Feasibility of performance measurement system for supply chain: a process-based approach and measures

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Abstract
Nowadays more than ever, supply chain management has gained a tremendous amount of attention from both the academic and practitioner communities. It provides a revolutionary management philosophy to cope with the increasing business competition and economy globalization. However, there exist many puzzles, especially in structure mapping and analysis, and performance measurement. The objective of this paper is to propose a process-based approach to mapping and analyzing the practically complex supply chain network. Via this approach, a process-based performance measurement system is proposed, in which a method called performance of activity is used to identify the performance measures and metrics.

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1. Introduction

There are increasing changes in the modern business environment, which features more customized product and service and cost-efficient production. The tendency of economic globalization and the advent of all kinds of management technologies largely prompt business competition, as well as providing the opportunities to succeed. Enterprises strive to achieve competitive advantage through satisfying customers effectively and efficiently. Effectiveness requires that enterprises be equipped with customer-focused common goals among all the related suppliers and manufacturers. The business success now depends largely on the capability of quick response to customer requirements. The suppliers and manufacturers need to cooperate and coordinate in sharing the common goal and strategy of improving product quality and customer service level. On the other hand, efficiency demands enterprises meet with customer requirements economically. Business entities make a profit through increasing sales as well as reducing costs. New technologies, such as just-in-time (JIT) manufacture and lean production (LP), originate from, and in turn underpin, the trend of cost reduction and inventory level decreasing along the value chain. This also calls for collaboration between the suppliers and manufacturers. Addressing these considerations, supply chain management (SCM), which has evolved out of logistics management, is encountering increasing interest in both the academic and practitioner communities (Ross, 1997).

SCM represents a state-of-the-art management tool used to enhance overall customer satisfaction that is intended to improve competitiveness and profitability (Giunipero and Brand, 1996). It addresses such modern business issues as: long-term strategic alliance and supplier-buyer partnership, cross-organizational logistics management, joint planning and control of inventory, and information sharing (Beamon and Ware, 1998; Chandra and Kumar, 2000). Cooper *et al.* (1997) describe the conceptual framework of SCM, which consists of three major and closely related elements: business processes, management components, and the structure of the supply chain as shown in Figure 1.

In order to survive in the global competition and sustain long-term advantages, more and more enterprises have introduced SCM. According to Christopher (1992), leading-edge companies have realized that the real competition is not company against company, but rather supply chain against supply chain.

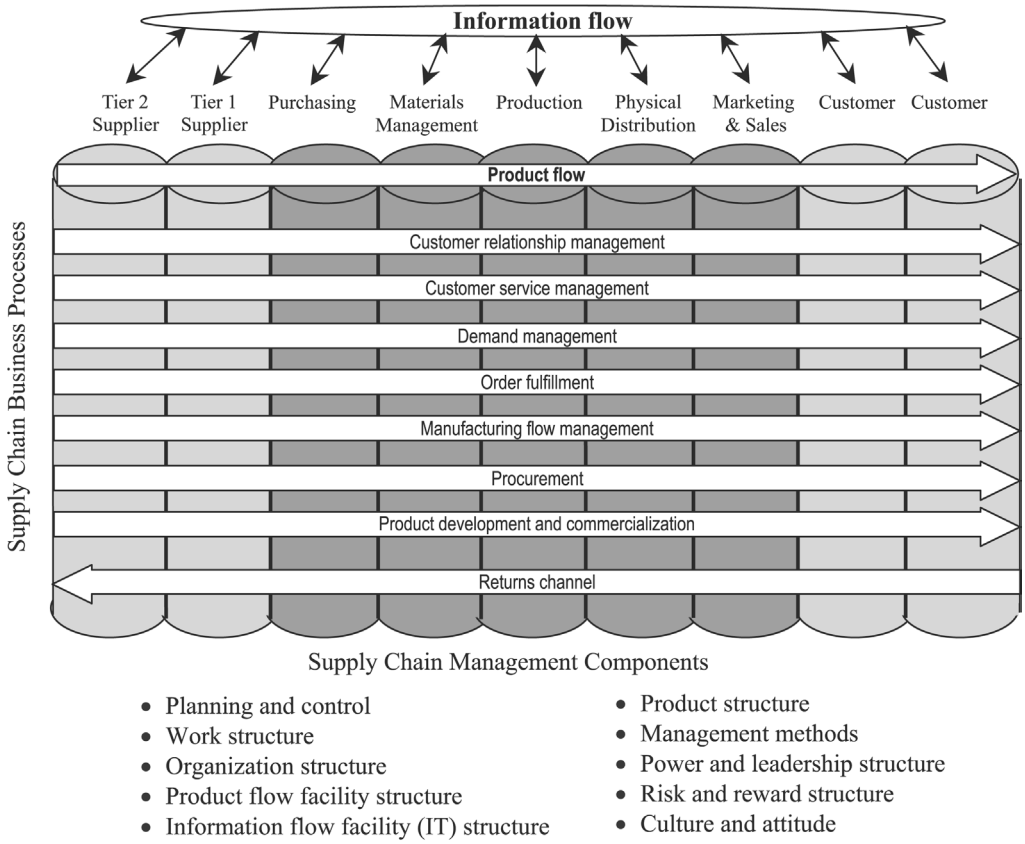
Along the decades of evolution of SCM, a steady stream of literature has presented all kinds of models and theories (Beamon, 1998). These various literatures contribute notably in providing continual guidelines for optimization and improvement of supply chain design, modeling, implementation, and management.

However, SCM is a fairly new philosophy for academics and practitioners (Moore, 1998). Further attention and more efforts are required, especially in:

- mapping the supply chain network structure and business processes;
- achieving really seamless integration of supply chain entities and processes; and
- evaluating the performance of the entire supply chain (Gunasekaran *et al.*, 2001; Holmberg, 2000; Lambert *et al.*, 1998; Lambert and Cooper, 2000; Lummus and Vokurka, 1999; Van Hoek, 1998).

This paper is organized in six sections. In Section 1 the context of SCM has been simply reviewed, and some confused issues are

Figure 1
A framework of supply chain management



discussed. Section 2 reviews the relevant literature concerned with the current state of performance measurement of SCM. A few critical issues of performance measurement in SCM are highlighted. In Section 3, it is suggested that a system perspective be adopted so as to encourage global optimization. A process-based model is proposed to analyze, manage the supply chain, and measure supply chain performance. Section 4 implements the proposed process-based approach in performance measurement of SCM with seven steps of process decomposition. There is then presented an approach to identifying and employing the performance measures and metrics in Section 5. It is called performance of activity (POA). In this connection, the research attempts to build an innovative method to measure the performance of the process and activity in the complex supply chain network. Section 6 presents the conclusions.

2. Performance measurement and performance improvement in SCM

Traditionally, performance measurement is defined as the process of quantifying effectiveness and efficiency of action (Neely *et al.*, 1995). In other words, measuring performance means transferring the complex reality of performance into a sequence of limited symbols that can be communicated and reproduced under similar circumstances (Lebas, 1995). In modern business management, performance measurement goes well beyond just quantification and accounting. It is supposed to contribute much more to business management and performance improvement in the various industries. Sink and Tuttle (1989) claim that you cannot manage what you cannot measure. From the management perspective, performance measurement provides necessary information of management feedback for decision makers and managers. It plays the important roles of monitoring performance, enhancing motivation, improving communications, and diagnosing problems (Rolstandas, 1995; Waggoner *et al.*, 1999). Furthermore, performance measurement provides an approach to identifying the success and potential of management strategies, and facilitating understanding of progress and position. Hence, it assists in directing management attention, revising business goals, and

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re-engineering business process (Beamon and Ware, 2000; Kuwaiti and Kay, 2000; Van Hoek, 1998).

According to Beamon (1999), there is very little literature available in PMSs design and performance measures selection for SCM, though various theories and models of PMSs have been proposed and applied in place. Only a few literatures (Beamon, 1998, 1999; Gunasekaran *et al.*, 2001; Holmberg, 2000; Narasimhan and Jayaram, 1998; Van Hoek, 1998) till now have covered performance measures and PMS of the supply chain.

Although researchers continue the attempts to build the new measures and metrics for SCM, most of the current PMSs of supply chain in place are harassed by too many defects to meet with the requirements of SCM. Besides criticism (Holmberg, 2000) about non-connection with strategy and biased focus on financial metrics, there are some in-depth problems of PMSs in supply chain context including:

- lack of balanced approach to integrating financial and non-financial measures;
- lack of system thinking, in which a supply chain must be viewed as one whole entity and the measurement system should span the entire supply chain; and
- loss of supply chain context, and hence this kind of PMS encourages local optimization (Gunasekaran *et al.*, 2001; Holmberg, 2000; Van Hoek, 1998)

Lambert *et al.* (1998) assert that it is much easier to write a definition for SCM than to implement it, and call for building theory and developing tools and methods for SCM practice. During the extended period of evolution of SCM in academia and practice, especially for enterprises newly introducing SCM, there is an urgent need of PMS fit with the supply chain context to support decision-making and performance improvement.

3. An analytic model of the supply chain

The objective of this paper is to propose an innovative approach with a process-based model of supply chains, by which the supply chains are analyzed and measured. A new concept of performance of activity (POA) is proposed in the research to identify and employ performance measures and metrics.

3.1 System perspective

By its very initiatives, a supply chain should be viewed as one single entity and managed as a whole, in which all the members are functionally integrated and synchronized with mutual goals. Accordingly, the supply chain is neither just a collection of independent, self-centered enterprises through the business relations, nor the coordination of interfaces between the fragmented functions of the supply chain components. The inward-looking view is not only incompatible with excellent SCM, but also leads to the key reasons that most of the current PMSs failed are invalidated in the supply chain context. When it comes to performance measurement, this self-focused view encourages local optimization of individual entity.

Therefore performance measurement should take a holistic system perspective beyond the organizational boundaries. All the participants of supply chains are intended to share mutual customer-focused goals and cooperatively provide products and services that satisfy customers' requirements. Subsequently, the performance of supply chains needs to be assessed across the organizations so as to encourage global optimization along the supply chain channel. Gunasekaran *et al.* (2001) suggest that the focus of measures should be taking the supply chain perspectives and covering the overall performance rather than only the local entity. Bititci (1995) also asserts PMSs must be researched in a holistic context applying to all aspects of the manufacturing business.

3.2 Process-based model

A supply chain focuses on the integration of business processes. One of the definitions of SCM, by the Global Supply Chain Forum (GSCF), is typically described as follows:

> Supply chain management is the integration of key business processes from end user through original suppliers that provide products, services, and information that add value for customer and other stakeholders.

The definition highlights SCM's initiatives of integrating and managing multiple key processes within and beyond the boundaries of the individual organizations. Lambert and Cooper (2000) claim that successful SCM requires a change from managing individual functions to integrating activities within key supply chain business processes. Accordingly, this paper proposes the analysis method based on a process-based approach. The process-based perspective not only goes compatibly with the initiatives and requirements of SCM, but also shapes an analytic approach to mapping the structures and relationships among the supply chain network.

Changchien and Shen (2002), who employ business process reengineering in SCM, propose process-based management and

virtual organization in SCM. Basically, process refers to linked activities with the purpose to produce products or services for customers within or outside the company (Kanji and Wong, 1999). In SCM, the network of organizations is structured through upstream and downstream linkages among the processes and activities that add value along value chain (Christopher, 1992). the process-based model of a supply chain blurs organizational and departmental borders between the connected processes and activities, thus diluting the structural barriers and encouraging cross-organizational optimization.

Process models can be built from their missions and particular functions among the inter- and intra-organizations of the supply chain. Many authors such as Changchien and Shen (2002) and Chan and Choi (1997), propose the methodologies to build and analyze the business processes. In the model of this paper, a process in the supply chain is concerned about a series of activities from original suppliers and manufacturers to retailers that add value for the end customers. The core business processes, which are of essential importance to business objectives and strategies, are suggested to be identified and confined herein as the framework of performance measurement. For any supply chains, the general processes and structure can be depicted as shown in Figure 2, in which six core processes are linked. These core processes categorize the typical function areas in supply chains. In detail, suppliers assume the functions of supplying materials and some outsourcing functions such as product design; inbound logistics takes the role of supply base management, inbound materials transportation and storage; outbound logistics takes the part of outbound product transportation, distribution, and warehousing. In practice, the supply chain processes that need to be measured can be grouped into these six core processes with the corresponding functions across organizational boundaries of firms and departments.

The key processes identified can be further decomposed into sub-processes and activities to address their detailed performances. All of these key processes and sub-processes compose a hierarchy of a supply chain model, which is the framework of the proposed PMS.

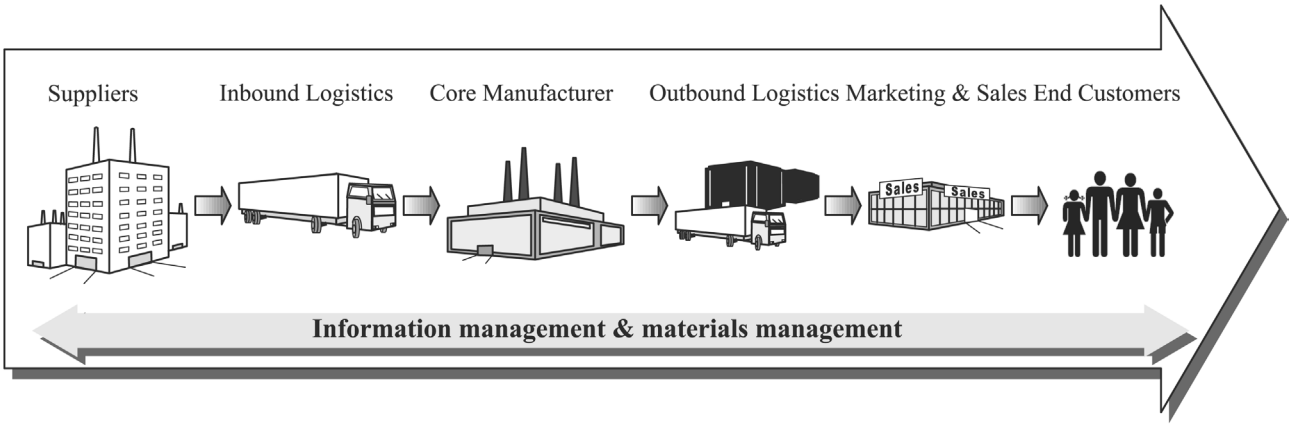
4. The method of performance measurement of the supply chain

In the measurement community, there is always a debate whether performance indicators should be focused on activities and processes, or on results (Kueng, 2000). From the cause-effect view, the activities determine the results. In other words, good results are achieved through the good associated activities. Traditional PMSs, which rely heavily on such financial results as profit and return on investment, are obsolescent due to their failure to support continuous improvement.

Process-based performance measurement does not only fit with the nature of SCM, but also contributes much more to continuous improvement of SCM. Assessing process performance provides an opportunity for examining the effectiveness of process management. The main advantages of adopting process-based performance measurement that can be achieved in SCM are highlighted as follows:

- To provide the opportunity of recognizing the problems in operations and taking corrective action before these problems escalate (Kueng, 2000).

Figure 2
Supply chain process model



- To facilitate linking with the operational strategies, identifying success, and testing the effect of strategies.
- To support in monitoring the progress.
- To assist in direct management attention and resources allocation.
- To enhance communication of process objectives and position among the processes involved in the supply chain, thus improving trust and common understanding.

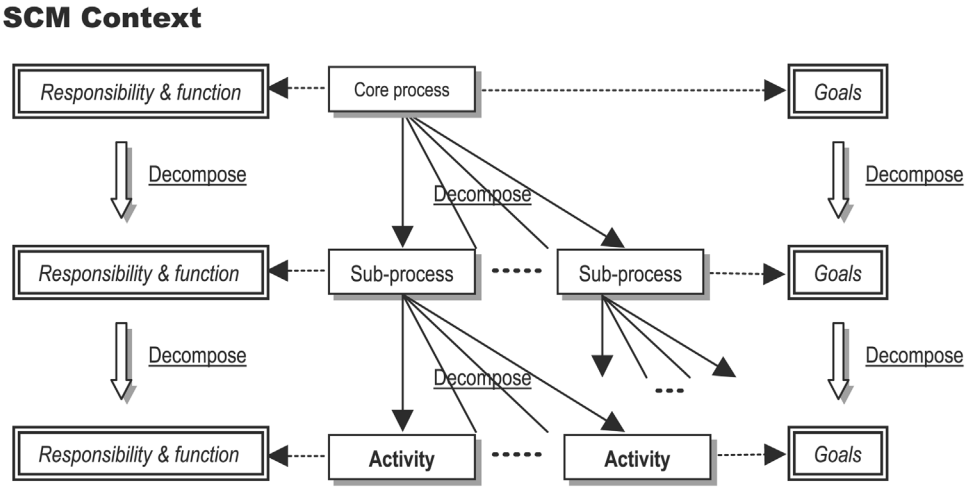
Process-based measurement provides strong assistance with timely information in enhancing integration and improvement of the cross-organizational processes. From a system perspective, assessing all the processes involved beyond organization boundaries can simplify the measurement tasks and support global optimization among all the interrelated processes.

The next stage is how to implement the process-based performance measurement of the supply chain. According to Davenport (1993), a process is defined as a structured and measured set of activities designed to produce a specific output for a particular customer or market. In the supply chain model proposed here, each process that individually takes an irreplaceable role is composed of a set of activities, each of which performs a specific set of functions. The performance of each process is the aggregated results of the performance of all its lower-hierarchy activities and sub-processes. Henceforth, assessing the activities performance can depict the effect of corresponding process. In other words, measuring the higher process performance is transformed into assessing the activities and processes performance in the lower hierarchies.

However, the definition and boundary of each process vary from organization to organization. It is a burdensome task to identify and decompose the involved processes. Herein is proposed a series of steps and processes of analyzing and decomposing the processes to be measured (Figure 3):

1 *Identifying and linking all the involved processes of inter- and intra-organization*. The related processes in the supply chain are identified according to the domains to be measured. These domains may be a broader process performing a set of specific functions, such as procurement and transportation, a specific project, and may be a series of products. In this step, all the related processes can be taken into considerations. Then the second step will be used to simplify them.
2 *Defining and confining the core processes*. As discussed previously, not all the processes involved in the supply chain network are value-added, nor deserve the same management attention. Furthermore, the boundaries of each process may vary. It is necessary to confine the boundary and define each process before analyzing it. Adding value is one of the critical principles of identifying and confining the core processes. Core processes can be defined based on the strategic objectives of supply chains by taking into account the customers' and suppliers' viewpoints (Korpela *et al.*, 2001).
3 *Deriving the missions, responsibilities, and functions of core processes*. Besides the definitions, the responsibilities and functions of each process should be made clear. The missions and responsibilities that state what the process does provide overall guidance and direction for managers and cooperators understanding what to manage and measure. With the clear definitions and functions of the processes, supply chain managers are able to review the processes and eliminate non-value-added processes and activities. For example, the mission of the purchasing process is buying the right materials from suppliers in order to keep production and operations running smoothly. In detail, it is typically responsible for maintaining a continuous supply of materials in good quality and reasonable price, minimizing the inventory investment, developing the supplying channel and maintaining the supply base, and maintaining good relationship and cooperating with suppliers. The missions and responsibilities also provide visions for decomposing the core processes.
4 *Decomposing and identifying the sub-processes*. One of the approaches employed to identify the core processes is to break down the procedure according to product flow and other operation flow. However, the core processes are aggregation of a broad set of sub-processes, and rather general. It is necessary to decompose core process into detailed sub-processes on the lower level. For example, order processing process can be decomposed into lower-level sub-processes as follows: order entry, credit check, documentation, order picking and loading, and delivery.
5 *Deriving the responsibilities and functions of sub-processes*. Similar to the core process, the responsibilities and functions of each sub-process are derived from the strategies and missions, and defined into

Figure 3
The general structure of the decomposing process



statements to enhance understanding and communication. In contrast with those of the core process, the definitions of sub-process's responsibilities are more detailed, and closer to operational directions. These definitions provide the indications for identifying the elementary activities in the next step.

6 *Decomposing and identifying the elementary activities of sub-processes*. There are two reasons that this step is necessary. First, some of the sub-processes decomposed are still rather general and difficult to measure. Second, some non-value-added activities can be eliminated and redesigned in the detailed examination. Not all the sub-processes need to be decomposed. It depends mainly on the requirements of measurement.

7 *Linking goals to each hierarchy from process to elementary activity*. All the involved processes are decomposed into measurable elements. When supply chain managers set up the strategies and common goals for the entire system, the goals for the processes always may be presented in the forms of either quantitative value, such as percentage of increasing and decreasing, or qualitative expression. For example, cutting the inventory carrying costs by 10 percent. These goals and objectives are rather general and aim at middle management of core processes. Hence, the high-level goals are decomposed and linked with the processes and activities in the lower hierarchies. It is suggested to assess the performance by comparing the current values against historical and goal values (Kueng, 2000). In fact, the goals for processes and activities provide the targets for the day-to-day operations and executions.

Worth noting here is that the involved processes and activities should be carefully confined and selected to assist the strategy of eliminating the non-value-added activities. The decomposition of process hierarchies draws a clear picture of processes and their activities. It provides an opportunity for re-examining and re-designing the processes, and easy access to measuring process performance. Most importantly, the process framework of hierarchical structure provides the base of measuring process performance, through the method of performance of activity (POA) proposed in the next section.

5. Adopting the measures via performance of activity method

It was discussed previously that process-based performance measurement benefits significantly in SCM. The remaining question is how to implement it? The concept of performance of activity is presented in this paper, which is an innovative method of identifying new measures and metrics and employing them in SCM.

5.1 The method of performance of activity

A process can also be described as a collection of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs, a structure for action (Cooper *et al.*, 1997). Accordingly, for a process or an activity, it consumes particular resources as the inputs, and adds value to the materials and products, or provides services as the outputs. From a broad sense, the

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consumed resources involve time, labor, capital, power, land, facilities, etc.; resource consumption leads to costs of the activity. The outcomes are the value-added products and services. Besides the most often used measures – productivity, efficiency, and utilization – there are other different, particular aspects of performance that are used to assess the specific activity and process from the viewpoints of managers and customers. For example, customers often regard reliability in timeliness and being free from errors as the critical performance of order delivery. Buyers particularly emphasize flexibility in supplying frequency and lot size as one of the foremost performances when assessing the supplier. That is to say, consequently, there are many particular aspects of performance in evaluating a specific process or activity. There is a steady stream of performance measures and metrics being identified to support performance improvement and decision making. However, managers confront another puzzle: how to select the suitable measures to equip. This case is more urgent, especially in performance measurement of SCM. Supply chains managers are often confused with the vast amount of measures and performance indicators that are often used to assess some specific aspect(s) of single organization, rather than the overall performance of the whole supply chain system.

In order to build a comprehensive view, herein is proposed the concept of POA. It includes a board of performance metrics, each of which represents one of the dimensions of activity performance. They cover inputs and outcomes, and both tangible items and intangible ones. The board of performance metrics, called metrics board, are suggested summarily as follows:

1 *Cost – the financial expense to carry out one event or activity*. Cost is always one of the indispensable aspects in assessing the performance of the business activities and processes. Since the resources are consumed, there exists cost. This dimension records the inputs consumed, and also reflects the effectiveness of cost control. Besides the entire cost of a specific activity or process, the percentages of individual cost, such as labor cost, materials cost, or rework and scraps, in the whole need to be measured and evaluated, the effect of cost control.
2 *Time – the time between the beginning and completion of one specific event or activity*. Time is an important resource in modern business environments, especially where JIT and quick response prevails. The shorter the response time, the more customer satisfaction. Similar to cost, time is another indispensable dimension. All the operation times of each activity together compose the response time of the entire supply chain. Hence, in order to understand the supply chain operation, it is necessary to measure the activity time. Similar to cost, the percentages of individuals in the whole chain need to be assessed.
3 *Capacity – the ability of one specific activity to fulfill a task or perform a required function*. This dimension mainly concerns the maximum amount of tasks that a process or an activity can complete under the normal conditions. Production capacity and transport capacity are two typical examples.
4 *Capability – a talent or ability of one activity to be used, treated, or developed for the specific purposes and required functions*. It is the aggregate ability by which the activity or process functions. Here four dimensions, which are most often used, can be identified with the purpose of covering the most important aspects of an activity's capability.
   - *Effectiveness – the ability of one specific event or activity to achieve an intended or desired effect in performing the functions or taking the responsibilities*. Each process or activity is supposed to perform the specific functions in the operation context. Some of them perform materials transferring and handling, and others perform manufacturing. Effectiveness of the activity or process is concerned with ability to perform the due functions. In warehouse management, inventory accuracy in cycle counting and documents is one of the performances in effectiveness of inventory management. Inventory accuracy is critical for controlling stock loss and warehousing costs.
   - *Reliability – the ability of one specific event or activity to perform a required function under stated conditions for a stated period of time*. Reliability emphasizes the conditions under which the activity or process is performed. It reflects the dependability, especially from customers' viewpoint. For example, customers expect the delivery reliability in timeliness and being free from errors as an important performance measure. Similarly, transportation reliability, material supplying reliability, and order

processing reliability are often used to assess the performance of the corresponding process and activity.

- *Availability – the ability to bring about effective or beneficial results or the degree to which one specific functional activity is ready when needed*. Availability refers to the readiness, i.e. the degree, percent, or probability that a system will be ready or available when required for use. It reflects one of the aspects of management effect of specific activities and processes. For example, inventory availability in each storage node is a critical performance for inventory management. Order fill rate and stockout rate are two aspects of inventory availability. Order fill rate refers to the percentage of demand order which can be immediately filled from stock. Stockout rate is related to the frequency of stockout per order cycle. Another example is order and inventory information availability, which reflects the cooperation effect of supply chain members in sharing real-time information about the order and inventory level. The information sharing is important for improving planning and controlling inventory investment.
- *Flexibility – the ability of one specific activity to adapt to the varying functional requirements or respond to the changes*. Flexibility is based on the range of a variable capacity of tasks, processes or activities that can be completed in the specific period of time and at a reasonable cost. It reflects the ability of the activity and process to deal with the changing requirements or emergent situations. Flexibility is critical, especially in the cases of quick response and JIT environment. Most often, production flexibility in volume and product mix can be used to assess the production process. Other examples are transportation flexibility in goods mix and goods lot size, and order delivery flexibility in lot size.

5 *Productivity – the rate at which one specific event or activity adds value at the cost of resources*. It is based on the ratio of the effective or useful output to the total input, e.g. capital, labor, raw materials, and energy. It measures the extent to which the resources are being used effectively in transforming inputs to outputs. Total productivity, multi-factor productivity, and partial factor productivity are often used. Total productivity is based on the ratio of total output to total input reflects. Multi-factor productivity, based on total output to subset of input, shows the interaction between each input. The multi-factor productivity most often used considers labor and materials, or labor and capital. Partial factor productivity, based on the ratio of total output to single input, reflects the impact of single input separately on the output. Labor, capital, materials, energy productivity are suggested.

6 *Utilization – the utilizing rate of the resources to carry out one specific activity*. In such cases as warehousing process and production process, the utilization of space and labor are the important measures. Utilization reflects the ability of resources management and the effect of strategies and planning.

7 *Outcome – the results or value added of one specific activity and event*. Outcomes of an activity or a process may be the value added to products and services, and may be just the finished products. For example, in transportation and storage, outcome is fairly intangible and is not easy to measure. In most practical cases, outcome is not certain to be measured, except in a production process that produces goods.

In the metrics board above, the hard measures: cost, time, capacity, productivity, and utilization are tangible, and thus relatively easy to collect data. Other soft measures: effectiveness, reliability, availability, and flexibility are intangible, and thus cannot be directly measured. The latter need to be transformed to other performance indicators. For example, production flexibility can be measured by assessing product volume flexibility and product mix production and others. Delivery flexibility can be measured by assessing in-time delivery rate and errors rate. Each of the metrics describes one critical dimension of performance of the activity and process. It is impossible for these metrics to cover all the dimensions of any activity performance. All of them together are intended to cover the overall visions of performance in common use from the standpoints of both suppliers and buyers.

When identifying new performance measures and metrics, managers can consider from all the related dimensions in the metrics board. The metrics board is a referential category to prompt new ideas. For existing measures, they can be linked into the categories through the related dimensions of the metrics board. Whether internal personnel or external customers are investigated, whether using performance

measures questionnaires or adopting the brainstorm method, they can identify the measures and metrics with the metrics board as the access. Another point worth noting is that not all the dimensions in the metrics board need to be used; the selection of the dimensions is based on the actual requirements. This method is called POA. In these cases above, the metrics board can categorize the performance indicators that suppliers and buyers are concerned about, and rearrange them in a systematic structure.

5.2 Example of the POA method

In order to gain an intuitive insight into the method of POA, it is helpful to show a simple illustration here. The inventory management process will be considered in the following section.

The functions of inventory management are holding the materials and products to balance the supply and demand, and to protect from uncertainty. The responsibilities are storing and handling the inventories to ensure them to be in good quality and condition, and also planning, transferring, and delivering the materials according to the demand and storage level. Moreover, inventory management should ensure filling the demand order to keep the supply chain process running smoothly, and to meet with the need of JIT production and transportation. On the other hand, supply chain managers strive for minimized inventory investment in the whole system. In this connection, the main goal in the supply chain context is minimizing the inventory level and investment, while ensuring meeting the customers' requirements; to assume that supply chain managers need to assess the performance of the materials management. In the measurement context, one of the tasks is assessing the performance of inventory management on each logistics node.

There are a number of performance measures and indicators for assessing effectiveness of inventory management. For example, commonly used are inventory carrying costs, order fill rate, stockout possibility, and space utilization. All kinds of existing performance measures and indicators are dispersed and isolated. With the modularized metrics board, managers can systematically categorize the performance measures into the holistic, balanced dimensions.

The simplified illustration of identifying and linking the performance measures and indicators can be outlined as follows:

- *Cost – inventory carrying costs*. Inventory management accounts for a mass of total materials handling costs. Effective management should achieve lower costs. Hence, inventory-carrying costs deserve much attention in assessing performance of inventory management. Inventory capital cost, storage space cost, and risk cost are the three key parts of inventory carrying costs.
- *Time – flow rate*. Inventory flow rate is based on ratio of the inventory level (in terms of stock units or value) to average inventory cycle time. Flow rate is an indicator of cycle time of inventory within the warehouse. The faster inventory flows through the warehouse, the lower investment on inventory and the improved investment on inventory returns.
- *Effectiveness – inventory accuracy*. This concerns inventory record errors when physically cycle counting and checking at regular intervals. Maintaining high inventory accuracy is critical, not only for financial controls, but also for effectiveness of subsequent materials requirement planning and order delivery. Inventory accuracy indicates the effectiveness of both physical inventory management and documentation management.
- *Availability – inventory availability*. Availability is one of the most important performances from the customer viewpoint. Inventory availability indicates the customer service level and is largely concerned with customer satisfaction. The two often-used measures are order fill rate (order availability) and stockout rate (stock unit availability). The former is based on the percentage of demand order filled from stock in total. The latter refers to the rate of stockouts and the duration of stockouts.
- *Productivity – inventory productivity*. For the inventory management process, which consumes a great amount of inputs: labor, facilities, capital, space, and energy, assessing its productivity is indispensable traditionally. The total productivity, multi-factor productivity, and partial factor productivity, all need to be measured.
- *Utilization*. Most of the resources, which inventory management process consumes, deserve attention in utilization. Besides utilization of labor, facilities, and capital, there are two more: working inventory rate and stock unit utilization. The former is based on the percentage of working inventory in the total inventory held. It

indicates the effectiveness of inventory holding strategies. The latter refers to the storage space utilization, which indicates the effectiveness of storage policies.

In the example, it is illustrated that the metrics are selectively adopted according to the management and measurement emphasis.

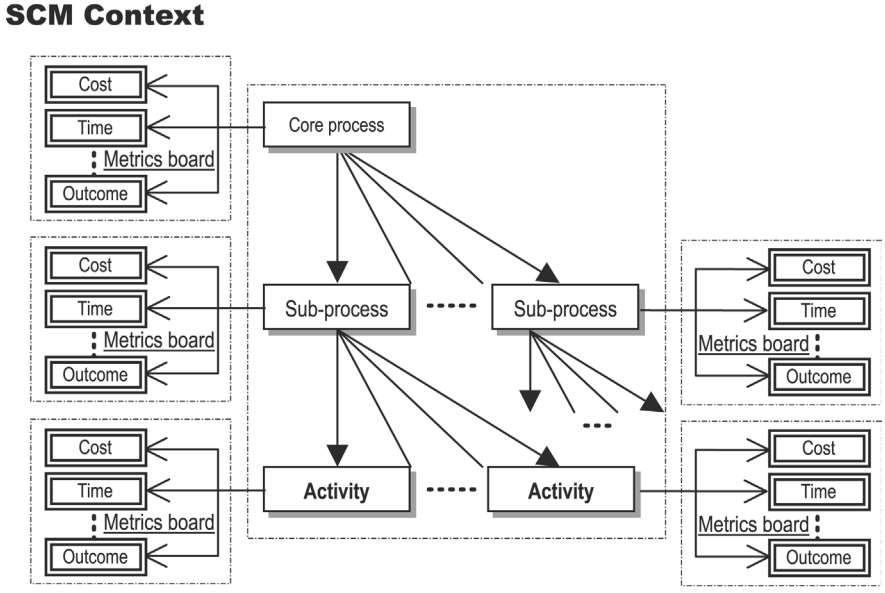
5.3 Implementing the POA method

When implementing POA, measurement participants can analyze each activity to identify performance measures. In addition, when there is a need for assessing the whole performance of a high-level process, it also can be similarly analyzed with the metrics board. For example, as a core process, purchasing is decomposed into other sub-processes and elementary activities. Each activity is measured from the necessary dimensions of the metrics board. The purchasing cost should be assessed as a whole performance to benchmark effectiveness of purchasing cost control. In this connection, purchasing cost can be linked with the core process level as the whole performance of purchasing process. The cases for other processes and sub-processes in each hierarchy are similar to this. Each hierarchy is analyzed via POA to reflect the performance of different operation and management levels. The illustration of application of POA in each hierarchy is presented in Figure 4.

As discussed previously, it is impossible for the metrics board to cover all the existing and new performance measures. Hence, in practice, the measures that cannot be categorized into any dimension of the metrics board need to be supplemented as the additional items. For example, managers of the supply chain may want to put more emphasis on quality management and improvement within the related processes, thus they want to identify the effect of quality control. Hence, all these measures and indicators of quality control performances can be linked with the activities and processes as the additional dimensions.

When it comes to financial performance indicators such as net profit, market shares, and return on investment, it is suggested not to include them into the performance measures in assessing the processes performance in supply chain context. SCM demands and encourages both risk sharing and profit sharing among the supply chain members. The goals of improving performance demand cooperation in decision making and operational level. In process management, independently emphasizing financial performance encourages the win-loss mode of doing business and encourages pushing costs to others, rather than cooperating on each node and each project. Measuring financial performance in a single organization will not provide necessary assistance for performance improvement of the entire supply chain. Henceforth, including the financial performance of low-hierarchy processes is neither necessary nor helpful for assessing the supply chain performance. It is suggested that for the financial performance, such as net profit and

Figure 4
The general structure of applying POA



market shares, there are measured only when assessing the holistic performance of the entire supply chain.

To sum up, the method of POA not only provides an approach to identifying and selecting the performance measures via the standardized access, but also helps to benchmark the performance among the processes and activities in the same hierarchy.

First, the metrics board covers the overall performance dimensions that are tangible and intangible. All tangible and intangible performance can be expressed through the performance indicators in common use. As the example described previously, one of the capabilities of inventory management, i.e. inventory availability, can be expressed through the performance indicators: order fill rate (order availability) and stockout rate (stock unit availability). Obviously, inventory availability is an intangible performance measure; but the two commonly used indicators that customers pay much attention to, i.e. order fill rate and stockout rate, are measurable, and the data are easy to collect. Furthermore, the metrics board categorizes the isolated performance measures into the balanced dimensions, thus avoiding partial focuses. Existing performance measures always build the community where some performance aspects are focused. For example, only product quality is measured, or customer satisfaction is assessed. These partially focused measurement methods can tell the performance of the specific areas, but fail to assist in understand all over the supply chain system. The multi-dimensional metrics board of POA can address this problem with its balanced view.

Second, due to the modularized performance dimensions in the metrics board, managers can intuitively compare the performance among the different processes with the same performance dimensions. This will be a benefit when benchmarking the related processes involved in the same supply chain. With the results of measurement and comparison, the top and middle management can analyze the strength or weakness in the operation nodes, and hence benchmark the effectiveness of strategies and revise them. The information about the difference of individual process operations provides direction in allocating management attention and bottleneck resources. This analysis and management method spanning the entire process supply chain is just compatible with the system perspective.

Conclusions

This paper reviews the important issues of SCM and current state of performance measurement in supply chain environments. The developing state of SCM has continued accompanied with puzzles. The complexity of practical supply chain shapes the difficulties in mapping supply chain structure, managing integrative relationships, and measuring the system performances. In particular, with respect to performance measurement, the existing literatures that are relevant to performance measures selection and PMSs design rarely cover the supply chain context, although they have contributed significantly to performance improvement and business management.

System perspective is suggested in the management or performance measurement in the supply chain environments. A process-based approach has been proposed, with the objectives of identifying the participants and analyzing the structure of supply chain. Besides structure analysis, this approach is used to build the process-based performance measurement of SCM. This kind of PMS achieves many advantages, such as supporting continuous improvement and facilitating communication of goals and progress. A new method of selecting and employing performance measures has been suggested, based on a metrics board, which consists of the holistic dimensions of activity performance. These dimensions include inputs, outcomes, and other critical aspects of activity performance from the viewpoint of both suppliers and customers. The method of POA is aimed to facilitate identifying and employing the performance measures and indicators from a systematic access. In today's business environments, all types of performance measures, as well as their selection methods, have matured through the extended evolution. However, there is a need of a suitable approach to aggregating the existing or new performance measures into the holistic, integrated system in order to assess the supply chain. This paper attempts to make its due contribution, and also intends to call for further research in performance measurement of SCM.

References

Beamon, B.M. (1998), "Supply chain design and analysis: models and methods", *International Journal of Production Economics*, Vol. 55, pp. 281-94.

Beamon, B.M. (1999), "Measuring supply chain performance", *International Journal of Operations & Production Management*, Vol. 19 No. 3, pp. 275-92.

Beamon, B.M. and Ware, T.M. (1998), "A process quality model for the analysis, improvement and control of supply chain systems", *Logistics Information Management*, Vol. 11 No. 2, pp. 105-13.

Bititci, U.S. (1995), "Modeling of performance measurement systems in manufacturing enterprises", *International Journal of Production Economics*, Vol. 42, pp. 137-47.

Chan, S.L. and Choi, C.F. (1997), "A conceptual and analytical framework for business process reengineering", *International Journal of Production Economics*, Vol. 50, pp. 211-23.

Chandra, C. and Kumar, S. (2000), "Supply chain management in theory and practice: a passing fad or a fundamental change?", *Industrial Management and Data Systems*, Vol. 100 No. 3, pp. 100-13.

Changchien, S.W. and Shen, H.Y. (2002), "Supply chain reengineering using a core process analysis matrix and object-oriented simulation", *Information & Management*, Vol. 39, pp. 345-58.

Christopher, M. (1992), *Logistics and Supply Chain Management*, Pitman Publishing, London.

Cooper, M.C., Lambert, D.M. and Pagh, J.D. (1997), "Supply chain management: more than a new name for logistics", *The International Journal of Logistics Management*, Vol. 8 No. 1, pp. 1-13.

Davenport, T.H. (1993), *Process Innovation – Reengineering Work through Information Technology*, Harvard Business School Press, Boston, MA.

Giunipero, L.C. and Brand, R.R. (1996), "Purchasing's role in supply chain management", *The International Journal of Logistics Management*, Vol. 7 No. 1, pp. 29-37.

Gunasekaran, A., Patel, C. and Tirtiroglu, E. (2001), "Performance measurement and metrics in a supply chain environemt", *International Journal of Operations & Production Management*, Vol. 21 No. 1/2, pp. 71-87.

Holmberg, S. (2000), "A system perspective on supply chain measurement", *International Journal of Physical Distribution & Logistics Management*, Vol. 30 No. 10, pp. 847-68.

Kanji, G.K. and Wong, S. (1999), "Business excellence model for supply chain management", *Total Quality Management*, Vol. 10 No. 8, pp. 1147-68.

Korpela, J., Lehmusvaara, A. and Tuominen, M. (2001), "An analytic approach to supply chain development", *International Journal of Production Economics*, Vol. 71, pp. 145-55.

Kueng, P. (2000), "Process performance measurement system: a tool to support process-based organizations", *Total Quality Management*, Vol. 11 No. 1, pp. 67-85.

Kuwaiti, M.E. and Kay, J.M. (2000), "The role of performance measurement in business process re-engineering", *International Journal of Operations & Production Management*, Vol. 20 No. 12, pp. 1411-26.

Lambert, D.M. and Cooper, M.C. (2000), "Issues in supply chain management", *Industrial Marketing Management*, Vol. 29, pp. 65-83.

Lambert, D.M., Cooper, M.C. and Pagh, J.D. (1998), "Supply chain management: implementation issues and research opportunities", *The International Journal of Logistics Management*, Vol. 9 No. 2, pp. 1-19.

Lebas, M.J. (1995), "Performance measurement and performance management", *International Journal of Production Economics*, Vol. 41, pp. 23-35.

Lummus, R.R. and Vokurka, R.J. (1999), "Defining supply chain management: a historical perspective and practical guidelines", *Industrial Management & Data Systems*, Vol. 99 No. 3, pp. 11-17.

Moore, N. (1998), "Supply chain management", *Work Study*, Vol. 47 No. 5, pp. 172-4.

Narasimhan, R. and Jayaram, J. (1998), "Causal linkages in supply chain management: an exploratory study of North American manufacturing firms", *Decision Science*, Vol. 29, No. 6, pp. 579-605.

Neely, A., Gregory, M. and Platts, K. (1995), "Performance measurement system design: a literature review and research agenda", *International Journal of Operations & Production Management*, Vol. 15 No. 4, pp. 80-116.

Rolstandas, A. (1995), *Performance Measurement: A Business Process Benchmarking Approach*, Chapman and Hall, New York, NY.

Ross, D.F. (1997), *Competing Through Supply Chain Management: Creating Market-winning Strategies through Supply Chain Partnerships*, International Thomson Publishing, New York, NY.

Sink, D.S. and Tuttle, T.C. (1989), *Planning and Measurement in Your Organization of the Future*, Industrial Engineering and Management Press, Norcross, GA.

Van Hoek, R.I. (1998), "'Measuring the unmeasurable' – measuring and improving performance in the supply chain", *International Journal of Supply Chain Management*, Vol. 3 No. 4, pp. 187-92.

Waggoner, D.B., Neely, A.D. and Kennerley, M.P. (1999), "The forces that shape organizational performance measurement systems: an interdisciplinary review", *International Journal of Production Economics*, Vol. 60, pp. 53-60.