9. SUPPLY CHAIN PERFORMANCE MEASUREMENT

If the performance of a system cannot be measured, it cannot be efficiently managed. Unfortunately, it is difficult to select appropriate supply chain performance metrics because of the complexity of the supply chain and ever-changing business environments. Beamon [1998] noted that the establishment of appropriate performance measures is an important element of supply chain design and analysis. An ability to effectively measure supply chain performance will be critical to any extended enterprise, and to the organisations within. Since conventional measurement systems may not be valid beyond organisational boundaries, a new performance measurement system is required. Lambert and Pohlen [2001] summarised the need for new types of metrics for SCM as follows:

- The lack of measures that capture performance across the supply chain
- The requirement to go beyond internal metrics and take a supply chain perspective
- The need to determine the interrelationship between corporate and supply chain performance
- The complexity of SCM
- The requirement to align activities and share joint performance measurement information to implement strategy that achieves supply chain objectives
- The desire to expand the “line of sight” within the supply chain
- The requirement to allocate benefits and burdens resulting from functional shifts within the supply chain
- The need to differentiate the supply chain to obtain a competitive advantage
- To goal of encouraging cooperative behaviour across corporate functions and across companies in the supply chain

It is generally known that properly designed performance metrics give rise to more opportunities to identify and eliminate problems, and to meet customer expectations. On the other hand, inappropriately designed metrics will result in failure to respond to the customer.

9.1. PERFORMANCE MEASUREMENT FRAMEWORKS

A number of performance measurement frameworks and related metrics have been proposed. Beamon [1998] classified performance metrics into two categories; qualitative metrics for which there is no single direct numerical measurement, and quantitative metrics that may be directly described numerically. Qualitative measures include customer satisfaction, flexibility, information and material flow integration, effective risk management and supplier performance. Quantitative measures include measures based on cost and measures based on customer responsiveness. This author also developed a new framework for performance measurement. Within this framework, a supply chain performance measurement system that consists of a single performance measure is generally inadequate, since it is not inclusive and ignores the interactions among important supply chain characteristics. Key strategic elements in the organisation include the measurement of resources, output and flexibility. Therefore, as shown in Figure 12, a supply chain measurement system must put emphasis on three separate types of performance measures: resource measures (R), output measures (O) and flexibility measures (F). Each of the three types of measures has important characteristics and interacts with others.

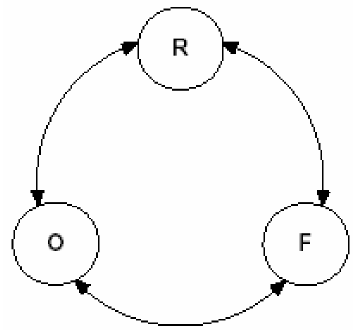

Figure 12: The supply chain measurement system [Beamon, 1999]

Beamon believed that an effective supply chain performance measurement system must contain at least one individual measure from each of the three identified types shown in Table 3.

Performance measure type	Goal	Purpose
Resources	High level of efficiency	Efficient resource management is critical to profitability
Output	High level of customer service	Without acceptable output, customers will turn to other supply chains
Flexibility	Ability to respond to a changing environment	In an uncertain environment, supply chains must be able to respond to change

Table 3: Goal of performance measure types [Beamon, 1999]

Gunasekaran et al [2001] classified performance metrics into four groups along the four links of an integrated supply chain, named as follows: plan, source, make/assemble and delivery/customer. Measures for *plan* include the order entry method, order lead-time and the customer order path. Measures for *source* include supply chain partnership and related metrics such as the level of information sharing and buyer-vendor cost saving initiative. Measures for *make/assemble* include the range of products and services, capacity utilisation and effectiveness of scheduling techniques. Lastly, measures for *delivery/customer* include measures for delivery performance evaluation such as on-time delivery, and measures for total distribution cost. A final class of metric addressing customer satisfaction was added. The framework is illustrated in Figure 13.

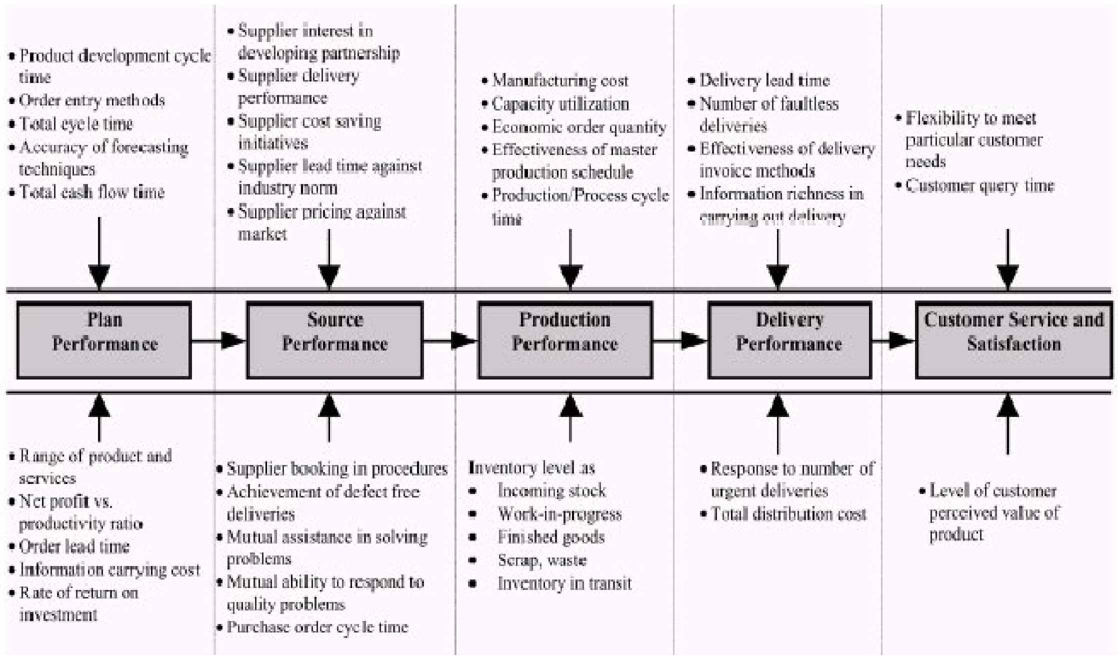

Figure 13: Metrics at 5 basic links in a supply chain [Gunasekaran et al, 2001]

Gunasekaran et al [2003] extended this framework to include a temporal dimension. Metrics for each of the four processes were further divided into strategic, tactical and operational metrics.

Chan and Qi [2003] developed a performance measurement framework for the supply chain with a process-based approach, as Figure 14 shows. In this model, a process in the supply chain is a series of activities from original suppliers and manufactures, through to retailers, which add value for the end customers, each performing a specific set of functions. The performance of each process is the aggregated results of the performance of all preceding activities. Therefore, assessing the performance of activities can depict the effect of corresponding processes. Based on the model, the authors proposed a 'metrics board' of performance measures, covering inputs and outputs, both tangible and intangible. The metrics board include cost, time, capacity, capability (effectiveness, reliability, availability, and flexibility), productivity, utilisation and outcome. When identifying new performance metrics, all the related dimensions in the metrics board can be considered.

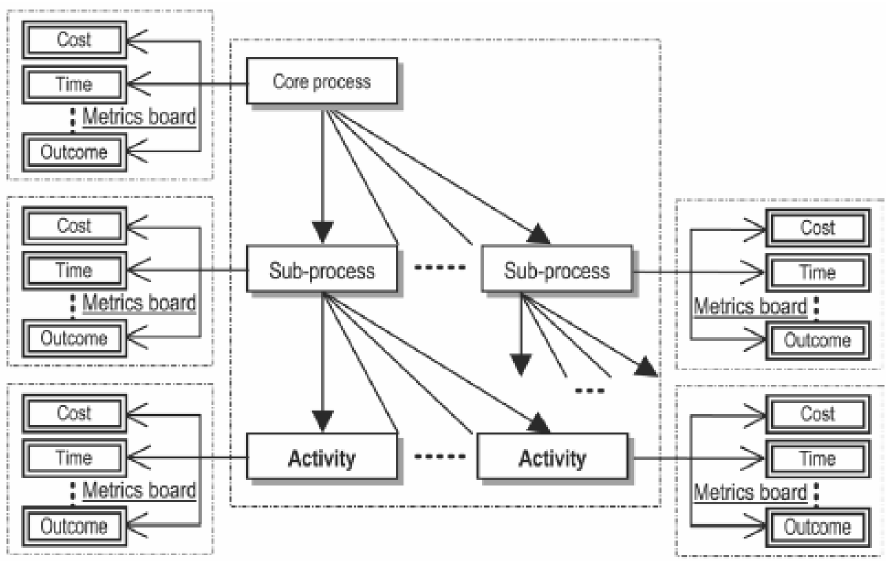

Figure 14: Applying supply chain metrics based on process [Chan and Qi, 2003]

Hausman [2002] emphasized that businesses need to migrate from single-dimensional measures to multi-dimensional ones and from a single-enterprise focus to a cross-enterprise focus. He identified that Supply Chains need to perform on three key dimensions:

- Service
- Assets
- Speed

Hausman also stressed that businesses using multi-dimensional performance measures should recognize that not all dimensions are equally important, and some tradeoffs are necessary. Understanding tradeoffs and as a result, knowing how to set priorities and targets is crucial. An example of an important tradeoff is the balance between inventory level and customer service. Figure 15 shows such a balance before product localization postponement (also called ‘late customization’) and after postponement.

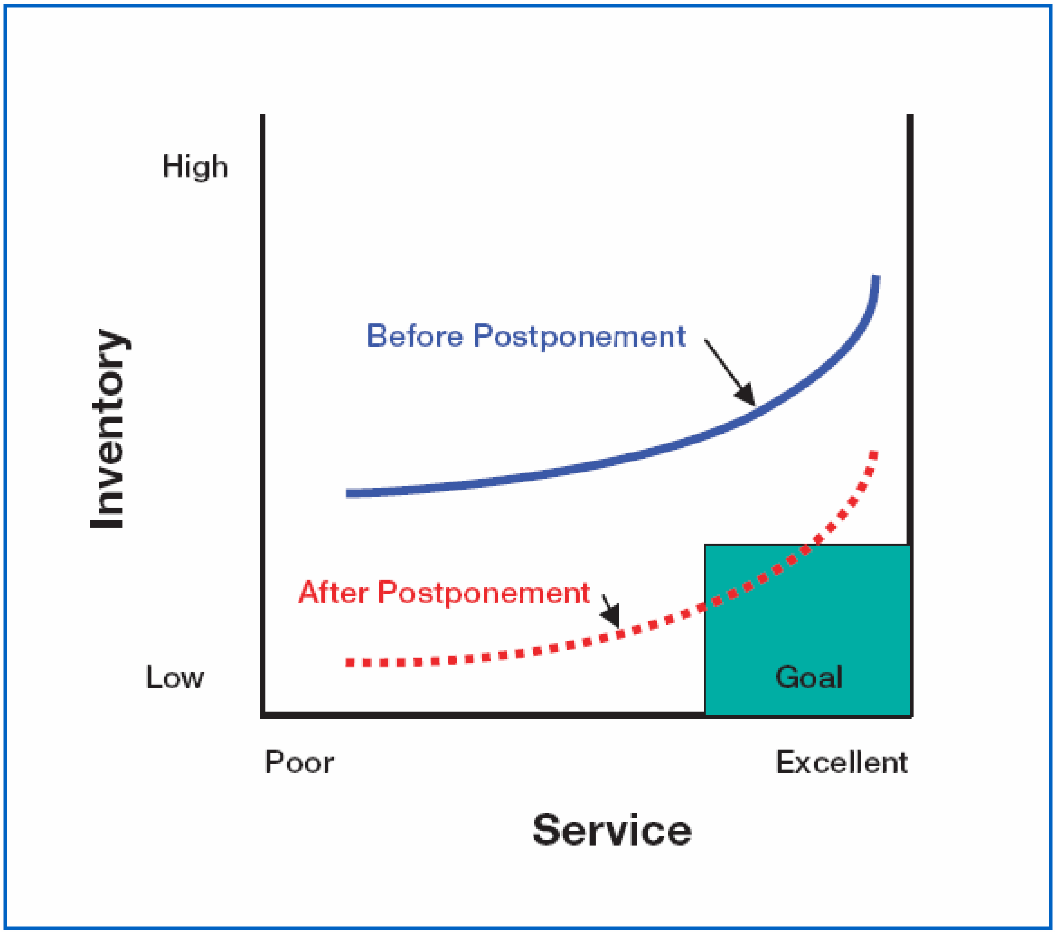

Figure 15: Tradeoff curve for inventory and service [Hausman, 2002]

Hofman [2004] described AMR Research's three-tiered Hierarchy of Supply Chain Metrics (Figure 16) and a top-down approach of executive assessment, diagnosis and identification of corrective action.

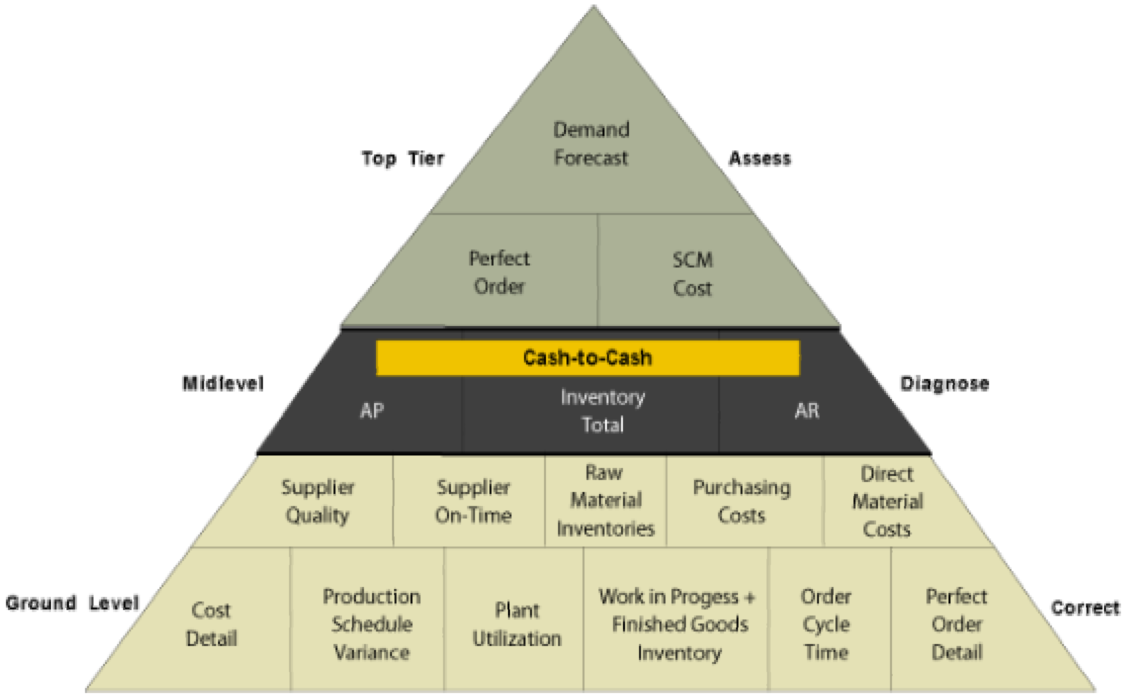

Figure 16: The AMR Research hierarchy of supply chain metrics [Hofman, 2004]

The CorVu white paper “Improve Supply Chain Performance” [CorVu, 2002] describes a list of supply chain metrics based on the four perspectives of the balanced scorecard method: financial, customer, internal, and innovation and growth.

It is perhaps the Supply-Chain Council [2004] that set the industry standard with its Supply Chain Operations Reference (SCOR) model, which integrate the well-known concepts of business process reengineering, benchmarking, and process measurement into a cross-functional framework. SCOR contains:

- Standard descriptions of management processes
- A framework of relationships among the standard processes
- Standard metrics to measure process performance
- Management practices that produce best-in-class performance
- Standard alignment to features and functionality

Figure 17 illustrates the SCOR model’s three-level structure:

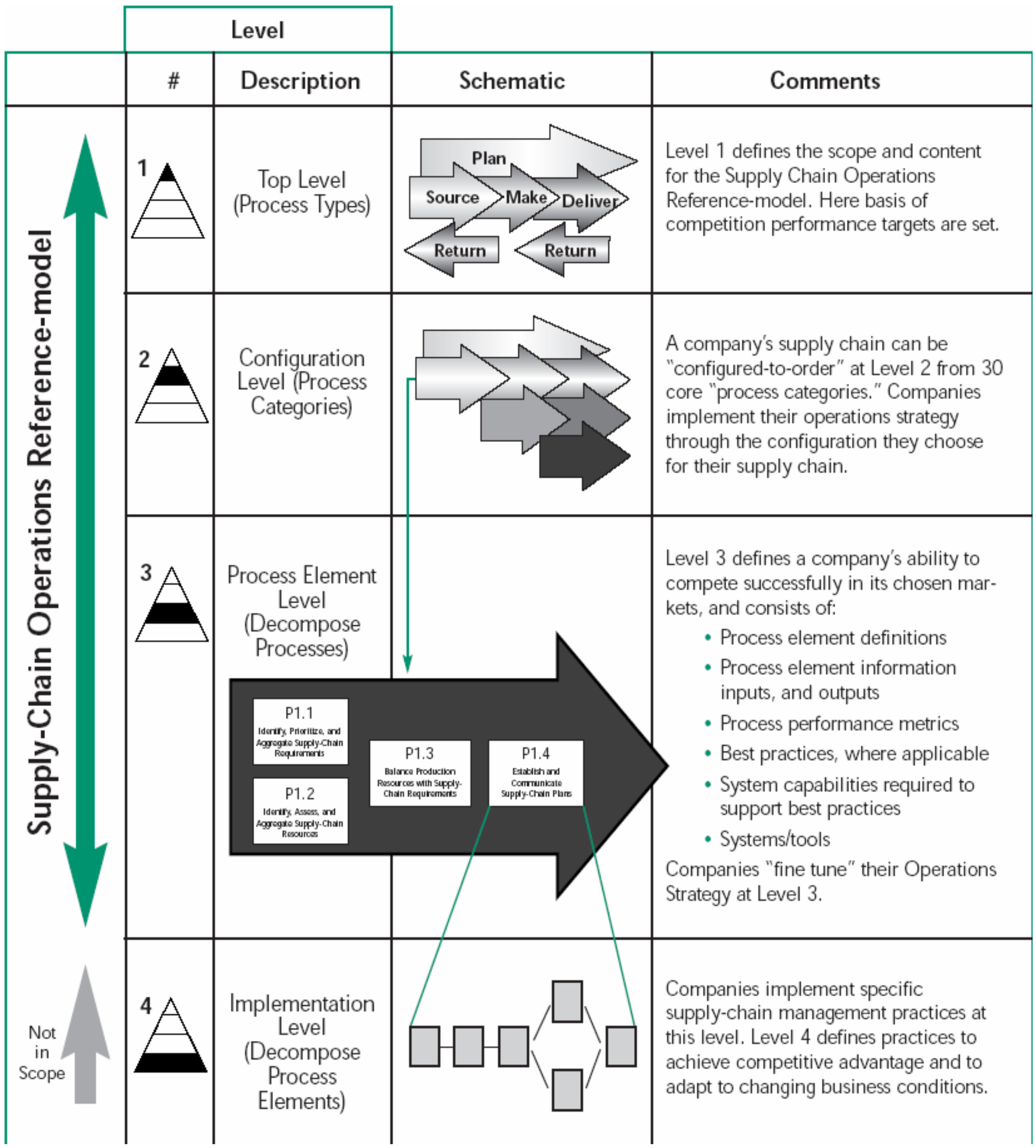

Figure 17: Supply Chain Operations Reference model, showing three levels of process detail [Supply Chain Council, 2004]

The system is not ideal for all supply chains, however. Dutta [2004] described some of its present limitations, explicitly excluding sales and marketing (demand generation), research and technology development, product development and some elements of post-delivery customer support. All of these have some impact and influence on supply chains.

In summary, a performance measurement framework should strive to include metrics from each different category in the following dimensions:

- The transformation dimension [Beamon, 1998]: The resource measures (R), output measures (O) and flexibility measures (F)
- The business process dimension [Supply-Chain Council, 2004]: top level five distinct management processes: Plan, Source, Make, Deliver, Return. This is then drilled down to important 2nd level and 3rd level processes.
- The business excellence dimension [Chan and Qi, 2003]: cost, time, capacity, capability (effectiveness, reliability, availability, flexibility), productivity, utilisation and outcome
- The management level dimension [Gunasekaran et al, 2001]: strategic, tactical and operational

9.2. PERFORMANCE METRICS BENCHMARKING AND INTERRELATIONSHIPS

Christopher [1998] outlined the need for supply chain/logistics benchmarking, what to benchmarking (based on the SCOR model), supply chain processes mapping and setting benchmarking priorities.

Kleijnen and Smits [2003] summarized how economic theory differs from business practices in the treatment of multiple metrics. Economic theory tends to use scoring methods such as Kiviat graphs, empirical utility measurement, uncertain attribute values, mathematical programming (including goal programming), fuzzy set theory etc. In practice managers use multiple performance measures; a single measure does not suffice.

9.3. PERFORMANCE MANAGEMENT

Cokins [2004] of the SAS institute described performance management as a framework that tightly integrates the business improvement and analytic methodologies executives are already familiar with. These include strategy mapping, balanced scorecards, costing (including activity based cost management), budgeting, and forecasting, and resource capacity requirements.

Miller [2000] identifies the key issues that companies face in addressing supply chain performance improvements as the capture of critical quantitative performance data across (and between) functions, plus qualitative insight into supplier and partner relationships.

Toni and Tonchia [2001] found that the main performance management systems in the literature can be grouped into five categories:

1. Models that are strictly hierarchical (or strictly vertical), characterized by cost and non-cost performances on different levels of aggregation, till they ultimately become economic-financial.
2. Models that employ a balanced scorecard or *tableaux de bord*, where several separate performances are considered independently; these performances correspond to diverse perspectives (financial, internal business processes, customers, learning/growth) of analyses.
3. Models that can be called 'frustum', where there is a synthesis of low-level measures into more aggregated indicators, but without the scope of translating non-cost performance into financial performance.
4. Models that distinguish between internal and external performances.
5. Models that are related to the value chain.

9.4. PERFORMANCE MEASUREMENT FOR SUPPLY CHAIN LOGISTICS IN THE PROJECT

As described in Section 6.1, there are several measurement frameworks and classification systems for performance metrics in recent literature. Generally, performance measurement is based upon the firm's strategy, aiming to support the implementation and monitoring of strategic initiatives. For the purposes of WP 2.5 it is necessary to define a framework within which the efficiency of a simulated supply chain can be assessed. A measurement strategy with three categories of metric has been adopted. These are cost, customer service and capability, each described in the subsections that follow.

9.4.1. Metrics based upon cost

Cost will clearly be a metric for supply chain performance measurement because cost is incurred in so many activities. Cost-effectiveness can be achieved through efficiency in resource utilisation. The cost of inventory will be important, including the costs of raw materials, work-in-progress, finished goods and obsolescence; mean inventory level and stock turnover rates are appropriate performance measures.

Examples of cost-based metrics for supply chain performance measurement include:

- **Total cost:** Total cost of resources used through the supply chain
- **Manufacturing cost:** Total cost of manufacturing, including labour, maintenance, scrap and rework costs
- **Distribution cost:** Total cost of distribution, including transportation, warehousing and handling costs
- **Stock Turns:** Indicates the comparison between the total number of items in stock and their usage rate. Operational efficiency regarding inventory level can be measured through the stock turnover. Inventory across the entire supply chain might be used, or just finished product inventory

9.4.2. Metrics based upon customer service

One of the top-level aims of the enterprise will be to achieve a high level of customer satisfaction. One of the principal services would be to provide a required product at the right place on time. Hence, product availability and the delivery performance will both be important measures. Availability of products can be assessed through metrics such as fill rate, backorder rate and stock-out rate. Some researchers claim that reliability is more critical than fast delivery as collaboration and cooperation become key issues across the supply chain, and on-time delivery will become a critical measure of customer service. In addition, reduction in lead-time will reduce response time and reduce uncertainty, so that customer satisfaction will also be improved.

Examples of supply chain metrics based upon customer service include:

- **On-time delivery rate**: Percent of orders delivered on time or before the due date
- **Delivery lead-time**: Lead time typically refers to the amount of time elapsed from order, until delivery to the customer.
- **Manufacturing lead time**: Amount of time elapsed to produce a required product or batch
- **Fill rate:** The rate of orders filled immediately from stock
- **Backorder rate**: Percent of items backordered due stock-out
- **Stock-out rate**: Percent of being out of stock for a requested item

9.4.3. Metrics based upon Capability

Chan and Qi [2003] define capability as a talent or ability to be used, treated or developed for specific purposes and required functions. They suggest it is the aggregate ability by which an activity or process functions. In other words, it is not a separate measure, but a measure combined with other dimensions such as measures on cost and customer service, as explained previously. In particular, rapidly-changing customer expectations and supply chain dynamics make capability a very important measure because companies have to respond to market requirements and the business environment. The detailed capability metrics proposed are as follows:

- **Capacity**: The maximum number of a product that can be delivered by using available resources over a specified time period.
- **Efficiency (Productivity)**: The rate of output against the cost of resources.
- **Reliability**: The ability to perform the required functions (i.e. producing and delivering a required product/service) over a time period (Manufacturing reliability, delivery reliability, transportation reliability and order processing reliability are specific performance measures).
- **Flexibility**: The ability to respond to changes and new requirements. Beamon [1999] identified four sub-types of flexibility: volume flexibility for a product, delivery flexibility, flexibility for producing a variety of products, and new product flexibility.

- **Quality**: The ability to perform a required process without mistakes. Detailed quality measures include the number of customer complaints, proportions of scrap and rework and frequency of engineering changes and concessions, etc.

9.4.4. Metrics for tasks 2.5.3 and 2.5.1

For Task 2.5.3, it is proposed that a weighted multi-criterion profile is developed, based on the above measures. The weighted profile will be used to assess the performance of various supply chain scenarios, as simulated. Weightings will be adjusted and validated to provide a robust and realistic performance assessment system.

The weighted measure should also be used jointly with a set of Key Performance Indicators (KPI), which is a small subset of the above measures. Due to the nature of the aerospace supply chain (e.g. the predominant risk and revenue sharing agreements), the KPIs selected for Task 2.5.3 consist of delivery lead-time, WIP costs, and manufacturing reliability. These can be calculated as follows:

Delivery lead time = ordering lead time + manufacturing time + delivery time;

Manufacturing reliability = (operating time - downtime) / (operating time);

WIP costs = material costs + holding cost.

(All these KPIs will be averaged over a certain time period.)

For task 2.5.1, we introduce the concept of measuring total supply chain performance via cross-enterprise metrics. These metrics will still be based on the three categories but on a much simpler basis.

In addition to the two similar measures of total supply chain cost and supply chain cycle time, we also introduce a new supply chain resilience/robustness measure, similar to that proposed in [RLSN, 2003]; the supply chain cycle time resilience ratio. This new measure is defined as:

$$\frac{\text{Supply chain cycle time under variation}}{\text{Normal supply chain cycle time}}$$

This measure would reflect supply chain's capability to respond to variations, especially step changes. The closer to 1, the more resilient the supply chain is.