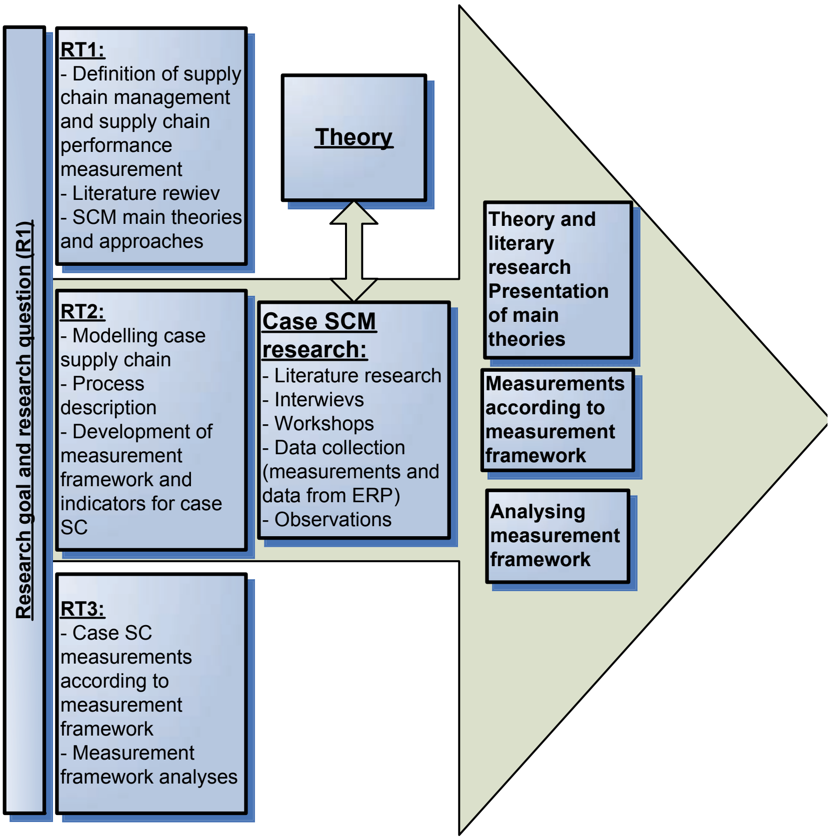

Fig. 1. Research design of the study.

The case SC research was carried out together with theory matching. In this research empirical data was collected during the years 2006–2009. Data collection method consisted mainly of interviews, workshops, collecting data from ERP systems, observations and measurements in case SC. It was a great advantage that the researcher was working at the case company and therefore data collection from different sources was possible. Research started with literature review and first data collection in 2006. Data was collected from ERP systems, several interviews and workshops. Furthermore, the first measurements in case SC were carried out. After the first literature review, the measurements theory and empirical studies were compared and analyzed. Analysis of the first measurements was carried out at the end of 2006 and the beginning of 2007. Also the second measurement phase was started. Data was collected with same methods: ERP systems, several interviews, workshops and measurements in the case SC. After the second measurements and data collecting it was time for theory matching and analysis of the results. In 2008, the pre-results of the research were obtained. Those were analysed and verified in 2008–2009. The third measurement phase was ongoing during 2006–2009. The third measurement was mainly focused on interviews and observations. In that measurement period the target was to verify previous measurements.

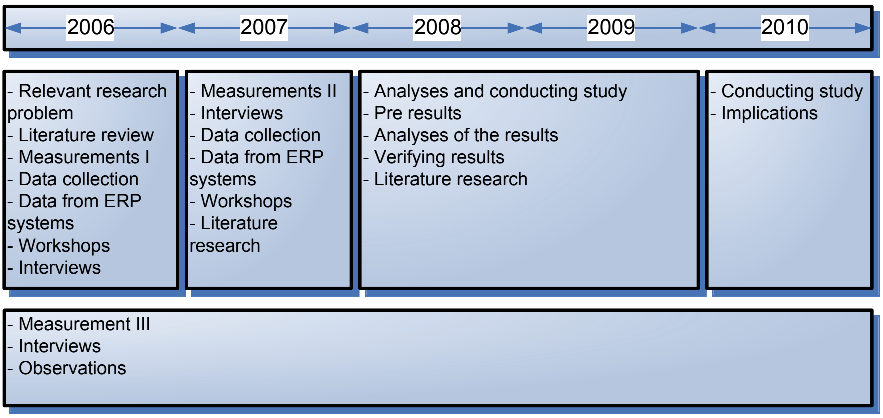

Fig. 2. Data collecting during 2006–2010.

Finally, the results of the research provided answers to the research questions:

(R1) How to measure supply chain performance in manufacturing industry?

(RT1) How can the performance of the supply chain be measured?

– Theory and literary research
– Presentation of main theories: SCM and SC performance measurement

(RT2) With which indicators can the performance of the supply chain in the manufacturing industry be measured?

– Case SC performance measurement framework

(RT3) How do the indicators selected represent the supply chain?

– Measurements according the measurement framework
– Analysis of the measurement developed framework

1.8 Structure of the thesis

The study consists of five chapters. In chapter one, background for the study, SC frame of reference as well as necessity of measuring the SC, the challenges in measuring it and research problems are discussed. The case is described and delimited. Furthermore, how the case company and the case production plant are linked to the steel and metal industries is discussed. The research problem and research question as well as the tasks are presented. Research methods as well as research paradigms are presented, selected and justified. Finally, structure of the study is presented.

In chapter two, the primary approach for SC performance measurement is presented. SCM is defined on the basis of published conclusions of various researchers. The chapter also presents new movements of SCM: agility and lean SCM. SC performance measurement approaches are presented by referring to most central publications by leading researchers. Furthermore, challenges for SC performance measurement are analyzed and, finally, conclusion of SC performance measurement is made. In the chapter, the research task RT1 is answered.

In chapter three, indicators for the SC of the case company are established. To establish the indicators, Finnish engineering industry is discussed. The supply chain of the case company is modelled and various stages of the SC are described thoroughly. In the chapter, the research task RT2 is answered. Finally, on basis of the case description and the theoretic frame of reference SCM performance measurement in the case company is established.

Chapter four discusses how SC performance measurement in the case company is conducted on the basis of measurement system established in the previous chapter. The measurements are conducted with help of indicators selected. Usability of the indicators is analyzed and conclusions regarding functionality of the measurement system are made. In the chapter, the research task RT3 is answered.

Chapter five presents the conclusions of this thesis as well as the theoretical and practical contributions of this research. The chapter evaluates the validity and reliability of the study. Finally, the chapter provides recommendations for future research.

2 Supply chain 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 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. Research shows that there are many approaches which have been developed in the past decades. This research introduces main approaches for SC performance measurement. The research focus is to present SC performance measurement in the 1990's and 2000's. SC performance measurement is one of the core elements of developing SCM and therefore supply chain performance measurement should follow the corporate strategy.

2.1 Supply chain management

In the field of research of industrial economics, new business environment development and management approaches, concepts and methods have been introduced during the decades. SCM pulls together these business concepts and approaches from various decades. Approaches such as these are, among others, Just in Time (JIT), Total Quality Control (TQC), Total Quality Management (TQM), Lean Thinking (LT), Time-Based Management (TBM), Lean, Activity Based Management (ABM) and Business Process Reengineering (BPR) (Laamanen & Tinnilä 2002).

Concepts can be divided into quality-based approaches, time-based approaches and combinations of these. First time-based trends of SCM can be perceived in JIT production philosophy in the 1970's. Products of the right quality manufactured JIT is the general understanding regarding JIT philosophy. Furthermore, JIT has been understood as minimizing stocks, but also as a more extensive executive philosophy. Qualitative management philosophies TQC and TQM date back to 1970's and 1980's. TQM is a business philosophy that seeks to encourage both individual and collective responsibility in seeking quality at every stage of the production process from initial design and conception to after sales service. TQC is an operational strategy to continually and incrementally change and improve every aspect of operational components: equipment, procedures, skills, throughput time, quality, supplier relationships, products, service design, etc. (Krajewski & Ritzman 2002, Krajewski *et al.* 2007)

LT and TBM were management concepts of the 1980's. The focus of LT has essentially been on elimination of waste. The upsurge of interest in lean manufacturing can be traced to Toyota Production Systems with its focus on reduction and elimination of waste. (Christopher & Towill 2001) TBM seeks to reduce the time needed in taking a product from development to delivery to the customer along a SC. The purpose is to decrease time spent in all of the processes such as lead-times, developments times, waiting times, set-up times and bottlenecks. (Stalk & Hout 1990)

ABM and BPR were released in the 1990's. ABM focuses on the management of activities as a way to increase customer value and profit. ABM includes cost driver analysis, activity analysis and performance measurement. (Plowman 2001) BPR was introduced as a management concept of the critical analysis and radical redesign of existing business processes to achieve breakthrough improvements. BPR is fundamental reconsideration and radical redesign of organizational processes in order to achieve cost reduction and improved efficiency and effectiveness like cost, service and speed. (Iskanius 2006)

Supply chain management (SCM) is a management concept of the 2000's. It includes divisions from the management concepts of the 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 Supply Chain Forum is generally accepted as a norm (Cooper *et al.* 1997, Lambert *et al.* 1998):

> *"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"*

Christopher uses the terms "supply network" or "supply web" to describe the net-structure of most of the SC's. He emphasizes the network-nature of his SC definition (Christopher 1998):

> *"Supply chain is a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer".*

2.1.1 Definitions of supply chain management

SCM business concept has been a famous topic for many IEM researchers. Each researcher has several ways to define SCM. SC is described as a chain linking each element from customer and supplier through manufacturing and services so that the flow of material, money and information can be effectively managed to meet the business requirement.(Stevens 1989)

Aitiken (2005) defines SCM as following (Aitken *et al.* 2005):

> *The supply chain is defined as the network of connected and interdependent organizations that work together to enable the flow of products into markets, whereas a "pipeline" is defined as the specific operational mechanisms and procedures that are employed to service specific product/market contexts.*

SCM emphasises both the overall and long-term benefit for all parties in the SC through co-operation and information sharing. Simchi-Levi *et al.* (2004) define SCM as (Simchi-levi *et al.* 2004):

> *A set of approaches used to efficiently integrate suppliers, manufacturers, warehouses and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimize system-wide costs while satisfying service-level requirements.*

SCM is generally considered to involve integration, coordination and collaboration across organisations and throughout the supply chain (Stank *et al.* 2001).

Nayron (1999) defines supply chain as following (Ben Naylor *et al.* 1999):

> *A supply chain is a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via a feed forward flow of materials and feedback flow of information.*

SCM has been defined as "the integration of key business processes from end user through original suppliers that provides products, services, and information that adds value for customers and other stakeholders". SCM theory clearly addresses the limitations in improving demand chain performance through the transfer of demand information when lead-times are long. (de Treville *et al.* 2004)

SCM is the design of the firm's customer relationship, order fulfilment and supplier relationship processes and the synchronization of these processes of its suppliers and customers in order to match the flow of services, materials and

information with customer demand. The purpose of SCM is to design the SC and to synchronize the key processes of the firm's suppliers and customers, so as to match the flow of services, materials and information with customer demand. (Krajewski *et al.* 2007)
The term SC is used to describe the flow of goods from the very first process encountered in the production of a product right through to the final sale to the end consumer. SCM can be used to describe a number of concepts in the processes inside a manufacturing organisation; purchasing and supply management occurring within dyadic relationships; the total chain; and finally, a total firm network. (Bruce *et al.* 2004)

A good working definition of a SC is that described by Stevens (Stevens 1989):

> *A system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feedforward flow of materials and the feedback flow of information.*

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

> *"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."*

Supply Chain Council (2005) defined that there are four basic processes in the SC: plan, source, delivery and return. Plan refers to processes that balance aggregate demand and delivery requirements. Sources are processes that transform product to a finished state to meet planned or actual demand. Delivery is a process in which the finished goods are delivered to a customer. Return is defined as processes associated with returning or receiving returned products. (Iskanius 2006, Supply Chain Council 2005)

The combination of processes of several companies and customer's processes is called the SC. Management of SC's is called Supply Chain Management a.k.a. SCM. SCM is a substantially more extensive concept than logistics. SCM is defined as management of upstream and downstream business relationships together with suppliers and customers. SCM aims at producing large customer value with smaller total costs for the whole SC. (Christopher 1998)

SCM encompasses co-operation of various functions between suppliers and customers. Most essential divisions of SCM are those of managing business relations and managing customers. Actual competition takes place along the whole SC when companies involved in the SC have the prerequisites for competitive operations. From the point of view of the SC, moving the orders upstream or downstream does not make the aggregate more competitive. Costs are divided – with respect to the whole SC – by the price requested from the client. Logistics cannot be replaced with help of SCM, but both of the philosophies – logistics and SCM – need to be discussed in tandem with each other. (Christopher 1998)

A network of companies to which interdependent organizations have linked up can be regarded as a SC. Organizations co-operate in order to control, manage and improve material and information flows from suppliers to end users. A supply chain is described as a chain that creates products or services and forwards them from suppliers to customers. In reality, a SC is not a separate chain. Therefore, a supply network would be more appropriate term to describe a SC. The network consists of company's partners as well as various suppliers and clients. Also customers of the customers are part of the network that a company builds around it. (Christopher 1998)

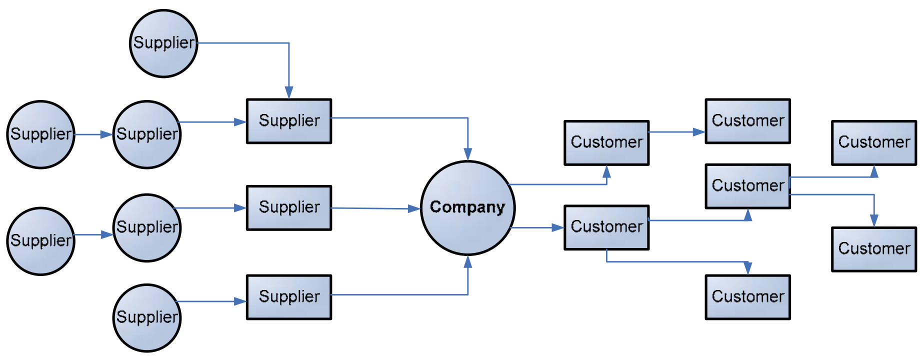

Fig. 3. Delivery network.

Data systems are used as a link to incorporate the function of a SC. Data systems enable functioning of SC and delivery process. The function of data systems is to share information to all various participants in the SC. One of the company success factors is the skill to use data systems in an efficient manner in activities including various organizations. One of the main goals of SCM is to decrease or remove the stocks in the chain. This is often carried out by sharing information regarding demand and stock levels with help of data systems. (Christopher 1998)

2.1.2 Supply chain integration

Integration of the SC is generally described as co-operation between various functions. SC integration implies process integration like supplier collaboration, common information systems and shared information. (Christopher 1998, Paulraj *et al.* 2006) There are key processes that can be integrated across the SC: customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement and product development. In some cases it is even sufficient to integrate only one process. (Lambert *et al.* 1998)

According to Pagell (2004), SC integration can be defined as (Pagell 2004):

> *a process of interaction and collaboration in which companies in a supply chain work together in a cooperative manner to achieve mutually acceptable outcomes*

SC integration can also be defined as (e.g. (Bowersox *et al.* 1999, Frohlich & Westbrook 2001, Zhao *et al.* 2008),:

> *the degree to which an organisation strategically collaborates with its partners and manages intra- and inter-organisational processes in order to achieve efficient and effective flows of products, services, information, money and decisions*

According to Treville (2004), supply integration includes JIT delivery, reduction of the supplier base, evaluating suppliers based on quality and delivery performance, establishing long-term contracts with suppliers, and eliminating paperwork. Demand integration includes increased access to demand information throughout the SC to permit rapid and efficient delivery, coordinated planning, and improved logistics communication. Supply integration is integration that supports the efficient manufacture and delivery of goods. Demand integration stands for integration that supports market mediation with the primary role of demand integration being transfer of demand information to facilitate greater responsiveness to changing customer needs. (de Treville *et al.* 2004)

Stevens (1989) identifies four stages of SC integration (Stevens 1989):

- *Baseline.* Fragmented operations within an individual company. Planning very short term, almost reactive.
- *Functional integration.* Limited integration between adjacent functions. Focusing on the inward flow of goods. Poor visibility of real customer demand.
- *Internal integration.* Involves integrating the aspects of the SC that are directly under the control of the company.
- *External integration.* The scope of integration is extended outside the company to embrace suppliers and customers.

The definition of SC integration best acknowledged by its researchers is the following (Christopher 1998, Lambert *et al.* 1998):

Supply chain integration is process integration upstream and downstream in the supply chain

Lee (2000) divides SC integration into three dimensions: information integration, coordination as well as resource sharing and organisational relationship linkage. Thus, three main aspects in integration seem to be information integration, organisational or relationship integration and process integration. (Lee 2000)

2.1.3 Theory of constraints

Theory of constraints (TOC) is a system based assumption which assumes that every organization or production line has at least one constraint. The aim of TOC is to maximize profit by making use of the factor which is limiting the process more and more efficiently. TOC is maximizing throughput while minimizing operating expenses for labour, sales and administration. The first step to start utilizing TOC is to find out the constraining factor. Usually constraint is in a one operation unit in the production line. Constraint could be also the limited time of one or a few key employees. When the constraining factor has been identified, management should examine how the capacity of constraint could be increased. (Bushong & Talbott 1999)

Krajewski *et al.* state that one way to redesign a process is to analyse capacity of the process. Capacity is the maximum rate of output for a process. Capacity plans are usually made on two levels, one being the long term capacity plan and other the short term capacity plan. Capacity can be measured by output measures and input measures. One interesting way to measure capacity is utilization. Utilization is the extent to which equipment, space or labour is currently being used. Bottleneck is an operation that has the lowest capacity of a given operation in the process and thus limits the systems output. TOC is an approach for management that focuses on whatever impedes progress toward the goal of maximizing the flow of total value-added funds or sales less discounts and variable costs. Bottleneck is in the process, but a constraint can be anywhere in the SC. (Krajewski *et al.* 2007)

The basis of constraint philosophy is a company's goal to make profit so that it can meet the expectations of all interest groups in a satisfactory manner. Factors related to business and production are reviewed from the point of view of business economics. Constraint philosophy includes company's business and product management. The fundamental goal of a company is to show a profit. Success is measured by a company's net profit, profit of invested capital and with help of cash flow. These key figures improve at the same time as business develops. Constraint philosophy has extended to a doctrine of management for production and a whole company. (Goldratt & Cox 1992)

The term "constraint" stands for factors that limit gaining of money. These factors may be situated in production or in support functions of productions. A constraint can develop to production if the materials do not reach the warehouse in time or if a company has deficiencies in materials. A constraint that is located in production is called a bottleneck. In a bottleneck, the capacity of a stage of work does not meet the capacity required in the next stage of work. Interferences and delays accumulate in a completely balanced production line. One can try to improve capacity management by storing products as buffer stocks between each stage of a production line. However, storing will often cost more than obtaining extra capacity to the bottleneck. (Gustafsson *et al.* 1988)

The determining indicators of constraint philosophy are, according to Goldratt (Goldratt & Cox 1992):

- Flow-through is the pace with which the system produces money from products sold.
- Warehouse is all the money that the system has invested in buying all material that is to be sold.
- Manufacturing costs is all the money that production system uses in order to convert the material into products.

Goldratt (1992), the author of the constraint philosophy, determines the goal of constraint philosophy as following (Goldratt & Cox 1992):

> *The goal of a company is to increase net profit by increasing simultaneously both profit of invested capital and cash flow, which, altogether, means making money.*

A constraint sets the pace for the whole production line. It also defines the pace with which products can be manufactured from the production line. The time lost due to a constraint can never be reclaimed. Therefore constraints should be monitored and used in a more effective manner. Possible interruption of production in the constraint has a direct effect on the profit of the company. Undisturbed functioning in the constraint is sought to be secured with help of buffer stocks. Buffer stocks in between other stages of work can be regarded as unnecessary because they only increase internal effectiveness. These stocks do not have an effect on the material flow that passes through the whole company and neither does it affect productivity of a company. The time saved in other stages of work does not affect the productivity of a company; it is the constraint that defines it. (Goldratt & Cox 1992)

Goldratt (1992) and Krajewski (2007) list five measures to be carried out when developing constraint philosophy (Goldratt & Cox 1992, Krajewski *et al.* 2007):

- Identify the constraint or constraints in the system.
- Decide how to rationalize their utilization in order to the best possible benefit to be obtained.
- Subordinate all other activities to the decision mentioned above.
- Widen the constraints in the system.
- If the constraint has been widened, return to the item 1 but do not let slowness in changes cause a new constraint.

According to constraint philosophy, a company’s flow-through is measured in money on basis of actual sales. Variable and fixed costs are regarded as equal and they are included in operating costs. Indicators of constraint philosophy are used to rationalize usage of existing resources. The aim of production is to at the same time manufacture more complete products for sale, to function with low costs and with help of small stocks. Production of a company may not necessarily be effective as a whole even if efficiency rates for individual machines might be high.

Profitability of a company improves when all the indicators improve in parallel. (Gustafsson *et al.* 1988)

2.1.4 Order penetration point and Decoupling point

In order oriented production, production receives starting impulse from the customer's order. The product is manufactured according to the customer's requirements. Order Penetration Point (OPP) is the point in a company's logistics chain where the product is marked to be delivered to a specific customer. OPP divides production into upstream and downstream. In OPP upstream the stocks are managed on the basis of prognoses in stock-oriented manner. After OPP – that is to say in downstream – the flow is directed by the order from the client. The delay the customer experiences in lead-time is the time spent from after the order to delivery. Pull-oriented production is based on prognoses regarding orders from customers on the basis of which production is started. Variation in size of the stock is due to erroneous prognoses regarding the orders from customers. Suction-oriented production is based on actual demand. With help of suction oriented production it is possible to regulate the size of stocks. Combination of suction and pull-oriented production can effectively minimize the variation in incomplete production. Determining the place of directing point depends on characteristics of production and the product. (Christopher 1998) OPP is the stage in the production line from where production is on order. Production in front of the OPP is for general purpose and based on forecast while every part produced or assembled behind the OPP is dedicated to a customer. (Andries & Gelders 1995)

OPP can be located to various places in the order stage of work. When designing to an order (Design to Order, DTO), production is started in a project-based manner. When manufacturing to an order (Manufacture to Order, MTO), raw materials, materials and capacity are timed and allocated with help of product-specific information, and one is able to deliver the product within the delivery time specified in the order. This way, tailored products can be manufactured, although the time spent in order increases and effectiveness of process worsens when amount of variation increases. When assembling to an order (Assemble to Order, ATO) material is obtained in order-oriented manner. This way, end product stock can be eliminated. When manufacturing to stock (Manufacture to Stock, MTS), the delivery can be quickly taken care of when the manufacturer has warehouses for the products. (Christopher 1998, Mason-Jones & Towill 1999)

Krajewski *et al.* (2007) present three production and inventory strategies: Make-to-stock, assemble-to-order and make-to-order. These inventory strategies should be coordinated with process choice. Make-to-stock strategy involves holding items in stock for immediate delivery, thereby minimizing customer delivery times. Assemble-to-order strategy is for producing a wide variety of products from relatively few assemblies and components after the customer orders are received. Make-to-order strategy is used by manufacturers that make products to customer specifications in low volumes. (Krajewski *et al.* 2007)

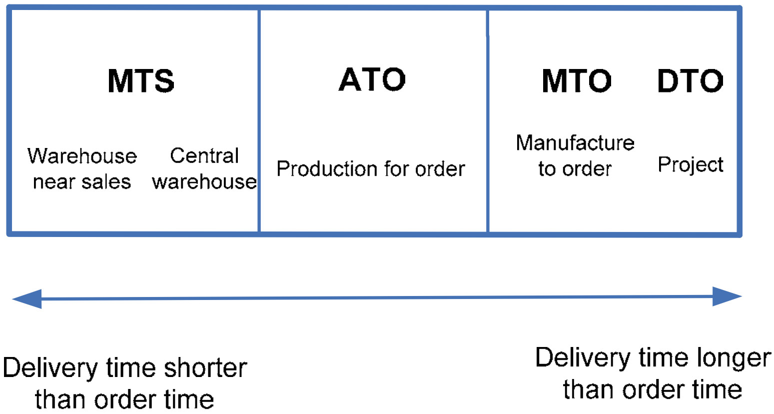

Fig. 4. Production and inventory strategies.

Value Offering Point (VOP) is a certain point in the customer's demand chain. At this point the supplier meets the demand of the customer. VOP can be located in three different places in the demand chain. Usually, VOP is located in the purchasing department when the supplier can see the demand from orders. In Vendor Managed Inventory (VMI) the supplier takes care of the customer's stock functions. By following the usage of stock the supplier can meet the demand with notably lower costs than in ordinary order procedure. The supplier sees to it that no stock deficiency for products of large consumption is created. VOP can be located also in production. Then the supplier can avoid manufacturing products which do not meet customer's needs. In its most customer-oriented option, VOP has been transferred all the way to the customer. (Hoover *et al.* 2001)

The decoupling point is the position in the material pipeline where the product flow changes from push to pull mode. It should therefore also correspond to the Demand Penetration Point, the point in the product axis to which the customer's order penetrates. It is a point where order driven and forecast driven activities meet. The material decoupling point acts as a buffer between upstream and downstream players in the SC. This enables upstream players to be protected from fluctuating consumer buying behaviour and therefore establishing smoother upstream dynamics while downstream consumer demand is still met via a product pull from the buffer stock. According to Mason-Jones, the decoupling point separates the part of the SC that responds directly to the customer from the part of the SC that uses forward planning and a strategic stock to buffer against the variability in the demand of the SC. Positioning of the decoupling point therefore depends on the longest lead-time an end-user is prepared to accept and the point at which variability in product demand dominates. (Mason-Jones & Towill 1999)

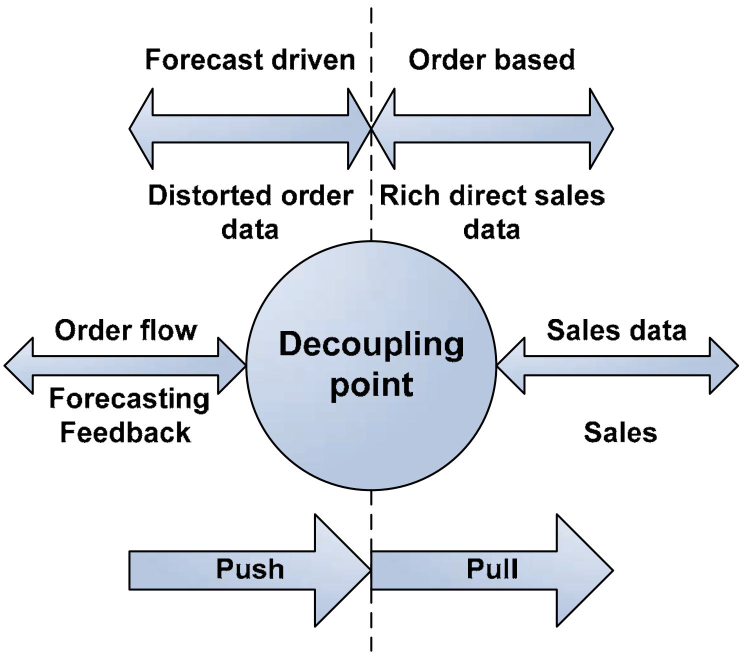

Fig. 5. Material decoupling point.

The decoupling point is the point in the chain at which inventory is held to permit an upstream focus on efficient supply and a downstream focus on market mediation. (Ben Naylor *et al.* 1999) The decoupling point separates the part of the SC geared towards directly satisfying customer orders from the part of the SC based on planning. The decoupling point is also the point at which strategic stock is held as a buffer between fluctuating customer orders and/or product variety and smooth production output. Positioning of the decoupling point is also associated with the issue of postponement which increases the efficiency as well as the effectiveness of the SC. This is achieved by moving product differentiation (at the decoupling point) closer to the end user. (Mason-Jones *et al.* 2000)

The lean approach can be applied to the SC upstream of the decoupling point as the demand is smooth and standard products flow through a number of value streams. The agile paradigm must be applied downstream from the decoupling point as demand is variable and the product variety per value stream has increased. (Mason-Jones & Towill 1999)

2.2 Agility

A division of SCM, agility, is regarded as a trend of the 2000's, even though it has its roots at the beginning of the 1990's. The roots of agility are based on time based competition and LT philosophies. On the whole, in literature Agility is regarded as flexibility.

Preiss (2005) defines agility as following (Preiss 2005):

> *Agility is a comprehensive response to the business challenges of profiting from rapidly changing, continually fragmenting, global markets for high-quality, high-performance, customer-configured goods and services. It is dynamic, context-specific, aggressively change-embracing, and growth-oriented. Agility is a comprehensive response to new competitive forces that have undermined the dominance of a mass production system.*

Due to the diverseness of Preiss' definition it is hard to accept agility as so wide a concept. According to Goldman (1995), the definition is notably simpler (Goldman *et al.* 1995):

> *Agility is the ability of an enterprise to quickly respond to changes in an uncertain and changing environment.*

Aitiken (2005) defines agility as following (Aitken *et al.* 2005):

> *Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes and, in particular, mindsets. A key characteristic of an agile organization is flexibility.*

Christopher (2000) presents the most relevant definition of agility (Christopher 2000):

> *Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets. A key characteristic of an agile organization is flexibility. Agility might, therefore, be defined as the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety.*

Also Harrison and van Hoek (2008) emphasize the extended enterprise nature of the concept by defining agility (Harrison & Van Hoek 2008) as following:

> *Agility is a supply-chain-wide capability that aligns organizational structures, information systems, logistics processes and, in particular, mindsets.*

Kidd (2000) defined agility as following (Kidd 2000):

> *Agility is the ability of an enterprise to change and reconfigure the internal and external parts of the enterprise – strategies, organization, technologies, people, partners, suppliers, distributors, and even customers in response to change unpredictable events and uncertainty in the business environment.*

Agility is often used as a synonym of Lean. According to Christopher, Agility is not like Lean, because Lean is defined as doing more with less. In real life, many of those companies who use lean as a production philosophy are anything but agility. Agility is a valid philosophy when variety is high and volume is low. Lean is usable in the opposite kind of situation, that is, when variety is low and volume is high. (Christopher 2000)

According to Christopher, the idea of agility in the context of SCM focuses around responsiveness. Conventional SC's have been lengthy with long lead-times and they have been forecast-driven. Agile SC's are shorter and seek to be demand-driven. A further distinction is that because conventional SC's are forecast-driven, it implies that they are inventory-based. Agile SC's are more likely to be information-based. (Christopher *et al.* 2004)

Specifically the agile SC is (Christopher *et al.* 2004):

- Market sensitive – it is closely connected to end-user trends.
- Virtual – it relies on shared information across all SC partners.
- Network-based – it gains flexibility by using the strengths of specialist players.

– Process aligned – it has a high degree of process inter-connectivity between the network members.

According to Christopher, market sensitive agile SC means that the SC is capable of reading real demand and responding to it. The use of information technology to share data between buyers and suppliers is a *virtual* SC. Virtual SC's are information-based rather than inventory-based. Process integration agile SC means collaborative working between buyers and suppliers, joint product development, common systems and shared information. Network agile SC means that partners are linked together as a network. (Christopher 2000)

2.3 Lean Supply Chain Management

The focus of the lean approach has essentially been on the elimination of waste. As stated before, the upsurge of interest in lean manufacturing can be traced to the Toyota Production Systems with its focus on the reduction and elimination of waste. Lean concepts work well in such companies where demand is relatively stable and hence predictable and where variety is low. (Christopher & Towill 2001)

Agarwal (2006) presents new approach to lean as following (Agarwal *et al.* 2006):

> *Lean is about doing more with less. Lean concepts work well where demand is relatively stable and hence predictable and where variety is low. Conversely, in those contexts where demand is volatile and the customer requirement for variety is high, a much higher level of agility is required. Leanness may be an element of agility in certain circumstances, but it will not enable the organization to meet the precise needs of the customers more rapidly.*

According to Naylor, leanness means developing a value stream to eliminate all waste – including time – and to ensure a level schedule. The focus of lean supply management is elimination of all waste, including time, to enable a level schedule to be established. (Ben Naylor *et al.* 1999)

Despite the presence of lean manufacturing facilities in the SC where throughput times were being dramatically reduced, customers would still experience significant delays in delivery of their orders. (Bruce *et al.* 2004) In a lean manufacturing environment demand should be smooth, leading to a level schedule. The level schedule is a pre-requisite for the elimination of all waste. By eliminating waste, businesses will maximise their profit through minimising their physical costs. Combining agility and leanness in one SC via the strategic use of a decoupling point has been termed leagility (the combination of the lean and agile paradigm). (Mason-Jones *et al.* 2000)

According to Christopher, lean and agile are not mutually exclusive paradigms and may be paired to advantage in a number of different ways. Difference between leanness and agility in terms of the customer is that service level is the critical factor calling for agility whilst cost, and hence the sales price, are clearly linked to leanness. Whereas quality, service level, and lead-time are market qualifiers for lean supply, with the market winner then being cost, the latter benchmark is merely an important qualifier in agile supply. (Christopher & Towill 2001)

According to Christopher one of the more interesting debates in recent years concerning SC strategy has concentrated on the relative merits of lean and agile philosophies. Lean concepts work well there, where demand is relatively stable and hence predictable and where variety is low. Agility is concerned primarily with responsiveness. It is about the ability to match supply and demand in turbulent and unpredictable markets. In essence, it is about being demand-driven rather than forecast-driven. Agility is a business-wide capability that embraces organisational structures, logistics processes and, in particular, mind-sets. A key characteristic of an agile organisation is flexibility. The origins of agility as a business concept lie in flexible manufacturing systems. (Christopher *et al.* 2006)

Leagility is a combination of the lean and agile paradigm within a total SC strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the decoupling point. Through exploitation of the volatility of the marketplace agile businesses will strive to maximize their profitability. (Mason-Jones *et al.* 2000)

The need for agility and leanness depends upon the total SC strategy, particularly considering market knowledge and positioning of the de-coupling point. Combining agility and leanness in one SC has been termed le-agility. (Ben Naylor *et al.* 1999) Leagility is the combination of the lean and agile paradigms within a total SC strategy by positioning the decoupling point as the need for responding to a volatile demand downstream yet providing level scheduling upstream from the market place (Hoek 2001).

SC's would combine both lean and agile principles to ensure the highest level of market responsiveness combined with low cost and efficient processes. The particular value stream configuration in which upstream processes are lean and are then followed by downstream agile processes has been termed league. (Ben Naylor *et al.* 1999) In upstream, lean processes enable a low cost and a low risk SC while the downstream process is managed by agility and high levels of customer responsiveness. There are a small number of performance criteria which constitute of market qualifiers and order winners. These criteria are: price, quality, delivery lead-time, and reliability. Different SC strategies may be required. When the key requirement is short lead-times, the focus is clearly on agility. In Agility, quality and reliability could be the market qualifiers. When price is the criterion for winning orders, then quality and reliability could be the market qualifiers. (Aitken *et al.* 2005)

Agility will be used downstream and leanness upstream from the decoupling point in the SC. League is cost effectiveness of the upstream chain and high service levels in the downstream chain. Quality, service level and lead-time are market qualifiers for lean supply. When the market winner is cost, the latter benchmark is a qualifier in agile supply. Agility and leanness require high levels of product quality. They also require minimum total lead-time. The total lead-time has to be minimised to enable agility, as the demand is highly volatile and thus fast moving. If a SC has a long lead-time it will not be able to respond quickly to demand. Lead-time needs to be minimised in lean manufacturing, because in lean definition time is waste and leanness tries to eliminate all waste. The difference between leanness and agility in providing total value to the customer is that service is the critical factor for agility whilst cost and sales price, are crucial for leanness. (Mason-Jones *et al.* 2000)

According to Mason-Jones (2000) Lean/Agile supply distinguishing attributes are (Mason-Jones *et al.* 2000):

- typical products: commodities/fashion goods
- marketplace demand: predictable/volatile
- product variety: low/high
- product life cycle: long/short
- customer drivers: cost/availability
- profit margins: low/high
- dominant costs: physical costs/marketability costs
- stock out penalties: long-term contractual/immediate and volatile

- purchasing policy: buy goods/assign capacity
- information enrichment: high desirable/obligatory
- forecasting mechanism: algorithmic/consultative.

The aim of leanness is cost reduction with total waste removal. Agility requires design for total flexibility. Agility and lean approaches will maximise the profits of the two parts of the SC. Leanness will maximise profits through cost reduction and by providing suitable service. Agility maximizes profit through providing what the customer requires and reducing costs. The leagile SC enables the upstream part of the chain to be cost-effective and the downstream part to achieve high service levels in a volatile marketplace. (Mason-Jones *et al.* 2000)

2.4 Performance measurement in supply chain 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 & Tuttle 1989)

Performance measurement can be defined as the process of qualifying the efficiency and effectiveness of action. A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action. (Neely *et al.* 1995) SC performance measures should be linked with strategies. (Holmberg 2000, Lambert & Pohlen 2001, Morgan 2004, Neely *et al.* 2000b) According to Chan (2003), performance measurement is supposed to contribute much more to business management and performance improvement in industry. Performance measurement provides the necessary information for management feedback for decision makers. Performance measurement provides an approach to identifying the success and potential of management strategies, and facilitating the understanding of the situation. It assists in directing management attention, revising company goals, and re-engineering business processes. Performance measurement is helpful in the improvement of SCM. (Chan 2003a)

SC Performance Measurement is a system that provides a formal definition of SC performance model based on mutually agreed upon goals, measures, measurement methods that specify procedures, responsibilities and accountability of SC participants and the regulation of the measurement system by SC participants. (Eccles & Pyburn 1992, Holmberg 2000)

Many firms are adopting strategic performance measurement systems that provide information that allows the firm to identify the strategies offering the highest potential for achieving the firm's objectives, and align management processes, such as target setting, decision-making, and performance evaluation, with the achievement of the chosen strategic objectives. Ittner (2003) argues that strategic performance measures must be aligned with the firm's strategy and/or value drivers. Under this approach, performance is theoretically enhanced when "measurement gaps" between the firm's strategic priorities and measurement practices are minimized. Performance is expected to be lower when the strategic performance measurement system places either less or more emphasis on a measurement practice than the level required by the firm's strategy and value drivers. (Ittner *et al.* 2003)

According to Hervani (2005), corporate performance measurement continues to grow and encompass both quantitative and qualitative measurements and approaches. The variety of performance measures depends greatly on the goal of the organization or the individual strategic business unit's characteristics. Companies must consider existing financial measures such as return on investment, profitability, market share and revenue growth at a more competitive and strategic level when measuring performance. Other measures like customer service and inventory performance are more operationally focused, but may necessarily be linked to strategic level measures and issues. (Hervani *et al.* 2005)

Performance measurement system may be unique to each individual organization, reflecting its fundamental purpose and its environment. Performance measurement systems may have either tangible or intangible measures with a balance of both types used to measure performance (Hervani *et al.* 2005):

- Measures should be dynamic and present at multiple levels.
- Products and processes need to be included.
- Systems and measures are best developed with a team approach with derivation from and links to corporate strategy.
- Systems must have effective internal and external communications.
- Accountability for results must be clearly assigned and it must be understood.
- Systems must provide intelligence for decision makers and not merely compile data.
- System should be capable of linking compensation, rewards, and recognition to performance measurement.

Hervani (2005) states that performance measurement must evolve to performance management where the organization develops the appropriate organizational structure and the ability to use performance measurement results in order to actually bring about change in the organization. Elements of these efforts are central to total quality and continuous improvement programs, where performance measurement is critical to any organization in managing their operations. Performance measurement has many uses including the determination of the efficiency and effectiveness of an existing system or to comparing competing alternative systems. Performance measurement is typically used to plan, design, implement and monitor proposed systems. (Hervani *et al.* 2005)

According to Ghalayini (1996), performance measures have been primarily based on management accounting systems. This has resulted in most measures focusing on financial data. Ghalayini (1996) presents the eight most commonly cited limitations of traditional performance measures as well as traditional accounting system, which is the basis for traditional performance measures (Ghalayini & Noble 1996, Ghalayini *et al.* 1997) :

- Lagging metrics. Financial reports are usually closed monthly and this is why they are lagging metrics that are a result of past decisions. Managers consider financial reports too old to be useful for operational performance assessment.
- Corporate strategy. Traditional performance measures have not incorporated strategy. The objectives have rather been minimizing costs, increasing labour efficiency and machine utilization.
- Relevance to practice. Traditional performance measures aim at quantifying performance and other improvement efforts in financial terms.
- Inflexible. Traditional financial reports are inflexible in that they have a predetermined format which is used across all departments.
- Expensive. The preparation of traditional financial reports requires an extensive amount of data which is usually expensive to obtain.
- Continuous improvement. Setting standards for performance measures in general conflicts with continuous improvement.
- Customer requirements and management techniques. Traditional performance measures are no longer useful since in order to meet customer requirements of higher-quality products, shorter lead-time and lower cost management have given shop floor operators more responsibility and authority in their work.

Neely (1995) presents a performance measurement system that can be examined at three different levels (Neely *et al.* 1995):

- the individual performance measures
- the set of performance measures
- the performance measurement system as an entity
- the relationship between the performance measurement system and the environment within which it operates.

According Neely (1995), the system can be analysed by exploring issues such as (Neely *et al.* 1995):

- Have all the appropriate elements (internal, external, financial, nonfinancial) been covered?
- Have measures which relate to the rate of improvement been introduced?
- Have measures which relate to both the long- and short-term objectives of the business been introduced?
- Have the measures been integrated, both vertically and horizontally?
- Do any of the measures conflict with one another?

Finally, at the highest level, the system can be analysed by assessing (Neely *et al.* 1995):

- whether the measures reinforce the firm's strategies
- whether the measures match the organization's culture
- whether the measures are consistent with the existing recognition as well as reward structure
- whether some measures focus on customer satisfaction
- focus on the effects of competition.

Melnyk *et al.* (2004) present three basic functions provided by metrics: control, communication and improvement. Control means that metrics enable managers and workers to evaluate and control the performance of the resources. Metrics communicate performance for internal needs and external stakeholders' purposes. Well-designed and communicated metrics provide the user a sense of knowing what needs to be done. Improvement means that with metrics it is possible to identify gaps between performance and expectation and that is the way how to start development. (Melnyk *et al.* 2004) Successful performance measurement system could be a proactive guide for operations and strategic management.

(Bititci 1994) Factors for management's needs for managing the SC include (Lambert & Pohlen 2001):

- performance measurement across the entire SC
- the need to determine the interrelationship between corporate and SC performance
- the complexity of SCM
- the requirement to align activities and share joint performance measurement information to implement strategy that achieves SC objectives
- the requirement to allocate benefits and burdens resulting from functional shifts within the SC
- the need to differentiate the SC to obtain a competitive advantage
- the goal of cooperation between functions in the SC.

There are no metrics for measuring total SC performance and usually metrics have to be developed separately for each case. Research of SCM performance metrics is extremely important, because of SCM diversity, and in order to have many performance measurement approaches like financial, non-financial, qualitative and quantitative, plan, source, make, deliver, time, cost, quality, flexibility and operational approaches.

2.5 Historical approach for supply chain performance measurement

Over the last decade there have been numbers of articles where theory and practice of SCM have been studied. SCM performance or capability does not have so much consideration in the SCM research field. (Beamon 1999, Chan & Qi 2003b, Gunasekaran *et al.* 2001) Companies have realized that there is a huge potential in developing SCM. This is one reason for SCM capability measure metrics being needed. Measuring SCM capability is the most important way to start development work of the whole SCM.

According to Ghalayinin (1996), the literature concerning performance measurement has had two main phases. The first phase began in the late 1880's and went through the 1980's. In this phase the emphasis was on financial measures such as profit, return on investment and productivity. The second phase started in the late 1980's as a result of changes in the world market. Companies began to lose market share to overseas competitors who were able to provide higher-quality products with lower costs and more variety. To regain a competitive edge companies not only shifted their strategic priorities from low-cost production to quality, flexibility, short lead-time and dependable delivery, but also implemented new technologies and philosophies of production management. Traditional performance measures have many limitations and the development of new performance measurement systems is required for success. (Ghalayini & Noble 1996)

Morgan (2004) presents a history of performance measurement. The roots of performance measurement are in 15th century Venice, when accounting was founded with the invention of double entry book keeping. Double-entry book accounting measurement system was successful until the early 1900s. Concepts of performance measurement have been challenged by accounting professionals. Morgan divides traditional performance measures into four categories: financial, operations, marketing and quality. Financial measures are common measures like stock turnover, ROE, ROCE, current ratio, gross profit, gearing, etc. Those metrics are available after some time period, when the production action is already carried out. The problem of using financial metrics is that those are not relevant in day-to-day operations. Actually financial metrics are more useful at top management level, where the strategic decisions are made. Operations measures are operations lead-time, labour utility, set-up time, machine utility, process, etc. Metrics are useful for low level management who are dealing with day to day business. Marketing measures are market share, orders on hand, order lead-times, delivery performance, time to market etc. Quality measures are percentage of rework, rejects, conformance, scrap, liability costs and the kinds of measures that measure poor product quality. (Morgan 2004)

According to Ramaa (2009), the performance indicators first appeared in the form of the combination of financial and non- financial criterion. In the 19th century, the performance indicators were in the following forms: the cost per yard and the cost per metric ton. At the beginning of the 20th century, diversification and authorization have induced the reformation of performance measurement. DuPont company (1903) had executed the “rate of return on investment” to appraise the performance of different units and developed the “DuPont system scale”. After Second World War, the environment faced by enterprises was full of uncertainty and variation and it had to balance the relations of marketing, research and development, human resource and finance. Thus, different indicators including financial indicators and non-financial indicators emerged. (Ramaa *et al.* 2009)

In the 1990's, several researchers introduced SC performance measurements which are based on time and inventories. Levy introduces performance measures such as average finished goods inventory and demand fulfilment. (Levy 1995) Christopher presents SC performance measures such as order cycle time, order completeness and delivery reliability. (Christopher 1992) Delivery performance, lead-time, level of defects and responsiveness was Lambert's and Sharman's approach to SC performance measures. (Lambert & Sharma 1990) Cohen and Lee introduce material inventory, work in process inventory, finished goods inventory, fill rates, stock out frequencies and lead-time measures. (Cohen & Lee 1990) Davis presents inventory levels, inventory investment, order fill rate, line item fill rate and average number of day's late measures. (Davis 1993) Measures introduced by Lee and Billington are inventory turns, line item fill rate, order item fill rate, total order cycle time, total response time to an order, average backorder levels and average variability in delivery. (Lee & Billington 1992) Neely *et al.* introduce several ways for measuring SCM performance. Furthermore, other researchers introduce further approaches to performance measurement: the BSC (Kaplan & Norton 1992), the performance measurement matrix (Keegan *et al.* 1989), performance measurement questionnaires (Dixon 1990) and criteria for measurement system design (Globerson 1985). Neely *et al.* (1995), has been cited by many researchers of SCM measurement (Beamon 1999, Beamon & Chen 2001, Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2004). Neely states that performance measurement can be analyzed in three levels: the individual metrics, the set of measures or performance measurement system as an entity and, the relationship between the measurement system and the internal and external environment in which it operates. Capability can be measured by measuring the 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. (Neely *et al.* 1995, Shepherd & Gunter 2006)

In the 2000's, SCM performance measurement is presented using different approaches. Shepherd and Günther (2006) categorize SC performance measurement research into operational, design and strategic research. (Shepherd & Gunter 2006) Operational research develops mathematical models for improving SC performance. (Lin *et al.* 2005, Smith *et al.* 2005) Design research focuses on optimizing performance through redesigning the SC. (Shepherd & Gunter 2006) Design research can be categorized according to the type of research model: deterministic analytical models (Chen *et al.* 2005), stochastic analytical models (Chiang & Monahan 2005), economic models (Wu 2005) and simulation models (Hwarng *et al.* 2005, Reiner 2005). Strategic research evaluates how to align the SC with a firm's strategic objectives (Balasubramanian & Tewary 2005). Gunasekaran *et al.* state that there is a greater need to study the measures and metrics for the following reasons (Gunasekaran *et al.* 2001):

1. Lack of a balanced approach. Companies have realized the need for two types of measurement approach: financial and non-financial metrics. Financial measures and metrics are important for strategic decisions and external reporting whereas non-financial measures are extremely important for day-to-day ground level operations.
2. Lack of a clear distinction between metrics at strategic, tactical and operational levels. Metrics can be used in every level where it would be most appropriate. Different metrics are suitable for different levels and therefore it is difficult to find metrics which are valid for every management level.

2.6 Purposes of supply chain performance measurement

SCM has clearly gained a status in IEM sciences. SCM is difficult to measure, because it is such huge a concept. Van Hoek identifies the problem of measuring SCM in the research paper titled "Measuring the unmeasureable - measuring and improving performance in the supply chain management".(Hoek 1998) Researchers have clearly stated that SCM measurement is extremely complicated due to the fact that approach perspective to SCM has so many variations and different meanings. Measurement has been studied since the concept of SCM was founded. There are several extremely good researchers who have made a great deal of groundwork for base research of SCM capability and measuring SCM.

Why should the SC be measured? The main purpose is to get information for top management's needs, but also several kinds of SCM measures are needed at every management and operational level. SCM should be measured because of the management interest in measuring how efficient SCM is. Usually there are several kinds of interests and several management levels which are interested in knowing about SCM capability and performance. Measuring is also needed when SCM is going to be developed. Developing SCM needs a qualified measurement system for measuring SCM performance. Performance measurement systems play important role in manufacturing firms in operations and in business strategy implementation. Performance measurement system provides information for the monitoring, control, evaluation and feedback functions for operations management. It can be a driver for motivation, management action, continuous improvement and the achievement of strategic objectives. (De Waal 2003, Kaplan 1996, Lohman *et al.* 2004, Neely *et al.* 1994, Tapinos *et al.* 2005)

Gunasekaran (2004) as well as Gunasekaran and Kobu (2007) argue that the new era performance measurement metrics should (Gunasekaran *et al.* 2004, Gunasekaran & Kobu 2007):

- Truly capture the essence of organisational performance.
- Be based on company strategy and objectives.
- Reflect a balance between financial and non-financial measures.
- Relate to strategic, tactical and operational levels of decision making and control.
- Be comparable to other performance measures used by similar organisations.
- Clearly define the purpose, data collection and calculation methods, update and monitoring mechanisms and related procedures.
- Vary between organisational locations and be under control of the evaluated organisational unit.
- Allow setting targets, aggregation and disaggregation.
- Allow prioritisation/weighting.
- Facilitate integration.
- Avoid overlaps.
- Be able to handle complex overhead structures.
- Be simple and easy to use, preferably in the form of ratios rather than absolute numbers.
- Be specific and non-financial, rather than aggregate and financial, to be more actionable.
- Be determined through discussion with all the parties involved and serve the needs of people from all levels (not only upper management).
- Adopt a proactive approach, enabling fast feedback and continuous improvement.
- Be valid and reliable.
- Be coherent and transparent.
- Be experience based.
- Allow testing, reviewing, revising and refining, which involve organisational learning.
- Result in minimum number of indicators that provide reasonable accuracy with minimum cost.

- Be able to measure partnership, collaboration, and agility.

2.7 Designing performance measurement system

Ghalayini (1996) states that traditional performance measures have many limitations that make them less applicable in today's competitive market. Performance measures are based on outdated traditional cost management systems, lagging metrics, they are not related to corporate strategy, and they are inflexible and expensive and contradict continuous improvement. Various integrated performance measurement systems need to be developed. According to Ghalayini (1996), there is still a need for an integrated dynamic performance measurement system that has the following characteristics (Ghalayini & Noble 1996):

- a clearly defined set of improvement areas and associated performance measures that are related to company strategy and objectives
- stresses the role of time as a strategic performance measure
- allows dynamic updating of the improvement areas
- performance measures and performance measures standards
- links the areas of improvement and performance measurement to the factory shop floor
- is used as an improvement tool rather than just a monitoring and controlling tool
- considers process improvements efforts as a basic integrated part of the system
- utilizes any improvements in performance (i.e. going beyond just achieving improvement and actively planning for the utilization of benefits from an overall company perspective)
- uses historical data of the company to set improvement objectives and to help achieve such objectives
- guards against sub-optimization
- provides practical tools that could be used to achieve all of the above.

Purposes of a performance measurement system according to (Gunasekaran & Kobu 2007) are the following:

- identifying success
- identifying whether customer needs are met

- better understanding of processes
- identifying bottlenecks, waste, problems and improvement opportunities
- providing factual decisions
- enabling progress
- tracking progress
- facilitating a more open and transparent communication and co-operation.

Maskell (1992) presents seven principles of performance measurement system design (Maskell 1992):

- The measures should be directly related to the firm's manufacturing strategy.
- Non-financial measures should be adopted.
- It should be recognized that measures vary between locations – one measure is not suitable for all departments or sites.
- It should be acknowledged that measures change as circumstances do.
- The measures should be simple and easy to use.
- The measures should provide fast feedback.
- The measures should be designed so that they stimulate continuous improvement rather than simply monitor.

Wisner (1991) proposes nine-step "process" for developing a performance measurement system (Wisner & Fawcett 1991):

- Clearly define the firm's mission statement.
- Identify the firm's strategic objectives using the mission statement as a guide (profitability, market share, quality, cost, flexibility, dependability, and innovation).
- Develop an understanding of each functional area's role in achieving the various strategic objectives.
- For each functional area, develop global performance measures capable of defining the firm's overall competitive position to top management.
- Communicate strategic objectives and performance goals to lower levels in the organization. Establish more specific performance criteria at each level.
- Assure consistency with strategic objectives among the performance criteria used at each level.
- Assure the compatibility of performance measures used in all functional areas.
- Use the performance measurement system to identify competitive position, locate problem areas, assist the firm in updating strategic objectives and

making tactical decisions to achieve these objectives, and supply feedback after the decisions are implemented.

- Periodically re-evaluate the appropriateness of the established performance measurement system in view of the current competitive environment.

Thakkar (2009) recommends some features for the metrics used in SC performance measurement (Thakkar *et al.* 2009):

- measurement system should have the capability to capture the essence of organizational performance
- measurement system should ensure an appropriate assignment of metrics to the areas where they would be most appropriate
- minimum deviations should exist between the organizational goals and measurement goals
- metrics should reflect an adequate balance between financial and nonfinancial measures
- measures should reflect their clear linkages with various levels of decision making such as strategic, tactical, and operational level.

According to Thakkar (2009), SC performance measurement is a difficult proposition because it is affected by many aspects of the firm's operations and environment. The measurement should be understandable to all people involved in the SC and should offer minimum opportunity for manipulation. Thakkar (2009) presents metrics for SC performance measurement (Thakkar *et al.* 2009):

- Total SC cost. The cost of fulfilment as a percentage of revenues or cost of fulfilment per case ordered.
- Service level. This includes fill rate (availability- ratio of number of items ordered by customers and number of items delivered to customers), operational performance (in terms of average order cycle time, consistency of order cycle time and/or on-time deliveries. and service reliability (deals with accuracy of work in order entry, warehouse picking, document preparation, etc.).
- Asset management. Utilization of capital investments in facilities and equipment as well as working capital invested in inventory.
- Customer accommodation. This aims to capture measurement of perfect orders, absolute performance and customer satisfaction.
- Cash-to-cash cycle time. This is the time required to convert a dollar spent on inventory into a dollar collected from sales revenue.

- Benchmarking. It makes management aware of the state-of-the-art business practices. It may include internal benchmarking, competitor benchmarking and unrestricted benchmarking.

According to Brewer and Speh (2001), SC performance measurement tools and systems include the following (Brewer & Speh 2001) :

- Overcoming mistrust. Traditional SCM practices have been adversarial. Trust in data sharing, acquisition and monitoring needs to be built.
- Lack of understanding. Multi-organizational measures are difficult to understand for managers focused on internal systems.
- Lack of control. Managers and organizations wish to be evaluated on measures they can control. Inter-organizational measures are difficult to manage and thus control.
- Different goals and objectives. Different organizations have different goals and thus would argue for different measures.
- Information systems. Most corporate information systems are incapable of gathering non-traditional information relating to SC performance.
- Lack of standardized performance measures. Agreed upon measures in terms of units to use, structure, format, etc. may not exist.
- Difficulty in linking measures to customer value. Linkage to stakeholder value (expanding to environmental issues) is becoming more complex. With regards to internal customers, it may be difficult to define who is the customer when these internal customers are also part of the SC.
- Deciding where to begin. Developing SC-wide performance is difficult since it is not always clear where the boundaries exist in SCM.

The performance measurement system requires developing and reviewing at a number of different levels as the situation changes (Bourne *et al.* 2000):

- The performance measurement system should include an effective mechanism for reviewing and revising targets and standards (Ghalayini *et al.* 1997).
- The performance measurement system should include a process for developing individual measures such as performance and circumstances change (Dixon 1990).
- The performance measurement system should include a process for periodically reviewing and revising the complete set of measures in use. (Wisner & Fawcett 1991).

- The performance measurement system should be used to challenge the strategic assumptions (Bourne *et al.* 2000).

However, the integrated measurement systems have their limitations, which, according to Ghalayini (1996), are the following (Ghalayini & Noble 1996):

- They are mainly constructed as monitoring and controlling tools rather than improvement tools. Thus, they do not explicitly consider the integration of continuous improvement.
- They do not provide any mechanism for specifying which objective should be met in a specific time horizon.
- They are not dynamic systems. They do not allow any systematic revision of critical areas, performance measures, historical data, decisions and outcomes.
- They do not look ahead to predicting, achieving and improving future performance. They are only concerned with present performance.
- Although some of them stress the importance of global optimization versus local optimization, they do not provide any mechanism to achieve this, especially at the operational level.
- Most of these systems do not stress the importance of time as a strategic performance measure.
- None of the models provides a specific tool that could be used to model, control, monitor and improve the activities at the factory shop floor.

2.8 Supply chain management performance measurement approaches

2.8.1 Map model -framework

Lambert and Pohlen (2001) present a "map model"-framework for developing SCM performance metrics. The framework consists of seven steps to build up SCM performance framework (Lambert & Pohlen 2001):

1. Map the SC and identify where the key linkages exist.
2. Use the customer relationship management and supplier relationship management processes to analyze each link and determine where additional value can be created.
3. Develop customer and supplier profit and loss statements to assess the effect of the relationship on profitability and shareholder value of the two firms.

4. Realign SC processes and activities to achieve performance objectives.
5. Establish non-financial performance measures that align individual behaviour with SC process objectives and financial goals.
6. Compare shareholder value and market capitalization across firms with SC objectives and revise process and performance measures as necessary.
7. Replicate steps at each link in the SC.

2.8.2 Inventory, time, order fulfilment, quality, customer focus and customer satisfaction

Ramdas and Spekman (2000) present six approaches to measuring SC performance: inventory, time, order fulfilment, quality, customer focus and customer satisfaction. These approaches are defined as following: inventory means inventory levels, inventory turns and inventory costs. Time is defined as product-development time, time to market and time to break even. Order fulfilment captures the extent to which a SC partner affects order-processing time and shipment accuracy. Quality is seen as continuous improvement made by SC partners. Customer focus captures the extent to which a SC partner influences contribution margin, value added and customer value. Customer satisfaction means that a SC partner influences end customer satisfaction and account penetration. (Ramdas & Spekman 2000)

2.8.3 Six constructs approach

Li *et al.* (2005) identify six constructs of SCM practises: strategic supplier partnership, customer relationship, information sharing, information quality, internal lean practices and postponement. Strategic supplier partnership is a long-term relationship between an organization and its suppliers. It is designed to leverage the strategic and operational capabilities of individual participating organization to help it achieve significant ongoing benefits. Customer relationship includes managing customer complaints, building long-term relationships with customers and improving customer satisfaction. Close customer relationship is one device to differentiate from competitors and bring value to customers. Information sharing refers to the extent to which critical and proprietary information is communicated to one's SC partner. Information sharing is seen to be quite an important point in SCM research. Information quality refers to accuracy, timeliness, adequacy and credibility of information exchanged. This approach is connected very closely to information sharing. Sharing qualified information can lead to flexibility. Internal lean practices are the practices of eliminating waste in a manufacturing system. Waste is cost, tie, set-up times, small lot sizes and pull-production. LT and lean practices have become extremely important for effective SCM. Postponement means practice of moving forward one or more operations or activities to a much later point in the SC. In this context SCM activities include making, sourcing, delivering, time and postponement. (Li *et al.* 2005)

Li *et al.* (2005) identify performance outcomes as delivery dependability and time to market. Delivery reliability means capability of providing products to customer. Time to market means the time to introduce new products to market more quickly than competitors are able to do. (Li *et al.* 2005)

2.8.4 Process and management based metrics

Gunasekaran *et al.* (2001) present that SCM performance measures can be divided into financial and non-financial measures. In practical level there is a need for concentrating to operational measures instead of financial measures. Top management needs financial measures for management level decisions, but lower management and workers need operational measures for daily business. (Gunasekaran *et al.* 2004) Gunasekaran presents a framework with the metrics of SC performance. Framework consists of a table where in the left column there are four SC activities / processes: plan, source, make/assembly and deliver. On the top of the table there are strategic, tactical and operational management perspectives. (Gunasekaran *et al.* 2001)

- Metrics for planning: order entry method, order lead-time, the customer order path.
- Evaluation of supply link, evaluation of suppliers, strategic level measures, tactical level measures, operational level measures.
- Measures and metrics at production level: range of product and services, capacity utilization, effectiveness of scheduling techniques.
- Evaluation of delivery link, measures for delivery performance evaluation, total distribution cost.
- Measuring customer service and satisfaction: flexibility, customer query time, post transaction measures of customer service.

- SC and logistics cost: cost associated with assets and return on investment, information processing cost.

Gunasekaran *et al.* (2001) state that there should be several kinds of measures to be used in performance metrics: balanced approach, strategic, tactical and operational levels and financial as well as non-financial measures. SCM could be measured in various management or operation levels. Strategic level measures influence the top management decisions and also very often reflect the investigation of broad based policies and level of adherence to organisational goals. The tactical level deals with resource allocation and measuring performance against targets to be met in order to achieve results specified at the strategic level. Operation level measurements and metrics require accurate data and decision is made by low level managers. In operational level, metrics are relevant for day to day business and hence the main metrics are time related and non-financial metrics. There are also some financial measures such as cost per operational hour. Tactical level metrics are mainly non-financial metrics such as accuracy of forecasting techniques, purchasing order cycle time, etc. There are also financial measures such as supplier cost savings initiatives and delivery reliability. Tactical level measures are for middle management and there are several measures which can be used when SCM is going to be developed in a long time perspective. In strategic level there are financial metrics like total cash flow time and customer query time. Non-financial metrics include such metrics as order lead-time and delivery lead-time. Many of these metrics are time-related but also cost-related. These metrics are for top management for making strategic decisions as well as long-term plans and strategies. (Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2004)

According to Gunasekaran (2004), SCM performance metrics are the following (Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2004):

- Strategic level performance metrics
  - total SC cycle time, non-financial metrics
  - total cash flow time, financial and non-financial metrics
  - customer query time, financial and non-financial metrics
  - level of customer perceived value of product, non-financial metrics
  - net profit vs. productivity ratio, financial metrics
  - rate of return on investment, financial metrics
  - range of product and services, non-financial metrics

  - variations against budget, financial metrics
  - order lead-time, non- financial metrics
  - flexibility of service systems to meet particular customer needs, financial metrics
  - buyer-supplier partnership level, financial and non-financial metrics
  - supplier lead-time against industry norm, non-financial metrics
  - level of supplier's defect free deliveries, non-financial metrics
  - delivery lead-time, non-financial metrics
  - delivery performance, financial and non-financial metrics.

- Tactical level performance metrics

  - accuracy of forecasting techniques, financial and non-financial metrics
  - product development cycle time, non-financial metrics
  - order entry methods, non-financial metrics
  - effectiveness of delivery invoice methods, non-financial metrics
  - purchase order cycle time, non-financial metrics
  - planned process cycle time, non-financial metrics
  - effectiveness of master production schedule, non-financial metrics
  - supplier assistance in solving technical problems, non-financial metrics
  - supplier ability to respond to quality problems, non-financial metrics
  - supplier cost saving initiatives, financial and non-financial metrics
  - supplier booking in procedures, non-financial metrics
  - delivery reliability, financial and non-financial metrics
  - responsiveness to urgent deliveries, non-financial metrics
  - effectiveness of distribution planning schedule, non-financial metrics.

- Operational level performance metrics

  - cost per operation hour, financial metrics
  - information carrying cost, financial and non-financial metrics
  - capacity utilisation, non-financial metrics
  - total inventory as: financial metrics

    - incoming stock level
    - work in progress
    - scrap level
    - finnish goods in transit

  - supplier rejection rate, financial and non-financial metrics

– quality of delivery documentation, non-financial metrics
– efficiency of purchase order cycle time, non-financial metrics
– frequency of delivery, non-financial metrics
– driver reliability for performance, non-financial metrics
– quality of delivered goods, non-financial metrics
– achievement of defect free deliveries, non-financial metrics.

The main metrics categories are performance evaluation of planned order procedures, SC partnership and related metrics, production level measures and metrics, performance evaluation of delivery link, measuring customer service and satisfaction SC finance as well as logistics cost. Most important measures for SC capability in this thesis are metrics for performance evaluation of planned order procedures. It is a first step for any firm to put order in the database and that way further to production. Total order lead-time is defined as time between the receipt of customer order and the delivery of goods. The measure of total order cycle time consists of order entry time, order planning time, order sourcing, assembly and follow-up time as well as finished goods delivery time. (Gunasekaran *et al.* 2001)

Gunasekaran *et al.* (2004) introduce six metrics for measuring SCM capability and performance. Metrics are based on the following SCM processes: plan, source, make/assembly and delivery/customer. Metrics for order planning consist of the order entry method, order lead-time and the customer order path. Evaluation of supply link is measured with qualitative and quantitative approaches: evaluation of suppliers, strategic level measures, tactical level measures and operational level measures. Measures and metrics at production level include range of products and services, capacity utilization and effectiveness of scheduling techniques. Metrics at production level have the major impact on production cost, quality, speed of delivery and the kinds of areas which are extremely critical and that cause most of the costs for SCM. (Gunasekaran *et al.* 2004)

Evaluation of delivery link is always linked to customer satisfaction. Evaluation of delivery link measures are measures for delivery performance evaluation and total distribution cost. These measures are important for customers, because it is possible to attain delivery performance by reducing lead-times. Christopher (1992) presents also the concept of on time order fill, which has the same approach as Gunasekaran *et al.* (2004). Evaluation of delivery performance is also able to measure by number of faultless notes invoiced, flexibility of delivery systems to meet particular customer needs and total distribution cost. Customer service and satisfaction is able to measure by flexibility, customer query time and post transaction measures of customer service. SC logistics cost is a financial measure. It can be divided into cost-associated with assets and return on investment as well as information processing cost. (Gunasekaran *et al.* 2004)

Gunasekaran *et al.* (2004) present SC performance metrics framework. The framework is based on a research in which a great number of companies' SCM metrics needs were analyzed. Gunasekaran *et al.* (2004) divide performance categories in SC activities/processes (plan, source, make/assemble, and deliver) and management approaches: strategic, tactical and operational management perspective. Choosing the measurement metrics was based on a research where companies were asked which of the metrics is the most important for their business. The level of customer perceived value of a product was a highly important performance metric in strategic planning. In supplier metrics, a very important metric was supplier delivery performance. Percentage of defects, cost per operation hour and capacity utilization were the most important metrics in the production category. Delivery performance metrics is a highly important category, whose measurements are quality of delivered goods, on time delivery of goods and flexibility of services systems to meet customer needs. Some measures appear in more than one cell. This means that the measures may be appropriate at more than one management level. (Gunasekaran *et al.* 2004)

According to Gunasekaran *et al.* (2004), SC performance metrics framework consists of the following elements (Gunasekaran *et al.* 2004):

- Plan supply chain activity / process
  - strategic management level
    - level of customer perceived value of product
    - variances against budget
    - order lead-time
    - information processing cost
    - net profit vs. productivity ratio
    - total cycle time
    - total cash flow time
    - product development cycle time
  - tactical management level

    - customer query time
    - product development cycle time
    - accuracy of forecasting techniques
    - planning process cycle time
    - order entry methods
    - human resource productivity
  - operational management level
    - order entry methods
    - human resource productivity.
- Source supply chain activity / process
  - tactical management level
    - supplier delivery performance
    - lead-time against industry norm
    - supplier pricing against market
    - efficiency of purchase order cycle time
    - efficiency of cash flow method
    - supplier booking in procedures
  - operational management level
    - efficiency of purchase order cycle time
    - supplier pricing against market.
- Make / assemble supply chain activity / process
  - strategic management level
    - range of products and services
  - tactical management level
    - percentage of defects
    - cost per operation hour
    - capacity utilization
    - utilization of economic order quantity
  - operational management level
    - percentage of defects
    - cost per operation hour

    - human resource productivity index.

- Deliver supply chain activity / process
  - strategic management level
    - flexibility of service system to meet customer needs
    - effectiveness of enterprise distribution planning schedule
  - tactical management level
    - flexibility of service system to meet customer needs
    - effectiveness of enterprise distribution planning schedule
    - effectiveness of delivery invoice methods
    - percentage of finished goods in transit
    - delivery reliability performance
  - operational management level
    - quality of delivered goods
    - on time delivery of goods
    - effectiveness of delivery invoice methods
    - number of faultless delivery notes invoiced
    - percentage of urgent deliveries
    - information richness in carrying out delivery
    - delivery reliability performance.

2.8.5 Measures for supply chain actions

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. As stated before, the measures can be categorized into business process at strategic, operational and tactical management levels. (Shepherd & Gunter 2006)

Shepherd and Günther (2006) present a taxonomy of measures of SC performance. Measures are categorized into SC actions: plan, source, make, deliver and return. Measures also recognized are cost, time, quality, flexibility or innovativeness approach. Measures are divided into two classes: quantitative and qualitative measures.

The plan category measures are mainly cost and time based measures. Metrics are mainly quantitative measures. Cost-based measures are sales, profit, rate of return on investment, cost of goods sold and value added productivity. Time-based measures are, for example, total SC response time, order lead-time, order fulfilment lead-time, product development cycle time and percentage decrease in time to produce a product. In plan category there are also quality-based measures such as accuracy of forecasting techniques, fill rate, perceived effectiveness of departmental relations, order flexibility and also some flexibility and innovativeness measures. (Shepherd & Gunter 2006)

The source category consists mainly of quality-based measures like buyer-supplier partnership level, level of supplier's defect-free deliveries, supplier rejection rate and extent of mutual planning cooperation leading to improved quality. These measures are mainly qualitative ones. There are also some cost- and time based measures. (Shepherd & Gunter 2006)

The make category presents mainly cost-based measures like total cost of resources, manufacturing cost, inventory investment inventory obsolescence and work in process. In the make category the measures are mainly quantitative. There are also time-based measures like planned process cycle time, manufacturing lead-time, time required to produce a particular item tor set of items and also flexibility measures like production flexibility, capacity flexibility and volume flexibility. (Shepherd & Gunter 2006)

The delivery category approaches are mainly cost-, time- and quality-based measures. These are mainly quantitative measures. Cost-based measures are total logistics cost, distribution cost, delivery costs and transport cost per unit of volume. Time based-delivery measures are, for example, delivery lead-time, average lateness of orders and percent of on-time deliveries. (Shepherd & Gunter 2006)

Quality measures are delivery performance, delivery reliability, quality of delivered goods and flexibility measures are like delivery flexibility and transport flexibility. Return on investment category includes mainly quality measures such as customer satisfaction, level of customer perceived value of product, customer complaints and product quality. (Shepherd & Gunter 2006)

Table 1. Stages in supply chain, measures and analysis of the measures. (Artz 1999, Chan 2003a, Chan 2003a, Chan & Qi 2003b, Ellinger 2000, Graham *et al.* 1994, Gunasekaran *et al.* 2004, Hieber 2002, Maloni & Benton 1997, Parker & Axtell 2001, Sperka 1997, Van Der Vorst & Beulens 2002, Windischer & Grote 2003).

Cost, Time, Quality, Flexibility, Innovativeness	Measure	Stages in supply chain
Cost	Total logistics costs	Deliver
Cost	Distribution costs	Deliver
Cost	Delivery costs	Deliver
Cost	Transport costs	Deliver
Cost	Transport costs per unit of volume	Deliver
Cost	Personnel costs per unit of volume	Deliver
Cost	Personnel costs per unit of volume moved	Deliver
Cost	Transport productivity	Deliver
Cost	Shipping errors	Deliver
Cost	Delivery efficiency	Deliver
Cost	Percentage accuracy of delivery	Deliver
Cost	Total cost of resources	Make
Cost	Manufacturing cost	Make
Cost	Inventory investment	Make
Cost	Inventory obsolescence	Make
Cost	Work in process	Make
Cost	Cost per operation hour	Make
Cost	Capacity utilization as incoming stock level, work-in-progress, scrap level, finished goods in transit	Make
Cost	Inventory cost	Make
Cost	Inventory turnover ratio	Make
Cost	Inventory flow rate	Make
Cost	Inventory days of supply	Make
Cost	Economic order quality	Make
Cost	Effectiveness of master production schedule	Make
Cost	Number of items produced	Make
Cost	Warehouse costs	Make
Cost	Stock capacity	Make
Cost	Inventory utilization	Make
Cost	Stock out probability	Make
Cost	Number of backorders	Make
Cost	Number of stock outs	Make
Cost	Average backorder level	Make
Cost	Percentage of excess/lack of resource within a period	Make
Cost	Storage costs per unit of volume	Make

Cost, Time, Quality, Flexibility, Innovativeness	Measure	Stages in supply chain
Cost	Disposal costs	Make
Cost	Sales	Plan
Cost	Profit	Plan
Cost	Return on investment (ratio of net profits to total assets)	Plan
Cost	Rate of return on investment	Plan
Cost	Net profit vs. productivity ratio	Plan
Cost	Information carrying cost	Plan
Cost	Variations against budget	Plan
Cost	Total supply chain management costs	Plan
Cost	Cost of goods sold	Plan
Cost	Asset turns	Plan
Cost	Value added productivity	Plan
Cost	Overhead cost	Plan
Cost	Intangible cost	Plan
Cost	Incentive cost and subsides	Plan
Cost	Sensitivity to longer-term costs	Plan
Cost	Percentage sales of new product compared with whole sales for a period	Plan
Cost	Expansion capability	Plan
Cost	Capital tie-up costs	Plan
Cost	Warranty/returns processing costs	Return (Customer satisfaction)
Cost	Supplier cost-saving initiatives	Source
Cost	Percentage of late or wrong supplier delivery	Source
Flexibility	Delivery flexibility	Deliver
Flexibility	Responsiveness to urgent deliveries	Deliver
Flexibility	Transport flexibility	Deliver
Flexibility	Inventory range	Make
Flexibility	Production flexibility	Make
Flexibility	Capacity flexibility	Make
Flexibility	Volume flexibility	Make
Flexibility	Number of tasks worker can perform	Make
Flexibility	Mix flexibility	Plan
Flexibility	Number of new products launched	Plan
Flexibility	Flexibility of service systems to meet particular customer needs	Return (Customer satisfaction)
Flexibility	Supplier ability to respond to quality problems	Source
Innovativeness	Use of new technology	Plan
Quality	Delivery performance	Deliver
Quality	Delivery reliability	Deliver

Cost, Time, Quality, Flexibility, Innovativeness	Measure	Stages in supply chain
Quality	Number of on-time deliveries	Deliver
Quality	Effectiveness of distribution planning schedule	Deliver
Quality	Effectiveness of delivery invoice methods	Deliver
Quality	Delivery reliability for performance	Deliver
Quality	Quality of delivered goods	Deliver
Quality	Achievement of defect-free deliveries	Deliver
Quality	Quality of delivery documentation	Deliver
Quality	Inventory accuracy	Make
Quality	Percentage of wrong products manufactured	Make
Quality	Fill rate (target fill rate achievement & average item fill rate)	Plan
Quality	Order entry methods	Plan
Quality	Accuracy of forecasting techniques	Plan
Quality	Autonomy of planning	Plan
Quality	Perceived effectiveness of departmental relations	Plan
Quality	Order flexibility	Plan
Quality	Perfect order fulfilment	Plan
Quality	Customer satisfaction (or dissatisfaction)	Return (Customer satisfaction)
Quality	Level of customer perceived value of product	Return (Customer satisfaction)
Quality	Customer complaints	Return (Customer satisfaction)
Quality	Rate of complaints	Return (Customer satisfaction)
Quality	Product quality	Return (Customer satisfaction)
Quality	Buyer-supplier partnership level	Source
Quality	Level of supplier's defect-free deliveries	Source
Quality	Supplier rejection rate	Source
Quality	Mutual trust	Source
Quality	Satisfaction with knowledge transfer	Source
Quality	Satisfaction with supplier relationship	Source
Quality	Supplier assistance in solving technical problems	Source
Quality	Extent of mutual planning cooperation leading to improved quality	Source
Quality	Extent of mutual assistance leading in problem-solving efforts	Source
Quality	Distribution of decision competences between supplier and customer	Source
Quality	Quality and frequency of exchange of logistics information between supplier and customer	Source
Quality	Quality of perspective taking in supply networks	Source

Cost, Time, Quality, Flexibility, Innovativeness	Measure	Stages in supply chain
Quality	Information accuracy	Source
Quality	Information timeliness	Source
Quality	Information availability	Source
Time	Delivery lead-time	Deliver
Time	Frequency of delivery	Deliver
Time	Product lateness	Deliver
Time	Average lateness of orders	Deliver
Time	Average earliness of orders	Deliver
Time	Percent of on-time deliveries	Deliver
Time	Planned process cycle time	Make
Time	Manufacturing lead-time	Make
Time	Time required to produce a particular item or set of items	Make
Time	Time required to produce new product mix	Make
Time	Total supply chain response time	Plan
Time	Total supply chain cycle time	Plan
Time	Order lead-time	Plan
Time	Order fulfilment lead-time	Plan
Time	Customer response time	Plan
Time	Product development cycle time	Plan
Time	Total cash flow time	Plan
Time	Cash-to-cash cycle time	Plan
Time	Horizon of business relationship	Plan
Time	Percentage decrease in time to produce a product	Plan
Time	Customer query time	Return (Customer satisfaction)
Time	Supplier lead-time against industry norm	Source
Time	Suppliers booking-in procedures	Source
Time	Purchase order cycle time	Source
Time	Efficiency of purchase order cycle time	Source

2.8.6 Internal and external time performance

According to Ghalayini (1996), the time performance measurement approach is a new strategic performance measure that should be used to promote improvement. Time-based performance measurement has the limitation of over-emphasizing the role of time and not considering the impact of other operational performance measures with respect to time. In order to improve time performance, all operational performance measures should be measured, controlled and improved.

Ghalayini (1996) presents the main time-based metrics that companies could use in different areas (Ghalayini & Noble 1996):

1. New product development includes time from idea to market; rate of new-product introduction.
2. Decision making includes: decision cycle time as well as the time lost when waiting for decisions to be made.
3. Processing and production includes: value added as percentage of total elapsed time; uptime yield; inventory turnover and cycle time.
4. Customer service includes: response time; quoted lead-time; percentage deliveries of time; and time from customer's recognition of need to delivery.

De Toni and Tonchia (2001) present several indicators of internal and external time performance. According to their research, time performance indicators in order of superiority are the following: time-to-market, distribution lead-times, delivery reliability, supplying lead-times, supplier delivery reliability, manufacturing lead-times, standard run times, actual run times, wait times, set-up times, move times, inventory turnover, order carrying-out times and flexibility. Time performances are divided into external and internal times. Internal times can be split into run and set-up times on one hand and wait and move times on the other. Externally-perceived time performances can be divided in three parts: system times (including supplying, manufacturing and distribution leas times), delivery speed and delivery reliability (both from suppliers and to customers) and time-to-market (or time required to develop a new product). These time measures presented are called time performance. (Toni & Tonchia 2001)

Furthermore, De Toni and Tonchia (2001) state that performance can be present in four indicators: 1. cost/productivity, 2. time, 3. flexibility, 4. quality. First measure is cost-based and other three are non-cost performance measures. Cost-based performance include the following measures: affordability of the production cost, the productivity and the control of the working capital. Time is a performance measure which covers internal times and external times. Internal time stands for the time controlled by a firm but that is not perceived by a customer. External time is understood as the time that the customer perceives, such as delivery time and frequency of introducing new products. Performance measures in the quality approach are produced quality, perceived quality (customer satisfaction), in-bound quality (supplier's quality) and quality in terms of costs (cost of maintaining a high standard of quality). The most measured performance metrics are direct costs, labour productivity, the inventory and the net process times. Time-to-market, non-value-added times, delivery, quality produced and customer satisfaction are not measured as often. (Toni & Tonchia 2001)

De Toni (2001) presents performance dimensions and measures and divides these into two categories (Toni & Tonchia 2001):

1. Cost performance, including production costs and productivity.
2. Non-cost performance, regarding time, flexibility and quality.

The cost performances have a direct link to company's result like net income and profitability. Non-cost performances are not able to calculate like cost performances. One example mentioned is that an average delivery time three days shorter or a product of better quality surely has a positive impact on the economic and financial performances, but such an impact cannot be calculated like income or profitability. Time performance approach can be internal (performances perceived exclusively within the firm) and external (performances perceived also outside the firm, by the customers). Internal time performances are: 1. run and set-up times on one hand, 2. wait and move times. External time performances are: 1. system times (including supplying, manufacturing and distribution lead-times), 2. delivery speed and delivery reliability (both from suppliers and to customers) and 3. time to market (time required to develop a new product). (Toni & Tonchia 2001)

2.8.7 System dynamics, operational research, logistics, marketing, organization and strategy

Otto and Kotzab (2003), present six ways of measuring SCM capability. Main groups are system dynamics, operational research, logistics, marketing, organization and strategy. The idea of system dynamics is to manage trade-offs along the complete SC. Performance metrics are capacity utilization, cumulative inventory level, stock-outs, time lags, time to adapt and phantom ordering. The aim of operational research and information technology is to calculate optimal solutions within given degrees of freedom. Metrics are logistics costs per unit, service level and time to deliver. Logistic perspective target is to integrate generic processes sequentially, vertically and horizontally. In this category capability is measured by integration, lead-times, order cycle time, inventory level and flexibility. Marketing approach is to segment customers and connect them with the right channel. Measures are customer satisfaction, distribution cost per unit and market share/channel costs. Organization approach is to manage SC relations with measures of transaction costs, time to network, flexibility and density of relationships. The aim of the strategy perspective is to connect competencies and the ability to make profit. Performance metrics are time to network, time to market and ROI of focal organization. (Otto & Kotzab 2003)

2.8.8 Quantitative and qualitative measures

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. Cost is one of the quantitative measures and it can be measured by distribution cost, manufacturing cost, inventory cost, warehouse cost, incentive cost and subsidy, intangible cost, overhead cost and sensitivity to long-term cost. Resource utilisation means labour, machine, capacity, energy resource utilisation and performance measurement investigates the percentage of excess or lack of that particular resource within a period. Optimization can save both time and money and it can minimize the size of the company as well as improve its performance. (Chan 2003a)

Qualitative measures are quality, flexibility, visibility, trust and innovativeness. Time-based qualitative measures are the following: customer responses time, lead-time, on-time delivery, fill rate, stock out probability and accuracy. An especially important measure is lead-time which stands for the time required once the product began its manufacture until the time it is completely processed. Flexibility measurement metrics are divided into input, process, output and improvement categories. Input category is measured by labour and machine flexibility. Process flexibility is presented as material handling flexibility, routeing flexibility and operation flexibility. Output flexibility is presented as volume flexibility and mix flexibility. Delivery flexibility and improvement are divided into modification flexibility, new product flexibility and expansion flexibility. Visibility is measured by time and accuracy. Trust is measured by consistency, which means the percentage of late or wrong delivery to the next tier which leads to an inconsistent supply. Innovativeness is presented as a new launch of product and new use of technology. (Chan 2003a)

Beamon (1998) presents SCM performance measures in two groups: qualitative and quantitative, where customer satisfaction and responsiveness, flexibility, supplier performance, and cost are presented. Beamon (1998) identifies three types of measures: resources, output and flexibility. (Beamon 1998) Beamon (1999) also identifies two performance measures: cost and combination of cost and customer responsiveness. Cost consists of inventory costs and operating costs. Customer responsiveness measures include lead-time, stock out probability and fill rate. (Beamon 1999)

Beamon (1999) identifies new SCM performance framework, in which there are three separate types of performance measures: resource measures, output measures and flexibility measures. The goal of the resource measures is a high level of efficiency and the purpose of the resource measures is efficient resource management that is critical to profitability. The general goal of the resources is resource minimization. Resource performance measures include total cost of resources used, total distribution cost, total cost of manufacturing, costs associated with held inventory and return on investment (ROI). The goal of output measure type is a high level of customer service and the purpose of output measurement is that without acceptable output, customers will turn to other SCs, without acceptable output. Output measures include customer responsiveness, quality and quantity of final product produced such as number of items produced, time required to produce a particular item or set of items, number of on-time deliveries, proportion of orders filled immediately, profit, sales, backorder/stock out, customer response time, manufacturing lead-time, shipping errors and customer complaints. Flexibility goal is the ability to respond to a changing environment and purpose is that in an uncertain environment, supply chains must be able to respond to challenges that emerge due to changes. Flexibility is presented in four categories: volume flexibility, delivery flexibility, mix flexibility and new product flexibility. A measure that is chosen in the performance measure type categories must coincide with the organization's strategic goals. (Beamon 1999)

Chan (2003) introduces AHP for measuring SCM qualitative and quantitative measurements. AHP is a common tool for solving multi-criteria decision-making problems. AHP provides a framework for involving tangible and intangible as well as qualitative and quantitative approach. AHP provides versatility and power in structuring and analysing a complex multi-attribute decision-making problem, by giving means of quantifying judgemental consistency. (Chan 2003a, Korpela *et al.* 2001, Vargas 1990)

2.8.9 Innovative performance measurement method

As stated before, Chan and Qi (2003) present an innovative performance measurement method. The aim of the method is to build up a measurement team and members should be from different organizations. SCM should be measured beyond the organizational boundaries rather than focusing locally. SCM can be categorized into six general processes which are linked together: supplier, inbound logistics, manufacturing, outbound logistics, marketing and sales and end customers. (Chan & Qi 2003b)

Chan and Qi (2003) present input measures, output measures and composite measures. Input measures are time and cost. Time is a measurement for management performance and it is important for both internal and external customers. One important measure is operation time, which is closely related to customer satisfaction. Cost dimension is a measure for example labours capital, knowledge, facility and cost of scrap. Output measures include semi-finished products and finished products. Popular output measures are delivery reliability, and error-free and flexible production and new product introduction. Productivity, efficiency and utilization are performance measures. These measures are mainly operational performance measures which provide information regarding effectiveness of the management. The performance measurement team is composed of the representatives from various management areas of supply chain members. Members can be from shop floor, supervisors, manager and similar areas. The advantage of the members being from various management areas is that they have extensive skills to analyze performance in SCM. (Chan & Qi 2002, Chan & Qi 2003b)

2.8.10 Process based approach

With timely information, process-based measurement provides a great deal of support in enhancing integration and improvement of the cross-organizational processes. According to Chan (2003), the main advantages of adopting process-based performance measurement in SCM are (Chan & Qi 2003a):

- Providing the opportunity of recognizing the problems in operations and taking a corrective action before these problems escalate.
- Facilitating linking with the operational strategies, identifying success, and testing the effect of strategies.

- Support in monitoring the progress.
- Assisting in directing attention of the management attention and resources allocation.
- Enhancing communication of process objectives involved in the supply chain, thus increasing trust and common understanding.

According to Chan 2003, the steps and processes of analyzing and decomposing the process to be measured are the following (Chan & Qi 2003a):

- Identifying and linking all the involved processes of internal- and intra-organization.
- Defining and confining the core processes.
- Deriving the missions, responsibilities and functions of the core processes.
- Decomposing and identifying the sub-processes.
- Deriving the responsibilities and functions of sub-processes.
- Decomposing and identifying the elementary activities of sub-processes.
- Linking goals to each hierarchy from processes to elementary activity.

Process-based approaches are cost, time, capacity, capability, productivity, utilization, and outcome. Cost is the financial expense for carrying out one event or activity. It is always one of the indispensable aspects in assessing the performance of the business activities and processes. Time is an important resource in modern business environments. Capacity is the ability of one specific activity to complete a task or perform a required function. Capability measures include effectiveness, reliability, availability and flexibility measures. Utilization means the utilizing rate of the resources to carry out one specific activity. Outcome is the results or value added of one specific activity or event. (Chan & Qi 2003a)

2.8.11 Supply chain operations reference model

The supply chain operations reference (SCOR) model was introduced in 1996 by the Supply-Chain Council, which is a global organization of firms interested in SCM. The SCOR model is a business process reference model and it provides a framework that includes SC business processes, metrics, best practices, and technology features. The SCOR model attempts to integrate the concepts of BPR, benchmarking, process measurement as well as best practice analysis and apply them to SC's. According to Theeranuphattana (2008), the SCOR model offers users the following benefits (Theeranuphattana & Tang 2008):

- standard descriptions of management processes that make up the SC
- a framework of relationships among the standard processes
- standard metrics to measure process performance
- management practices that produce best-in-class performance
- standard alignment to software features and functionality that enable best practices.

Theeranuphattana (2008) presents that the SCOR model is based on five core processes: plan, source, make, deliver, and return. (Ren 2008, Theeranuphattana & Tang 2008) The SCOR model advocates hundreds of performance metrics used in conjunction with five performance attributes: reliability, responsiveness, flexibility, cost, and asset metrics. (Theeranuphattana & Tang 2008) Hausman (2004) states that in modern SCM, quality is taken as a given and that factors in quality management and improvement are somewhat separate from those in SCM development. (Hausman 2004) Supply Chain Council (2006) presents five attributes of SC performance (Theeranuphattana & Tang 2008):

1. *SC reliability.* The performance of the SC in delivering the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer.
2. *SC responsiveness.* The speed at which a SC provides products to the customer.
3. *SC flexibility.* The agility of a SC in responding to marketplace changes to gain or maintain competitive advantage.
4. *SC costs.* The costs associated with operating the SC.
5. *SC asset management.* The effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of the both assets: fixed and working capital.

2.8.12 Balanced scorecard approach

Several researchers have proposed using Balanced ScoreCard (BSC) to measure SCM capability. (Brewer & Speh 2000, Brewer & Speh 2000, Forker *et al.* 1997, Gunasekaran *et al.* 2001, Hoek 1998, Lapide 2000, Lin *et al.* 2002, Mehrjerdi 2009, Yamin *et al.* 1999)

Kaplan and Norton (1992) present BSC model to evaluate corporate performance in four types of approaches: the financial, the internal business process, the customer as well as learning and growth. The name of this concept comes from of a set of items that maintain a balance between short term and long term objectives, between financial and non-financial measures, between lagging and leading indicators and between internal and external performance perspectives. BSCs have two main approaches: customer perspective and financial perspective. Customer perspective, which is a value-adding view and financial perspective, is the shareholders' view. The approach mission of customer perspectives is to achieve vision by delivering value to customers. It is also an internal perspective (process-based view) and its aim is to promote efficiency and effectiveness in the business processes. Mission of financial perspective is to succeed financially, by delivering value to the shareholders and to achieve the vision, by sustaining innovation and change capabilities, through continuous improvement and preparation for future challenges. This approach has also learning and growth perspective in future view. (Bhagwat & Sharma 2007b, Kaplan & Norton 1993, Kaplan & Norton 1996, Kaplan & Norton 1992, Kaplan 1996, Neely *et al.* 1995)

Bhagwat and Sharma (2007) introduce BSC approach: financial metrics, customer perspective, internal business perspective as well as innovation and learning perspective. Financial performance measures the company's financial result. Profitability, growth in sales turnover and maximizing wealth of shareholders are also the metrics of BSC financial metrics. Evaluating customer perspective approach is to find out how customers see the business. Measures also include lead-time, quality of products and services, company's performance service and cost effectiveness. Internal business perspective measures business processes that have the greatest impact on customer's satisfaction factors. Innovation and learning perspectives can win efficiency to firm's operative business in the future. (Bhagwat & Sharma 2007b, Kaplan & Norton 1992, Neely *et al.* 1995)

2.8.13 Supply chain operations reference – Balanced scorecard approach

Kaplan and Norton (1992) have developed the BSC model which relates to the different classes of business performance: financial and nonfinancial, internal and external. (Kaplan & Norton 1992) According to Thakkar (2009), SCOR and BSC are to ensure the greater effectiveness of PMS system on the following grounds (Thakkar *et al.* 2009):

- BSC does not provide a mechanism for maintaining the relevance of defined measures. SCOR adopts a building block approach and offers complete traceability.
- BSC fails to integrate top level, strategic scorecard, and operational level measures potentially making execution of strategy problematic. SCOR clearly defines the type of process (planning, execution and enabling) and configures them to suit the SC requirements.
- BSC fails to specify a user-centred development process. A detailed exercise on SCOR generates sufficient information to even develop tailor-made software system.

Thakkar (2009) presents the SCOR-BSC framework that is related to various decision areas of SCOR model in Level 1. According to Thakkar (2009), for each SCOR decision area various SC planning processes are considered. Level 2 SCOR category and an appropriate plan-source-make-deliver configuration are chosen by an individual organization. The processes determined at Level 2 are now decomposed to sub-processes at Level 3 and process element definition, inputs-outputs, process, and performance metrics are summarized. Analysis is carried out to gain understanding regarding the difference between the present scope of performance measurement and proposed scope of SCOR-BSC framework to derive a suitable implementation plan (at Level 4). (Thakkar *et al.* 2009)

Thakkar (2009) presents several features of the SCOR-BSC framework (Thakkar *et al.* 2009):

- The framework includes both tangible and intangible measures. The hard measures cost, time, capacity, productivity, and utilization are tangible and thus it is relatively easy to collect data from them. Soft measures such as effectiveness, reliability, availability, and flexibility are intangible, and thus cannot be directly measured.

- Each of the metrics describes one critical dimension of performance of the activity and process.
- One important shortcoming of many firms is their inability or unwillingness to widen the scope of their measurement activities. The framework has conceptualized the various SCOR decision areas – plan, source, make, and deliver in a way that they are built on a cyclic view of SC and hence ensuring the linkage between organization specific performance measures and SCM-based metrics.
- The proposed framework clearly defines the inputs and outputs for each process.
- The framework includes metrics for various categories of BSC and users are advised to further classify them into strategic, tactical and operational level.

2.8.14 Approaches by other researchers

Neely *et al.* (1995) conducted a research project in the middle of 1990's and identified four approaches to performance system measurement: quality, time, cost and flexibility. Quality-based measuring of performance has focused on the number of defects produced and the cost of quality. Measureable dimensions in quality approach are performance, features, reliability, conformance, technical durability, serviceability, aesthetics, perceived quality, humanity and value. Time approach measures are manufacturing lead-time, rate of production introduction, delivery lead-time, due-date performance and frequency of delivery. Time is a source of competitive advantage as well as a fundamental measure of manufacturing performance. Cost approach dimensions are manufacturing cost, value added, selling price, running cost and service cost. Flexibility performance measures are material quality, output quality, new product, modified product, deliverability, volume, mix and resource mix. Flexibility dimensions are identified as range, cost and time. In the research of Neely *et al.* it was found that small and medium size companies are using plenty of different kind of measures. Performance measures should be derived from strategy. There are two basic types of performance measure approach: result related measures like competitiveness and financial performance and those that focus on the determinants of the results, like quality, flexibility, resource utilization and innovation. (Neely *et al.* 1995)

The approach of Maskell (1992) is that companies should have two kinds of measurements: financial performance measurements for strategic decisions and non-financial measures for day-to-day manufacturing operations. (Maskell 1992)

SC models, especially those that consider multiple echelon inventory management, have typically focused on performance measures such as cost (Cohen & Lee 1989, Cohen & Moon 1990, Lee & Feitzinger 1995, Tzafestas & Kapsiotis 1994) and a combination of cost and customer responsiveness (Altiok & Ranjan 1995, Arntzen *et al.* 1995, Cook & Rogowski 1996, Davis 1993, Lee & Billington 1993, Nicoll 1994, Towill *et al.* 1992, Wikner *et al.* 1991).

Reduction in the order cycle time is especially important because it leads to reduction in the SC response time. Reduction in SC response time is increasing customer satisfaction level. Order cycle time reductions lead to a reduction in the SC response time, which is an important measure and major source of competitive advantage. (Bhagwat & Sharma 2007b, Christopher 1992)

Bechtel and Jayaram (1997) present that measurement in the SC may use integrated measures that are cross-operational and can be applied to the entire process. These measures are, among others, time from cash to cash. The aim is to avoid optimization at one point in the SC. La Londe and Pohlen (1996) state that total costs of ownership and direct product profitability are focused at particular segments of the chain and cannot be used for measuring whole SC. Scapens (1998) presents that modern measurement systems should support innovative strategies like teamwork and non-financial measures like lead-times. Van Hoek (1998) presents a new SCM framework which is like a matrix model. In the horizontal axis there are contributions of organization to SC competitiveness approaches such as integration, customer service and cost-effectiveness. In the vertical axis there are strategy sophistication approaches such as cost saver, market penetration/market extension and market creation. (Bechtel & Jayaram 1997, Hoek 1998, Lalonde & Pohlen 1996, Scapens 1998)

According Kess *et al.* (2010), critical factors for an effective business value chain are the following (Kess *et al.* 2010):

- Internal operations: reliable production / service delivery system, materials/components commonality, flexible planning system, skilful and able planning staffs, good operations management.
- Relationships with suppliers: flexible suppliers in delivery, reliable suppliers with on-time delivery, the willingness of suppliers to share information, effective information and communication infrastructures of suppliers.
- Relationships with customers: availability of information from customers well in advance, customers being collaborative and willingness to share, customers with effective information and communication infrastructures.

De Toni and Tonchia (2001) present that in literature there are different kinds of performance measures, which can be divided to four categories (Toni & Tonchia 2001):

1. Cost and non-cost performance measures (Berliner & Brimson 1988, Lockamy & Cox 1994, Partovi 1994, Rangone 1996).
2. Balanced scorecard models, where performance is measured in financial, internal business process, customers, and learning/growth - fields. (Kaplan & Norton 1993, Kaplan & Norton 1996, Kaplan & Norton 1992, Kaplan 1996, Maskell 1992).
3. Internal and external performances (Toni & Tonchia 2001).
4. Value chain models (Toni & Tonchia 2001).

2.9 Challenges for supply chain performance measurement

> *"There were no performance measures from the complete supply chain. Many companies have this problem. Those that do have such metrics often do not monitor then regularly. Or their metrics are not directly related to customer satisfaction."* (Lee & Billington 1992)

One of the main challenges in SCM performance measurement is that measures are mainly internal logistics performance measures and do not capture the way the SC has performed as a whole. Internal logistics measures such as fill rate, lead-time, on-time performance, damage and responsiveness do not measure the whole SCM performance. (Lambert & Pohlen 2001)

There are some in-depth problems of PMSs in the SC context (Chan 2003a, Gunasekaran *et al.* 2001):

– The lack of a balanced approach in integrating financial and non-financial measures.
– The lack of system thinking, in which a SC must be viewed as a whole entity and the measurement system should span the entire SC.
– The loss of the SC context.

According to Lin (2010), there are four challenges in SC performance measurement. First, the majority of articles are focused on the study of intra-organizational performance – measures that do not measure SC performance as a whole. Secondly, the previous research did not consider the variation of measured values. The decision makers found it difficult to find real performance values, identify weak areas, take corrective actions, and make continual improvements. Thirdly, no common metrics existed for evaluating different processes on the same scale. Different characteristics of associated processes cannot be compared without using the correct metrics. Fourthly, the process teams should have motivation, capacity, and authority to improve processes and their results. Human attributes such as cooperation, skill, communication, etc. should have been considered as important dimensions of SC performance, but previous researches did not integrate these human attributes into the SC performance measurement model. (Lin & Li 2010)

Almost every researcher states in their articles that SCM performance measurement is not studied enough. Furthermore, almost every researcher identifies that more research regarding SCM performance or capability measurement should be carried out. Research-related issues are the factors influencing the successful implementation of performance measurement systems (Bourne *et al.* 2000, Bourne *et al.* 2002), the forces which shape the evolution of performance measurement systems (Kennerley & Neely 2002, Waggoner *et al.* 1999) and the way performance measurement systems are maintained over time so they remain aligned with dynamic environments and changing strategies (Bourne *et al.* 2000, Kennerley & Neely 2003).

Gunasekaran (2004) and Gunasekaran and Kobu (2007) state that problems in performance measurement frame of references include (Gunasekaran *et al.* 2004, Gunasekaran & Kobu 2007):

- Incompleteness and inconsistencies in performance measurement and metrics.
- Inability to represent a set of financial and non-financial measures in a balanced framework, some measures concentrating on financials, others concentrating on operational measures.
- Large number of metrics, makes it difficult to identify the critical few among trivial many.
- Inability to connect the strategy and the measurement.
- Biased focus on financial metrics.
- Too much inward looking.

2.10 Conclusion of supply chain performance measurement

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

- a performance measurement matrix (Keegan *et al.* 1989)
- financial and/or non-financial metrics (Gosselin 2005, Ittner *et al.* 2003, Kaplan & Norton 1992, Lambert & Pohlen 2001, Lawrie & Cobbold 2004, Neely 1999, Olsen *et al.* 2007, Tangen 2004, Tapinos *et al.* 2005, Thakkar *et al.* 2007)
- qualitative or quantitative approach (Beamon 1999, Chan 2003a)
- balanced scorecard approaches (Bhagwat & Sharma 2007a, Bigliardi & Bottani 2010, Brewer & Speh 2000, Brewer & Speh 2001, Chia *et al.* 2009, Dror 2008, Epstein & Manzoni 1998, Kaplan 1993, Kaplan & Norton 1992, Kaplan & Norton 1996, Kaplan & Norton 2001, Kaplan 1996, Lawrie & Cobbold 2004, Thakkar *et al.* 2007, Xu & Li 2008)
- performance prism (Neely *et al.* 2000a)
- performance measurement questionnaire (Dixon 1990)
- Van Hoek's matrix model (Hoek 1998)
- cost and non-cost (Gunasekaran *et al.* 2001, Toni & Tonchia 2001)
- quality, cost, delivery and flexibility (Shepherd & Gunter 2006)
- cost, quality, resource utilization, flexibility, visibility, trust and innovativeness (Chan 2003a)
- resources, outputs and flexibility (Beamon 1999)
- SC collaboration efficiency; coordination efficiency and configuration (Shepherd & Gunter 2006)
- input, output and composite measures (Chan 2003a)
- strategic, operational or tactical management approach (Gunasekaran *et al.* 2001)
- SC process based measuring approach (e.g.(Chan 2003a, Shepherd & Gunter 2006)
- six-sigma approaches (Dasgupta 2003, Lin & Li 2010, Ramaa *et al.* 2009, Wang *et al.* 2004, Xu 2008)
- measuring SC in multiple levels (Lin & Li 2010, Shepherd & Gunter 2006).

There is a set of contributions in the area of SC performance measurement. Chan and Qi (2003) proposed a process-based PMS for mapping and analyzing complex SC networks (Chan 2003a); 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 include 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 modelling and analytic network process (Thakkar *et al.* 2007).

Table 2. Performance measurement approaches. (Beamon 1999, Chan 2003a, Chan 2003b, Chan & Qi 2003b, De Toni & Tonchia 2001, Fynes *et al.* 2005, Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2005, Hieber 2002, Holmberg 2000, Li *et al.* 2005, Li *et al.* 2007, Lockamy III & McCormack 2004, Ramaa *et al.* 2009, Ren 2008, Stephens 2001, Suwignjo *et al.* 2000, Tangen 2004).

Author	Framework / Performance measures / Performance Measurement System (Quality (Q) Cost (C) Delivery(D) Flexibility (F) Agility (A) Responsiveness(R) Non-financial (NF) Qualitative (QL) Quantitative (QN))	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 & 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 & Qi 2003	Input, output and composite measures, processes of supply chain	QN, QL

Author	Framework / Performance measures / Performance Measurement System (Quality (Q) Cost (C) Delivery(D) Flexibility (F) Agility (A) Responsiveness(R) Non-financial (NF) Qualitative (QL) Quantitative (QN))	Category of Measure
Chunhua *et al.* 2003)	Quality, cost, delivery and flexibility perspective performance measures at department, enterprise and supply chain level	C, Q, QN, F, A
Chan *et al.* 2003	Innovative Performance Measurement Method	Q, QN, QL
Tangen 2003	Financial, time based measures, non cost	C, T, NF
Ren *et al.* 2004	Active performance management system	QN, QL
Lockamy & McCormack 2004	SCOR model	QN
Parsons *et al.* 2004	Relationship between productions run lengths and overall supply chain performance	QN, Q
Schonsleben 2004	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
Wu *et al.* 2005	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 *et al.* 2005	Theoretical framework for the performance measures of World Class Manufacturing	QN, Q, C
Mao *et al.* 2006	Supporting evaluation level(HITS-Human, 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

2.10.1 Main approaches for manufacturing industry

According to the literature review it is possible to nominate the following principal approaches for SC performance measurement:

- management approach
- time based approaches
- quantitative and qualitative measures.

Management approach

Gunasekaran *et al.* (2004) divide performance categories in SC activity/processes (plan, source, make/assemble, and deliver) and management approach to strategic, tactical and operational management perspectives. As stated before, measurement metrics were chosen based on a research in which companies were asked which of the metrics is the most important for their business. Gunasekaran *et al.* (2004) present that SCM performance can be measured in three different management levels. The levels are strategic, tactical and operational level. Strategic level measures performance for needs of top management. These measures are usually corporate level performance measures. The tactical levels measure performance against targets and also collect feedback from mid-management level. Operational level metrics require data that is relevant to low level management. (Gunasekaran *et al.* 2004)

Time based approach

The time-based measuring approach seems to be one of the most wide-known SCM capability measures among researchers. Time is also identified as the next source of competitive advantage. (Balsmeier & Voisin 1996, Kessler & Chakrabarti 1996, Mehrjerdi 2009, Stalk 1988, Vesey 1992) Therefore it seems that even though time has been quite a common measure in SC performance it is still an accurate and useful measure. Lead-time, order cycle time, time-to-market and other time measures are actually relevant for every management level. Operational, tactical and strategic management are of interest for time measurement of SC performance. Time is the same for everyone and every company, every production line and all people and therefore it is easy to measure. When comparing cost or financial metrics and time, it is clear that time is a more stable measure than other financial metrics and cost. It is not possible to change the time currency like money.

Quantitative and qualitative measures

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 2003a) Beamon (1998) presents SCM performance measures in two groups – qualitative and quantitative – where customer satisfaction and responsiveness, flexibility, supplier performance, costs and other measurements for SC modelling are presented. As stated before, Beamon (1999) identifies two performance measures: cost and combination of cost and customer responsiveness. Cost consists of inventory cost and operating costs. Customer responsiveness measures include lead-time, stock out probability and fill rate. (Beamon 1999)

Conclusion

It is very clear that SC performance should be measured using different kinds of approaches. In measuring SC performance it seems to be relevant to use the following SC operations: plan, source, make, deliver and return. Furthermore, there should be financial and non-financial metrics as well as quantitative and qualitative measures. As Craig states, SCM should be measured at multiple levels. (Shepherd & Gunter 2006) It is important to develop more non-financial metrics due to the fact that these metrics can present more information than the basic financial metrics. The total SC performance measurement is challenging. However, even if it is challenging it is possible!

3 Developing SCM measurement system for the case company

In Finland, growth of the engineering industry took place during the time after the Second World War. After the end of the Second World War the era of reconstruction of the country as well as war indemnity payments began. Due to these reasons the state systematically established and supported the engineering and steel industries. Decades later, engineering industry has gone through substantial changes. Along with the changes, especially measuring SC has become an important, indicative element when making various decisions in the field of industry. This chapter concentrates especially on the Finnish engineering industry, the engineering industry branch of the case company, the trajectory of manufacturing pre-fabricated plate products and the case company. Furthermore, SCM indicators are created to measure cost-effectiveness of the case company's SC.

3.1 Finnish engineering industry

Finnish engineering industry has developed over the decades with support from the state. Typically the engineering works of the metal industry are small or medium-sized firms in private ownership. In addition to the forest industry and the shipbuilding industry, there are a few significant main suppliers of the metal industry operating in Finland. Most typically, Finnish engineering works manufacture parts or subassemblies for different fields of industry according to the requirements of customers. Part of the engineering works production has also been their own products which are manufactured in small or medium-sized batches. Engineering works have networked with the largest main suppliers. This networking can be regarded as exceptionally wide-ranging and of good quality. Furthermore, it can be considered as an efficient alternative for the whole SC.

Considering its population, Finland can be even regarded as a concentration of steel industry. The foundation of the Finnish engineering industry lies in some – in Finland's scale – large steel companies. Steelworks manufacture standard and special steel products that are mainly sold for export, but part of the steel remains for the home market as well. In Finland, the steel industry creates good conditions for the availability of material for the main suppliers in the metal industry as well as to the small and medium-sized companies.

The most essential competitive element in Finnish metal industry is unquestionably advanced subcontracting networking. Subcontracting and networking have gone through a substantial change during the 1990's and 2000's. The depression of the 1990's created necessity to make the SC's more effective and to pay especially close attention to which products are worth self-manufacturing and which products should be subcontracted from the network. The dot-com bubble of the end of the 1990's and beginning of the 2000's was a tonic to metal engineering. IT companies operating in Finland used Finnish subcontractors and the networks were functioning excellently. After the bursting of the bubble the harsh reality was revealed and IT companies started to look for manufacturing networks from countries with cheaper labour. Numerous engineering works in the metal industry found themselves without work and the special knowledge as subcontractors of the IT products was of no value anymore. It was time for a new radical change that in many of the companies required turning back to traditional production of metal industry.

The threat for metal industry in the 2000's has been the purchases of engineering works moving to countries with cheaper labour. Main suppliers manufacture, in particular, large-lot production parts and subassemblies in countries with cheaper labour. Finnish metal industry has tried to keep up with this cost competition with high quality, prompt delivery times and agility. Due to networking of steel industry, SCM has an outstandingly significant role. Therefore one must be able to measure SCM in order to be able to develop it as well.

3.1.1 Concentrating on essential business

In Finnish metal industry, metal products have traditionally been self-manufactured all the way. Typical products of metal industry engineering works include plate works, welding, machining, assembly, surface treating and finishing. Successful production plant has to concentrate on essential business. In practice, in an engineering works concentrating on essential business means to evaluate which is the most refining and value increasing stage of operation. It has to be determined what the customers are actually ready to pay for.

Small and medium-sized engineering works have progressively concentrated on essential business. Larger main suppliers have started concentrating on essential business substantially earlier and this has contributed to the emergence of subcontractor networks. The emergence of subcontractor networks dates back especially to the time after the depression of the 1990's. Due to rigorous competition there was a need to come up with cost savings in order to gain the sales. The dot-com bubble of the 2000's can be regarded as another clear creation period of subcontractor networks. The role of IT main suppliers became that of being managers of the networks and not as performers of the value-adding work. So the IT industry searched for such companies from the metal industry that would have less heavy cost structure and that would be more cost-efficient. Subcontractor network extended and culture changed.

After the bursting of the dot-com bubble, problems for the Finnish subcontractors began. During the dot-com bubble, massive sales did not compete so much with prices than with availability. After the bursting of this dot-com bubble the situation changed completely: now competition was all about prices. This turned out to be detrimental for many Finnish subcontractors in the field of metal industry. New customers had to be found. Main suppliers started to move their production as well as their subcontractor network abroad. Small Finnish subcontractors were not ready to establish manufacturing operations abroad – they settled for their lot.

After various stages of development, engineering works industry turned into a subcontractor network where the one who can control the whole SC will be most successful.

3.1.2 Manufacturing prefinished products

Concentrating on core knowledge and along with that using the subcontractor networks has forced engineering works to use more and more ready-made parts and subassemblies. In this study, prefinished products are defined as plate parts that are flame-cut or plasma-cut from steel. Typically, the thickness of plate parts is approximately 10–150 mm and they are cut from different steel qualities. Steel parts include also holes, bevelling and surface finishing as painting.

Manufacturing of prefinished products has traditionally been one of the stages of work for an engineering works. This stage of work has taken place at the beginning of manufacturing process. However, this stage of work has been given up due to the fact that efficiency in manufacturing prefinished products depends substantially on utilization rate of the steel plate to be cut. The less waste that is produced from the plate, the more profitable it is to manufacture prefinished products. At engineering works different blocks are manufactured from several plates of different thickness and of various steel qualities. Therefore, the amount of waste has traditionally been considerable when manufacturing plate parts at engineering works. Due to this, manufacturing of plate parts has concentrated in engineering works and steel industry where plate parts are manufactured as mass production. This way the amount of waste can be minimized and operations can be made more efficient.

Subcontracting of prefinished products has developed during the decades. Most typically prefinished products are manufactured for large steel integers where the main supplier sells directly to the end user. This applies also to the products of the case company.

Manufacturing of prefinished products has been networked as well. Typically the raw material, steel, is purchased directly from a steel factory or it is obtained through intermediaries. In the manufacturing process also subcontracting is needed for manufacturing prefinished plate products. The most typical stages of work to be subcontracted are machining, bevelling and surface finishing. Manufacturing plate products by flame cutting or plasma cutting is core knowledge for a production plant that manufactures prefinished products. Machining and surface finishing require especially good expertise. Therefore the endeavour is to subcontract these stages of work from such companies that are, as their core business, concentrated in these stages.

In Finland there are approximately 5–10 leading companies that manufacture prefinished products. Companies are either specialized in manufacturing plate parts or they function as service centers for steel companies. Customers of these manufacturers include solution suppliers of main suppliers or main suppliers as well as medium-sized engineering works. Also small and medium-sized companies manufacture prefinished plate products. There are a few dozen such companies. The products of small and medium-sized companies usually include various other products. The customers are usually consumers or small engineering works.

Manufacturing of prefinished plate products is regarded as a continuously growing business. There are markets to be gained in Finland as well as abroad. In Finland it is possible for the business to grow for a few more years still, but the largest growth potential in Europe is in Central-Eastern Europe and in Eastern Europe. Engineering industry in Eastern Europe and in Central-Eastern Europe is developing in the same manner as it developed in Finland. The pressures caused by efficiency force the industry towards the same, more networked operations model as in Finnish engineering works. The same applies also to outsourcing the supplying of prefinished plate products from a manufacturer that is concentrated in manufacturing steel parts.

As a whole, concerning prefinished plate products, there are clear advantages of centralization to be gained. Benefits of scale do themselves justice when products for several different customers can be manufactured from the same steel plates, in which case the use of steel plates becomes more effective and only little waste is produced.

3.2 Case company

Rautaruukki supplies metal-based components, systems and solutions to the construction and engineering industry. Ruukki is the brand name for the company. Ruukki adopted a new business philosophy in 2003 when its business model was changed. Ruukki moved from supplying steel products to producing metal solutions. Ruukki has a very wide selection of metal-based products and services. Rautaruukki has operations in 27 countries and it employs approximately 12 000 people. The company's main office is located in Helsinki, Finland. Rautaruukki Oyj was established in 1960 and it is quoted on the Helsinki Stock Exchange. (Rautaruukki Oyj 2010)

Ruukki has three divisions to service its customers' needs: Ruukki Construction, Ruukki Engineering and Ruukki Metals. Ruukki Construction supplies metal-based solutions for the construction industry. Rautaruukki's vision is to be the most desired metal-based solutions supplier in 2008–2010. The company aims at extending the proportion of solutions businesses. It is aimed at Construction and Engineering divisions to account for more than the amount of net sales of Metals. The main market will be in Eastern Central Europe. (Rautaruukki Oyj 2010)

3.2.1 Steel Service Centers

Under Ruukki Metals division of the case company there are steel service centers which serve as steel refiners. Steel service centers manufacture blocks cut from steel plates according to customers' requests. Products are cut by using flame cutting, plasma cutting and laser cutting methods. Their customers consist of lifting and transportation equipment industry, wind power industry and engineering industry both in Finland and abroad.

The case production plant began its activities in April 2005. The amount of employees has grown steadily since starting the steel service centers and at the same time, the amount of products manufactured has increased. The production plant functions in two halls which share a total square area of approximately 8 000 square meters.

The number of machines has been increased substantially since the early stages of operations. The production plant has five gas cutting machines and three plasma cutting machines. Four of the gas cutting machines are manufactured by Messer. Two of these use five burners and the other two use four burners which have been equipped with bevelling units. The gas cutting machine uses five burners. Cutting tables of the gas cutting machines are 3.5 meters wide. The length of the cutting tables of Messer gas cutting machines is 16 meters. The length of the cutting tables of gas cutting machines is 13 meters. With Messer machines it is possible to cut blocks that are 150 millimetres thick. When using flame cutting machines the plate to be cut can be 200 millimetres at its thickest. Two plasma cutting machines cut blocks with two burners and the Messer plasma cutting machine uses one burner. The cutting tables of the plasma cutting machines are 10 and 16 meters long. Plasma cutting tables are 4.5 meters wide and it is possible to cut plates that are maximum of 16 and 32 millimetres thick. The width of the operating range of the Messer plasma cutting machine is 4.5 meters and the length 13 meters. The plate to be cut can be 32 millimetres at its thickest.

There are four edging presses at the production plant. Bevelling lengths are 4200 millimetres, 6000 millimetres and 8000 millimetres. Bevelling machines have compression force of 3200 kilo Newton, 4000 kilo Newton, 5000 kilo Newton and 8000 kilo Newton. The maximum width for blasting machine is 1500 millimetres and the minimum thickness of plate is four millimetres. Four machines are used in bevelling. Moreover, several forklifts and cranes are used at the production plant.

3.2.2 Production control system

The case production plant has in use a production control system which is customized for steel service business as a production control and planning system. The production control system has extensive software for pre-finishing functions of material. It includes production scheduling, production control and various other functions related to production. The production control system has been tailored to meet the needs of the steel service centers. The system includes the following items: Order input, Order status, Cutting, Work queue, Workshop, Inventory, Customers, Packing and Delivery.

In the Order Input item it is possible to track and review information regarding all orders. The order can be tracked according to different stages of work. These stages of work are: Order, Production order not planned, Planned production order, Unplaced production order, Placed production order, Material order completed, In production, Ready and All orders. It is possible to search orders from all stages of work within all fields entered, such as by order number. All information regarding the order, such as order number, customer's order reference, date of the order, due date, customer, by whom the order is processed, etc., can be found from the order. When managing the order, it is possible to review information regarding a specific order, such as search number, drawing number, principal measurements, routing information and other various data. From the Additional instructions field one can see the picture of the product as well as any further information regarding the order. By viewing order rows one can follow-up in which stage of work the blocks ordered are at any moment.

In the Cutting section gas cutting or plasma cutting is planned. In the Work queue section it is possible to review work queues. Through this section the foremen regulate collecting of material and capacity utilization rate. In the Work queue, there are views regarding loading of all loading groups, that is, machine groups. Through this session it is possible to review loading per each machine. Stages of work are signed off as started and finished with help of Interned-based software through the Work shop section. Main users of the Work shop section are the workers who report information to the system.

Through the production control system it is possible to produce reports regarding the various functions of production. When using the report application, one chooses the required report, enters the possible definitions, after which the reports can be printed out in pdf or xls format. Report types include, among others, search numbers not reported, failed reservations updates, internal reliability of delivery for geometry, uncompleted jobs per customer and date, final report, cycle of blocks, block warehouse, duty cycle, disposition load per machine, internal reliability of delivery, kilos per customer, status of planning and order information. Reports can be produced for different purposes as needed.

3.2.3 Order processing and order planning process

Order processing, as a whole, takes place in the centralized order processing function. Order processing starts when the order is received in the order processing function. Orders come in mainly by fax or e-mail. In order processing, information regarding prices, materials and stages of work are reviewed together with offer calculation department. Furthermore, revision information of the items are reviewed and updated if needed. Offer calculation maintains the tariffs in Excel files, where the person processing the order can check the prices for products before confirming the order to a client. Excel tables also contain the information regarding stages of work and materials for the products. If the product has not been previously manufactured, the persons calculating the offer and processing the order review the new product and process the price data, stages of work as well as the materials information. A new Excel table is compiled based on this information and the table is saved. The person processing the order enters the information regarding the order into the production control system. All information regarding the order (customer, date of delivery, ordered items, prices and number of pieces) is to be entered to the system. The orders are manually entered to the production control system.

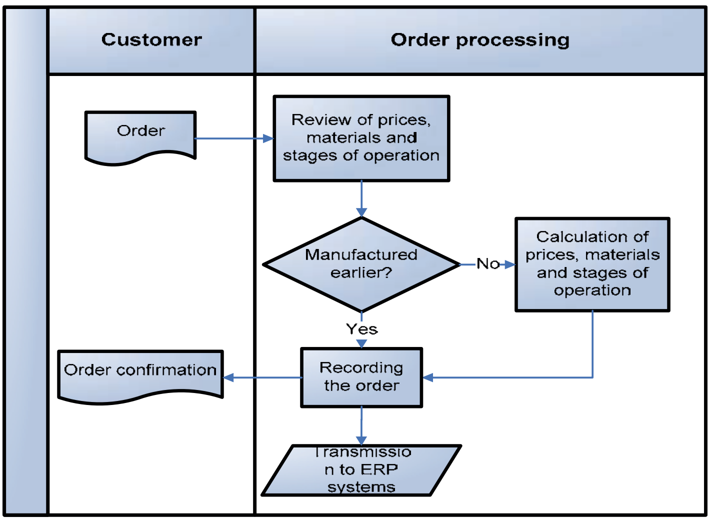

Fig. 6. Order processing.

Order processing begins in the case production plant when the order appears in the Order Input section. A note regarding order processing being finished appears in the Work queue. The order is released for production planning. This provides production planning an opportunity to start reviewing the order and check the routing of stage of production. If the product has been manufactured before and geometry of the product has been created, the product is released for disposition. If the product has not been manufactured before and geometry has not been created, a picture of the block is drawn either with cad-software or the Cutting function in the production control system. After this, the product is released for disposition. In the Disposition section the products to be disposed are selected on basis of date, scanting and quality of material and they are dispositioned on the plates to be cut. The aim is to get as many products as possible on the plates and to disposition the plate in such a way that as little waste as possible is produced. During disposition, the the availability of material is checked from the production control system. If needed, amount of material is checked by checking the status of material warehouse. In the Work Queue a machine where the work is dispositioned is selected. After this, calcination trajectory is prepared for disposition and finally the order is transferred to the Work Queue.

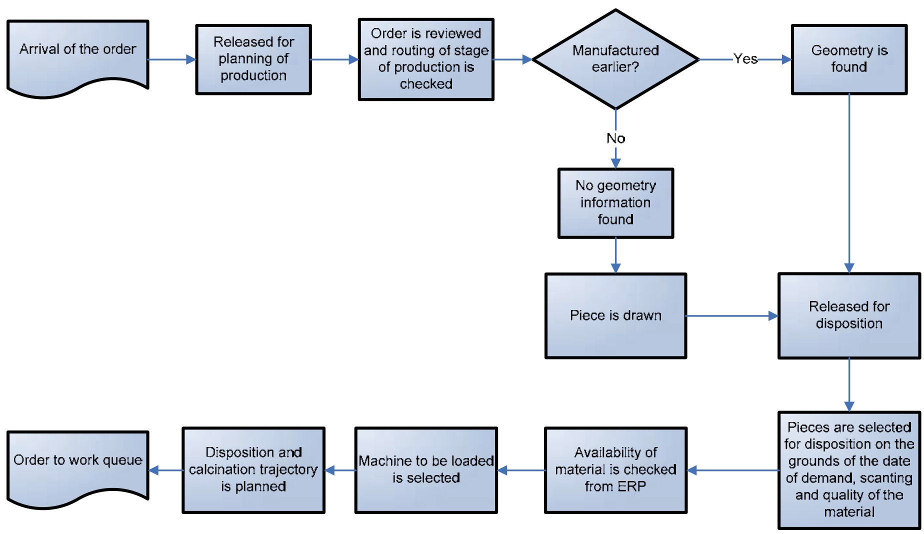

Fig. 7. Production planning process.

3.2.4 Production process

The production process includes picking up the material from the warehouse, all stages of work allocated to the product, collecting and dispatch. Stages of work are flame or plasma cutting, bevelling, shot blasting, edging and finishing. In the production process the material is moved using bridge cranes, pillar cranes and forklifts. Production functions in a manner in which, after one stage of work is completed, the material is transferred to the next stage of work.

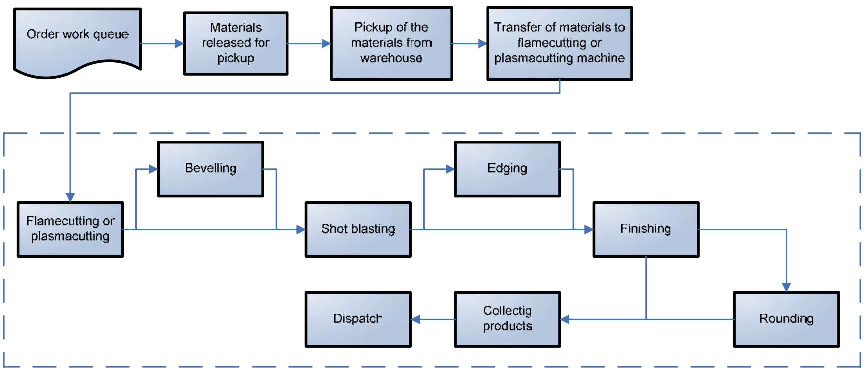

Fig. 8. Overview of the production process.

Picking up the materials from warehouse

The production process starts when the foreman releases materials to be picked up from the warehouse. Management is able to regulate application of load by releasing plates for pick-up. Store men obtain the information of the plates from production control system. Plates are picked up either from the block warehouse or from the material warehouse. After this the plates are taken to cutting table using forklift.

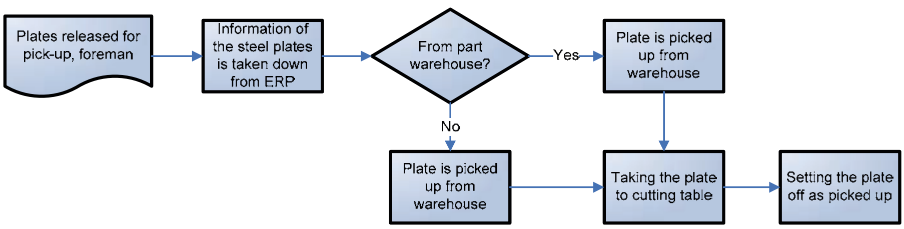

Fig. 9. Picking up the steel plates for cutting.

Cutting

The cutting stage of work is divided into four main stages: checking the material, preparative tasks, cutting tasks and finishing tasks. The cutter retrieves the disposition of cutting from the production control system. The cutter checks the material and enters the melting number to the system. In reviewing material, thickness of the steel quality, quality of surface, sufficiency of material and evenness of the surface is checked. In preparatory tasks the material is cleaned of extra dirt. Heads are chosen according to the means of cutting. Furthermore, the pressures are adjusted and the flames are checked. In flame cutting, verticality of burners towards the plate is adjusted. If needed, the burner intervals are checked and adjusted. After this, work specific cutting values, preheating time, cutting speed and cadence time are adjusted for the flame cutting machines. For plasma cutting machines, current, voltage and cutting speed are adjusted.

Cutting begins by dispositioning the block on the plate. After the first block has been cut the measurements of the part cut are reviewed. If there are various different blocks on the plate, measurements of the first block of each type are reviewed. Possible tolerance measurements are checked and complied with. Production planning adds the tolerance information for the blocks and the cutter is able to perform the check. If there are any problems in the program, possible fixing of compensation or program is performed. After this, the blocks dispositioned on the plate are cut. During cutting, the cutter reviews the condition of the heads as well as the quality of combustion trace. Furthermore, movements of the machine, backlashes, flames, possible movement of the plate and movements caused by heat expansion are followed up.

In finishing works the blocks are reported as ready and they are removed from the table to a box or they are moved to beds. Each batch is marked by printing out an adhesive label per product lot from the production control system. The blocks can be identified with help of the adhesive label. Adhesive labels contain, among other things, name of the customer, possible additional notes requested by the customer, production order reference number and names and due dates of the next stages of work. Waste material is removed from the cutting table to waste beds. If any blocks are rejected they are reported to the production control system. Finally, the complete products are checked and the blocks are transferred to the next stages of work.

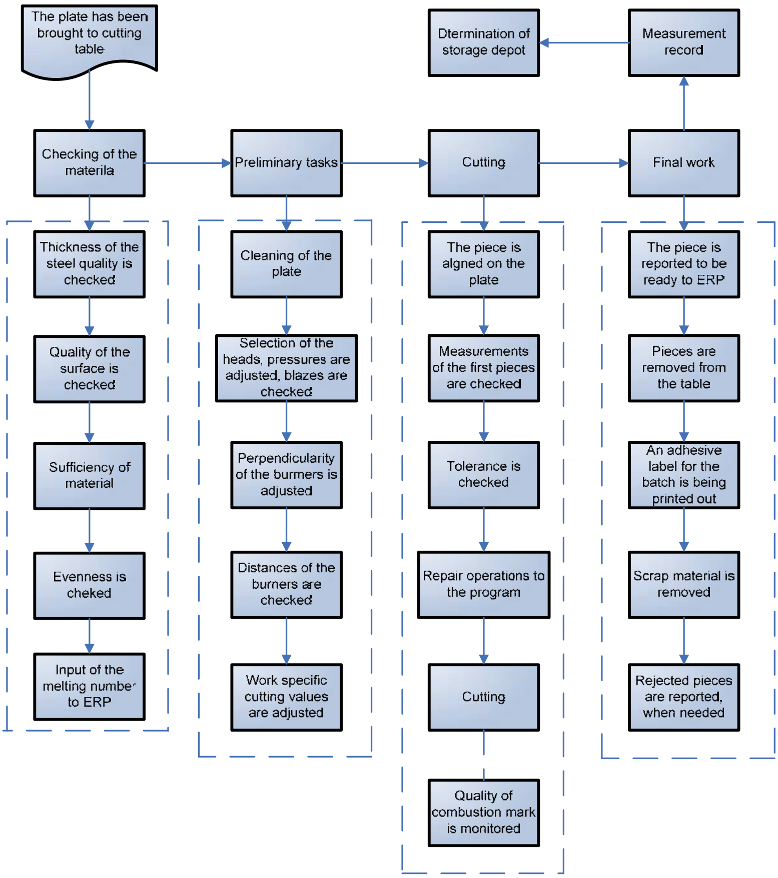

Fig. 10. Description of cutting process.

Bevelling

Bevelling is conducted manually with bevelling machines, flame cutting bevelling cutting machine, manual bevelling machine or flame bevelling machine. The works to be bevelled are selected from the production control system. After this, working instructions are reviewed and settings according to the working instructions are created for the machine used. After bevelling is completed, a verifying measurement is made. Here the user checks the first block that was bevelled after making the settings. Bevelling is finished off by removing burrs and extra material. Markings are made to the block and if needed, a measurement record is compiled. Finally, the block is reported to be ready and a warehouse depot is specified for the block, or it will be transferred to the next stage of work.

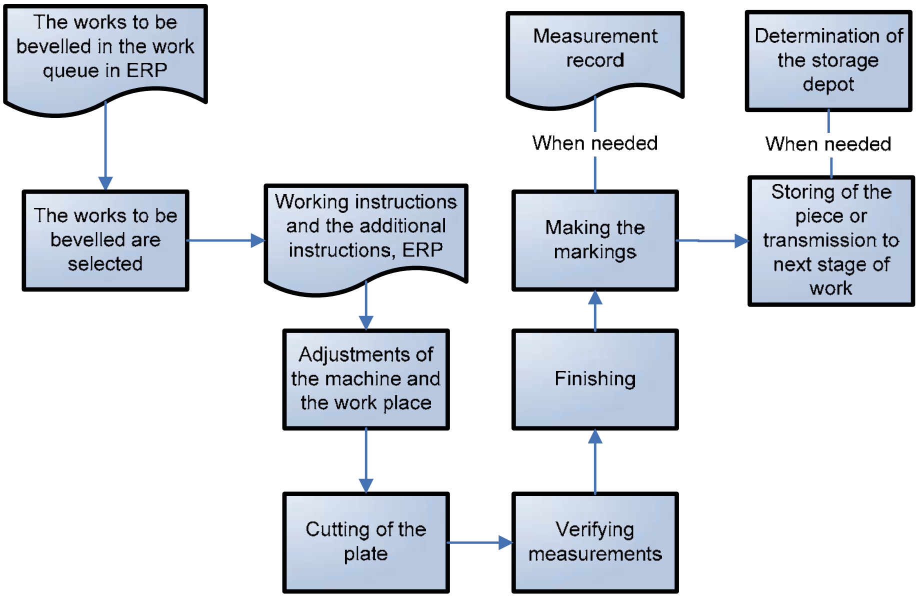

Fig. 11. Description of bevelling process.

Edging

In edging, the works are selected from the production management system according to dates or edging tools used. The disposition report as well as adhesive labels come along with previous stages of work. Furthermore, attached to the blocks there are adhesive labels on the basis of which the block can be individualized. Edging instructions as well as further instructions are reviewed from the production management system. The working program to be used in edging is created by providing title of material, thickness and length. With help of the working program the forces to be used are defined. Information from the working program is recorded in the production management system. The edging picture is processed and reviewed for edging, after which the tools needed are installed on the edging press. Bloom is placed on the working surface with help of back stops or the help marks cut in cutting. If the help marks or back stops cannot be used, the line to be edged is dimensioned on the block. After this, the corner is edged and checked. Tolerance check-up is conducted according to tolerances used in the production line unless customer has suggested any other special requirements. The special requirements can be seen from the work order. If no need for corrections is perceived, edging of the block is completed and the block is checked. If a defect that results in the block not being suitable for market appears in the block and it is not possible to repair it, the block is rejected. If the block can be repaired, repair is conducted and edging of the block is completed. During edging the factors affecting the result, like movements of the machine, accuracy of upper and lower tools and back stops are monitored. When the work is completed the blocks are signed off as ready in the production management system and they are either stored or moved to the next stage of work.

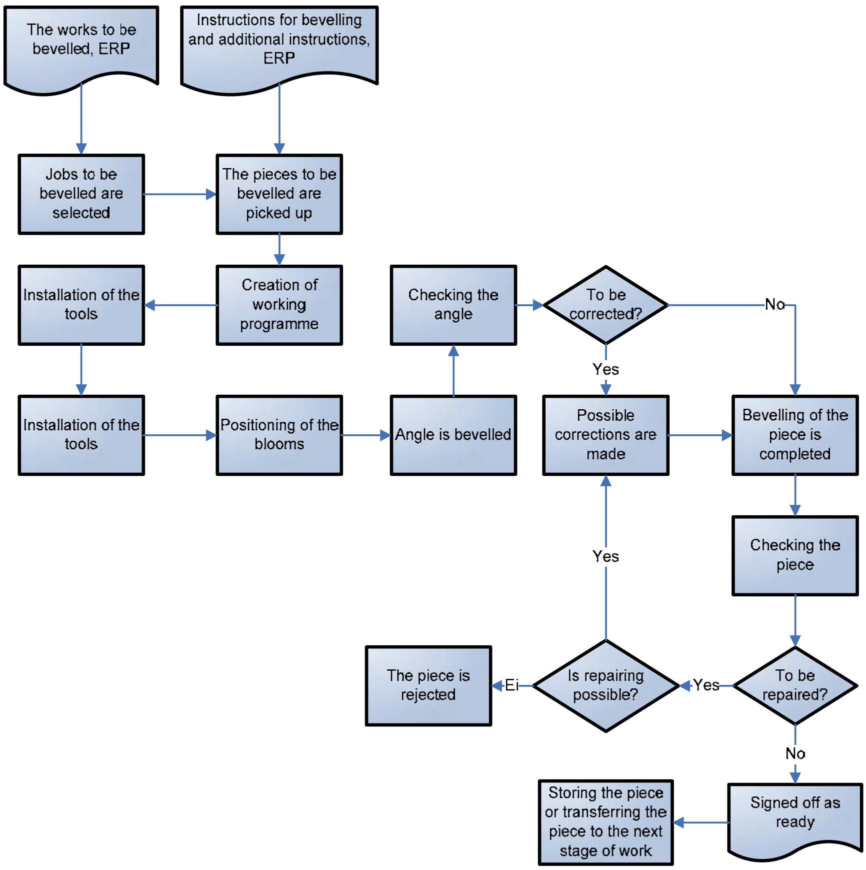

Fig. 12. Edging process.

Shot blasting

Shot blasting is carried out when it is included in the operation chain. With shot blasting unit it is possible sand-blast a 1.5 meter wide block. If the blocks are wider, a subcontractor needs to be used for sand-blasting. Normal sand-blasting degree is Sa 2,5 (ISO 8501), according to which, when viewing with the naked eye, on the surface there must not be visible traces of oil, fat, dirt, mill cinder, rust, paint or foreign matters. It is also possible to use other, separately defined quality standard of cleaning if this has been specified by the customer or in the order. Shot blasting is begun by reporting the work as started in the production control system. After this the blocks are lifted on the shot blasting line with forklift or manually. The line rolls the block through shot blasting. Small blocks are blasted through a net. After blasting the blocks are reported as ready and they are moved with forklift to the next stage of work or they are stored to wait for collection and dispatch.

Finishing and plate rounding

Finishing is done manually by using corner grinders, drums, pneumatic chippers and other possible equipment. Works to be finished are retrieved from the production control system and the works are reported to have started. Blocks are picked up to worktable of the post. Blocks are abraded with a corner grinder in the horizontal position from both sides. Alternatively it is possible to use an abrasive belt grinder or chisel. Next, the whole block is finished and starting and ending points of burning are abraded. Quality requirements for finishing are that any burrs still attached in to block are removed well enough, measuring accuracy for the blocks is maintained and that the amount of blocks does not change. Blocks are lifted with the help of forklift or cranes. The block is signed off in batches as ready into the production control system. Finally, the block is stored or moved to the next stage of work.

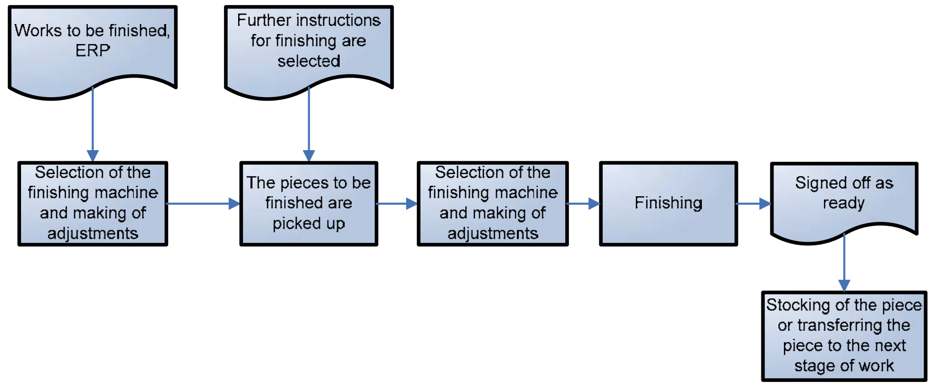

Fig. 13. Finishing process.

The Plate rounding machine is designed to roll cylindrical, conical or round shapes through deformation of material. The block is manufactured by pushing the material through bowls, when the block moulds itself to its shape when the casters are rolled. Starting of the plate rounding stage is reported to the production control system. With help of lines made on the plate it is possible to make the right kind of roundings. The plate is placed into the machine and rounding is performed. Between the roundings the rounding angle is measured. Finally, the clevis is opened and the rounded block is lifted off the machine. The work is reported as ready and it is moved to the warehouse or to the next stage of work.

Warehouse functions

Collecting and dispatch are carried out in co-operation with the production assistant, warehouse and transport services subcontractor. The production assistant reviews the completed orders from the production control system. Completed positions of order are signed off on the production control system and a dispatch is automatically printed out for the warehouse foreman. The warehouse foreman organizes collecting of the product after which the products are packaged. In collecting, it is possible to follow the customer's instructions regarding arrangement of the products for transport. Products are packaged and covered with cellophane. If no missing blocks or any other mistakes are discovered, dispatch is completed. If there are any abnormalities in the blocks, the supervisor in charge of repairing or re-manufacturing the blocks is informed. Dispatches are returned to the warehouse foreman who arranges the order of transport from the subcontractor. The subcontractor takes care of the transportation arrangements but loading of the goods is done by the warehouse. The warehouse foreman forwards the certificate of the material, bill of freight and consignment note to the production assistant who archives the documents.

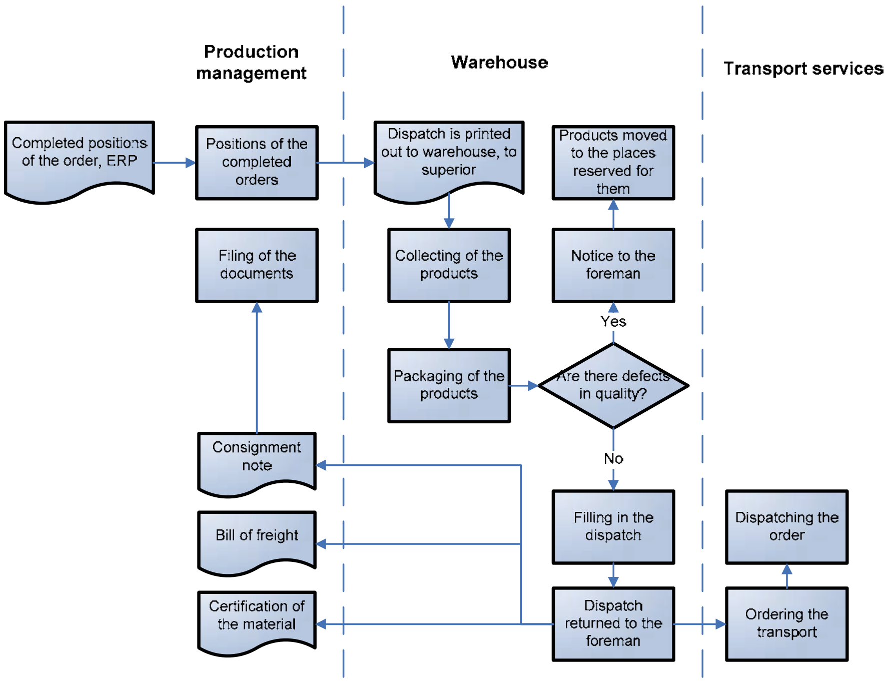

Fig. 14. Collecting and dispatch process.

3.2.5 Quality system

The case production plant has a certified SFS-EN ISO 9001:2000 quality control system. Adopting a quality control system was a strategic decision for the organization. This international standard encourages adopting a process-like operations model when developing the quality control system as well as when carrying out and enhancing its effectiveness in order to increase customer satisfaction by fulfilling the customer's requirements.

To be able to function effectively, an organization must identify and manage many interrelated functions. A function, where resources are used and managed in such a way that it enables input to be turned into output, can be regarded as a process. Usually an output of one process directly forms the input for next process.

Applying a process system in an organization, identifying processes and their interactions and managing processes can be referred to as a process-like operations model.

The building of the quality system was started immediately after launching the production at the case production plant. On the basis of standard, an operating system has been established. The system includes codes of conduct, process descriptions and descriptions of industrial safety functions, product-specific instructions as well as memos and reports. The quality engineer is responsible for the operating system being up to date. The operation system is updated in connection with changes. Activities are monitored by conducting steel service center’s internal audits.

3.3 SCM performance measurement in 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. If the case company does not remain lean, prefabricated products can be imported to Finnish markets from central Eastern Europe or even from China. With Finnish cost levels, one has to be the best in their field and specialize in doing exactly what one can do best. Prefabricated 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.

Foundation of indicators is acquaintance with the case company and the engineering works field it represents and process descriptions. In process descriptions, all production processes of the case company were described. Order book analysis describes the present state of the company as well as to which products and customers one has to focus in measurements.

The SC of the case company can be measured with following indicators, taking into consideration the special characteristics of the SC:

- order book analysis
- profitability
- time
- managerial analysis.

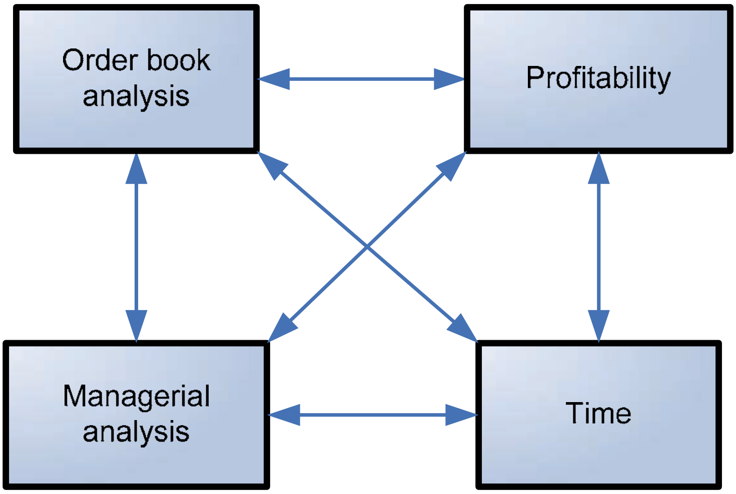

Fig. 15. SC performance measurement indicators.

3.3.1 Order book analysis

Measuring the SC of a production plant has its foundation on order book analysis. According to the survey to literature, order book analysis can be categorized to non-financial metrics (Gosselin 2005, Kaplan & Norton 1992, Lambert & Pohlen 2001, Lawrie & 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, Toni & 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 the most central indicators. Especially typical to the operation of the case company is that there are products that are manufactured for the other divisions of the company. Due to this it is worth analyzing how the so called internal customers of the company affect the load and reliability of the production plant. The proportion of external customers of the production must also be established.

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, essential measurable quantity. In the light of previous amounts produced – together with the sales forecast obtained from sales – it is possible to plan the future capacity and future production.

One of the cornerstones of customer satisfaction is on-time delivery. On-time delivery means an order that is completed exactly at the right time; not an order completed ahead of time nor an order that was completed behind the schedule either. On-time delivery has been placed as an indicator also for the whole consolidated corporation of the case company. Customer satisfaction is closely related to fulfilling the promises to the customers. When a good on-time delivery is achieved it is possible to lead the production in a more effective manner and introduce the prognoses for loading of production. On-time delivery reflects the operational culture of the production plant well. To achieve good on-time delivery depends usually on leading the company operations, management and especially SCM. The significance of on-time delivery has been emphasized due to minimizing invested capital being one of the essential goals of all members of the SC. Customers seem to have pressure on the same direction. One has to be able to decrease stock and incomplete production in order to release capital. This goal is reached only by operating in a prompt manner in the SC and by making sure that manufacturing of products is completed just on time.

One sector of order book analysis is quality of the product and especially deviations from the quality. One has to find the golden mean in quality of the products and quality standard. It does not pay off to manufacture too good quality because the costs will in that case increase. On the other hand, producing bad quality does not pay off either because repairing the reclamations is expensive. Furthermore, with bad quality one can easily ruin a good relationship with a customer. One has to find a product quality standard which will satisfy the customers' needs but which is not too expensive to manufacture. It is worth measuring product quality due to the fact that this helps analyze in which stage of production product quality is not been reached and errors occur. It is also good to divide the product qualities according to stages of work so that one can analyze which stage of work causes deviations in the product quality.

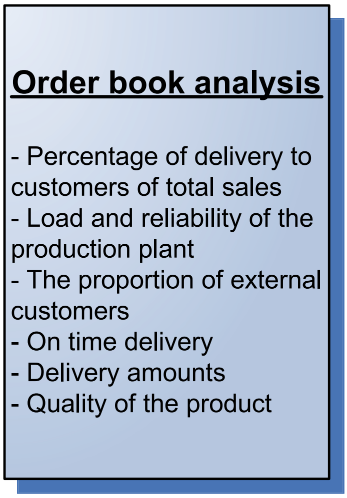

Fig. 16. Order book analysis measures.

3.3.2 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, Kaplan & Norton 1992, Lambert & Pohlen 2001, Lawrie & Cobbold 2004, Neely 1999, Olsen *et al.* 2007, Tangen 2004, Tapinos *et al.* 2005, Thakkar *et al.* 2007, Toni & 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.

A significant part of the overall cost of the order consists of material expenses. After this the costs resulting from processing can be predicted on the basis of realized hourly rates. The largest element of cost, raw material, has in the case of the case company been manufactured at its own steel factory or been bought from outside the company. Especially close attention has to be paid on following-up the costs of steel. Transparency of costs and fast transferring of price changes to product calculation has to be flexible. The amount of invested capital has to be maintained as low as possible because in this way one can ensure the effect of a possible nosedive or rise in prices of raw materials to capital. Due to this, raw material stocks and uncompleted production should be kept at their minimum during the whole SC.

The cornerstone of efficacy in the steel service business is minimizing the waste produced in cutting steel plates. When cutting blocks from steel plates it is especially important that all possible blocks of the same steel quality in the order book are planned to cut from a single steel plate in such a way that the plate can be used as efficiently as possible. One has to be able to disposition the blocks to be cut from steel to steel plate in such a manner that the utilization rate of the plate is as high as possible. Waste of steel plates is expensive to the company because the waste has to be sold forward as steel waste. Naturally, compensation from steel waste is considerably lower than the compensation from the blocks that have been cut. The more successful the disposition on the plate is the more profitable the blocks manufactured are. Disposition of the blocks to be cut on steel plate depends on the volume of orders. If the volume of orders is extensive enough it is possible to find suitable disposition entities. When the volume of orders is inadequate, disposition functions will become very challenging.

The profitability indicator is divided into profitability analysis of the blocks in the order. Each part belonging to an order should be profitable to manufacture. A situation where part of the products is unprofitable and part of the products profitable has to be avoided, even though the order as a whole would still be profitable. When each of the parts is priced correctly and its profitability is ensured, the customer does not have doubts about correct pricing of the products. The worst scenario would be the customer ordering only the unprofitable products from the production plant and buying the products with good margin from somewhere else. In order to eliminate this situation, after a delivered order one must conduct re-calculation which consists of evaluating all the costs for the order and comparing these to sale prices.

3.3.3 Time

Lead-time is in many studies considered to be one of the central indicators in manufacturing industry. De Toni *et al.* present time-based indicators as non-cost indicators, where time can be measured as internal or external time. (Toni & Tonchia 2001) Gunasekaran *et al.* (2004) present a great deal of time-based measures. (Gunasekaran *et al.* 2004) Time is also identified as the next source of competitive advantage (Balsmeier & Voisin 1996, Kessler & Chakrabarti 1996, Mehrjerdi 2009, Stalk 1988, Vesey 1992). 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. At steel service centers measuring lead-time is extremely challenging due to diverging and converging production control. Diverging production control draws from the products cut from various steel plates. On the order there may be several products which are manufactured from steel plates with different thickness. Blocks from different orders are gathered for the steel plate to be cut. Consequently, completion of the whole order takes place at different times, depending on planning of production. The products completed at different times are put together at the latest in the collecting stage of work where each of the orders is collected.

Time between order and delivery is an indicator that the customer is especially interested in. Sales makes the customer a promise regarding time of delivery and the customer expects the company to comply with it. Time between order and delivery for prefabricated products has to be extremely short because complete products often go to the customer's production lines and they are used as raw material for various machines and devices. When making a sales contract the time of delivery and often also possible sanctions – should the company not be able to comply with time of delivery – are also agreed upon.

One goal of the time between order and delivery is to measure and decrease production lead-time. Production lead-time begins when the order is placed into production and ends when the products are ready to be delivered. Continuous decreasing of production lead-time is feasible by renewing processes and developing new methods. It is possible to decrease lead-time by investing in new machines and devices.

The production time of order is an essential quantity. On the basis of production time it is possible to analyse the development of stages of work as well as development of working methods. Another essential indicator is intermediate storing time of products, which can be calculated by subtracting production time from total lead-time. If the SC is working effectively, it is possible to eliminate the free time (the time during which the products are waiting for the next stage of work in an intermediate depot or buffer stock) for all products. Similarly, invested capital can be eliminated and better prerequisites for prompt functions can be established.

On-time delivery is a time-based indicator and it suits well for measuring the function of a hectic steel service center with a poorly predictable order book. The goal of on-time delivery is minimum of 98 percent and on-time delivery is calculated in days. From a customer point of view on-time delivery of prefinished components is critical due to the fact that products for several customers go directly to a manufacturing process. If the customer has planned production in such a way that the manufactured products go straight to production, on-time delivery is also a factor contributing to customer satisfaction.

The aim is to eliminate the amount of incomplete production with on-time delivery. The intention is to manufacture only the products that should be completed within a certain time frame. This ensures that there are not too large amounts of incomplete production in the production process. This way the amount of company capital invested in incomplete production is decreased.

The significance of on-time delivery has grown among customers. This is due to the fact that also customers aim at minimizing the amount of incomplete production and decreasing stock values.

3.3.4 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, Gunasekaran *et al.* 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.

Managerial analysis can be performed by a person involved in the SC, by a manager or by external experts. Analysis can be conducted by visual perception, collecting information by interviewing people working in different stages of the SC or with help of information obtained from data systems. The role of the analyst is to come to conclusions of the whole as well as come up with a general view of it.

The goal of analysis is developing the SC. To be able to develop the SC to be more cost-effective and competitive, one has to analyze the results from the measurements.

4 Supply chain process profitability in the case study

In this chapter the SC is measured with previously established indicators. The indicators consist of four different parts: order book analysis, outcome, time and managerial analysis. In order book analysis, the production plant's completed output and reliability of delivery in different years are reviewed. SCM can be also measured from the point of view of outcome, in which case profitability of completed products is measured. Also the costs of the SC are observed. Time-based measuring of the SC is conducted by measuring the delivery cycle, delivery accuracy, production time and its subdivision into operational times. The SC is also measured by analyzing the whole SC and its various parts. Finally, functionality of established and tested measuring systems is analyzed in measuring the case SC.

4.1 Order book analysis

At the case plant products are manufactured in a customer-oriented manner. The products are parts cut from steel plates that will be upgraded at various mechanical engineering companies. The products are mainly different and therefore it is extremely challenging to carry out mass-customization and warehousing. An exception is made by certain products of a few large customers, for which the demand can be predicted fairly well. Possible revisions to the parts made by customers or even changes in assemblies are challenging.

Customers of the case company's case production plant are divided into contract customers and non-contract customers. The aim of the company is to create long-term contracts and partnerships with strategically important customers. The goal is to produce additional value for customers. Instead of selling only steel plates or strip products, additional value for the customer can be created by selling the products as ready cut steel parts. Contract customers have made a contract with the case company regarding manufacturing of the parts to be cut. The aim is to make long-term contracts which are tailored to meet customers' needs. Most typically, the load of contract customers varies a great deal. Capacity is sold to non-contract customers if it is estimated that the products can be manufactured in tandem with the products for contract customers. Contract customers are divided with various steel service centers in such a way that each steel service center can specialize in serving specific customers. The aim above all is to centralize the customers that are using the same plate thickness to the same product plants, so that it is possible to use steel plates in a more effective manner.

Customers of the case production plant in 2006–2009 are presented in the image below. In 2006 the production plant had 79 customers, whereas in 2008 it had 264 customers. There has been a considerable increase in the number of customers. The production plant serves corporate group's internal customers, whose proportion of the total production was significant each year. In 2009 volumes of internal customers increased and volumes of external customers decreased. Due to this, the number of customers in 2009 was 189. Compared to the volume of the production plant, the number of customers is very considerable.

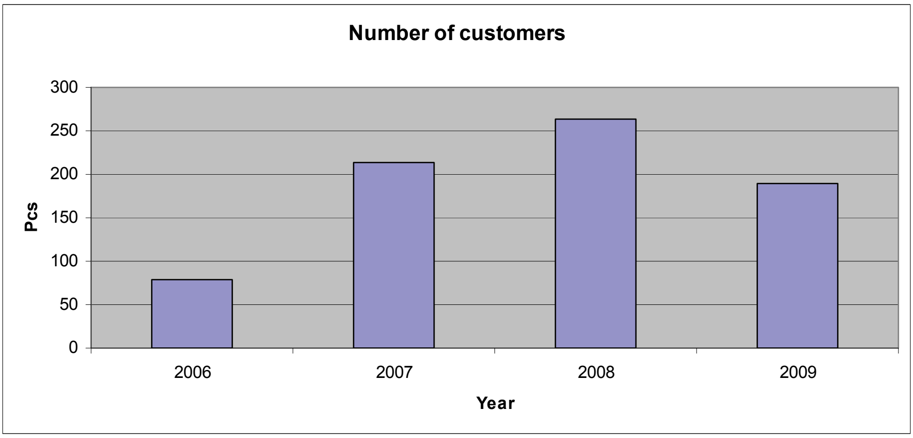

Fig. 17. Number of customers 2006-2009.

During the period under study, the proportion of external customers in the output has varied tens of percents. At its largest, the proportion of production for external customers was less than 50 percent of the total production in 2007. The proportion for external customers reached its minimum in 2009 when just over 20 percent of production was manufactured for them.

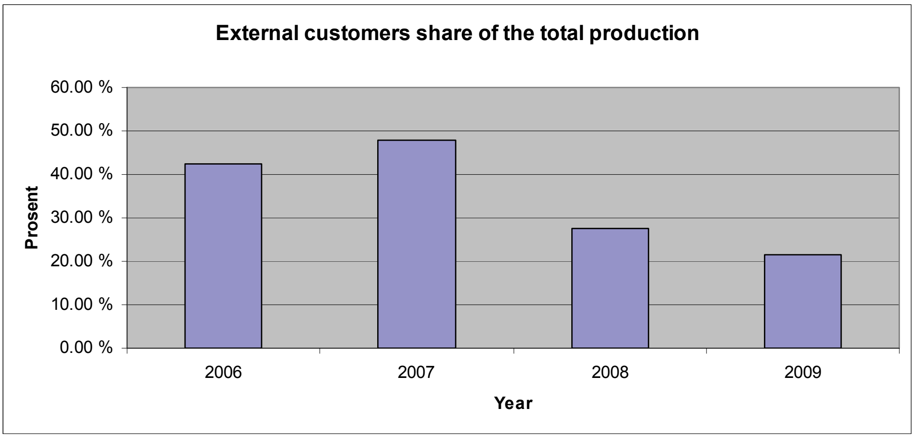

Fig. 18. External customers' share of the total production from 2006 to 2009.

Manufacturing volumes per customer are divided among the 20 largest customers so that the first four customers form the largest portion of sales. These customers are internal customers. Volume of external customers is roughly the same with regards to all the 16 biggest customers. After this the volumes decrease to very small amounts. Considering the number of customers there are numerous low volume customers.

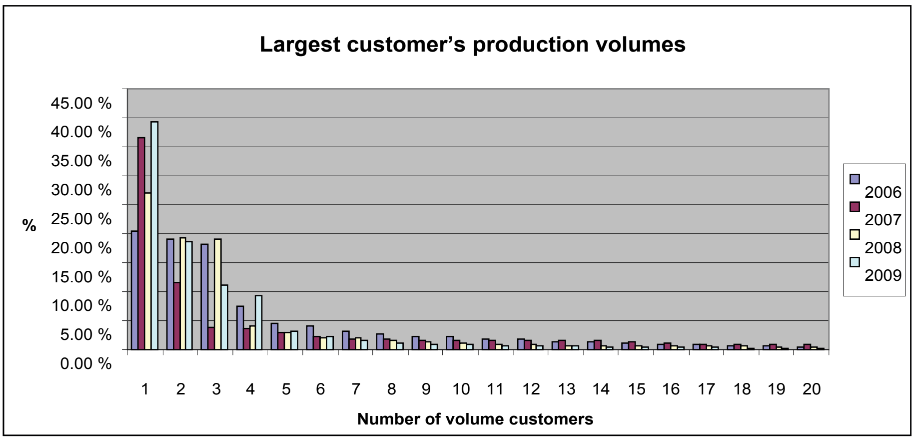

Fig. 19. Largest customers' production volumes 2006–2009.

The case production plant began its activities in 2005, when production facilities were installed in the steel service center, personnel were hired and production was commenced. In 2005, 955 tons was manufactured. In 2006, increasing production as well as rationalization of the production facilities begun. Furthermore, in 2006 a new operation control system was implemented in the production plant. In 2006, 8118 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 15508 tons, which is nearly double with regards to year 2006. In 2008 the amount produced increased from before to 24 147 tons, which is 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. As demand from external customers faded, the compensating fact proved to be the moving of work loads of the large consolidated company from another production plant to the case production plant which could function very efficiently. Especially significant is the fact that since 2005 the stock of machines has not changed much. The whole SC has been developed and growth has been wilfully forged.

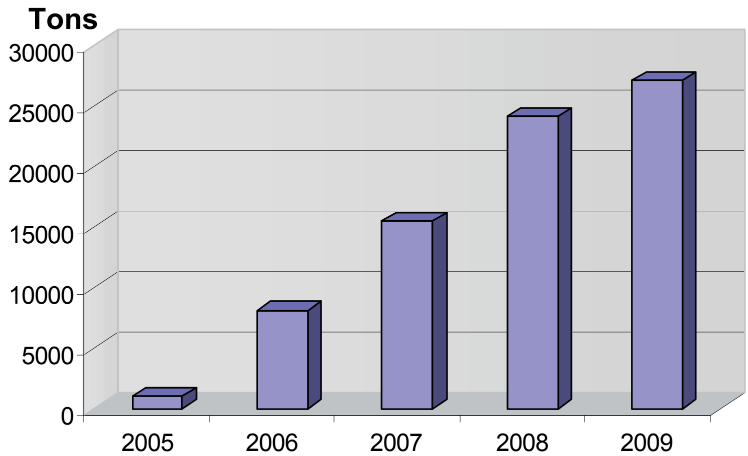

Fig. 20. Output in tons completed at the case production plant, 2005–2009.

The monthly variation in output has been substantial. The diagram shows that during the first month after starting production in 2005, one ton of products was manufactured, whereas in March as much as 227 tons was manufactured. Growth of production appeared as a distinct trend as volume increased. Monthly output of 2006 grew distinctly compared to the previous year. Growth in the output quadrupled from 277 tons to 1275 tons per month. Due to this considerable variation, the degree of capacity utilization has been challenging. During some months there has been plenty of work and during others not. On the other hand, during this year the production plant has increased its production considerably and this has without doubt caused irregularity in the load.

In 2007 – the year of rapid growth – output ranged from 840 tons to 2040 tons. Variation has steadied but it is still treble. However, output has clearly steadied and it is an average of 1000 tons to 2000 tons. Implementing the production control system has clearly affected the stability of production at the beginning of the year. It has been possible to equalize the load and the peaks in loading have been caused deliberately. In 2008 output varied from 1421 tons to 3252 tons. Variation has clearly steadied in 2009 when variation was from 253 tons to 2510 tons. In the event, variation has been more subtle, because in June the whole production plant has been closed due to vacations. The volume of orders has clearly steadied in 2008 and 2009.

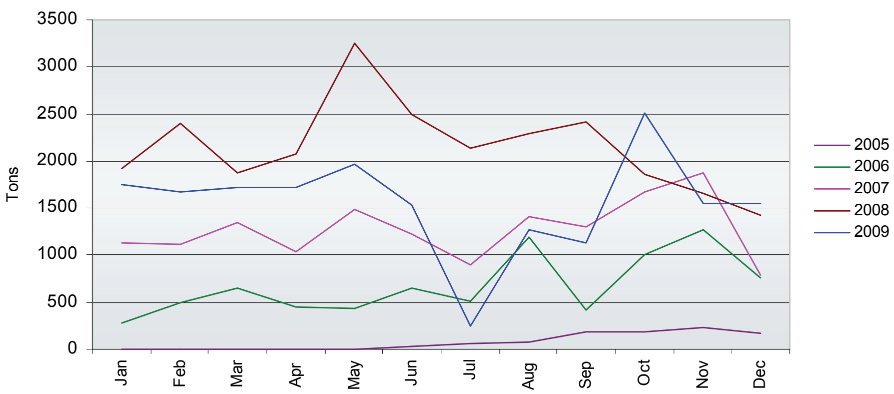

Fig. 21. Output of the case production plant in 2005–2009.

4.2 Delivery reliability of the orders

Delivery reliability of the orders is measured with the help of the operation control system. Sales enter the delivery date into the system. The shipment is also recorded into the system. In delivery reliability, the dates of promised time of delivery from sales and the dispatched order are compared. The delivery is in time if the dates match. The production must not be completed too early since in this case storing will cause problems and capital is unnecessarily bound to the production process. Furthermore, customers would like to avoid receiving the products too early because prefabricated products are often taken directly to the customers' production process. Hence delivering goods beforehand raises a need for warehousing and increases the amount of customers' capital bound to production.

In 2005 delivery reliability averaged out 37.5 percent. This was very poor, and was largely due to the challenges related to the production process that were caused by starting production. Also irregularity in load of production can be regarded as a significant reason for delivery reliability being poor. Growth has not been moderate and therefore it has been hard to maintain delivery reliability at an high level. Furthermore, training the personnel and installing new machines consequent upon starting production have in their part caused delivery reliability to be low.

In 2006 delivery reliability averaged out 47.33 percent. Delivery reliability was at its worst in October, when products were delivered on time from the production plant to the customer with 8.5 percent certainty. At its best delivery reliability was 93.6 percent. Variation has been considerable and the vigorous growth appears as weak delivery reliability. Although the output has been considerably large during some months, it has been possible to maintain delivery reliability even above the average. When delivery reliability has been weak, smaller amounts of completed products have been manufactured. It has to be taken into account that production has been increased a great deal and due to this the ratio of output to delivery reliability is not interdependent.

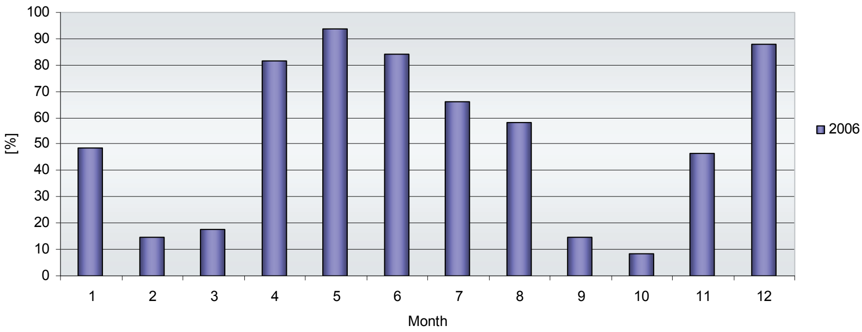

Fig. 22. Delivery reliability per month in 2006.

There was a very significant improvement in delivery reliability in 2007. It averaged out 96.8 percent. Furthermore, production was increased with determination. Production volumes are clearly connected to delivery reliability. During the months when products have been manufactured in larger amounts than usual, delivery reliability has been slightly weaker. Use and more efficient utilization of the new operation control system introduced in 2006 can be also regarded as a significant factor. It has been possible to control the capacity more efficiently and with improved tools. Furthermore, along this study a SCM development project was launched in production. This project appears to be successful especially with regards to delivery reliability.

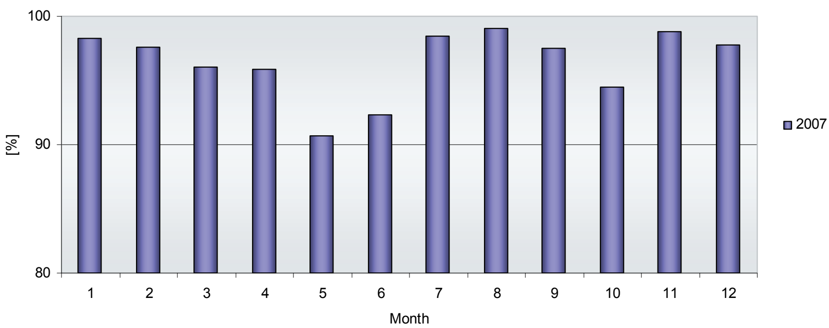

Fig. 23. Delivery reliability per month in 2007.

After growth in production settled in 2008 and 2009, it has been possible to maintain delivery reliability on a good level. In 2008 delivery reliability was 96.5

percent, as well as 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.

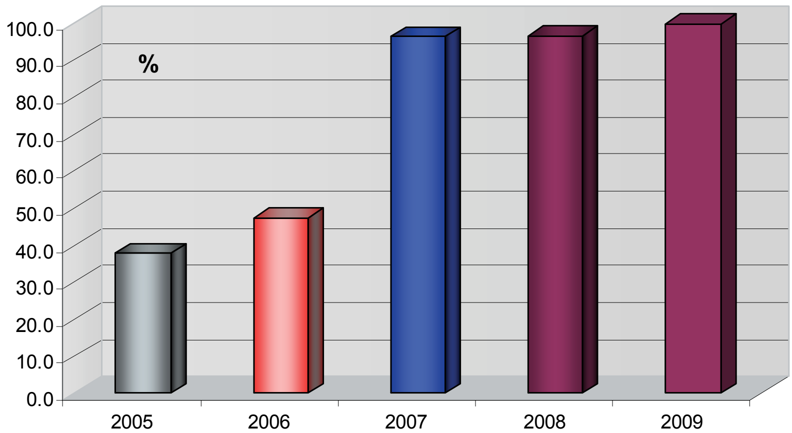

Fig. 24. Delivery reliability per year in 2005–2009.

4.3 Lead-time and profitable analysis in the first measurement

The first phase of lead-time and profitability analysis was conducted in 2006. The two largest customers of the production plant were chosen as case customers because they form the largest proportion of sales. Customer A is an internal customer and Customer B is an external customer. Product A is manufactured for the Customer A and Product B is manufactured for the Customer B. As for case customers, cost-efficiency, lead-time, delivery reliability and efficiency of the SC are reviewed.

4.3.1 Product A supply chain process

Customer A outsourced welding activities to the case company. The aim of outsourcing was to supply products as subassemblies directly to Customer A's production line. The customer's products are welded assemblies that are manufactured from steel and are very heavy. The customer purchases a welded integer from the case company. It includes cut steel parts manufactured by the case production plant as well as welding and surface finishing performed by another production plant of the case company. Customer A purchases also several other products from the case company, but Product A has clearly the largest volume. From Customer A the case company obtains good prognoses with help of which it is possible to load the production several months ahead.

Two production plants of the case company are involved in the SC process of Customer A: sales and order processing organizations. This study focuses especially in using the indicators developed for measuring the SC at the case production plant. Also the other production plant of the case company is discussed. There the steel parts manufactured by the case production plant are welded and surface finishing is performed before delivering the products to the customer.

The supply process starts at the arrival of an order from Customer A. The order is processed and entered into the case company's production control system. The order is processed in the order receiving function and the data is transferred to the production control and operation control systems. In processing the order, stages of work to be conducted for each position of the order are specified. If a new product is concerned, the offer calculation department will calculate prices for the products. This is the procedure with regards to part of Customer A's orders, if prices for the orders have not been previously calculated.

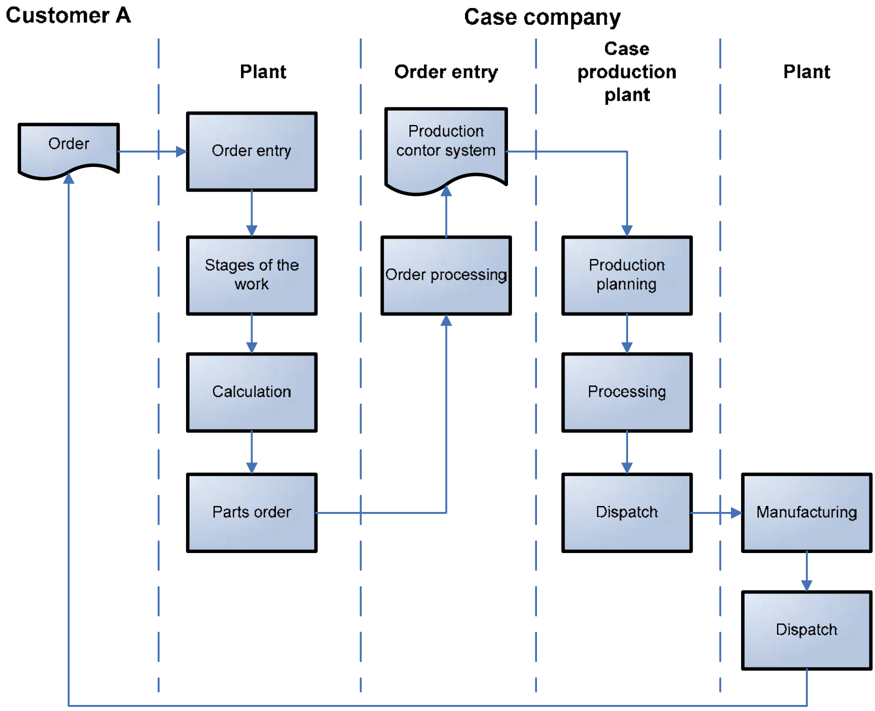

Fig. 25. Units and their functions involved in producing the products for Customer A.

Typically, lead-time from the case company to the customer is from three to eight weeks after the case company's receipt of the order. Customer A predicts its needs months ahead but taking advantage of the prognoses is challenging, because customer A may make changes to the prognoses before the order is received by the case company.

4.3.2 Supply chain process of the workshop A

Manufacturing process of the case production plant is started when an open order arrives as the production control system's order item. Production planning plans the order to be cut from different steels in such a manner that it is possible to load production evenly and that usage of steel plates is as efficient as possible. Manufacturing of products for Customer A includes the following stages of work: cutting, finishing, bevelling, roll hardening and blasting. Manufacturing the products requires flame cutting and plasma cutting machines, finishing machines, bevelling machines, mangle, grain blasting machine, bridge cranes and forklifts.

Production requires a space estimated at 510 square meters. For manufacturing an order at least one production planner and eight workers are needed. After the production process the products are collected and dispatched to the case company's other production plant for welding and surface finishing.

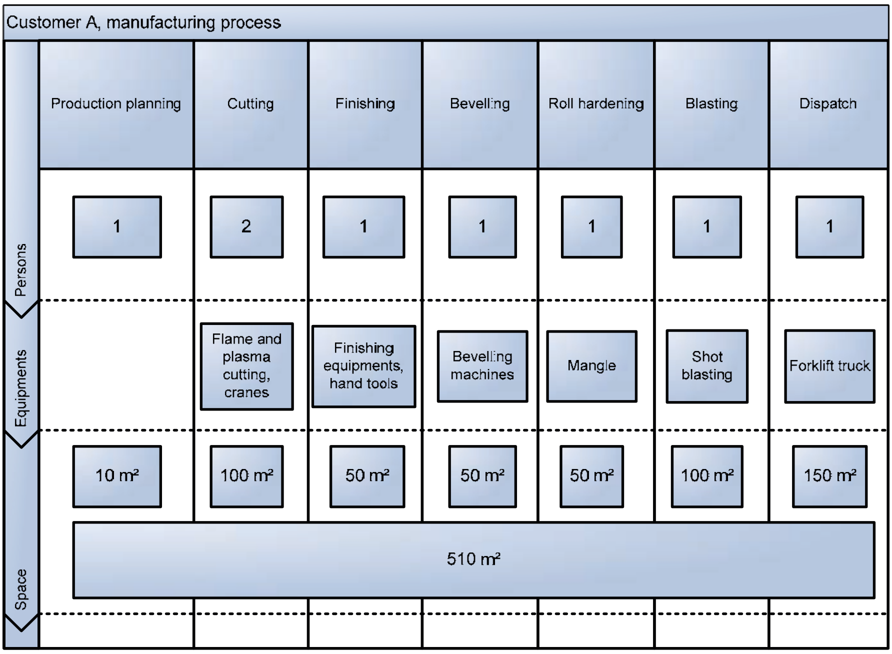

Fig. 26. Manufacturing process of products for Customer A at the case production plant.

4.3.3 Supply chain process of workshop B

Products are transported to workshop B by vehicles. Products are received and checked. In assembly, the products are assembled for welding. After this the product is welded manually. Especially in batch production, utilization of robotic welding is being aimed at. The product is finished, sand-blasted, reviewed, heated, surface-finished, and finally it is dispatched to the customer. At the moment, 35 employees and four clerical employees are involved in the production process. Production uses approximately 3 600 square meters of hall space. Production requires approximately 13 MIG welding devices, two welding robots, two annealing furnaces, sand blasting and testing equipment, painting line, turntables, jigs, robust working surfaces, lift tables and cranes.

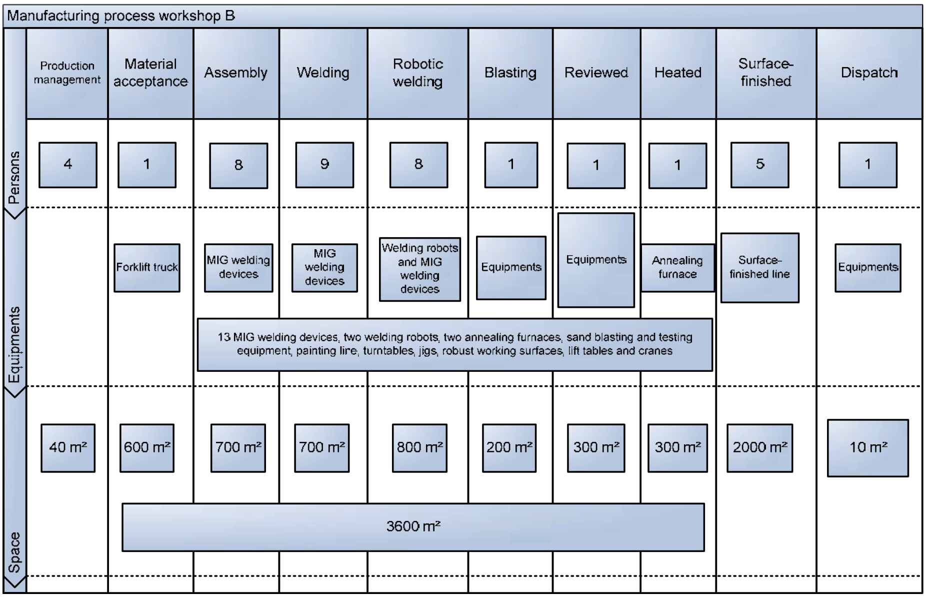

Fig. 27. Manufacturing process of products for Customer A at the case company's production plant B.

4.3.4 Product A profitability

Profitability of manufacturing the products for Customer A was reviewed in 2006 and 2007 on the basis of indicators established in the study. Customer A is one the most significant customers of the case production plant. Due to this, the customer's product with the largest volume (Product A) was selected for analyzing. Of all products of the case production plant ordered by Customer A, this product has been manufactured by far the most. Therefore, the analysis compiled from the products ordered by Customer A gives a good overview about profitability of the case production plant. An order of Customer A was selected for review. The order arrived on 16.5.2006 and the date of delivery was 8.6.2006. The order included eight products which consisted of 352 parts. Weight of the order was approximately 16.4 tons. The order included several plates of various thickness from which the products were cut.

A crucial factor for cost-efficiency was to define machine hour rates. Machine hour rates were defined from the case company's production control system and with the help of cost accounting. When analyzing price information it was perceived that the prices haven't been updated for a long time. Prices of the parts in proportion to their weight vary a great deal. A typical selling price which matches the selling prices of a steel plate sold directly to the customer was assumed as the price of material.

The realized hours spent in production were collected from the production control system. Reporting of hours was questioned, major errors were removed and the time spent on producing this stage of work was measured. Hours from all stages of work are not reported to the production control system and therefore some manual measurements had to be carried out. Time spent in picking up material, collecting and dispatch was measured by clocking the time spent in those stages of work.

All information was tabulated. With help of the table it was possible to carry out all necessary calculations for estimating profitability. Summary of cost-efficiency is presented in the table where profitability was reviewed by part and by order. Profitability varied a great deal between different parts. 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 3. Cost efficiency of Product A of Customer A.

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

4.3.5 Lead-time for product A

Concerning products for Customer A, the problem has been long lead-times. Lead-time study was carried out by collecting information regarding completed orders of Product A in 2006. 19 similar kinds of 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.

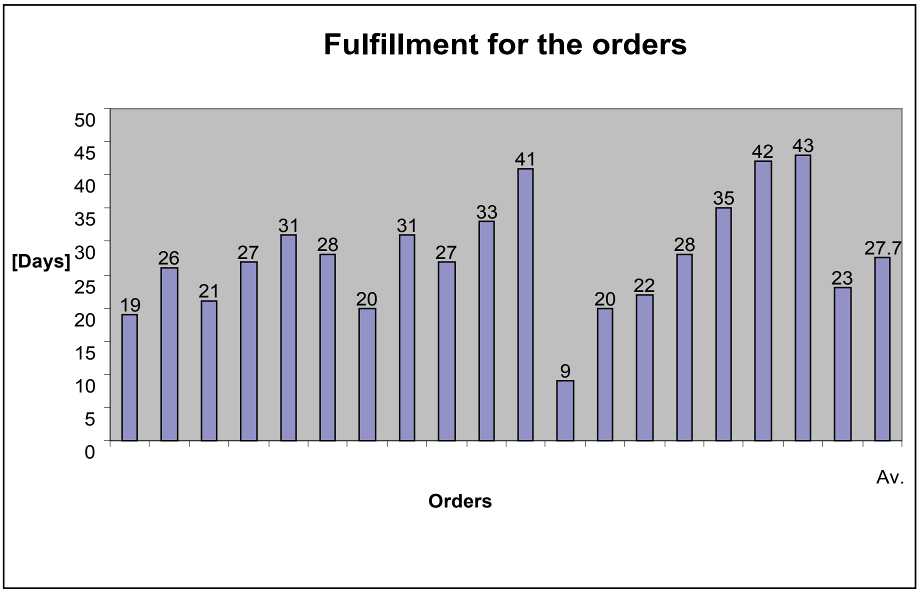

Fig. 28. Periods for the fulfilment for the orders, Customer A, Product A.

Delivery accuracy for orders of Customer A's Product A varied a great deal. At the beginning of the year all orders were overdue as much as eight days. Delivery accuracy for the latest orders was 100 percent. Five of the orders were delivered 1–6 days earlier than the given time of delivery.

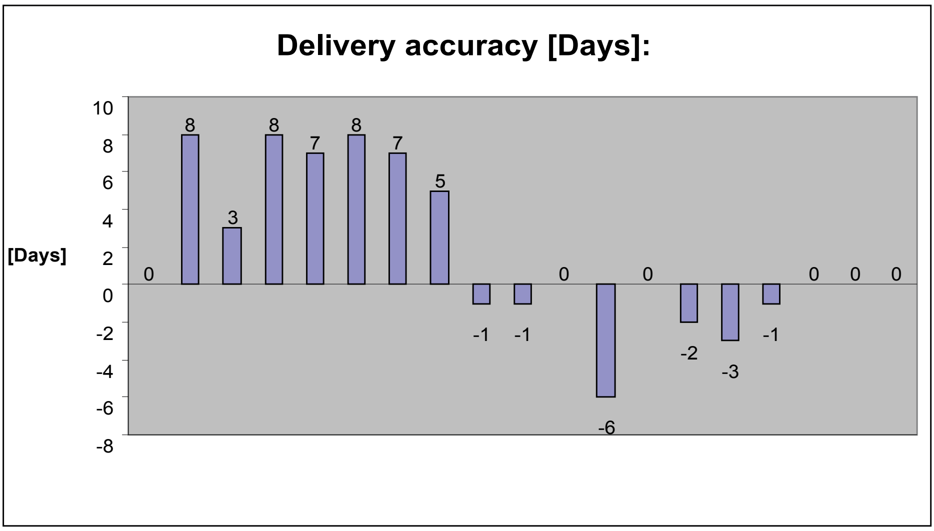

Fig. 29. Delivery accuracy, Product A.

4.3.6 Process time

The order under review included eight blocks of Product A. Usually the products have been ordered as sets of six blocks. 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 for order was 24.3 percent. Lead-time of the SC was 23 days.

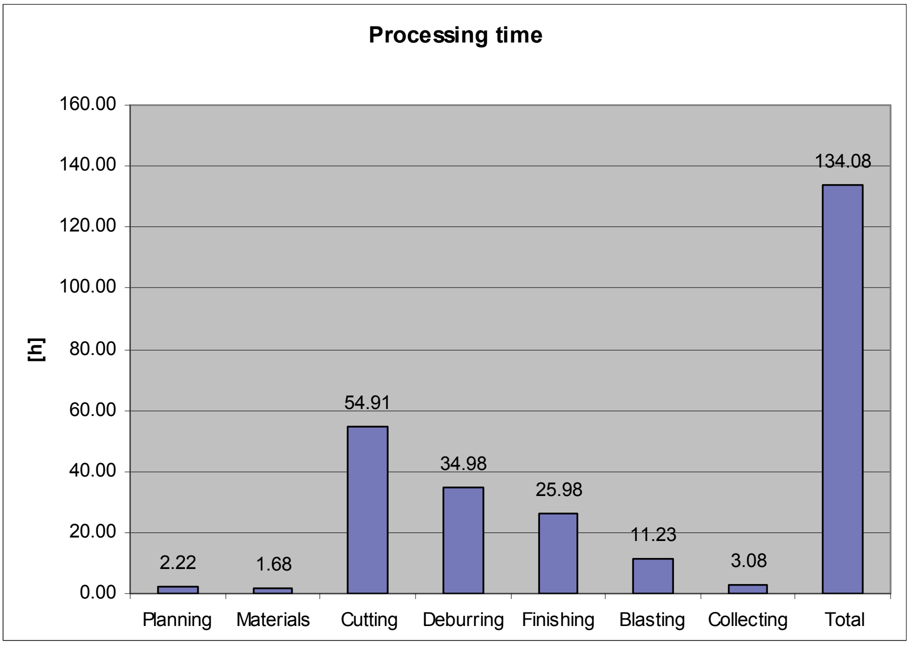

Fig. 30. Processing time of the order of Product A.

Proportion of stages of work in production time was studied by counting up actual production times of all the stages of work in the orders and comparing them to the production time of the whole order. Cutting took 54.91 hours and was 42 percent of the production time. Cutting is the most time-consuming process of the product-refining processes. The most surprising discovery was the fact that deburring took 34.98 hours and made approximately 26 percent of the production time. Bevelling took 25.98 hours that equals 19 percent of production time. Picking up material, planning, collecting and blasting make up 13 percent of production time. According to the study, waiting periods between stages of work are rather long.

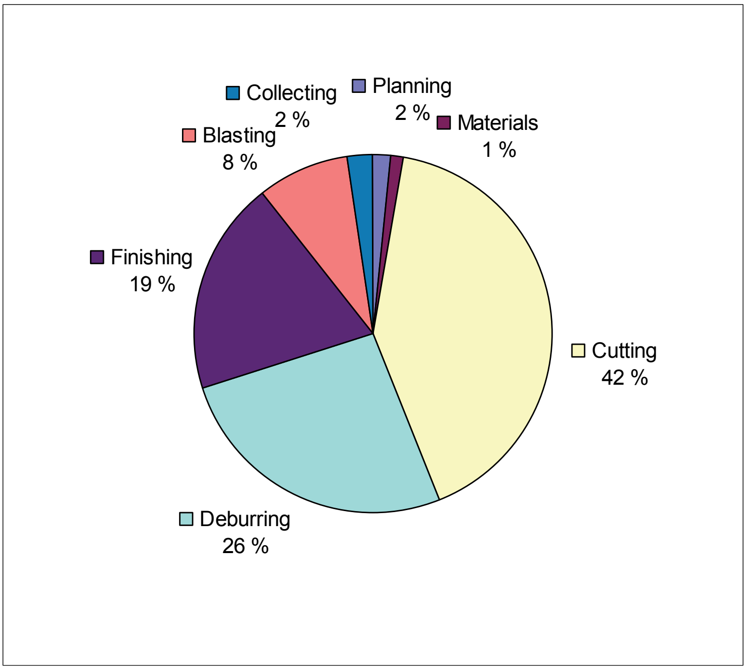

Fig. 31. Proportion of stages of work in production time, Product A.

4.3.7 Product B supply chain process

Customer B orders the steel parts for the products from the case company and manufactured products are transported abroad to Customer B's production plant for welding. The customer provides sales forecasts to the case company. This way the case production plant is able to plan its production months ahead. Forecasts become materialized at the customer's end rather well and loading of production process can be carried out based on these prognoses.

The SC process for Customer B begins when the order arrives at order processing. The order is processed in the order processing organization and the data is entered into the operation control system. From there the order is automatically transferred to the production control system. In order processing, the stages of work to be performed for each position in the order are specified. The supply process of the case production plant begins when the order is received in the production control system and planning of production can be started.

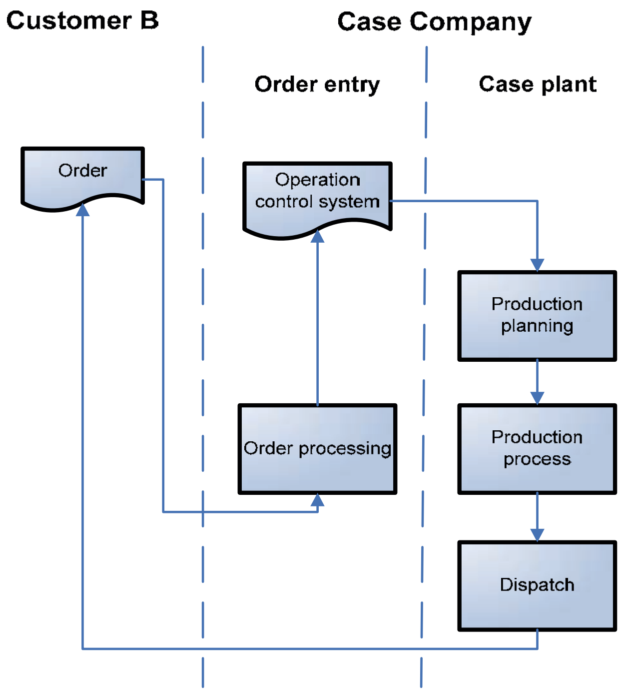

Fig. 32. Supply process of products of Customer B.

4.3.8 Product B profitability

Profitability of manufacturing products for Customer B was studied as one part of the study. Customer B is the largest customer of the case production plant and therefore customer-specific profitability has a significant effect on profitability of the production plant. Profitability was analyzed by Product B, which has the largest volume of the products for Customer B.

An order that came in on 12.7.2006 and was dispatched on 9.8.2006 was selected for review. The order included parts for eight products which consist of 592 blocks. Weight of the order was 29.08 tons. The order included several different thicknesses of plate and several different steel materials. For measuring cost efficiency, the same machine hour rates used in studying profitability of Product A were used. Price level that corresponds to sales prices of different materials to the customer was assumed as the price of material. When reviewing prices of the products it was discovered that the prices had not been updated for a long time.

Production time spent in manufacturing the order was determined on the basis of reports as well as by clocking different stages of work. Some erroneous reporting was noticed in reporting of hours. Actual values for these erroneous values were defined. Picking up material, collecting and dispatch were measured during the production of the order. All the information regarding actual hours was put together in a table with the help of which profitability calculations were carried out. Final results were gathered in a summary table where the results were reviewed part- and order-specifically. 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 4. Customer B, cost efficiency of product B.

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

4.3.9 Product B lead-times

Lead-times of Customer B's Product B were studied by collecting the information regarding completed orders in 2006. 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 period for fulfilment 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.

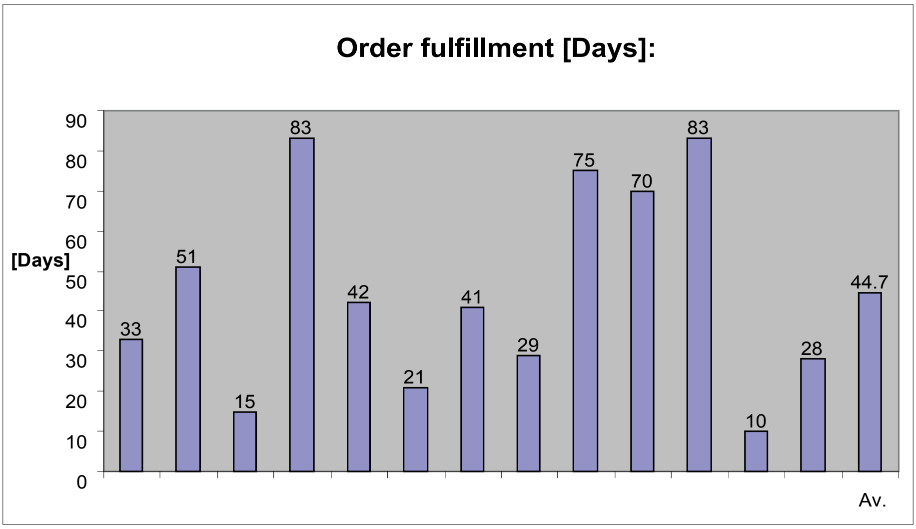

Fig. 33. Periods for fulfilment of an order, Customer B, Product B.

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 before the agreed date of delivery. None of the orders was 100 percent delivered on time. Towards the end of the period under review shipments were delivered as much as 35 days late.

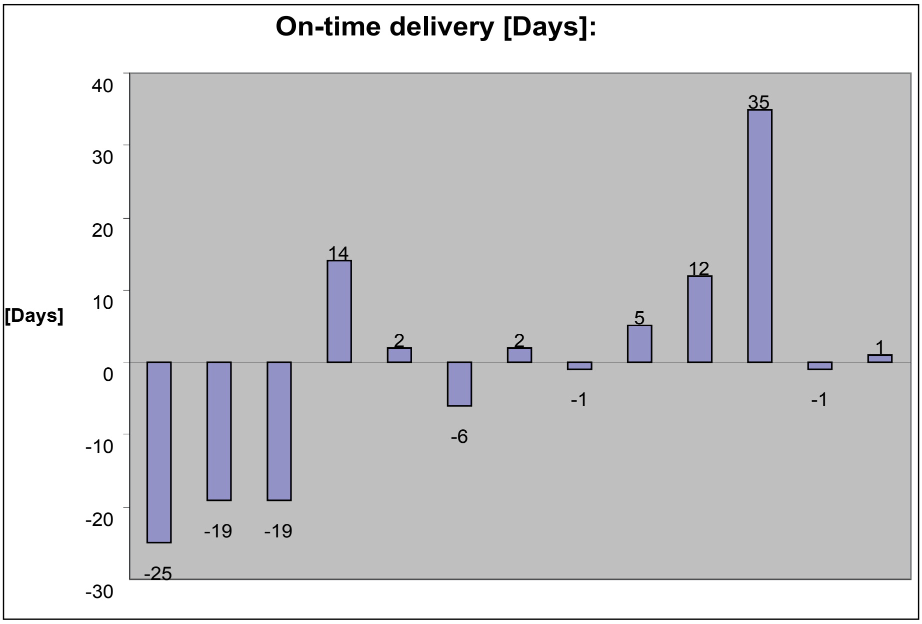

Fig. 34. On-time delivery, Customer B, Product B.

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 next stage of work. Due to this the proportion of process time in the period for fulfilment of an order is small.

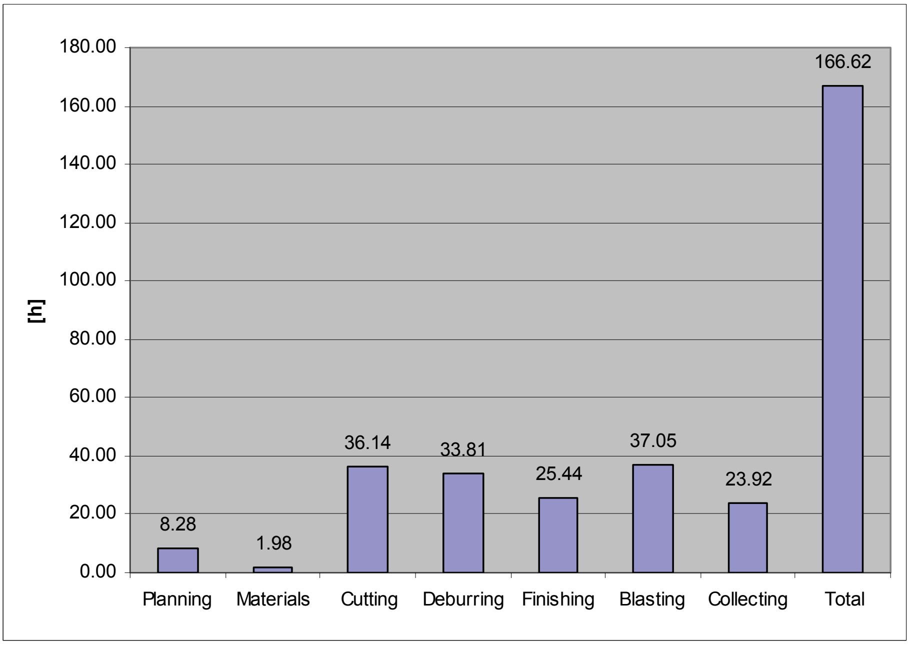

Fig. 35. Process time, order of Product B.

Percentages of work stages of production time was studied by adding up all the actual manufacturing times of each stage of work and comparing them to the production time of the order. Cutting took 36.14 hours, which is 23 percent of the production time for the whole order. Cutting takes most time from the production time. The proportion of edging in the production time was 37.05 hours, which is approximately 22 percent of the production time used in producing the order. Deburring took 33.81 hours and 20 percent of the total production time. The proportion of deburring in the production time is surprisingly large and due to the stage of work being very manual it results in high costs. Sand blasting took 25.44 hours, approximately 15 percent of the production time. Collecting took 23.92 hours, approximately 14 percent of the production time. The proportion of time spent in collection also for Customer B's product is very significant. It is a time-consuming stage of work. Customer B has provided very strict instructions on how the products are to be packed and dispatched to customer. It takes two employees and approximately three days in one shift to carry out this stage of work. The proportion of planning and materials management functions in the production time is approximately 6 percent.

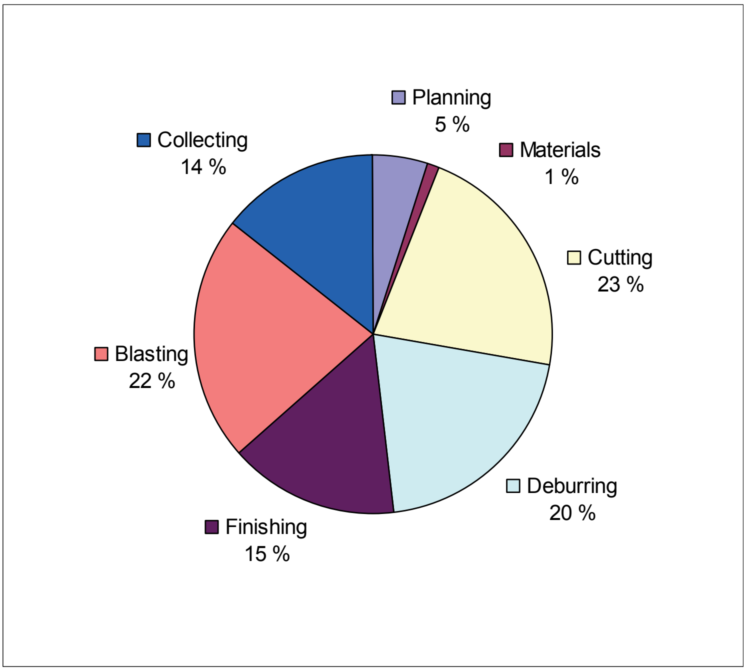

Fig. 36. Percentage of production time, stages of work, Products B.

4.4 Lead-time and profitability analysis in the second measurement

Second phase of measuring the SC was carried out in 2007. Only Customer A was selected for review due to the fact that co-operation between the case company and Customer B had ended. The measurements were conducted in the same environment as in the previous year. This was to verify the functionality of the indicators established in measuring the SC.

The SC of Customer A has remained similar to what it was in the previous measurement. Between the measurements the whole SC has been developed. Focuses of development have been decreasing lead-times as well as improving delivery accuracy and cost-efficiency.

4.4.1 Product A profitability

A typical order that included parts for ten products was selected for review. Production time was studied using the same procedures as earlier. Times were obtained from the production control system and by measuring stages of work manually. 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 8 completed products for the order instead of the 10 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 5. Customer B, cost-efficiency of Product B.

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

4.4.2 Lead-time of product A

During the second measurement, lead-times were studied by collecting the information for 2007 regarding the orders to be measured. During the measuring period, a total of 18 products were manufactured. 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 9 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.

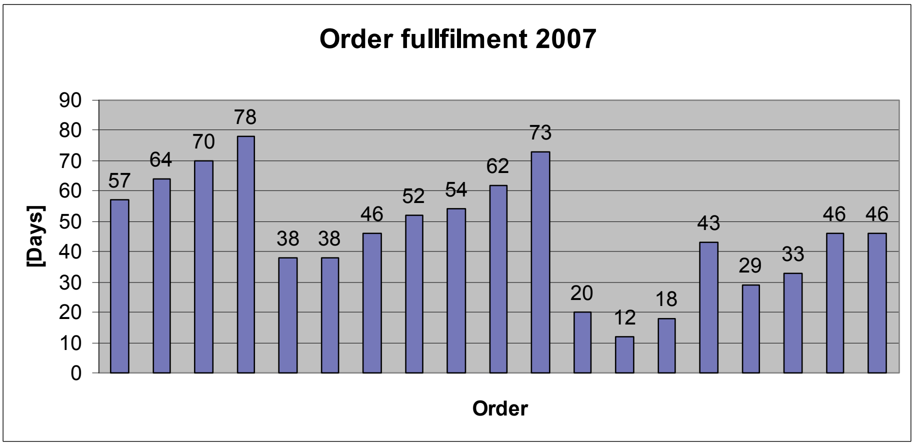

Fig. 37. Period for the fulfilment of an order 2007, Product A.

Delivery accuracy was studied for the same orders. Dispersion of delivery accuracy 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 delivery accuracy 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 delivery accuracy has increased.

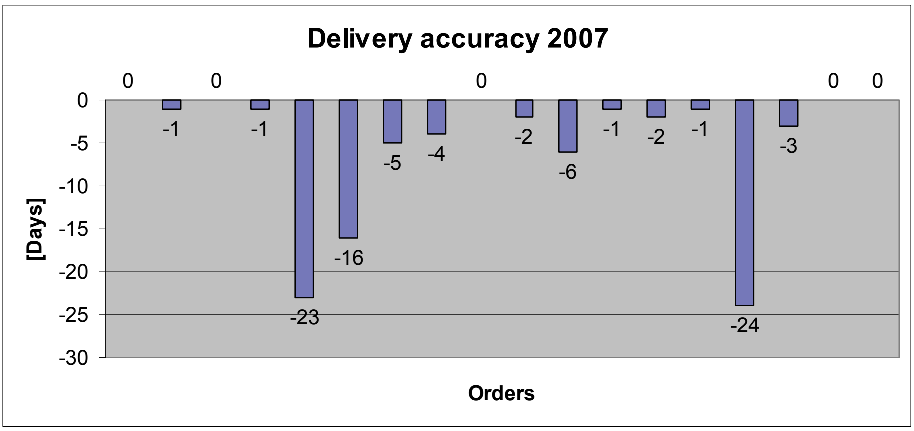

Fig. 38. Product B, delivery accuracy in 2007.

4.4.3 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 products of ten pieces and the latter products of eight pieces. In completing the whole order, the proportion of process time in the whole period for the fulfilment of an order was 14.1 percent. Lead-time of the SC was 34 days.

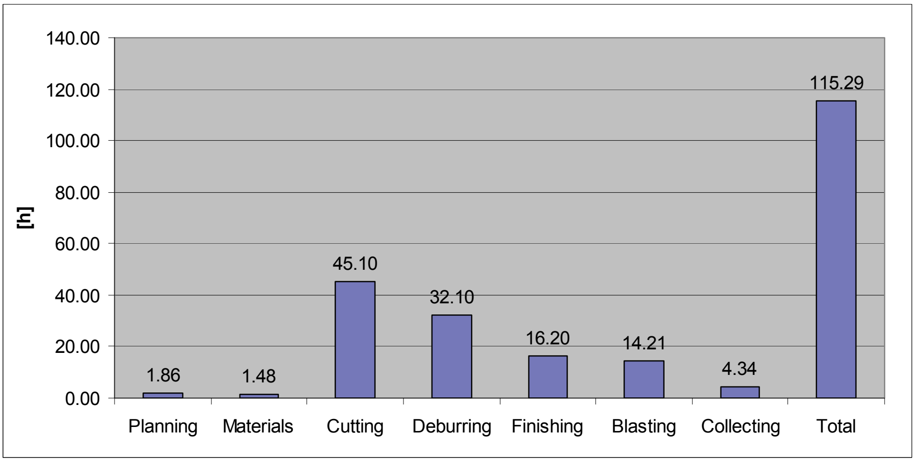

Fig. 39. Product A, process time in hours during the second measurement.

The proportion of work stages in the production time was studied also in the latter measurements. Cutting took 45.10 hours, whereas a year earlier it took 54.91 hours. Cutting makes up 39 percent of the total production time and hence it decreased by four percentage units. Deburring took 32.10 hours, in which an improvement of two hours could be perceived. Bevelling took 16.20 hours, which showed improvement compared to the 25.98 hours in the previous measurements. Bevelling makes up 14 percent of the total production time. Picking up material, planning, collecting and blasting took seven percent of production time. Development of five percent has taken place.

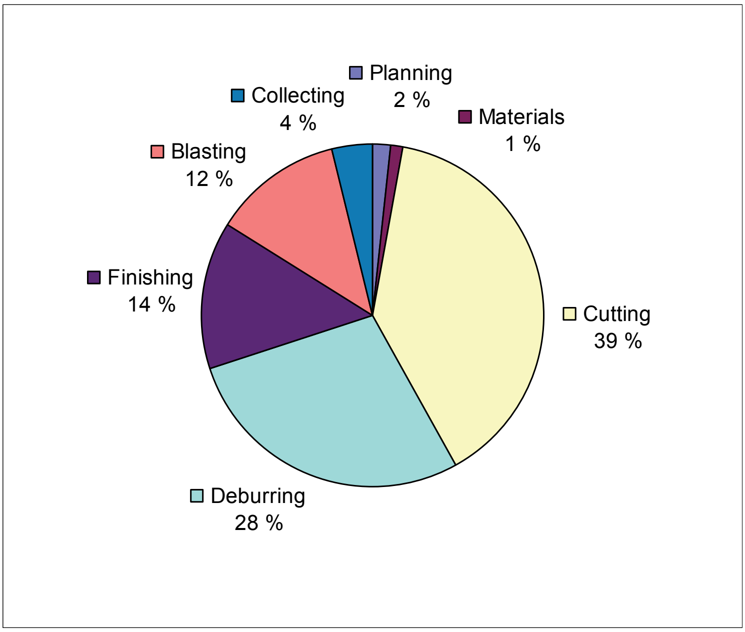

Fig. 40. Percentage of work stages from the production time in 2007.

4.5 Managerial analysis of supply chain 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 fulfilment of an order is approximately between 10–25 percents. 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.

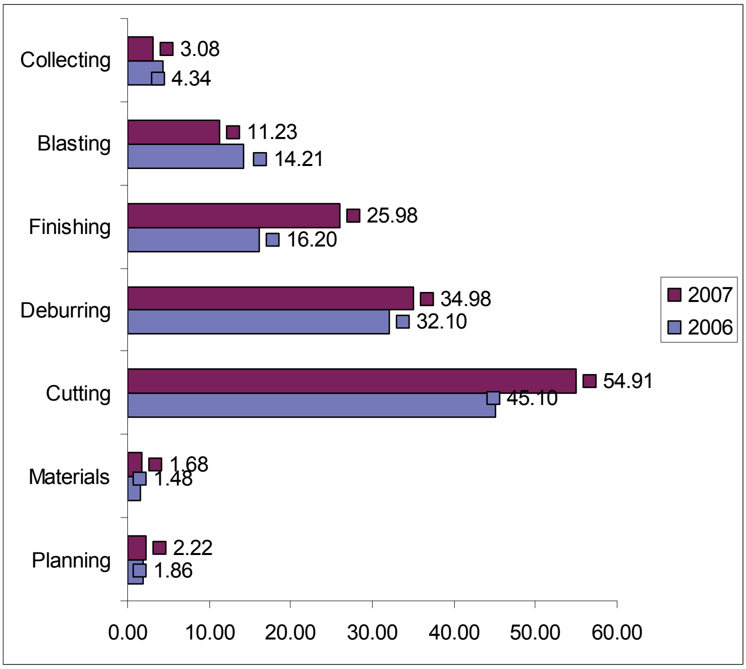

Fig. 41. Proportion of work stages in production time in 2006 and 2007.

Comparison information regarding Product A in 2006 and 2007 is presented in the table. In 2006, one order included parts for the 8 products manufactured by the customer and in 2007 the order contained parts for 10 manufactured products. Profitability of the order has turned from deficit 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 6. Comparisons of Product A in 2006 and 2007.

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

In the case production plant's SC process, typical problems presented in literature can be perceived. The case production plant was established in May 2005, when production activities were launched. During the study, the production plant has been started up and only during the last two years the amounts produced have been stabilized. New production plant is also an advantage, because the unit does not yet have traditions to be followed but processes are created and developed continuously.

Efficiency of production as well as cost-effectiveness would have to be improved by increasing the production amounts manufactured by the company. Bottlenecks should be eliminated from production and capacity should be proportioned evenly between different stages of work. The best result could be achieved if the end of the production line contained more capacity than at the beginning of it. This way production could be made pull production, lead-times could be decreased and cost-efficiency could be improved. The study showed that the bottlenecks are located in production planning, bevelling and finishing.

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' predicting. 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 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.

The case production plant should search for alternative solutions for clearing the overcapacity. Finding possible subcontractors and making a co-operation agreement would improve flexibility and especially delivery accuracy.

It is possible to automate the production of the production plant in order to increase efficiency. With the help of automation, notable benefits could be attained. They would be realized when various stages of work speed up. Bevelling and finishing are stages of work that require the employees to work manually. These stages of work are very expensive because they tie up human resources. In these stages of work one should invest in automation, and new innovations to automation should be developed. Also logistics of the production line should be made more streamlined. In production, blocks are moved between various stages of work. Moving is often done with the help of forklifts or bridge cranes. The blocks could be moved by using an automated line or by changing the layout of production line into a more production line-like direction.

Initial and final reporting should be made more efficient. Work stages are reported to the production control system so that production can be directed and followed up through the system. It is important that a profitability review can be carried out from the actual production and in this way taking care that the produced orders are profitable. The basis of a profitable business is cost-based pricing. Pricing of the blocks should be based on the actual costs. It is very challenging to review actual costs in retrospect. The case production plant needs a tool to review the actual costs for a block with respect to selling price. Based on this, a true price based on actual costs can be defined.

Steel plates are stored in open storage areas. There is a great risk for the material to be ruined because in a coastal climate steel rusts easily. After a steel plate has rusted, it may have to be sandblasted to get it clean. The open storage area causes problems especially in the winter, because picking up materials becomes more difficult. Expensive raw material should be stored in indoor warehouses or in a storage hall. This would protect the material from non-marketability risks caused by climate.

One substantial problem of the case production plant is shortages of material. It has often been perceived in product planning that according to the data system there has been material in the warehouse, but physically the storage depot has been empty. Material shortages have tried to be reduced by moving steel plates from other production plants.

Problems in the SC can be divided into inter-functional problems and problems in production. Irregularity in capacity caused by load can be regarded as a general, significant problem. One has not been able to define the capacity accurately. Furthermore, monitoring of capacity is carried out with help of the production control system. Capacity control of the production control system is not extensive enough to define the actual value of capacity. Irregularity in capacity dates back to sales. Interaction between sales and production has to be increased in order to improve capacity control.

Inter-functional problems are often caused by deficiencies in the flow of information. There is not enough communication between departments. The goals of various departments are often inconsistent. The goal of sales is to sell as many products as possible for the best possible price with short times of delivery. The goal of production is to manufacture high-quality products in a cost-efficient manner. Times of delivery promised by sales or demanded by a customer are not necessarily met due to overload of the production plant or other production related reasons.

The case production plant does not have enough information regarding profitability of operations and profit. Financial administration of the case production plant is taken care of in a centralized manner and following up the costs for a specific order is challenging. Following up with profit of the orders is challenging because the systems cannot automatically carry out actual cost calculating for the orders manufactured.

Short times of delivery are a challenge for the entire SC. If production planning has taken longer than expected or if order processing has delayed, the basis for production to deliver the order on time to the customer may not be too good. Production functions 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, large buffer and intermediate stocks are created in production. A significant amount of capital is tied up in buffer stocks and lead-times increase. Capacity of production process is not divided evenly in the various process stages. At the beginning of the production line there is significantly more cutting capacity than in the bevelling and finishing at the end of the line.

Irregularity of the load causes problems in production. Load varies a great deal each week. During overload, the products do not meet their times of delivery. During under-capacity machines are standing still and employees do not have work to do. The bottleneck places of work get backed up and it often takes too much time to clear the backlog. Employees have not been trained to be multi skilled, but each employee is responsible for his / her own post.

4.6 Analysis of the measurement system

By utilizing indicators presented in literature and in articles, indicators for the case SCM were established. Order book analysis, time, profitability and managerial analysis were selected as indicators for measuring the SC of the case company's production plant. The purpose of the study was to establish indicators and test their functionality. In the measurements, the wish was to review the SC especially in a customer-oriented manner, because this way it is possible to affect the development of the SC most effectively. When the basis of development is the customer, developing has substantially better conditions to follow through with reforms in various functions.

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. Order book analysis also included analysis regarding the case production plant's output from 2005–2009. Furthermore, delivery accuracy of the SC was studied on a monthly basis for the period in question. With the help of order book analysis it is possible to obtain an overview of volume of orders, production volumes and delivery accuracy of the case production plant. Changes in volumes due to launching of the case production plant as well as developing the production were particularly studied. Production volumes have increased significantly since establishing the production plant. Regardless of this, delivery accuracy has been remarkably good after the first years. The SC of the case production plant can be regarded as well-controlled with regards to order book analysis because it has been possible to keep promises to the customers very well with regards to times of delivery.

Order book analysis can be regarded as an especially good way to measure the SC from the production and customer point of view. The study shows that order book analysis can be regarded as a good indicator. 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. With help of the indicator, the information obtained from the case production plant is extremely valid and it provides a very good overview regarding the SC for a period of several years. Results obtained regarding the case SC with help of the indicator are of good quality. Furthermore, with help of the results it is possible to draw conclusions regarding fields to be developed for the future.

With help of literature survey, cost-efficiency was defined as an indicator of the SC. In measuring the SC, cost-efficiency stands for defining the costs of the products to be manufactured on the basis of measured production times as well as machine hour rates. The foundation of business is to show a profit and one has to be able to manufacture each order in a profitable manner.

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. Furthermore, during the first period of measurement, cost-efficiency for the products of another significant customer was measured. Measurement could not be carried out for this another significant customer's products during the second measurement period because co-operation with this client ended.

The results obtained when measuring cost-efficiency were reliable and they could be utilized very well. In analyzing the results, significance of determining cost-efficiency for each product or order to be manufactured is emphasized. Actual cost calculation, where the costs resulting from manufacturing the product are obtained and compared to the selling price assumed from the orders is needed.

According to the literature survey, time is regarded as a very significant indicator of the SC. The SC was measured from this point of view 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 delivery accuracy measurements are related to time. Furthermore, delivery accuracy was reviewed from two different periods of time.

Time-based indicators proved to be very necessary in measuring the SC of the case production plant. Time-based measurement of the case company's SC was established during the study and it was developed significantly. Time-based measuring is very significant especially for the case production plant due to its activities being very quick. It has to be possible to serve customers with very short times of delivery. Furthermore, the volume of orders is extremely short and hard to predict. The significance of time in continuous developing is very remarkable. Time lays a foundation also to measuring cost-efficiency, because the basis is measuring costs according to machine hour rates and time spent in different stages of work.

According to the recognized academic Goldrat (1992), the most essential indicator of the SC is lead-time. The basis of improving profitability of a production plant is decreasing lead-times. The study proves Goldrat's theory right, because time can be regarded as a most essential indicator for the SC. (Goldratt & Cox 1992)

The challenge of time-based measurements was inaccurate, time-based measuring of product control systems. Because time has to be measured accurately, measurement needs to be smooth and reporting needs to be efficient. Measuring should be automatic and very straightforward in order to be able to eliminate sensitivity for errors. In time-based measurements of the case production plant there were clearly challenges particularly in measuring time. Time is an indicator which can not be bought. It is running all the time and we cannot change that. For the part of the case production plant time is a really good indicator for the SC. With this indicator, very worthwhile information is obtained from the whole SC.

Managerial analysis is an analysis by persons involved in the SC or people monitoring the effectiveness of SCM from the outside. In managerial analysis measurement the aim is to draw conclusions regarding the entire SC and avoid partial optimization. Analysis is also conducted with help of time- and cost-efficiency-based indicators of the SC.

In the analysis the focus was on analyzing time and cost-efficiency indicators. Primarily, results from two different measurement periods were analyzed. Furthermore, problems in the SC as well as reasons for them were analyzed. Problems of new production plant are essentially related to management of capacity as well as to learning production operations and automation. The production plant was launched in 2005 and due to this product process was developed significantly during the whole study. The results come out particularly from utilization rate of production capacity as well as from the good results of delivery accuracy.

The analysis concentrated also on rationalizing capacity management of the production plant. Capacity management has to be rationalized, because its effect on SCM of the case production plant is obvious. Capacity has to be maintained with regards to systems, and sales prognoses have to be got into systems so that production can be prepared for prospective production volumes. Sales have to be able to react to usage of capacity. Furthermore, especially regarding promises made by sales, like defining times of delivery, have to be made based on lead-times and loading of the SC. Also emergence of material shortages is related to SCM. Due to material shortages, production is not able to initiate the production process before material has been received at the production plant.

As a whole, functionality of the indicators established for SCM can be rated as very good. Along with testing the indicators as well as success of the test measurements it can be stated that they can be utilized outstandingly and that it is possible to make the SC more effective on the basis of the measurement results obtained.

5 Conclusions

In this chapter, the main findings of this study are presented and theoretical contributions and practical implications of the thesis are assessed. Furthermore, the reliability and validity of the study are evaluated. Finally, the implications of the study are discussed and some recommendations for further research are proposed.

5.1 Conclusions

This study was conducted in the field of research of industrial engineering and management. Measuring SC performance in manufacturing industry was selected as the research topic. A typical SC of a steel and metal industry production plant that manufactures pre-fabricated products was selected as a SC to be measured.

SCM has been studied a great deal during the past few decades. Studying SCM can be regarded as a certain kind of trend of the 2000's in the industrial management field of research. Even though SCM has been studied a great deal, the amount of studies regarding how to measure supply management chain is very scarce. In this study, the theoretical frame of reference was built on articles and literature published in the 2000's. There is plenty to be discovered in SC measurement theory. No metal and engineering industry related articles about measuring SCM were found. The study drew together the theoretical framework of reference of SCM and the theories related to SC management performance measurement.

The research goal was formed as following:

The goal is to deepen knowledge in supply chain performance measurement in manufacturing industry

The research problem is presented as a question:

(R1) How to measure supply chain performance in manufacturing industry?

In this study, the research goal was answered by getting acquainted with the theoretical framework of reference of SCM and by collecting available relevant theoretical information regarding measurement of the SC. Based on the theoretical framework of reference, a series of indicators was established, to which indicators describing capacity of the SC were selected. The indicators were tested by measuring the SC of the case production plant. After this, the results were analyzed and it was noted how the indicators represent performance of the SC.

The purpose of the first research task (RT1) was to get acquainted with the latest publications discussing SCM and SCM performance measurement. The first research task was stated as following:

(RT1) How can the performance of the supply chain be measured?

There are several definitions of SCM. The definitions, however, share a great deal of similar elements. According to Christopher (1998), the terms "supply network" or "supply web" describe the net-structure of most of the SCs. He emphasizes the network-nature of his SC definition (Christopher 1998):

> *"Supply chain is a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer".*

Areas related to SCM include SC integration, principles of production control, TOC, and OPP. Integration of the SC is generally described as cooperation of various functions. SC integration implies process integration like supplier collaboration, common information systems and shared information. (Christopher 1998, Paulraj *et al.* 2006) TOC is a system-based assumption stating that every organization or production line has at least one constraint. The aim of TOC is to maximize profit by using more and more efficiently the factor that is limiting the process. (Bushong & Talbott 1999) In order-oriented production, production receives the impulse to start production from the order of a customer. The product is manufactured according to customer's requirements. OPP is the point in the company's logistics chain where the product is marked to be delivered to a certain customer. (Christopher 1998)

SCM includes agile - and lean operations philosophies. Christopher presents the most relevant agile definition (Christopher 2000): Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets. A key characteristic of an agile organization is flexibility. Agility might, therefore, be defined as the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety. The focus of the lean approach has essentially been on the elimination of waste or much. (Christopher & Towill 2001)

SCM performance or capability has not received so much consideration in SCM research field. (Beamon 1999, Chan & Qi 2003b, Gunasekaran *et al.* 2001) The goal of SCM performance measurement is to give an overview of the selected SC. Based on this it is possible to develop the SC. As Sink states: ”You cannot manage what you cannot measure”, (Sink & Tuttle 1989) According to Melnyk, metrics should provide control, communication and improvement. (Melnyk *et al.* 2004)

Christopher presents SC performance measures such as order cycle time, order completeness and delivery reliability. (Christopher 1992) Shepherd and Günther (2006) categorize SC performance measurement research into operational, design and strategic research (Shepherd & Gunter 2006). Neely *et al.* (1995) conducted a research project in the middle of the 1990’s and identified four approaches to performance system measurement: Quality, Time, Cost and Flexibility. Neely *et al.* (1995) introduced several ways for measuring SCM performance (Neely *et al.* 1995). Furthermore, other researchers introduced approaches to performance measurement: the BSC (Kaplan & Norton 1992), the performance measurement matrix (Keegan *et al.* 1989), performance measurement questionnaires (Dixon 1990) and criteria for measurement system design (Globerson 1985). Neely *et al.* (1995) have been cited by many researchers of SCM measurement (Beamon 1999, Beamon & Chen 2001, Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2004).

Beamon 1999 identifies two performance measures: cost and combination of cost and customer responsiveness. Cost consists of inventory cost and operating costs. Customer responsiveness measures include lead-time, stock out probability and fill rate. (Beamon 1999) Ramdas and Spekman (2000) present six approaches to measuring SC performance: inventory, time, order fulfilment, quality, customer focus and customer satisfaction. (Ramdas & Spekman 2000) Li *et al.* (2005) identify six constructs of SCM practices: strategic supplier partnership, customer relationship, information sharing, information quality, internal lean practices and postponement. (Li *et al.* 2005)

In SC performance measurement field of research, the publications most referred to are those of Gunasekaran. Gunasekaran *et al.* (2004) states that SCM performance measures can be divided into financial and non-financial measures. At a practical level, one needs to concentrate on operational measures instead of financial measures. Top management needs financial measures for management level decisions, but lower management and workers need operational measures for daily business. SCM performance metrics could be divided into three management levels: strategic, tactical and operational management. (Gunasekaran *et al.* 2004) Gunasekaran *et al.* (2001) presents a framework of SC performance. A framework consists of a table where, in the left column, there are four SC activities / processes: Plan, Source, make/assembly and delivery. (Gunasekaran *et al.* 2001) Shepherd and Günter (2006) categorize SC performance measures into five SC processes: plan, source, make, deliver and return or customer satisfaction as well as to whether they measure cost, time, quality, flexibility and innovativeness and whether they are quantitative or qualitative measures. Measures could be categorized into the business process such as strategic, operational and tactical management levels. (Shepherd & Gunter 2006)

De Toni and Tonchia (2001) present several indicators of internal and external time performance. Time performance was involved in research and the result in order of superiority is: Time-to-market, distribution lead-times, delivery reliability, supplying lead-times, supplier delivery reliability, manufacturing lead-times, standard run times, actual run times, wait times, set-up times, move times, inventory turnover, order carrying-out times and flexibility (Toni & Tonchia 2001). Otto and Kotzab (2003), present six way of measuring SCM capability: dynamics, operational research, logistics, marketing, organization and strategy (Otto & Kotzab 2003). 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 2003a). Kaplan and Norton (1992) present balanced scorecard (BSC) model to evaluate corporate performance in four types of approaches: financial, internal business process, the customer and learning as well as growth (Kaplan & Norton 1992).

The challenge in SC performance measurement has been developing a series of indicators that presents the whole SC. One of the main challenges in SCM performance measurement is that measures are mainly internal logistics performance measures and do not capture the way the SC has performed as a whole. Internal logistics measures such as fill rate, lead-time, on-time performance, damage and responsiveness are not measuring the whole SCM performance. (Lambert & Pohlen 2001) After getting acquainted with literature, the conclusion presented by Shepherd was agreed with:

SCM should be measured at multiple levels. (Shepherd & Gunter 2006)

With help of the second research task (RT2) a series of indicators for the case company's SC is established. (R2) was stated as following:

(RT2) With which indicators the performance of the supply chain in the manufacturing industry can be measured?

Engineering works have concentrated on core business and therefore the steel industry has met the need to manufacture prefabricated steel products. Measuring the SC in metal and steel industry has hardly been studied at all. To solve the research problem, a SC of a Finnish steel company manufacturing prefabricated products was selected to be studied. In the study, machinery as well as the production control system of the case production plant were presented. Furthermore, descriptions of the processes of order processing, production planning and production processes were established.

As it emerged from the theoretical study, SCM has to be measured at various different levels using various approaches. For measuring the SC, the barometers have to be tailored case-specifically for each SC. Order book analysis, profitability, time and managerial implications were selected as indicators for the case SC.

Measuring SC of a production plant places its foundation on order book analysis. According to a survey of literature, order book analysis can be categorized to non-financial metrics (Gosselin 2005, Kaplan & Norton 1992, Lambert & Pohlen 2001, Lawrie & 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 approach (Gunasekaran *et al.* 2001, Toni & Tonchia 2001). The aim is to obtain 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. Weekly manufacturing amounts suggest the average load of production. One of the cornerstones of customer satisfaction is on-time delivery. On-time delivery refers to an order that is completed exactly at the right time; not an order completed ahead of time but not an order that was completed behind the schedule either. One sector of order book analysis is quality of the product and especially deviations from the quality.

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, Kaplan & Norton 1992, Lambert & Pohlen 2001, Lawrie & Cobbold 2004, Neely 1999, Olsen *et al.* 2007, Tangen 2004, Tapinos *et al.* 2005, Thakkar *et al.* 2007, Toni & Tonchia

2001). The indicator is made 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. The profitability indicator is divided into profitability analysis of the blocks in the order.

De Toni *et al.* present time-based indicators as non-cost indicators, where time can be measured as internal or external time (Toni & Tonchia 2001). Gunasekaran *et al.* (2004) present a great deal of time-based measures (Gunasekaran *et al.* 2004). Time is also identified as the next source of competitive advantage (Balsmeier & Voisin 1996, Kessler & Chakrabarti 1996, Mehrjerdi 2009, Stalk 1988, Vesey 1992). 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. One goal of the time between order and delivery is to measure and decrease production lead-time. On-time delivery is a time-based indicator and it suits well for measuring the function of a hectic steel service center with a poorly predictable order book.

Gunasekaran *et al.* (2001) state that several kinds of measures should be used in performance metrics: balanced approach, strategic, tactical and operational levels as well as financial and non-financial measures. SCM could be measured at a different management or operation level (Gunasekaran *et al.* 2001, Gunasekaran *et al.* 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 issues related to the SC that cannot be measured. The goal of analysis is to develop the SC. To be able to develop the SC in a more cost-effective and competitive direction, one has to analyze the results from the measurements.

The aim of the third research task (RT3) is to find out how the indicators established describe the SC of the case company as well as how they suit to measuring it. The research task was stated as following:

(RT3) How do the indicators selected represent the supply chain?

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 delivery accuracy 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 stands for defining 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 delivery accuracy measurements are related to time. Furthermore, delivery accuracy 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 (1992), the most essential indicator of the SC is lead-time (Goldratt & Cox 1992).

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.

Efficiency of production as well as cost-effectiveness would have to be improved by increasing the production amounts manufactured by the company. Bottlenecks should be eliminated from production and capacity should be proportioned evenly between different stages of work. The load of production has been varying a great deal at the case production plant. Monthly variation is very large. This is due to the short order book and weak practices in customers' forecasting.

Inter-functional problems are often caused by deficiencies in the flow of information. There is not enough communication between the departments. Goals of various departments are often inconsistent. Short times of delivery are a challenge for the entire SC. If production planning has taken longer than expected or if order processing has been delayed, the basis for production to deliver the order on time to the customer may not be too good.

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. 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.

5.2 Contributions and implications

5.2.1 Theoretical contribution

This study consists of two main contributions. First, SC performance measurement is presented. Second, a SC performance measurement framework for manufacturing industry is defined and verified in the case study.

Supply chain performance measurement

SCM and SC performance measurement approaches are presented in chapter two. SCM has been studied a great deal in the industrial management field of research. There were a few studies regarding SCM in steel industry. SC performance measurement has been studied very little and hardly at all in the field of manufacturing industry. In the literature survey, various approaches as well as the theoretical frame of reference for SCM performance measurement are presented. In this study, the SC was defined, according to Christopher (1998), as including members of a network involved in upstream and downstream (Christopher 1998). Elements of SCM performance measurement were discovered from publications of the leading researchers of the field, inter alia (Gunasekaran *et al.* 2001, Gunasekaran *et al.* 2004, Neely *et al.* 1995, Shepherd & Gunter 2006).

Supply chain performance measurement framework for manufacturing industry

The second contribution is based on a SCM performance measurement framework for manufacturing industry. There are several special features in measuring the SC of a manufacturing industry, especially in the case production plant that manufactures prefabricated products in the steel industry. These features have to be taken into account when selecting a framework of reference for performance measurement. Considering the special features of the SC, order book analysis, profitability, time and managerial implications were selected as a framework of reference of the manufacturing industry SC performance measurement framework. The elements selected as indicators of a SC in steel industry were verified in case study. The measurements were carried out during 2005–2009. The results of the measurements were good and they provided a good overview of the case SC performance measurement. The case measurements were conducted in a practical manner; by interviewing persons involved in the activities of the chain, observing the SC, measuring various product groups and by other research methods. The indicators suited very well for measuring performance of the case SC and it can be deduced that measurement framework at a general level serves measuring SC in manufacturing industry. It is not a primary goal of a case research to generalize the results. However, the possibility to generalize and duplicate the framework of reference is, in this study, possible.

5.2.2 Managerial implications

Studying SC performance measurement in a practical environment is rare. This study can be regarded as pioneer work in the manufacturing industry SCM performance measurement field of research. The starting point for the study was to obtain as well as to create new information of a relevant research problem that is related to practice.

SCM is often regarded as a very narrow function in manufacturing industry. In practice, however, almost each person working in manufacturing industry is involved in a SC. Developing the SC has been the goal of participants in manufacturing industry for several years, even for several decades. Development has often been limited to only one area and therefore the effects on the entire SC have been rather minimal. This study establishes practical tools for managers at various levels with which they are able to discern challenges related to managing as well as measuring the SC.

In the research, studies regarding SCM were read extensively. In addition to this, measuring SCM was studied in particular. This information is very beneficial to strategic level management. Continuous productivity goals as well as development projects in the steel industry are often part of SCM. Due to this, it is recommended to identify the basis of the phenomenon under discussion when defining projects.

Framework as a tool for practical supply chain 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 practise at a typical company that manufactures prefabricated products. This concretizes very well the chasm between theory and practise. 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 on the practical level extremely well when they are managing and developing the SC.

5.3 Reliability and validity of the study

The concept of pre-understanding refers to the researcher's insight into a specific problem and social environment before he or she starts research work – it is an input. Research quality is about reliability, validity, objectivity and relevance (Gummesson 2000). According to Easterby-Smith (2002), in hermeneutic research validity means that the study clearly gains access to the experiences of those in the research setting. Reliability means that there is transparency in how sense was made of the raw data. Generalizability means that the concepts and constructs derived from this study have relevance to other settings. (Easterby-Smith *et al.* 2002)

The researcher has graduated as a Master of Science in Technology from the Faculty of Technology of University of Oulu in 2006. The topic of the diploma thesis was cost-efficiency of parts manufacture. The study was conducted by analyzing a SC in steel industry. After graduating, the researcher has worked in the company under study in its SCM function as a manager. The researcher is acquainted with the field of study in practice and he has been involved in SCM. In practice, the researcher has not been involved in the SC studied, but he has participated in leading a larger entity. On the other hand, the researcher has had the possibility to affect the research subject but since the study subject has been in one limited SC, the researcher has been able to review the selected study subject in an objective manner. The study period was started in 2006 and lasted until 2010. During this time, the researcher has also worked in the SCM function. The researcher has conducted the study as a hobby, even though the topic of the study has been a part of the working environment. It can be stated that the researcher has increased understanding of the topic during the research work – it is an output. (Gummesson 2000)

In a case study, there are three main kinds of validity (Yin 2009) :

1. construct validity, establishing correct operational measures for the concepts being studied,
2. internal validity, establishing causal relationships whereby certain conditions are shown to lead to other conditions. This rarely has a major role in the case study,
3. external validity, establishing the domain to which a study's findings can be generalized.

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. Furthermore, the specialists had their own point of view on the research problem, which provided new information about the subject being studied. 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.

Internal validity was measured in pattern matching, grounded analysis and explanation building. Research was also a comparison with conflicting literature. SC performance measurement framework was conducted after extremely good analysis of SC performance measurement literature. Also alternative solutions were analyzed, but this chosen approach was most suitable for case SC performance measurement. External validity could be measured by using replication logic in multiple case studies. This study was a single case study, but even though only a single case was measured, the measurement framework could be used for measuring SC's in different contexts. Measurement framework could be utilized into various industries, but the practical measures should be made according to the needs of the industry in question. External validity can be measured by comparing the results with literature about the same area. This was done and different researches were reviewed. Several doctoral theses and journals were reviewed. Strong descriptions of the readers' own judgments are one measures to analyze research quality. The literature was reviewed and analysis of the study was made. Also all decisions were made based on the researcher's judgment. This study follows a case research approach and constructive qualitative research protocol.

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. In this case, the researcher was working in the same company in the SC function and the knowledge about this case was good. The aim of a case is not to generalize results in every case. It is more common to get a more holistic approach for research case by using case study method. During research, a database for raw data was built. All data is stored and database is well structured.

5.4 Future research

This research was a case study research with a single case. Research focus was in developing a SC performance measurement system based on literature reviews and published materials. After new construct of SC performance measurement system, the system was tested in the case company steel service centre, where SC performance was measured. The SC performance measurement system in the case SC was analyzed and it was clearly shown that the constructed measurement system was suitable for the case SC. It was accepted that the measurement system could not only be used in the steel industry but also the measurement framework could be used in manufacturing industry. However, the measurement system has to be constructed based on industry sector needs.

Multiple case study in different manufacturing industry areas

SCM performance measurement is not widely known in literature. Thus, this research was unique and needed especially by manufacturing industry. SC performance stands for different issues in every company and also in every industry area. It is not possible to use a SC performance measurement framework in every business sector without modification of this framework for business sector needs. Therefore, one aim for future research could be to carry out a multiple case study research in which the cases are selected from various industries. In this way, a more suitable measurement framework could be found for each industry.

In this study, a framework was chosen for manufacturing industry SC performance measurement. There were four different categories chosen for a valid framework. Those categories were selected due to the purpose of measuring case SC performance. In different SCs there could be different performance measurement categories. For example, in IT industry, the framework could be same but the approach for the framework would be different. The framework was used in this study measurement as the steel industry approach. Generally a framework is valid for every industry, but there should be a deep analysis on how to build up practical measures according to the framework.

More research regarding the SC and SC performance measurement is needed, especially in traditional industry sectors like the pulp and paper industry as well as in the steel industry. In this study it is stated that SCM is a 20th-century-trend in industry engineering and management science. There are several research fields in

SCM that should be researched more and more. SC performance measurement is one of the key elements for development of cost efficiency in the whole SC. Companies that are able to both manage the SC and measure it are the winners. In order to manage a SC efficiently, its performance needs to be measured continuously. Future success could be anywhere in the SCM field and therefore, it is worth studying SCM more.

Positivistic based supply chain performance research

This study was conducted as a hermeneutic, qualitative, inductive, case approach. In practice, managers and different management levels are using a more positivistic approach for measuring company's efficiency. Management is familiar with financial figures and used to combining and analyzing those figures. One possible future research area could be to find out a more positivistic based measurement approach for SCM performance measurement. It could also be analyzed in a different industry field. More challenging for SCM performance measurement is to construct number and figure based performance measurement metrics which are valid in every industry. Performance measurement also needs to be researched more globally and in different business cultures.

This study was carried out in manufacturing industry case SC and it answers its research question. Future research ideas were presented; hopefully future research will find answer to those questions.

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