Supply Chain Performance Metrics

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Abstract

Every CEO must always be concerned with the competition. In today's economy the battlefield is shifting from individual company performance to what we call *Supply Chain Performance*. Supply Chain Performance refers to the extended supply chain's activities in meeting end-customer requirements, including product availability, on-time delivery, and all the necessary inventory and capacity in the supply chain to deliver that performance in a responsive manner. Supply Chain Performance crosses company boundaries since it includes basic materials, components, subassemblies and finished products, and distribution through various channels to the end customer. It also crosses traditional functional organization lines such as procurement, manufacturing, distribution, marketing & sales, and research & development.

To win in the new environment, supply chains need continuous improvement. To achieve this we need performance measures, or "metrics", which support global Supply Chain Performance improvements rather than narrow company-specific or function-specific (silo) metrics which inhibit chain-wide improvements. We describe a number of supply chain performance measures which are expressly designed to support and monitor Supply Chain Performance improvements across the supply chain and illustrate the shortcomings of several common metrics.

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Charlie slammed the door on the way out of his boss's office. As operations manager for a major aluminum processing facility, he was proud of the fact that he had in past months achieved significantly high production figures for high margin specialty milled orders. But his boss had just berated him for producing fewer tons of low margin aluminum than budgeted. *Charlie was a victim of a "bad" performance measure or metric. Raw tonnage is an inappropriate measure of supply chain performance for a diverse product line where gross margin per ton varies considerably. The use of "bad" metrics can be a major impediment to the implementation of effective integrated supply chain management in today's highly competitive business environment .*

Introduction - Why a Top Management Concern?

Today's CEO can't simply focus on his or her company's performance in a vacuum; there is an emerging requirement to focus on the performance of the extended supply chain or network in which the company is a partner. The battleground will be Supply Chain vs. Supply Chain, with emphasis on continuous improvement across the extended supply chain. To maintain and encourage supply chain improvement we need to go beyond traditional functional and business performance measures and develop new metrics with enough detail and richness to handle Supply Chain performance rather than individual business performance.

Modern supply chains are highly complex and dynamic. They are characterized by constantly changing relationships and configurations, they support a proliferation of Stock Keeping Units (SKU'S), they use a mixture of manufacturing techniques (build-to-stock, make-to-order, Flow) to fulfill orders, and they involve multiple organizations. Furthermore, the emergence of the Internet as a new technology enabler has increased the number of customer interactions and product configurations, thereby presenting greater demands on supply chain management and performance. The ultimate goal and measure is customer satisfaction: the ability to fulfill customer orders for personalized products and services faster and more efficiently than the competition. It is critical therefore to focus management attention on the performance of the supply chain as an integrated whole, rather than as a collection of separate processes or companies.

What Are Integrated Performance Measures For Supply Chains?

Companies must focus on two dimensions of performance to ensure supply chain integration - multi-functional and multi-company. Supply chains span many functions in an organization, therefore, it is critical that performance measures are not narrowly defined. One-dimensional metrics such as capacity utilization, inventory turns or material

costs will lead to a distorted picture of the performance of a firm. Outstanding performance at one location in the chain is not sufficient for a supply chain to be successful if the rest of the supply chain is not up to par. The supply chain is only as strong as its weakest link.

Surface mount factories provide an example of how one-dimensional performance measures can be dangerous and misleading. A traditional measure of surface mount production lines is "cost per insertion," which is defined as the average cost incurred for each insertion of a component onto a printed circuit board. To minimize this measure, managers of such factories would create large production runs of the same batch to minimize changeovers and setups The result of these longer runs would be both a lowered cost per insertion and an increased inventory of finished goods. The overall performance of the surface mount factories could actually decrease despite the positive results of their cost-related performance measure.

As a second example, many companies focus their attention on minimizing freight costs, which are tangible, while ignoring the cost of inventory, which is often measured indirectly or sometimes not even tracked. As a result, we have seen companies using strict transportation policies like always shipping by full-truckloads or full container-loads, or always shipping by ocean or surface. Although the cost of transportation is minimized, the negative impact on inventory and customer service may be so great that the overall supply chain performance suffers.

Likewise, we have also seen companies that boasted great improvements in their own operational performance, but that did not impact the end-consumers due to the overall poor performance of the supply chain. In the early eighties, General Motors' Service Parts Operation was very efficient - their Parts Distribution Centers used scientific inventory management methods, and sophisticated transportation algorithms were used to manage their fleet and routing schedules. GM's service to their immediate customers, the GM dealers, was impeccable. Yet GM's customer service to end-consumers was consistently poorer than most of their competitors. The problem was that the GM dealers' inventory control systems were out of control. GM's supply chain problem was primarily at the dealerships; the wrong parts were stocked and the information system on inventory and parts usage was largely out of date. GM's operations exemplify the fact that a supply chain is only as good as its weakest link. While GM's factory performance was great, the overall supply chain was not competitive. Integrated performance measures must therefore be cross-enterprise in nature.

Adaptec, a fabless semiconductor company, has made great strides in supply chain improvement by integrating information flow between itself, its foundry supplier (TSMC in Taiwan), and its packaging partners in Hong Kong and Korea. Adaptec not only shares production forecasts and communicates purchase orders with its partners; it also shares prototype specifications and test results. This daily Internet-based collaboration has drastically reduced cycle times and inventory levels throughout the supply chain. Adaptec improved its competitiveness as its observed supply chain cycle times dropped from 110

days to 60 days. Tracking performance measures is crucial for successful implementation of information integration in the case of Adaptec and TSMC. It enabled the two parties to build trust, and provided the basis for the justification of the investment in IT enabling this tight sharing of information.

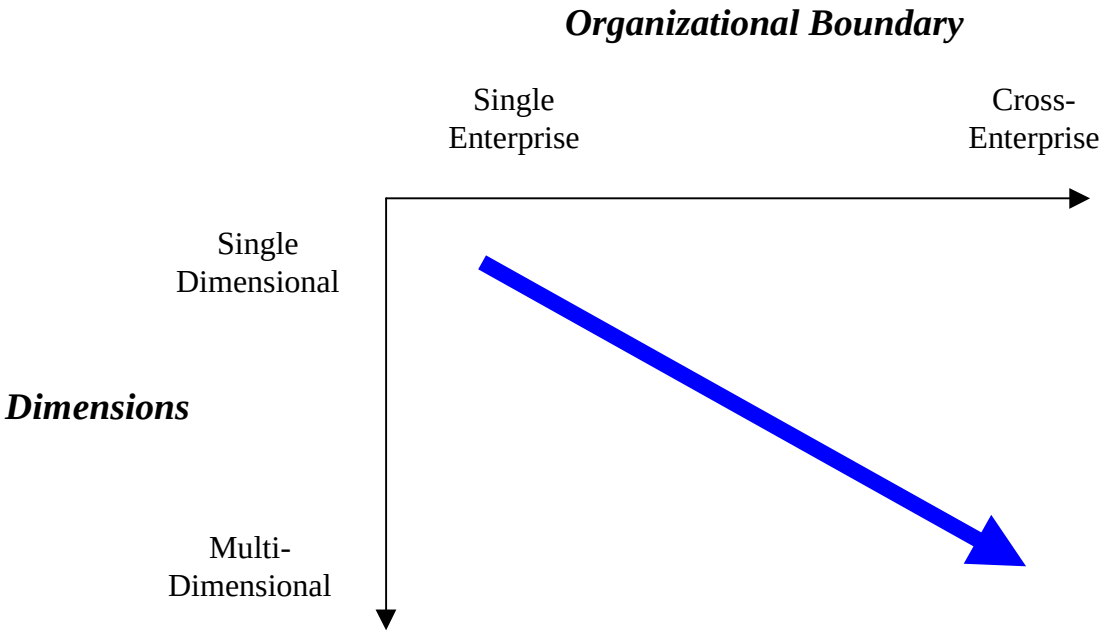


Figure 1. Evolution of Performance Measures for Supply Chains

Figure 1 illustrates the two-directional evolution of integrated supply chain measures. Businesses need to migrate from single-dimensional measures to multi-dimensional ones, and from a single-enterprise focus to a cross-enterprise focus.

Businesses that use 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 as two distinct performance measures. Figure 2 illustrates such a tradeoff. Instead of measuring these quantities separately and having their management occur on separate desks, the curve shows that for any given supply chain, there is a clear tradeoff between inventory and customer service. For a given supply chain structure and operating policy, customer service will improve as more inventory is available, and vice-versa. Focusing on only one of these twin goals is therefore counter-productive; businesses need to consider both goals simultaneously.

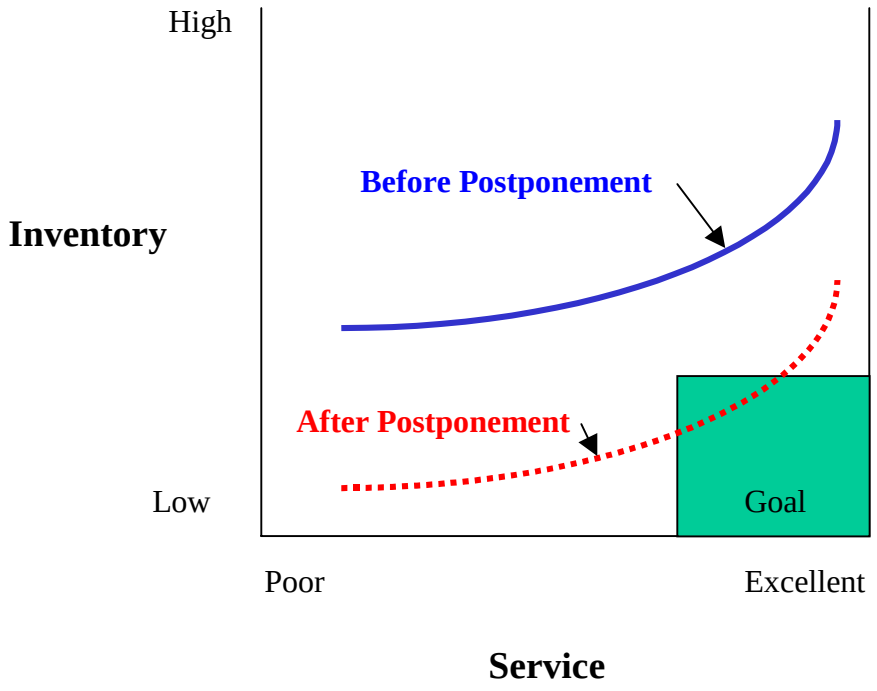


Figure 2. Tradeoff Curve for Inventory and Service.

Hewlett-Packard's Vancouver Division used tradeoff curves extensively to communicate the benefit of redesigning their inkjet printers, allowing localization to occur at their European Distribution Center (DC) rather than at their main Vancouver, WA factory. Localization refers to the use of specific components such as power supplies, plugs and manuals, "localized" to a specific printer market such as Spain, France or England. Initially, all printers were localized at the factory. However, given the long shipping times to Europe, this early commitment of printers to a specific regional market made it very difficult to match supply and demand across the various country markets in Europe. Frequently HP would find they had excess inventory of one type of printer while they had stockouts of another, due to difficulties in forecasting regional demand coupled with long shipping lead times from the USA. The solution was to redesign the printer so that the plant produced a generic printer; this was shipped to Europe and the localization was performed at the European DC, after ocean shipping had taken place. This made the supply chain much more responsive to variations in regional demand. This strategy, called *postponement*, is important for improving supply chains. The improvement in the supply chain is clearly demonstrated by the dotted tradeoff curve in Figure 2.

The Effect of the Internet

The Internet will have a major effect on supply chains. It will enable much richer, faster and easier collaboration across different partners in the supply chain; it will enhance the role of the customer in product development and drastically increase the potential for customer interaction; and it will simplify the task of implementing various supply chain improvements such as vendor-managed inventory (VMI). Procter & Gamble has a VMI relationship with Walmart to maintain and replenish product inventory at Walmart's sites. Walmart agrees to give control of replenishment timing and quantities to P&G, typically with limits on the levels of inventory allowed at the customer site. Walmart also agrees to share sell-through or POS (point-of-sales) data with P&G so that the manufacturer has up-to-date information on customer demand at all times. With the Internet, the information sharing across the supply chain occurs much more seamlessly and efficiently.

We need to ensure that the metrics used for supply chains include factors that capture the costs and benefits of the Internet as well as the investments and benefits of other supply chain improvement techniques.

A Taxonomy for Supply Chain Performance Metrics

Supply Chains need to perform on three key dimensions:

- **Service**
- **Assets**
- **Speed**

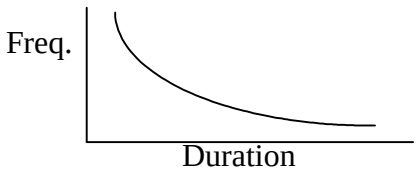
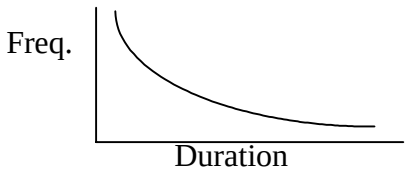
Service relates to the ability to anticipate, capture and fulfill customer demand with personalized products and on-time delivery; Assets involve anything with commercial value, primarily inventory and cash; and Speed includes metrics which are time-related—they track responsiveness and velocity of execution. Every supply chain should have at least one performance measure on each of these three critical dimensions. Note that Quality is absent here; in modern Supply Chain Management thinking, Quality is taken as a given. The diagnosis and improvement of Quality involves factors which are quite separate from factors used to improve Supply Chain Management.

We will explore each of these dimensions to show how a variety of specific metrics may be deployed, tailored to the industry involved.

Service Metrics

The basic premise for service metrics is to measure how well we are serving (or not serving) our customers. Generally it is difficult to quantify the cost of stockouts or late deliveries, so we normally set targets on customer service metrics. Also, the build-to-stock situation differs from the build-to-order situation, so related but different metrics are used in these environments. Table 1 contains some common service metrics used in these two environments. These are time-tested measures which continue to be valuable customer service metrics for supply chains.

Table 1. Customer Service Metrics: Build To Stock vs. Build To Order.

Customer Service Metrics	
Build To Stock (BTS)	**Build To Order (BTO)**
Line Item Fill Rate Complete Order Fill Rate	Quoted Customer Response Time % On-time Completion
Delivery Process On Time	Delivery Process On Time
$ Backordered/Lost Sales No. of Backorders	$ of Late Orders No. of Late Orders
Aging of Backorders:  	Aging of Late Orders: 
	Status information availability

An example of the Build-to-Stock (BTS) case would be an office supply product such as toner cartridges for printers and copiers. Customers expect these items to be immediately available at a moment's notice, and the supply chain must hold inventory to provide off-the-shelf service. In this environment both Line Item Fill Rate and Order Fill Rate are common metrics. The Line Item Fill Rate is the percentage of individual "lines" on all

customer orders which are filled immediately, while the Order Fill Rate counts as a success only those customer orders in which all "lines" have been filled. Customers prefer the latter result, of course, but if the typical customer order contains a large number of line items (say 100 or more), then the order fill rate is likely to be low, since it is very expensive to use safety stock to protect against incomplete orders in this situation. What companies typically do in this situation is have a back-up plan involving additional cost such as expedited delivery of a second shipment, or substitution of upgraded items for those not in stock.

Dell Computer is an example of the Build-to-Order (BTO) environment. Dell assembles each PC based on a specific customer's order and unique customer requirements. In this environment an important metric in Table 1 is the Quoted Customer Response Time (or standard lead time), which is not present in the BTS case. If this response time is very long, then it may be easy to meet but will not be competitive. In this situation the business metric needs to be aligned with the business strategy and value proposition of the business unit. Dell has worked long and hard to ensure that their quoted customer response time is very short since that is a key element of their value proposition.

Also note the delivery process is included in the performance metric in both cases. Even in the BTS case (where there is usually a delivery process), metrics should include both the delivery process and whether the order was filled when it was received.

Note the parallels between aging of backorders in the BTS case and aging of late orders in the BTO case. "Aging" refers to maintaining data on how long it takes to fill a backorder, or how long it takes to complete an order which is late. Tracking this data and maintaining it in an accessible database enables its periodic recall.

In the Internet environment, extensions of the customer order response time would include the on-line service response time of a website as well as the response time required to complete delivery of the product or service.

Inventory Metrics

The major asset involved in supply chains is inventory throughout the chain. The two metrics generally used for inventory are:

- Monetary Value ($, Yen, Euro, et cetera)
- Time Supply or Inventory Turns

Inventory can be measured as a time supply, for example a 3-week supply of inventory, or as inventory turns, defined as

$$\text{Turns} = \frac{\text{(Cost of goods sold)}}{\text{(Inventory Value)}}$$

The Time Supply or Turns measures relate to inventory flows; the Value of inventory relates to inventory as an asset on the firm's Balance Sheet.

Inventory Turns are often calculated in isolation, by accountants with access to financial and inventory data but without corresponding access to customer service data. Using any inventory metric in isolation is dangerous - it should instead be evaluated on a tradeoff curve as shown in Figure 2.

Time Supply and Monetary Value are useful comparison measures in certain situations. The Time Supply metric enables managers to make comparisons of inventory levels across categories, such as different lines of business or different divisions, since the data is adjusted to reflect the underlying "run rate" of the business. The Monetary Value metric is most relevant, since it measures funds tied up in inventory (working capital). One can have a very large "time supply" of inventory (e.g. a couple of years' supply of staples in your desk drawer at home) but if the value is relatively low, it is not a major concern.

A natural disaggregation of inventory in a manufacturing setting relates to the type of inventory: Raw Material (RM), Work-in-Process (WIP), and Finished Goods (FG). The danger in using these as separate metrics (as opposed to their sum) is that responsibility for them will differ, and one can easily envisage "gaming" taking place near the end of an accounting period as, for example, the person responsible for WIP inventory pulls very little material from RM inventory and also rushes to get out the most costly jobs. Then, at the beginning of the next accounting period, large volumes of RM are pulled onto the shop floor. Such behavior is not conducive to a smooth-running production facility.

Summing Inventory All Along The Supply Chain

An interesting theoretical question several years ago was:

> "What if your company tracked and summed up the monetary value of all inventory across your entire supply chain?"

How would this actually be carried out? Let's look at a supply chain for a PC manufacturer. Ideally one would track data on the levels of inventories for all major components (integrated circuits, hard disk drives, memory chips, monitors, motherboards) in upstream locations and then add their monetary value to inventories in transit and to WIP inventories at the assembly factory. Next, we would track and add all inventories downstream in the distribution channel, all the way to the end consumer's purchase point. This question is rapidly changing from a theoretical to a practical one as managers of supply chains cope with increasing pressures on customer service and asset performance. Compaq Computer and other PC companies now measure both their own inventory and the downstream inventory at their distributors. Procter & Gamble, with its Vendor-

Managed Inventory (VMI) process, routinely measures both its own inventory and downstream inventory of its products.

What is the corresponding trade-off curve for inventory vs. service for a company's *entire supply chain*? The inventory dimension adds up all the investment in inventory along the chain; but what service metric should be used? Presumably service to the ultimate customer, since that is the end purpose of the entire supply chain. See Figure 3.

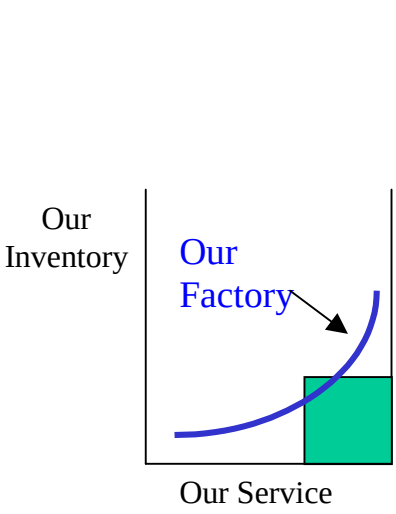


Figure 3a. Myopic View.

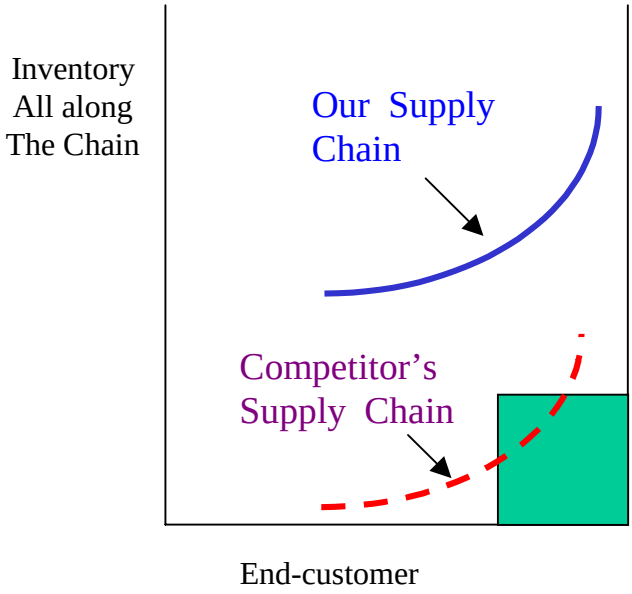


Figure 3b. Chain-wide View.

Figure 3. A Tradeoff Curve for the Entire Supply Chain.

Figure 3a shows that our factory is performing well when measured myopically by *its own* inventory and service tradeoff curve, but in Figure 3b our *supply chain* does poorly compared with the competitor's supply chain. In Figure 3b, for the same level of end-customer service, our supply chain has much higher inventories than that of the competitor.

Let's assume we were able to obtain the data to plot these results - both our company's and our competitor's supply chain - what have we learned? Our entire chain is vastly inferior to our competitor's, and our partners in the chain collectively have much more assets invested in inventory than the competitor's chain. It is only a matter of time until our chain loses serious ground, unless we take action. This action may require us to help our partners in our chain to perform their activities more effectively and efficiently; in

other cases such analysis may pinpoint the need to help the factory rather than our supply chain partners.

Indeed, the PC industry is faced with exactly the challenge shown in Figure 3. With the success of the direct sales model championed by Dell and Gateway, PC manufacturers such as IBM, Compaq and HP have discovered that their own operational performance (costs, inventory, service, etc.) is not sufficient to guarantee market success. Inventory held in the channel, the service provided by the channel, and the total costs of the supply chain of manufacturers and distributors will ultimately determine the competitiveness of their products. Joint performance measures, capturing both the performance of the manufacturers and their partners, are being adopted by the PC industry.

Most importantly, Wall Street pays attention to these issues and includes them in stock price evaluations. A recent article in the business press comparing two national office-supply outlets noted that while their sales volumes were quite different, their assets were almost identical; and the poorer performer was the outlet with the lower sales volume, of course.

Speed Metrics

There are a series of metrics related to timeliness, speed, responsiveness and flexibility. We've already discussed one - the Quoted Customer Response Time in a BTO environment. Others are:

- Cycle (flow) Time at a Node
- Supply Chain Cycle Time
- Cash Conversion Cycle
- "Upside" Flexibility

Let's consider each of these metrics in more detail. About a decade ago there was a major emphasis on "Cycle Time Reduction" in the industrial sector. This emphasis was and still is well-placed, since important supply chain benefits flow from reducing flow time: lowering lead time and WIP inventory levels. Consultants to an automotive components supplier, for example, found ways of reducing the factory response time from sixteen weeks to two weeks. The total inventory in the supply chain was reduced sharply, resulting in significant improvements in responsiveness to the customer.
The Supply Chain Cycle Time measures the total time it would take to fulfill a new order if all upstream and in-house inventory levels were zero. It is measured by adding up the longest (bottleneck) lead times at each stage in the supply chain. For example, consider a three-tier chain with each tier having a one-week lead time; then the supply chain cycle time would be three weeks. One high-tech company was able to reduce their supply chain cycle time from over 250 days to below 190 days; once they started measuring it, some obvious simple improvements were made.

The Cash Conversion Cycle (or Cash to Cash cycle time) attempts to measure the time elapsed between paying our suppliers for material and getting paid by our customers. It is estimated as follows, with all quantities measured in days of supply:

Cash Conversion Cycle = Inventory + Accounts Receivable - Accounts Payable

This measure appropriately includes Accounts Receivable and Accounts Payable since they, rather than inventory, may have more leverage for improvement in particular situations. When Digital Equipment Corporation (DEC) first studied its supply chain they found Accounts Receivable was averaging 91 days, due largely to customer complaints about errors in billing. With each day representing $60 million in uncollected funds, management attention focused quickly on this opportunity for improvement.

"Upside" flexibility refers to requirements, particularly in high-tech, that a vendor be prepared to provide say 25% additional material above and beyond the committed order, in order for the buyer to be protected when the buyer's demand is higher than forecasted. This is usually stated as a percentage of the amount on order, and sometimes contracts are explicit regarding the percentage of upside required within various time windows. For example, if an order for 100 PC Boards has a 2-week lead time, the buyer may request an additional 25 boards within one week of delivery and expect the supplier to provide this upside flexibility.

Links to Other Traditional Metrics

Some traditional manufacturing metrics can reinforce silo behavior or otherwise be an impediment to supply chain integration. One example is capacity utilization. In industries where capital costs are overwhelming, such as the semiconductor industry, there is tremendous pressure to focus on utilization of capacity, since most of the costs of producing the product reside in allocation of capacity costs (both physical plant and equipment). The danger here is not recognizing that there is always a tradeoff between capacity utilization and responsiveness. As long as there is any variability present, either in the order/demand stream or in processing time, then as one loads a facility closer to 100%, the queuing or waiting time increases exponentially (see Figure 4).

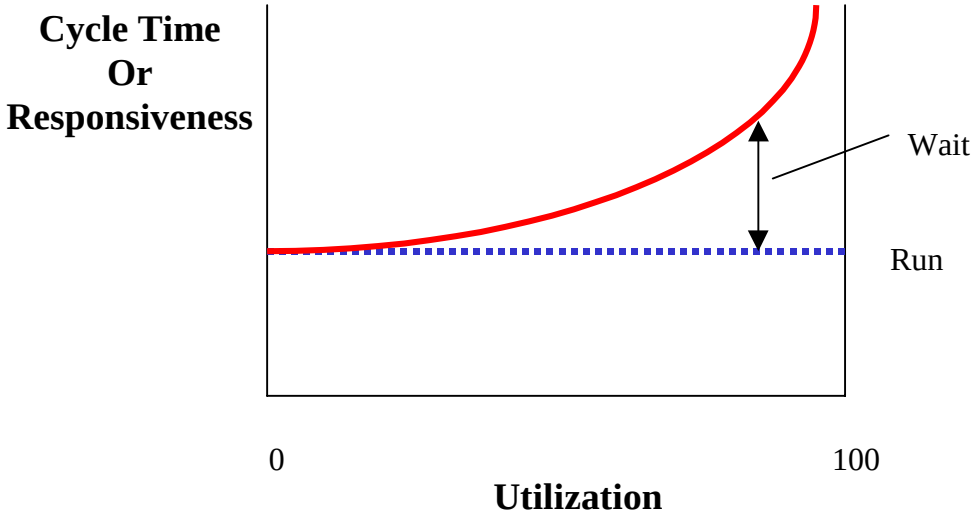


Figure 4. Capacity Utilization versus Responsiveness (Flow Time)

One major fab foundry has decided not to aim for the highest possible utilization, since doing so would make it very sluggish and unresponsive to unpredictable customer requirements. The queuing or waiting time between various semiconductor manufacturing operations would become excessive, total WIP inventory would increase dramatically, and the foundry would find it nearly impossible to deal with "rush" orders and unexpected surges in orders. They have decided that utilization alone is too narrow a metric, and that the tradeoff with responsiveness is critical for their competitive strategy and value proposition.

Alignment with Business Strategy

It is important to emphasize that "One shoe size doesn't fit all" - i.e., metrics must be tailored to the Value Proposition of the Supply Chain (why do customers buy from us?). Companies and Supply Chains differ in their business strategies and value propositions. A supply chain whose value proposition is low cost should not unduly emphasize flexibility and responsiveness metrics, since they could detract from that chain's fundamental competitive strategy. Similarly, one whose value proposition is innovative technology should not unduly emphasize cost factors, since they could detract from that chain's strategy. It is critical that the specific metrics chosen (and target goals along those metrics' dimensions) should align with the chain's business, product strategy and value proposition. Hence, if the strategy used is to be low-cost, then the relevant metrics could be costs, capacity utilization, labor productivity, information accuracy, etc. If the strategy is to be flexible and responsive, then the relevant metrics could be order response time, order change flexibility, product mix offerings, replanning times, and expediting capabilities.

Future Directions - Total Supply Chain Performance

Many companies have risen to the challenge of implementing cross-functional metrics. Fewer companies have yet risen to the twin challenge of implementing cross-enterprise metrics. These will be crucial in enabling top management to seek and monitor continuous supply chain performance improvements.

The internet is a key enabler of both supply chain performance improvements and richer supply chain performance measures. It facilitates the sharing of information in a collaborative and timely manner in a "hands-off" operation mode, which will undoubtedly be a major force in improvement of supply chains in the near term. But it also facilitates the development of cross-enterprise performance measures such as the inventory-service tradeoff curve for an entire supply chain (see Figure 3). Technology is also required to accomplish this, but the end result will be a more over-arching set of supply chain metrics which will be valid indicators of continuous improvement in supply chains.

In order to achieve chain-wide metrics, partners in a supply chain need to set aside concerns about "confidential information." One way to overcome such provincial thinking is to get all partners in a supply chain to recognize that their performance is actually measured by the end customer as their Total Supply Chain Performance, not their individual business-unit performance.

The battleground of the next decade will be supply chain vs. supply chain. Are you measuring the right things to win this battle?

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