TECHMIND RESEARCH
ISSN: 2291-2118

International Journal of Research in Business and Technology
Volume 6 No.2 April 2015

Measuring supply chain performance: A framework for prioritizing measures

Aron Chibba
School of Business and Engineering
University of Halmstad
Aron.Chibba@hh.se

Abstract- *One could consider changing the expression "organisations compete on a market" to "supply chains compete on a market". The reason for this is that most organisations are interested in reducing cost and increasing profitability. The need to evaluate the appropriate type of supply chain performance measure is therefore vital, as it can affect the decision-making process. The objective of this paper is to present a framework that identifies which performance measures and metrics should be prioritised in relation to the type of product manufactured and the type of supply chain using the product life cycle (PLC) approach. The framework presented consists of three descriptions of theories, which, when combined, provide valuable guidance for the prioritisation of performance measures. The three theories are: 1) type of supply chain, 2) type of supply chain performance measure; and 3) scope of measurement in the supply chain.*

Keywords- *Supply chain; Performance; Measure and metrics*

1. INTRODUCTION

During the last two decades supply chain management literature has evolved rapidly as a result of global competition and the introduction of information technology. Reducing cost and increasing profitability has always been of interest to organizations that compete on a market. Some researchers claim that it is the supply chain itself that competes on a market and not merely the organizations with their specific strategies and goals e.g. (Christopher, 1997) [8]. All members of the supply chain, both upstream and downstream, are actors who influence its output (e.g. quality, delivery, cost). In a framework that reflects manufacturing strategy issues in corporate decisions, (Hill, 2000) [30] describes how organizations can gain advantage over their competitors. He claims that supply chain strategy is part of the overall manufacturing strategy of an organization, and therefore the manufacturing performance affects the performance of the supply chain. The need to measure the correct metrics of performance within an organization is vital, due to the fact that it may affect the decision process. For example, if the measure fails to provide correct or relevant information about the process being measured, it could lead to a wrong decision followed by counterproductive actions. Several studies e.g. (e.g. Koh et al., 2007 [32]; Saad and Patel, 2006 [50]; Vereecke and Muylle, 2006) highlight the need to measure the efficiency of integrated supply chains. These studies have attempted to outline and describe different performance measures across and between organizations. However, the object of study of most researchers is the organization that operates within the supply chain, which means that the research outcomes do not actually capture the performance of the supply chain itself. (Lambert and Pohlen, 2001) also point out that most articles and discussions about supply chain measures/metrics are, in reality, about internal logistic performance measures. They argue that these measures do not capture the overall supply chain performance (SCP) nor do they indicate opportunities to increase competitiveness, customer value or value for each actor in the supply chain.

This paper focuses on analysing the supply chain performance of manufacturing organizations, i.e. the measures and metrics used to describe it. The result of this paper is relevant for all types of manufacturing organizations, in particular OEMs, Overall Equipment Manufacturers. The empirical data in this paper have mainly been collected from OEMs. This type of manufacturer usually operates downstream the supply chain, near the customer; therefore this paper is relevant for this part of the supply chain. How the supply chain of a manufacturing organization competes and develops in order to remain competitive is also focused upon and supply chain performance measures and metrics are analyzed. The unit of analysis is the supply chain type and its measures, sub measures and metrics. The main research question is: *What type of supply chain performance measures should be prioritised in different types of supply chains?*

The objective of this paper is to present a framework that indicates which performance measures/metrics should be prioritized depending on the type of supply chain operated by the organization, e.g. efficient, quick, agile, market responsive, lean, or hybrid. The objective is also to apply the life cycle (PLC) approach (Hill, 1993) to the market, in particular in the introduction, growth, maturity and decline phases, and combine it with the different supply chain measures and the scope inherent in the measurement situation. Some parts, involving the PLC and the type of supply chain, have already been described and presented by other researchers i.e. (Cigolini Cozzi, *et al*., 2004) [13]; (Aitken, Childerhouse *et al*., 2003) [1]; (Childerhouse and Towill, 2000) [7]; (Christoper and Towill, 2000) [10]. The "theory" about the measurement and metrics of supply chain performance in terms of what it is, how to measure it and, finally, how to choose the most suitable measures and metrics for different types of supply chains, will be presented. If, for example, the market is mature, cost is the right measure, or if the market is growing, delivery (time) could be the most suitable measure, or if the market is niche based or innovative, perhaps product characteristics, i.e. quality, are of great importance. The aim of this paper is to provide knowledge which can be used by organizations for developing and improving their supply chain, both upstream and downstream. The major contribution is the framework for determining and prioritizing which supply chain performance measures and metrics should be assessed. The framework can be used as a guideline to show manufacturing organizations e.g. OEMs, what aspects of supply chain performance are important to measure. The OEM can then monitor and evaluate the performance of the supply chain and use this information to introduce improvements.

The framework presented in this paper is based on previous research and empirical studies of two large multinational manufacturers of heavy vehicles. Delivery, quality, price, cost and flexibility are the measures particularly focused upon in this paper. The empirical work mainly focuses on overall equipment manufacturers i.e. OEMs and the appended papers consist of interviews with OEM managers for the most part from large enterprises (LE). The framework is therefore limited to these types of organizations, while the empirical work is mainly valid for downstream in the supply chain, i.e. near the end customer. The research takes an OEM perspective and does not include any interviews with suppliers and/or customers. Before including both suppliers and customers, more research is required about how a manufacturing organization such as an OEM measures and defines their type of supply chain. However, the theory presented does not solely focus on manufacturing but is relevant for all types of organizations.

2. METHOD USED TO DEVELOP THE FRAMEWORK

This paper has a descriptive rather than an explanatory approach. Case studies are often associated with descriptive and exploratory research. The method used to develop the framework in this paper is based on the scientific principle of adding small pieces of theory to well known existing theories i.e. deductive. The point of departure is the famous product life cycle (PLC) model with its four phases: introduction, growth, maturity and decline. This model served as a base for adding both old and new theory i.e. which types of products and supply chain are connected to each phase of the product life cycle and which types of performance measures and metrics are suitable as a means of assessment for manufacturing organizations and, finally, the point in the supply chain at which each performance measure should be applied. The first contribution is the connection of different types of supply chain to the product life cycle model. The theory of supply chain types e.g. efficient supply chain (ESC), quick supply chain (QSC), market responsive supply chain (RSC), agile supply chain (ASC), lean supply chain (LSC) and finally hybrid supply chain (HSC) is then added to the model and discussed. The types of products which can be connected to each type of supply chain are also presented and discussed. This provides the first input to the framework, *"type of supply chain"* e.g. efficient supply chain (grocery, newspapers)) and lean supply chain (automobiles). The types of supply chain performance measures and metrics that can be associated with each "type of supply chain" are then discussed and the outcome is the second input to the framework i.e. *"type of supply chain performance measure and metrics"* i.e. what type of performance measure and metrics should be measured. For example: an agile/quick supply chain requires speedy delivery, while a lean supply chain is more focused on cost reduction. The third and final input to the framework deals with the "*scope of measurement in the supply chain"* i.e. the most appropriate point in the supply chain for measuring performance. It could be between the organization and customer, the supplier or even internal measures within the organization or over the whole supply chain. These three parts of the framework provide an understanding of the need to choose the right type of performance to measure and where in the supply chain it should be measured.

Theory supporting the development of the framework is mainly collect from existing well known theory and the empirical work conducted in two large multinational manufacturers of heavy vehicles. It begins with an overview of the product life cycle (PLC) as a concept and proceeds by connecting different types of products with individual PLC phases. Supply chain theory is then described and linked to the PLC, together with supply chain performance measures and metrics and where in the supply chain an organization should measure performance.

The empirical work supporting the development of the framework is collected from a case study from two large multinational manufacturers of heavy vehicles. The two heavy vehicle manufacturers are part of a "heavy vehicles" group and also support CIL, Centrum for Information logistics, Ljungby, Sweden. The manager of CIL first contacted these two manufacturers to invite them to take part in the research project, after which we contacted them and described the project. The companies that we were about to study gave us their full support. Top executives allowed us access to required data i.e. personnel and meetings. We employed a qualitative research process, as our aim was to present the supply chain performance measures and metrics focused on by these two Heavy Vehicle manufacturers as a result of their position in the supply chain. We limited our interviews with managers to 2-3 hours per interview. At an early stage we made it clear that we wanted to interview the "owners" of the performance measure i.e. those who were responsible for measuring the supply chain performance, e.g. quality, delivery, cost (price) and flexibility. Together with the two manufacturers, we then defined our respondents as follows: Company As' Quality Assurance Purchasing Manager, Production Manager and Purchasing Manager and Company Bs' Quality Manager (also production manager at site 1, Production Manager site 1 and Production Manager site 2, Purchasing Manager (site 1 and 2) and finally Operating Purchasing Manager (site 1). The total number of respondents was seven. The interview questions were related to the supply chain, to performance, measures and metrics. The issues addressed in the interviews were based on earlier supply chain performance research and supply chain performance theories e.g. (Robson, 2004 [48]; Cigolini, Cossi *et al*., 2004 [13]). Staff interviewed included the managers from each company responsible for supply chain performance. The empirical content of the in this paper is mainly based on case studies, which seems to be the most appropriate data collection method when concepts and variables are difficult to quantify. One alternative approach could be to use a more quantitative method as well as a broader sample in order to be able to generalize the conclusions. The reasons for only choosing four metrics are that the measures chosen are the ones most frequently referred to by purchasing managers when selecting suppliers. Moreover, the presented work mainly focuses on large manufacturing organizations, especially OEMs.

3. THEORY SUPPORTING THE DEVELOPMENT OF THE FRAMEWORK

The concept of product life cycle (PLC) was first introduced in the 1950s by (Dean, 1950) [16], who used the concept in relation to the marketing role of the life cycle. It has since been widely discussed and reviewed by researchers including (Gardner, 1987) [19] and (Rink and Swan, 1979) [47], who presented surveys of the literature. However, the validity of the PLC concept has been questioned. According to (Pesonen, 2001) [45], most criticism of the life cycle concept was related to marketing issues. He argues that opponents mainly criticize the use of the bellshaped sales curve as default or self-evident product sales behavior. These researchers provide their point by illustrating the poor fit of the curves by means of empirical examples of product class, product form or brand. For example, (Cox, 1967) [14] who identified six different shapes of the product life cycle graph in a study of 256 pharmaceutical products, thus revealing that there are many products that do not follow the usual shape of the product life cycle presented in figure 3. However, other researchers (Barksdale and Harris, 1984) later presented evidence showing that the bell-shaped curve is a reasonable model of the sales record for many types of products. The concept of PLC is based on the fact that every product has a life in the market with respect to business, cost and sales measures. When a product is developed, it sooner or later enters the market. Sales grow slowly at first, until a critical mass of consumer awareness is achieved, after which sales grow rapidly until the demand cools off and the product enters a sustained period of slower growth. Later, the sales decrease gradually and then perhaps more rapidly. When sales reach a certain level, the organization has to consider ending the life of the product. The PLC is typically divided into four phases (Hayes and Wheelwright, 1984): introduction, growth, maturity and decline. However, some researchers add an initial phase of development, while others include a final cancellation phase or a saturation phase between maturity and decline. All types of products can be fitted into the PLC model, although different types of products, e.g. complex or simple, have a particular curve in the PLC. For example, an organization that manufactures white products, automobiles or forklifts is in a mature market (Selldin & Olhager, 2007 [51]; Cigolini, Cozzi *et al*. 2004 [13]; Huang, Uppal *et al*., 2002 [31]; Fisher, 1997 [17];).

3.1 Type of product characteristics in each stage of the PLC model

A product can either be functional or innovative, primarily depending on its demand characteristics in terms of the life cycle length, demand predictability, product variety, as well as market standards for lead times and service (Fischer, 1997). Some researchers (Huang, Uppal *et al*., 2002) also hold that products can be categorized into functional and innovative but add one more category i.e. hybrid products. *Functional products* are defined as simple products, synonymous with standard and commodity products i.e. grocery, pharmaceuticals, basic apparel (jeans and underwear), classic books. Their demand can be accurately forecast and their market share remains fairly constant. They also enjoy a long life-cycle with superficial design modification leading to different product types. Such products have a well defined process and it is reasonable to state that the organization has a long-term relationship with its suppliers in terms of material quality, delivery times and quantity discounts. *Innovative products* are defined as new products developed by organizations to capture new markets and designed to be acceptable to changing customer demands or derivative products for capturing a wider share of the market. Huang, Uppal *et al*. conclude that *hybrid products* consist of either different combinations of standard components, or a mix of standard and innovative components (Huang, Uppal *et al*., 2002) [31]. (Cigolini, Cozzi *et al*., 2004) [13] also categorized products and presented two distinct groups; complex products and simple products. Their description of "simple products" matches Huang, Uppal *et al*.'s description of functional products. However, their description of complex products does not fully agree with the descriptions of innovative or hybrid products. "Complex products" indicates the structural complexity of the end product i.e. number of parts, subassemblies and level in the bill of materials, which determines the number of manufacturing processes, suppliers and technologies that have to be managed and co-ordinated. However, a complex product can also be a functional one. Functional products are either simple (grocery, basic apparel) or complex (white goods, automobiles) and are described in the literature (Selldin & Olhager, 2007 [51]; Cigolini, Cozzi *et al*. 2004 [13]; Huang, Uppal *et al*., 2002 [31]; Fisher, 1997 [17]) as being in the maturity phase of the PLC. Innovative products are said to be in the introduction and growth phase (Selldin & Olhager, 2007 [51]; Huang, Uppal *et al*., 2002 [31]; Fisher, 1997 [17]). However, innovative products are described by (Cigolini, Cozzi *et al*., 2004 [13]) as being in both the introduction and decline phase. The reason for this is that innovative products have a short PLC e.g. three months to one year (Fischer, 1997) [17]. This means that the maturity phase is so short that it almost immediately goes from introduction and growth to decline with no time for the maturity phase. Hybrid products are described by (Huang, Uppal *et al*., 2002) [31] as consisting of either different combinations of standard components (functional products) or a mix of standard and innovative products, such as an automobile. Researchers seem to have a similar view and way of presenting product characteristics within the phases of the PLC (Selldin & Olhager, 2007 [51]; Cigolini, Cozi *et al*., 2004 [13]; Huang, Uppal *et al*., 2002 [31]; Fisher, 1997 [17]).

3.2 The type of supply chain connected to products within the PLC

This section gives a deeper understanding of how various products require different types of supply chains, in order to ensure effective manufacture. The types of supply chains presented are then connected to the PLC model. (Fisher, 1997) [17] has developed a model that can be considered a prescription for choosing the right supply chain i.e. efficient supply chain or a market responsive supply chain, for a certain product. A Physically Efficient supply chain is suitable for functional products, while a market responsive supply chain is appropriate for innovative products. Cigolini, Cozzi *et al*. also link product characteristics and type of supply chain, i.e. efficient, quick or lean supply chains, and conclude that:

- Mature and simple products require an efficient supply chain
- Mature and complex products require a lean supply chain
- Complex products in the growth phase require a lean supply chain
- Simple products in the introduction/decline phase require a quick supply chain

There are several types of supply chains described in the literature. (Fischer, 1997) [17] presented a model which links supply chains to products. The model describes two types of supply chains and connects functional and innovative products to them i.e. efficient supply chains (ESC) are matched to functional products while *market responsive supply chains* (RSC) are linked to innovative products. Market Responsive supply chains (RSC) have similar characteristics to agile supply chains (Selldin & Olhager, 2007). An *efficient supply chain, ESC*, brings products to the market that can broadly be considered as commodities and are often sold in high volumes (e.g. grocery, newspapers …). Because of the stability of their product flows, such organizations can invest in large and financial-intensive facilities, and improvement initiatives are focused on operations rather than product innovation. These types of products are in the maturity phase of the PLC. A *quick supply chain, QSC* (e.g. fashion apparel, white products) can be defined as "products whose demand is difficult to forecast". These types of organisations invest in manufacturing systems with a high variable vs. fixed cost ratio due to the fact that manufacturing flexibility is very important. These types of organisations are in the introduction (and decline) phase of the PLC. A *lean supply chain*, LSC, (e.g. automobiles) deals with a functional product, the demand for which can be forecast. LSCs also have intermediate characteristics: firms do not only compete on product price or novelty, but simultaneously on price, novelty, quality and customer service. An LSC employs continuous improvement processes in order to eliminate waste or non-value stops across the chain (Turkett, 2001; Christopher and Towill, 2000 [10]). The LSC employs both lean production and time compression to ensure economical, flexible and responsive operation. (Naylor *et al*., 1999) [41] presented a definition of leanness: to develop a value stream to eliminate all waste, including time and to enable a level schedule. Innovative products focus on capturing new markets and are designed to be acceptable to changing customer demands. (Huang, Uppal *et al*., 2002) argue that this type of product usually has uncertain demand and its design may be unstable; such products are in the introduction or growth stages of the product life-cycle. Huang, Uppal *et al*. claim that this justifies the use of an *agile supply chain* (ASG), the paradigm of which was presented by (Christopher and Towill, 2000) [10]. According to (Naylor *et al*. 1999), agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace. (Huang, Uppal *et al*., 2002) [31] presented a *hybrid supply chain* i.e. a combination of an LSC and ASC, which they claim might be the best choice for car manufacturers. In the example provided, they demonstrate that some automobile components may contain innovative features. As a result, these components may be produced using either lean or agile techniques. A hybrid supply chain may therefore be appropriate, as it consists of a mix of both lean and agile techniques. These products e.g. automobiles forklifts, rollers, pavers are in the introduction, growth and maturity phases of the PLC. (Naylor *et al*., 1999) also presented a supply chain which is a combination of LSC and ASC i.e. *Leagile supply chain*. This type of supply chain is described by (Christoher and Towill, 2000) [11] as both lean and agile i.e. agile enough to respond to what is actually selling (market driven) with availability as the market winner. (Christopher and Towill, 2000) [11] also presented a "customized leagile supply chain" which has a more customer driven approach where the market winner is lead-time, and an example of a product could be a personal computer. Dell supplies products that accord exactly with individual customer specifications.

3.3 Performance measures connected to the type of supply chain

As mentioned before the performance of the supply chain has been widely covered in the literature These studies highlight the need to measure the efficiency of the integrated supply chain. The efficiency can best be described by customers. (Petroni and Panciroli, 2002) [46] argue that customers usually retain suppliers who achieve the highest aggregate score on price, quality, flexibility of production and delivery times. (De Toni, Nassimbeni *et al*., 1994) [15] claim that an efficient high quality supply chain is dependent on the achievement of a high-level performance in terms of cost, quality and time-to-market. (Hayes and Wheelwright, 1984) [24] were the first to present methods for addressing operational strategy by means of four generic competitive priorities; quality, cost, flexibility and delivery, which are the dimensions on which a company chooses to compete within a target market. Their original formulation was applicable to all functions. (Hill, 2000) [30] also addresses competitive priorities such as price, cost reduction, delivery reliability, delivery speed, quality conformance, flexibility - increased demand, product range and design, which he terms order-winners or qualifiers. Since the beginning of the manufacturing era, performance measures have been important for organizations as a way of obtaining knowledge about what is happening around them. (Lambert & Pohlen, 2001) [34] argue that a well crafted system of supply chain metrics can lead to competitive advantage through differentiated services and lower costs. The performance of a supply chain can be viewed as a system of measures such as quality, delivery, flexibility and cost/price. Traditional performance measures such as profitability are less relevant for measuring supply chain performance.

A well known framework for benchmarking performance in the supply chain is that of the Supply Chain Council, which is a cross-industry association. Their model, known as SCOR (Supply Chain Operations Reference), is built around four major processes, namely: plan, source, make and deliver. These processes cover the key supply chain activities from the point of identifying customer demand to delivering the product. The main aim of this reference model is to provide a standard way of measuring supply chain performance and to use fixed metrics for benchmarking against other organizations (Christopher, 1998) [9]. The framework describes metric type, the expected outcomes and the diagnostics that can be predicted. However, the Supply Chain Council's integrated supply chain metric framework does not fully take an organization's type of product, type of supply chain or measurement situation into account.

An example of a supply chain performance measure could be delivery, sub measure could be "the ability to consistently deliver on the agreed due date", the metrics could then be presented as "% of on time delivery". Metrics is thus the system of parameters or methods for the quantitative assessment of a process to be measured, as well as the procedure involved in carrying out such a measurement. Metrics defines the items to be measured and is usually specifically related to a given subject area, in which case it is only valid within a certain domain and cannot be directly benchmarked or interpreted outside it. Generic metrics can, however, be aggregated across subject areas or business units of an enterprise.

The main idea behind measuring performance is to obtain information about what needs to be improved. Organizations today try to measure their overall customer service performance, and while the criteria considered vary, they usually include quality (of the product) and delivery time. However, the establishment of a measurement system requires knowledge about the processes within the organization and between customers and suppliers. To generate this knowledge the organization has to decide what performance metric to measure. As (Robson, 2004) [48] stated "without the knowledge of the exact circumstances under which a measurement system either will or will not improve the performance, it is difficult to genuinely justify the additional cost of implementing a measurement system". (Krausse & Pagell, 2002) [33] presented a table of performance items for assessing organizational strategy, the main idea being to describe "priority" e.g. quality (e.g. reliability, durability, and conformance), delivery (e.g speed, reliability), flexibility (e.g. volume, mix), cost (e.g. price, total cost) and innovation (e.g. process, product) as well as the focus of the manufacturing and purchasing items. For example, quality (reliability) in manufacturing is defined as "the ability to maximize the time to product failure or malfunction" while in purchasing the "supplier selection and retention decisions are based on the ability of a supplier to provide reliable inputs". However, there are several supply chain performance measures and metrics that can be assessed. Those most commonly used by practitioners i.e. purchasing managers as well as the most cited in research are: quality, delivery, cost and flexibility, which will be described in more detail below.

Quality has according to (Hill, 2000) [30], been thrust onto centre stage since the late 1970s. However, several companies have failed to compete in this domain. Hill holds that the definition of the term quality has been broadened to encompass many dimensions, resulting in a lack of understanding and subsequent lack of direction. One reason why companies do not compete in the quality domain is due to failure to clarify which dimension(s) of quality will provide the best result in given markets. One of the cited researcher who presented eight dimensions of quality is (Garwin, 1988) [20], e.g. Performance – a product'sprimary operating characteristics, Perceived quality – how a customer views the product. The dimensions of quality are generic dimensions that can apply to all types of products and services in all types of markets. These quality dimensions are well known and much cited. However, the term product quality, which is not mentioned, can be classified according to perceived quality i.e. how a customer views the product. Product quality is focused on the user of the product (or service, service quality). The user can be an organization or an individual, not necessarily the end customer but a customer within the supply chain i.e. an internal customer. The supply chain performance measure "quality" has several sub measures e.g. conformance quality, quality reliability and end product quality. In the literature, quality and delivery are described as important measures for monitoring the supply chain (Christopher and Towill, 2001 [11]; Aitken, Childerhouse *et al*., 2003 [1]; Hill, 1993 [29]).

Delivery performance has several sub-measures e.g. on time delivery, delivery reliability, faster delivery times, delivery service, delivery frequencies, delivery synchronization, delivery speed etc. Delivery reliability concerns supplying the ordered products on the agreed date. On-time delivery (OTD) is therefore a major concern of the manufacturing as well as the distribution function. (Hill, 2000) argues that in many businesses this criterion constitutes a qualifier. A study of the Indian automobile industry (Saad and Patel, 2006) [50] showed that the key supplier selection factors identified by most of the respondents were supply delivery lead time, historical rejection rate, geographical proximity and reliability. If organizations frequently miss the OTD date, they usually end up with a problem and have to improve quickly before customers change to a different supplier. OTD is a competitive factor and customers tend to measure this performance metric. Hill argues that a company wins orders through its ability to deliver more quickly than competitors or to meet the required delivery date when few or none of the competition can do so. He holds that there are two perspectives on the issue of delivery speed. One is when the process lead time, although shorter than the delivery time required by customers, is difficult to meet as a result of the current forward order load, i.e. the order backlog on the manufacturing capacity, which means that the process lead time to complete the order is greater than the delivery time required. The second perspective is when the process lead time is greater than the customer delivery requirement. Delivery has several sub metrics, and organizations decide which sub-measures are most appropriate to measure, e.g. delivery from suppliers, delivery within their own organization or delivery to customers.

Cost reduction both externally and internally in the supply chain is vital for improving productivity. Hill claims that many organizations do not concentrate their efforts in the area of greatest cost. Instead, they concentrate on reducing the cost of direct labour. (Gadde and Håkansson, 2001) [18] provided examples of what is usually known as indirect purchasing costs. These costs can be defined as: purchasing costs, goods handling costs, storage costs, financial costs, supplier handling costs, administration costs and development costs. Cost is strongly connected to the performance measure price. (Hill, 2000) [30] states that price is an increasingly important order-winning criterion, especially in the growth, maturity and saturation phases of the product life cycle. The task of manufacturing is to achieve the low costs necessary for price-sensitivity in the market-place. This measure is strongly connected to suppliers i.e. purchased items, as well as the manufacturing organization's own workforce.

Flexibility can be defined as "the extent to which a company intends to respond to market changes e.g. significant increases in demand" (Beamon, 1999 [4]; Hill, 2000 [30]). Or as (Harrison, 2001) states: "flexibility is the management of reacting to changes in demand by preserving the resources of time, money, materials, people, plants and suppliers until they are specifically required". Both definitions characterise flexibility as the capability to respond to individual customer requirements. This is a broad performance measure that includes: demand increases (volume), product range (mix), order handling (time), order size etc. Hill argues that, in some markets, a company's ability to respond to increases in demand is an important factor in winning orders. Japanese car manufacturers provide a good example of flexibility; they have established and continue to develop a production system capable of responding to individual customer requirements (Hill, 2000) [30]. (Slack, 1991) identified four types of system flexibility where each type can be measured in terms of range and response: volume flexibility (the ability to change the output level of products produced), delivery flexibility (the ability to change planned delivery dates), mix flexibility (the ability to change the variety of products produced) and new product flexibility (the ability to introduce and produce new products).

3.4 Appropriate supply chain performance measures

There are several types of supply chains described in the literature, i.e. efficient, quick, agile, lean and hybrid, all of which have different characteristics. Several researchers claim that the different types of supply chain require an individual focus in order to achieve optimal performance (Saad and Patel, 2006 [50]; Christopher, Peck *et al*., 2006 [12]; Mason *et al*., 2002 [39]; Christopher and Towill, 2000 [7]; Hoek, R. I., A. Harrisson, *et al*., 2001 [27]; Beamon, 1999 [4]). One could say that certain supply chain performance measures should be prioritized depending on the supply chain type. (Christopher and

Towill, 2000) [10], presented a model summarizing the transition in PC supply chain operations. The model shows the market winners or qualifiers e.g. quality, cost, lead time and availability and how these changed over a 20 years period from the early 1980s to the late '90s.

A primary efficient supply chain measure is cost e.g. total cost from suppliers through the internal supply chain to customer, or all types of cost that have a bearing on the cost of manufacture. The primary supply chain metric can be expressed as e.g. cost/purchased item. A quick, agile or market responsive supply chain (which has similar characteristics) has shorter lead times i.e. delivery as a primary measure, while flexibility (mix) of production and product quality are also primary measures. A shorter lead time from order to delivery is another important Lean supply chain measure, but not but not to the same degree as cost i.e. cost is more important than delivery. A hybrid (lean & quick/agile/market responsive) supply chain focuses on shortening the lead times at component level but without incurring cost, while in order to accommodate customer requirements, it follows the agile (quick/market responsive) supply chain performance measures at product level i.e. delivery, flexibility and quality. In figure 1, the PLC model has been modified in relation to appropriate measures for each type of supply chain and type of products.

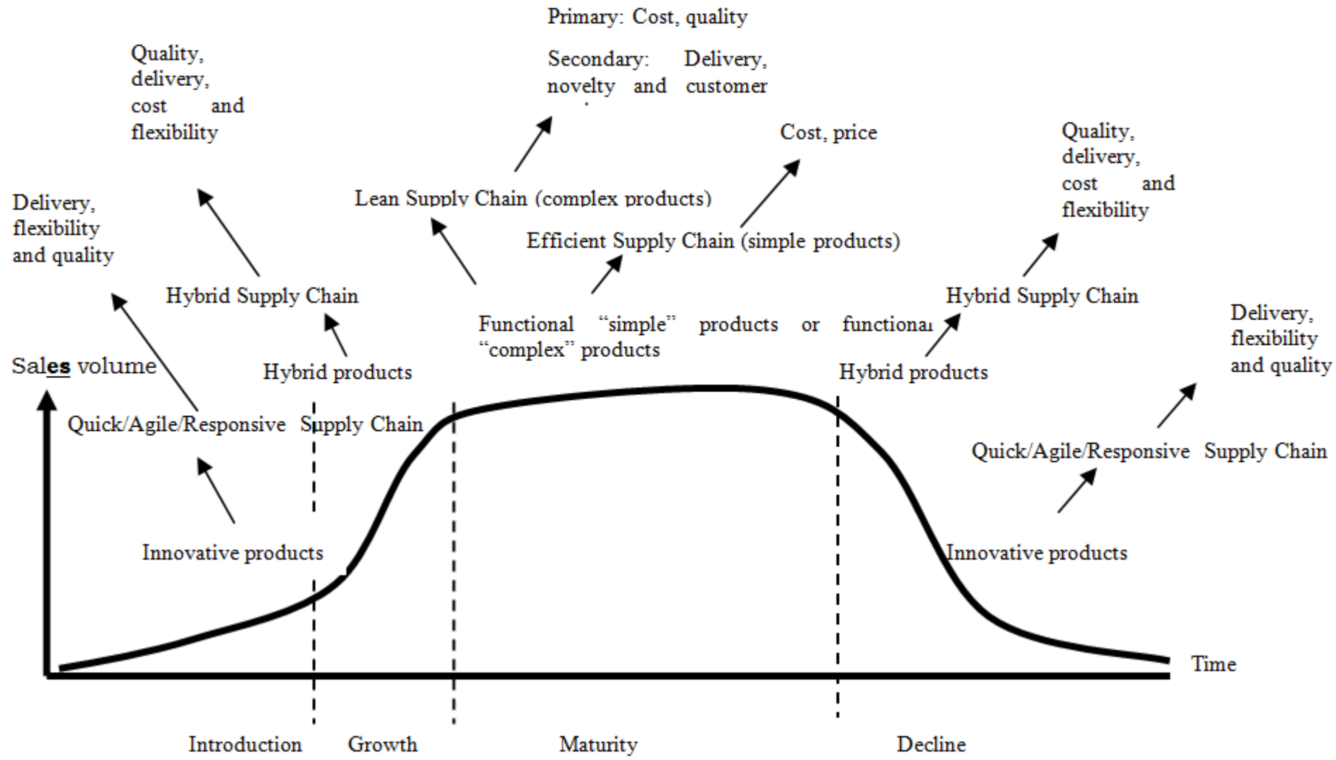

Figure 1. Phases in the product life cycle in relation to different product characteristics and their supply chains, measures and metrics

3.5 Scope of supply chain measurements

The production process in manufacturing organizations is often an activity that has a major impact on production cost, quality and speed of delivery. Therefore, the production process needs to be measured, managed and improved and suitable metrics established under the following three headings (Gunasekaran, Patel *et al*. 2001) [22]: range of products and services, capacity utilization and effectiveness of scheduling techniques. These types of measures are known as functional measures. *Functional measures* (type 1) depict the performance of a separate activity/function of the chain, e.g. flexibility (mix) of production – the ability to effectively produce a wide variety of different products, although they are not supply chain measures as such. However, Holmberg (2000) [28] claims that implementation of SCMs within an organization requires that the internal perspective on performance measures be expanded to include both "interfunctional" and "partnership" perspectives as well as the avoidance of an inward-looking and self focused management approach. There are also measures that show the performance of several interconnected functions i.e. head-processes. Metrics, such as cost (total cost), quality (part per million defects, PPM), non-conformities and delivery lead-time, is suitable for measurement. These types of measures are called *Internal integrated measures* (type 2) and depict performance across functional boundaries within the firm, e.g. quality (conformance) – the ability to manufacture a product whose operating characteristics meet established performance standards; Cost (total cost) – the ability to minimize the total cost of production (labour, materials, and operating costs) by means of efficient operations, process technology and/or scale economies; Delivery (speed) – the ability to minimize the time between the receipt of a customer order and final delivery, although it can be argued whether this is a supply chain performance measure. These measures shed light on organizational performance and are included in our study as (internal) supply chain performance measures. A study of the US food industry reported that poor co-ordination among supply chain partners wastes an estimated $30 billion annually (Fisher, 1997) [17], which highlights the importance of establishing partnerships in a supply chain. There is a set of criteria/parameters that should be considered when evaluating a partnership (Gunasekaran, Patel *et al.*, 2001) [22]. For example, the level of assistance in mutual problem solving supports buyer-supplier partnership development. Several researchers have suggested the following supply chain partnership evaluation criteria: level and degree of information sharing, the entity and stage at which the supplier is involved (Toni, Nassimbeni *et al.*, 1994), buyer-vendor cost saving initiatives (Thomas and Graham, 1996) [55], extent of mutual co-operation leading to improved quality (Graham, Dougherty *et al.*, 1994) [21] and the extent of mutual assistance in problem solving (Maloni and Benton, 1997) [38]. Other measures that merit consideration are quality (conformance, reliability), delivery performance (reliability), product price and flexibility of scheduling and production. These types of measures are known as *One sided integrated measures* (type 3) and depict performance across organizational boundaries as well as measuring chain performance across supplier or customer boundaries, e.g. total cost, total lead-time and delivery (speed) – the ability to respond in a timely manner to customer needs. Some researchers (Rushton and Oaxly, 1991 [49]; Thomas and Graham, 1996 [55]) claim that the largest cost component of logistics is transportation costs in the total chain. They state that the trucking cost is always the largest part of the total distribution cost. Therefore, it appears important to treat delivery and cost as a high priority metric. (Stewart, 1995) identified the following measures of delivery performance: delivery-to-request date, delivery-to-commit date, and order fill lead-time. These types of measures are known as *Total chain measures* (type 4), as they depict performance across organizational boundaries and measure the performance of the entire supply chain, including links to suppliers and customers, e.g. total chain costs – and provide an opportunity to minimize the total cost from supplier to end customer. The above measurement situations (type 1-type 4) can be linked to a model developed by the Supply-Chain Council (SCC) e.g. PLAN, SOURCE, MAKE and DELIVER. (Lockamy III and McCormack, 2004) [37] describe these four processes as follows: PLANNING deals with the decision-making area, e.g. demand planning, which includes forecasting development activities has a significant impact on supply chain performance. SOURCING handles supplier transactional collaboration activities and has a significant impact on supply chain performance within the Source decision area. MAKING planning process activities have a significant impact on supply chain performance within the Make decision area. Activities include: collaboration among the sales, manufacturing and distribution functions. (Lockamy III and McCormack, 2004) [37] argue that to ensure its effectiveness, the process must be integrated and coordinated across functional and organizational boundaries. In the DELIVERY decision-making area, delivery process measures have a significant impact on supply chain performance. According to (Lockamy III and McCormack, 2004) [37], these measures and metrics should document the supply chain inter-relationships in a manner that can be understood by the supply chain trading partners. Figure 8 shows the SCOR model combined with different supply chain performance measure situations.

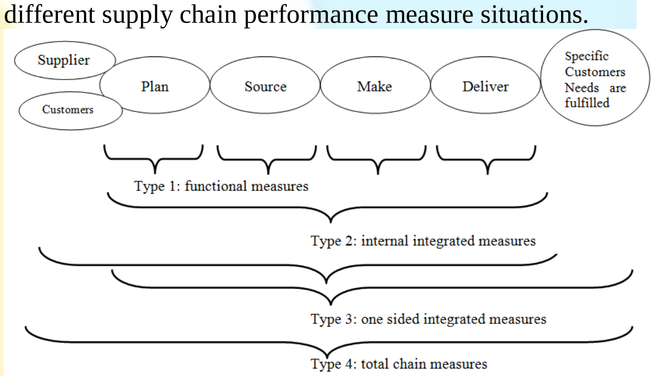

Figure 2. Four different types of supply chain performance measurement situations

This way of depicting the measurement situation provides a more concrete picture of where in the supply chain the performance measurement should be performed i.e. internally, customer side, supplier side or the whole supply chain. To find support from theory, the measurement situations presented above could be linked to (Hill, 2000) [30]description of the four phases i.e. Integrating the steps within the internal supply chain (phase1), procurement through finished goods (phase 2), coordinate activities between businesses (phase 3), and planning and executions of activities across the supply chain (phase 4). If we combine the model presented in figure 1 "Phases in the product life cycle in relation to different product characteristics and their supply chains, measures and metrics", with figure 2, "Four different types of supply chain performance measurement situations" we obtain a picture that can explain what types of supply chain performance measure are important and should be prioritized as well as where to measure a certain type of performance e.g. delivery (on time) from customer (type 3), in relation to e.g. types of products manufactured and types of supply chain.

4. EMPIRICAL WORK SUPPORTING THE DEVELOPMENT OF THE FRAMEWORK

Manufacturers of heavy vehicles e.g. forklifts, pavers, rollers etc produce products which are classified in the literature, e.g. (Fischer, 1997) [17]; Cigolini, Cozzi *et al.*, 2004[13]; and Huang, Uppal *et al.*, 2002 [31]) as functional products with innovative characteristics. This in turn indicates the type of supply chain in which the organization operates, (Cigolini, Cozzi *et al*., 2004[13] ; and Huang, Uppal *et al*., 2002), i.e. a hybrid supply chain as well as the phase of the product life-cycle in the market, i.e. introduction, growth and mature, (Cigolini, Cozzi *et al*., 2004 [13]; Hill, 2002 [30]). A Hybrid (lean & quick/agile/market responsive) supply chain focuses on shortening lead times, without incurring cost. Taken together, this indicates the types of performance measures and metrics that should be evaluated i.e. quality, delivery, cost and flexibility, (Cigolini, Cozzi *et al*., 2004 [13]; Hill, 2000 [30]). And finally we can also predict the scope of measurement situation type 1 – type 4 and combine it with our knowledge of which performance measures and metrics are appropriate for measurement. The data presented below (table P) are the results from the empirical work.

Table 1. The supply chain performance measures of two heavy vehicle manufacturers

	Performance measure	**Sub measure**	**Metric**
Type 1			
Functional measures	Quality	Quality conformance	PPM
	Cost	Productivity	Man hour/machine
Type 2			
Internal supply chain measures	Delivery	Lead time	Days
	Cost	Direct labour cost	SEK/machine
Type 3	**Supplier**	**Supplier**	**Supplier**
One sided integrated measures i.e. supplier or customer	Quality	Quality conformance	PPM
	Delivery	Reliability	%
	Price	Price/purchased item	SEK/item
	Customer	**Customer**	**Customer**
	Delivery	Reliability	%
	Quality	Quality conformance	PPM
	Service after delivery	Time to establish customer services	Hours
Type 4			
Total chain measures	Total cost	-	SEK
	Total lead time	-	Weeks

The presented empirical work of how two large multinational heavy vehicle manufacturers measure their supply chain seems to agree with the theory presented in this paper. These two OEMs have developed their supply chain for over 50 years and their products are in a mature marketplace. They operate downstream in the supply chain i.e. close to the end customer. The supply chain type can be classified as a hybrid, in which they try to achieve mass customization by postponing product differentiation until the final assembly by adding innovative components to existing products. When choosing suppliers they focus on low cost and high quality, along with delivery speed and flexibility of production. Both manufacturers focus on quality and shorter lead-times, but without leading to increased costs. Their supply chain measures and metrics indicate that they are in a mature market and that their products can be classified as functional with innovative characteristics and their supply chain as hybrid (between a lean and an agile/quick supply chain). They only work with a 1st tier supplier and they are near the end customer. We found evidence that these two organizations primarily focus on product quality, on-time delivery to customers and total cost from the point of order to payment from the customer. The product quality aspects of suppliers seem to be highly important i.e. should be prioritized, which also applies to the lead time from suppliers. The example reveals that these two heavy vehicle manufacturers should prioritise a greater level of interaction with 2nd and 3rd tier suppliers in order to decrease the total cost, shorten lead times and improve quality.

5. CONCLUSION

The purpose of this paper is to describe a framework for prioritizing the supply chain performance measures and metrics to be evaluated. The framework was developed on the basis of the empirical work carried out in this paper and knowledge from previous research. It describes several aspects that should be taken into account: The life-cycle stage of the manufactured products i.e. introduction, growth, maturity or decline. Furthermore, the characteristics of products in the supply chain i.e. can they be classified as functional, innovative or hybrid. What type of supply chain is considered i.e. efficient, quick, agile, market responsive, lean, or hybrid? Which type of supply chain performance measure and metric is important i.e. quality, delivery, cost or flexibility. And finally, what type of supply chain measurement situation is preferable. These measurement situations are described as type 1 – type 4. Type 1: functional measures depicting functional level performance, type 2: an internally integrated supply chain which shows the performance within the organization and between functions (cross functional), type 3, one sided integrated measures that depict the performance in relation to suppliers and/or customers, and finally type 4, which depicts performance over organizational boundaries (total chain) i.e. from raw material suppliers to the end customer and/or user. The framework presented in figure 3 has its base in previously presented literature and research i.e. well known theory and the empirical work in this paper.

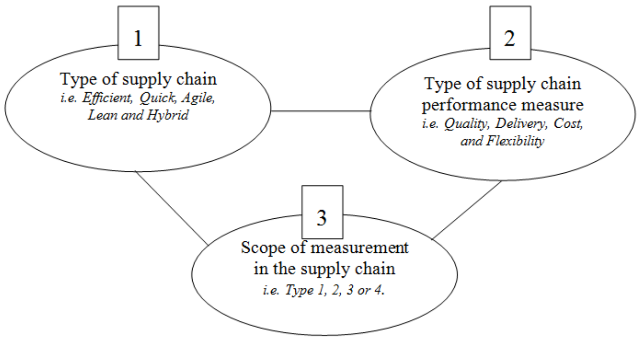

Figure 3. Framework for prioritizing supply chain performance measures

The above framework consists of three different descriptions of theories, which, when combined, provide valuable guidance for which performance measures a manufacturing organization should prioritize. These descriptions are supported by theory to varying degrees, as described below.

The type of supply chain (1) i.e. efficient, quick, agile, market responsive, lean and hybrid, is fully supported by theory. Also the empirical work seems to match. The type of products manufactured defined by (Fischer, 1997) [17] i.e. functional, innovative or hybrid, indicates, according to (Cigolini *et al*., 2004 [13]; Huang, Uppal *et al*., 2002 [31]), the phase in the product life-cycle into which the product can be classified i.e. introduction, growth, maturity, or decline. The product life-cycle phase in turn indicates the type of supply chain i.e. efficient, quick, agile, market responsive, lean or hybrid (Cigolini *et al*., 2004; Huang, Uppal *et al*., 2002 [31]; Aitken, Childerhouse *et al*., 2003 [1]; Christopher and Towill, 2001 [11]; Fisher, 1997 [17]). The number of supply chain types can be limited to 4, due to the fact that several types of supply chains have similar characteristics. Figure 1, seems to be a contribution to theory.

The type of supply chain performance measure (2) is also supported by the empirical work and by theory e.g. (Saad & Paatel, 2006 [50]; Krausse & Pagell, 2002 [33]; Gadde & Håkansson, 2001 [18]; Lambert & Pohlen 2001[34]; Stewart, 1995 [53]; De Toni and Nassimbeni, *et al*., 1994 ; Hayes and Wheelwright, 1984 [24]). However, the three level classification of the performance seems to be new: supply chain performance measures, sub-measures and metrics appear to be contributions to theory.

The scope of the measurement situation (3) is firmly grounded in theory e.g. (Hill, 2000 [30]; Stewart (1995) [53] and the SCOR (Supply Chain Operations Reference) model, which was further developed by the researcher. Measurement scope is presented for type 1 to type 4, see figure 2, which is, to the best of our knowledge, a contribution to theory.

These three descriptions of theory relate to each other. The type of supply chain (1) and the type of supply chain performance measure (2) are strongly linked; theory reveals that they are dependent on each other. Theory indicates which types of supply chain performance measures could be connected to each supply chain type. The connection between (1) and (2) is quite clear. The scope of the measurement situation (3) is also obvious due to the fact that the supply chain performance must be measured at some level or phase, i.e. type 1 – type 4. The type of supply chain performance measure (2) dependent on the type of supply chain (1) is also quite clear. This provides a picture of what an organization should focus upon i.e. which supply chain performance measure and metrics and at what point in the supply chain they should be measured.

REFERENCES

[1] Aitken, J. and Childerhouse, P. *et al.*, (2003), "The impact of product life cycle on supply chain strategy", *International Journal of Production Economics*, Vol. 85, saknas pp. 127-140.

[2] Barksdale, H.C. and Harris, C.E., (1982), "Portfolio analysis and the product life cycle". *Ong Range Planning*, Vol. 15, nr saknas pp. 74-83.

[3] Basu, R., (2001), "New criteria of performance management - A transition from enterprise to collaborative supply chain", *Measuring Business Excellence*, Vol. 5, No. 4, pp. 5-12.

[4] Beamon, M. B., (1999), "Measuring supply chain performance", *International Journal of Operations and Production Management*, Vol. 19, No. 3, pp. 275-292.

[5] Chan, F. T.S., Qi, H. J., *et al.*, (2003), "A conceptual model of performance measurement of supply chains", *Management Decision*, Vol. 41, No. 7, pp. 653-642.

[6] Chan, F. T.S. and QI, H, J, (2003), "An innovative performance measurement method for supply chain management", *Supply chain Management – An International Journal*, Vol. 8, No. 3, pp. 209-223.

[7] Childerouse, P. and Towill, D., (2000), "Engineering supply chains to match customer requirements", *Logistics Information Management*, Vol. 13, No. 6, pp. 337-345.

[8] Christopher, M., (1997), *Marketing Logistics*, Butterworth-Heinemann, Oxford.

[9] Christopher, M., (1998), *Logistics and Supply Chain Management: Strategies for Reducing Cost and Improving Service*, Harlow, Financial Times - Prentice Hall.

[10] Christopher, M. and Towill, D., (2000), "Supply chain migration from lean and functional to agile and customised", *Supply Chain Management: An International Journal*, Vol. 5, No. 4, pp. 206-213.

[11] Christopher, M. and Towill, D., (2001), "An integrated model for the design of agile supply chains", *International Journal of Physical Distribution and Logistics Management*, Vol. 31, No. 4, pp. 235-246.

[12] Christopher, M, H, Peck, *et al.*, (2006), "A taxonomy for selecting global supply chain strategies", *The International Journal of Logistics Management*, Vol. 17. No. 2, pp. 277-287.

[13] Cigolini, R., M., Cozzi, *et al.*, (2004), "A new framework for supply chain management" *International Journal of Operations & Production Management*, Vol. 24, No. 1, pp 7-41.

[14] Cox, D. L., (1967), "Product life cycles as Marketing Models", *The Journal of Business*, Vol. 40, No 4. pp. 375-384.

[15] De Toni, A, G. Nassimbeni, *et al.*, (1994), "Service Dimensions in the Buyer-Supplier Relationship: A Case Study" *International Journal of Physical Distribution & Logistics Management*, Vol. 24, No. 8, pp. 4-14.

[16] Dean, J., (1950), "Pricing policies for new products", *Harvard Business Review*, November, Vol. 28, No. 6, pp. 45-53.

[17] Fisher, M. L., (1997), "What is the Right Supply Chain for your Product?" *Harvard Business Review*: 105-116.

[18] Gadde, L. E., and Håkansson, H., (2001), *Supply Network Strategies*, John Wiley and Sons, UK

[19] Gardner, D., (1987), "The product life cycle: a critical look at the literature", *Review of Marketing*, pp. 162-194.

[20] Garwin, A. D., (1988), *Managing Quality*, The Free Press, New York.

[21] Graham, T. S, P. J. Dougherty, *et al.*, (2001), "Performance measures and metrics in a supply chain environment", *International Journal of Purchasing and Materials Management*, Vol. 30, No. 4, pp. 13-18.

[22] Gunasekaran, A, C. Patel, *et al.*, (2001), "Performance measures and metrics in a supply chain environment", *International Journal of Operations & Production Management* , Vol. 21, No. 1/2, pp. 71-78.

[23] Gunasekaran, A., Patel, C. and McGaughey, E., (2004), "A framework for supply chain performance measurement", *International Journal of Production Economics*, Vol. 87, pp. 333-347.

[24] Hayes, R. H., and S. C., Wheelwright, (1984), *Restoring our Competitive Advantage*, New York, Wiley.

[25] Hoek van, R.I., (1998), "Measuring the unmesurable" – Measuring and improving the performance in the supply chain", *Supply Chain Management*, Vol. 3, No. 4, pp. 187-192.

[26] Hoek van, R. I., (2001), "The contribution of performance measurement to the expansion of third party logistics alliances in the supply chain", *International Journal of Operations & Production Management*, Vol. 21, No. 1/2, pp. 15-29.

[27] Hoek van, R. I, A. Harrison, *et al.*, (2001), "Measuring agile capabilities in the supply chain", *International Journal of Operations and Production Management*, Vol. 21, No. 1/2, pp. 126-147.

[28] Holmberg, S., (2000), "A systems perspective on supply chain measurements", *International Journal of Physical Distribution & Logistics Management*, Vol. 30. No. 10, pp. 847-868.

[29] Hill, T., (1993), *Manufacturing strategy*, first edition, Palgrave, New York.

[30] Hill, T., (2000), *Manufacturing strategy*, second edition, Palgrave, New York.

[31] Huang, S.H. and Uppal, M., (2002). "A product driven approach to manufacturing supply chain selection", *Supply Chain Management: An International Journal*, Vol. 7, No. 4, pp. 189-199.

[32] Koh, L. S.C and Demirbag, M. *et al.*, (2007), "The impact of supply chain management practices on performance of SMEs", *Industrial Management and Data Systems*, Vol. 107, No. 1,pp. 103-124.

[33] Krause, D. R. and Pagell, M., (2002), "Strategic consensus in the internal supply chain: exploring the manufacturing purchasing link", *International Journal of Production Research* Vol. 4, pp. 3075-3092.

[34] Lambert, D.M. and Pohlen, T.L., (2001), "Supply chain metrics", *The International Journal of Logistics Management*, Vol. 12, No. 1, pp. 1-19.

[35] Landeghem van, R. and Persoons, K., (2001), "Benchmarking of logistical operations based on a casual model", *International Journal of Operations & Production Management*, Vol. 21, No. 1/2, pp. 254-266.

[36] Lai, K., Ngai E., *et al.*, (2001), "Measures for evaluating supply chain performance in transport logistics", *Transportation Research*, Vol. 38, pp. 439-456.

[37] Lockamy III, A. and McCormack, K., (2004), "Linking SCOR planning practices to supply chain performance", *International Journal of Operations & Production Management*, Vol. 24, No. 12, pp. 1192-1218.

[38] Maloni, M. J. and Benton, W. C., (1997), "Supply chain partnerships: opportunities for operations research", *European Journal of Operations Research*, Vol. 10, No. 10, pp. 1020.

[39] Mason-Jones, R. and Towill, R. D., (1998), "Time compression in the supply chain: information management is the vital ingredient", *Logistics Information Management*, Vol. 11, No. 2, pp. 93-104.

[40] Morgan, C., (2004), “Structure, speed and salience: performance measurement in the supply chain”, *Business Process Management Journal*, Vol. 10, No. 5, pp. 522-536.

[41] Naylor, R. and Dove, R., (1997), “Leagility: interfacing the lean and agile manufacturing paradigm in the total supply chain”, *International Journal of Production Economics*, Vol. 62, pp. 107-118.

[42] Novac, R.A., and Simco, S.W., (1991), “The industrial procurement process: a supply chain perspective”, *Journal of Business Logistics*, Vol. 12, No. 1, pp. 145-167.

[43] Oliver, R.K., & Webber, M. D., (1982), ”Supply-chain Management: logistics catches up with strategy”, in Christopher M (1982*) Logistics: The strategic issues*, Chapman & Hall, London, pp. 63-75.

[44] Otto, A. and Kotzab, H., (2001), Does Supply Chain Management really pay? - Six perspectives to measure the performance of managing a supply chain. Nurnberg, *Lehrstuhl fur Logistik*, Friedrich-Alexander-Universiteät**:** p. 17

[45] Pesonen, T. L., (2001), *Implementation of design to profit in a complex and dynamic business context,* University of Oulu, Finland.

[46] Petroni, A. and Panciroli, B., (2002), "Innovation as a determinant of suppliers' roles and performances: an empirical study in the food machinery industry", *European Journal of Purchasing & Supply Management*, Vol. 8, pp. 135-149.

[47] Rink, D. and Swan, J., (1979), “Product life cycle research: a literature review”, *Journal of Business Research*, Vol. 7, No. 3, pp. 219-242.

[48] Robson, I., (2004), "From process measurement to performance improvement." *Business Process Management Journal*, Vol. 10, No. 5, pp 510-521.

[49] Rushton, A. and Oaxly J., (1991), “*Handbook of Logistics and Distribution Management*, Kogan Page, London.

[50] Saad, M. and Patel, B., (2006), “An Investigation of supply chain performance measurement in the Indian automotive sector”, *Benchmarking: An International Journal*, Vol. 13, No.1/2, pp. 36-53.

[51] Selldin, E. and Olhager. J., (2007), “Linking products with supply chains testing Fischer´s model”, *Supply Chain Management: An international Journal*, Vol. 12, No. 1, pp. 42-51.

[52] Shepherd, C. and Gunter, H., (2006), “Measuring supply chain performance: current research and future directions”, *International Journal of Productivity and Performance Management*, Vol. 55, No. ¾, pp. 242-258.

[53] Stewart, G., (1995), "Supply chain performance benchmarking study reveals keys to supply chain excellence." *Logistics Information Management*, Vol. 8, No. 2, pp. 38-44.

[54] Towill, R. M. Naim, *et al.*, (1992), “Industrial Dynamics Simulation Models in the Design of Supply Chains”, *International Journal of Physical Distribution & Logistics Management*, Vol. 22, No. 5.

[55] Thomas, D. J. and Graham, T. S., (1996), “ Co-ordinate supply chain management”, *European Journal of Operational Research*, Vol. 94, No. 3, pp. 1-15.

[56] Tracey, M. and Tan C. L., (2001), "Empirical analysis of supplier selection and involvement, customer satisfaction, and firm performance", *Supply Chain Management: An International Journal*, Vol. 6, No. 4, pp. 174-188.