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Real World Supply Chain Assessment and Improvement: Lessons Learned in Training and Implementation

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EXECUTIVE SUMMARY

- Supply chain management is a complex process that requires a high-level dedicated governing body or steering committee to meet the various needs of the supply chain's multiple customers.

- An ongoing disciplined, deliberate assessment process that focuses on the supply chain structure, data, and performance metrics is required for thorough supply chain management.

- The article contains a case study that demonstrates the use of assessment information to carry out effective supply chain management.

The complexity of supply chain management requires a high-level dedicated governing body or steering committee to meet the various needs of the supply chain's multiple customers. Comprehensive supply chain management depends upon an ongoing disciplined, deliberate assessment process that focuses on the supply chain structure, data, and performance metrics. The case study demonstrates the use of assessment information to optimize inventory visibility, demand forecasting, and production predictability and flexibility to achieve ongoing improvement in total supply chain efficiency and effectiveness.

Introduction

A supply chain is the fundamental collection of production and distribution activities through which an organization makes goods available to its end users. If a supply chain works effectively and efficiently, the needs of customers can be satisfied. (We use the term "customers" in the broad sense, including end users, intermediate customers, employees, management, and stockholders). If a supply chain works poorly, an organization can experience undesirable effects such as high operating costs, poor product quality, late shipments, or surplus inventory. The end result may well be dissatisfaction on the part of one or more customer groups.
The purpose of this paper is to discuss some principles of supply chain assessment and improvement, based on our experiences as scholars and consultants. We aim to accomplish four main objectives:

1. Relate the relatively new principles of supply chain management to the more familiar principles of managing for quality,

2. Discuss ways in which we have successfully bridged the gap that separates supply chain theorists from supply chain practitioners,

3. Propose several principles by which an organization might prioritize its supply chain improvement activities (which things to do first, and which things to do later), and

4. Identify and discuss in some detail four cross-cutting issues in advanced supply chain management.

Supply chain management is the most recently proposed set of tools to replace the total quality paradigm, which itself replaced innumerable previous sets of principles and managerial tools. In our view, the fundamentals haven't changed; the principles of managing for quality are quite robust and are easily adaptable to the task of supply chain management. The most obvious element that is new about supply chain management is the unprecedented sophistication of its information technology.

The task of supply chain management is informed by a substantial academic literature from the fields of statistical forecasting, scheduling theory, inventory analysis, queueing theory, and other management sciences. Unfortunately, this literature is not immediately accessible to the
managers entrusted with actually operating and improving supply chains. It is our experience that this inaccessibility stems from several cultural differences between theorists and practitioners. For example:

- Theorists are accustomed to discussing what is possible in the abstract, whereas practitioners want to understand things as they relate to what exists now.

- Theorists tend to think in terms of optimization (which can take time), whereas practitioners would be happy just to achieve some significant degree of improvement (and the sooner the better).

- Theorists establish facts through rigorous mathematical proofs, whereas practitioners establish facts through illustration and experience.

We don't intend to suggest that either group is superior to the other. Rather, we propose that both groups are better off when they find ways to cooperate; each is enriched by interaction with the other. This is certainly the case in the context of supply chain management.

In our experience, supply chain improvement activities are best pursued in a rational sequence of events. For example, inventory reduction is a common part of supply chain improvement efforts, but there are different kinds of inventory held for different managerial purposes. Some kinds of inventory offer a more logical target for reduction early in the improvement process than others. We will propose some principles along this line during the course of this paper.
We will also discuss in some detail four "cross-cutting issues" that we have observed to emerge as an organization attains some degree of maturity in supply chain management. These issues are not felt at first; they emerge later in the supply chain improvement process because they involve higher-order interactions across organizational units and departments. An organizational structure for addressing and resolving these issues typically needs to be created.

These four issues are:

- Efficiently utilizing finished-goods inventory across multiple distribution centers,
- Keeping production reliable and responsive to variable demand,
- Spreading production smoothly over resources, and
- Effective production planning (either through pull systems or accurate forecasting).

We intend to discuss each of these issues in terms of how we have been able to communicate them to practitioners, how they are linked to each other and to strategic supply chain objectives, and how they can be effectively measured, improved and controlled.

The principles in this paper, though broadly applicable across many types of supply chains, are illustrated by examples from a particular training and consulting project for a large international organization in the business of producing high technology devices.

Assessing the Supply Chain

In the last decade, companies throughout the world have collectively spent billions of dollars to make their supply chains more effective and efficient. Some of these efforts have borne fruit, and some have not (Cooke and Peterson, 1997). Much of this expense has been for computer software and hardware. Investment in information systems is important for supply chain efficiency and effectiveness, but it is not the whole story.
Fundamentally, supply chains produce and distribute goods. Information moves through the supply chain to plan, manage and facilitate the movement of goods. Focusing on information alone will not solve supply chain problems. One first needs to get “down and dirty” and see how the goods are actually manufactured, stored, and distributed.

In the most generic sense, a production/distribution supply chain includes planning, production, warehousing, and distribution, with customer demand leading to a new cycle of planning. A typical supply chain is shown as Figure 1, which shows both the flow of goods and information.

![Figure 1. Generic Supply Chain Model.](image)

It should be noted that a supply chain is not a single process but is, rather, a system or collection of processes. The processes that make up the system are dependent on each other and must work in a highly coordinated way to meet customer’s needs effectively and efficiently. The process of assessment involves identifying the various activities that make up the supply chain,
including identifying the customers of each activity. The assessment also includes evaluating the activities with respect to *effectiveness* and *efficiency*, which are described below in more detail.

This, incidentally, is one of the areas in which practitioners are outpacing their academic counterparts. There is little in the way of a useful, widely accepted theoretical structure by which managers can approach the assessment of large scale supply chains with multiple measures of performance. Instead, the practitioners are forging ahead while the academics are following behind, learning from their counterparts' experiences.

It is not surprising to find during an assessment that no one manager or department “owns” a supply chain. Hence no one is responsible for its performance. This problem can be addressed by creating a *Supply Chain Steering Committee* consisting of high level managers. They are *chartered* by top management, meaning that they are collectively assigned certain responsibilities, including supply chain control and improvement. We will discuss the steering committee concept in greater detail later.

An integral part of the steering committee's responsibilities is to create and track metrics for the purpose of understanding and improving the supply chain. In the example used in this paper, a panel of 22 metrics was developed to support the activities of the steering committee. These metrics were organized into two categories, *Customer Focused* and *Company Focused*. In the first category are such things as backorders, fill rates and customer satisfaction survey results. In the second category are such items as lead-time variability, compliance with production schedules, and inventory levels.
The Structure of Assessment

Regardless of the size or complexity of a process (or collection of processes), assessment begins with description and measurement. We have found it useful to think about a supply chain in terms of four levels of increasing detail. At the highest level one may find a diagram similar to that shown in Figure 1. At the most detailed level one might find a production router that describes the fabrication of a part and its movement from machine to machine. Each level of detail provides value to the analyst.

The “Satellite View”

It is at the highest level of description that evidence or symptoms of a problem can be found. Aggregate measures of concepts such as customer dissatisfaction, backorders, order errors, or quality defects can be easily measured at this level. One can also conduct "cost of poor quality" studies and begin to see opportunities for cost reduction. (There is also value in taking cost analysis down to lower levels, to explore issues related to waste and rework in business and manufacturing processes.)

The “30,000 Foot View”

The second level of detail helps identify the functional departments involved in supply chain performance. At this level one sees such things as planning, fabrication, inspection, transfers to final stock, warehousing, distribution and customer ordering. At this level the decisions to be made by the analyst involve selecting which functions to include in an assessment and which to exclude.
The “500 Foot View”

It is at the third level that we begin to actually see in detail the movement of goods and information. For example, it is here that one should see the details of a production planning process, the structure of focused factories, warehouse receiving, storage, pick-and-pack, and shipping. In addition, the movement of goods to customers should be visible and measurable as well as the potential for bottlenecks, rework and waste at various locations throughout the supply chain. Perhaps most important, it is at this level that hypotheses attempting to explain supply chain deficiencies can be developed, explored, integrated and tested.

“Ground Level”

The fourth level of description, the production router level, is excellent for understanding the potential for improvement in the manufacture of a specific part or item. Here is where detailed cost accounting data are available and can be used to identify value added or non-value added costs. One might also find bottlenecks, rework, and waste at this level.

Data

To properly focus improvement activities, a supply chain assessment should be grounded in reliable quantitative data. Interviews and ad hoc statements by company employees will only go so far, because large supply chains are so complex that it is rare to find an employee who has the entire picture. More commonly, company employees have fragments of information. These need to be tested against hard data to provide support for hypotheses.

It is important for both managers and employees to realize that the supply chain is a dynamic, interconnected system of processes. The significance of this statement is that elements
of the supply chain interact with each other continuously. Figure 1 can be used to illustrate this concept with several examples:

- Poor production planning can put the wrong goods into production and inventory, creating shortages for end users or excess inventory for the manufacturer.
- Excessive lead times in production can extend planning horizons, weakening the accuracy of production forecasts.
- Shortages at distribution points can create a culture of hoarding which, in turn, forces extra production and, eventually, excess inventory.
- Poor inventory management at distribution points can create an illusion of demand, which distorts production planning and all the processes that depend on it.

Only by understanding the dynamic nature of this wonderfully elegant system can one hope to continuously improve it. This type of understanding is a difficult thing to achieve for many people in the middle and lower ranks of an organization; they are used to managing a single process or subprocess within the supply chain and may not have any sense of perspective as to where their own process fits in.

For this reason we have found it useful to devote some training resources to helping supply chain participants understand the larger picture. This can be accomplished with simple games, such as simulating an assembly line with poker chips that move in accordance with rolls of dice. As "inventory" accumulates in the system and "production schedules" break down, practitioners can get a basic grasp of the principles of inventory flow, random events, and queueing systems, which are the building blocks of supply chain theory. Operations management professors have
developed a large number of these instructional games; a useful collection of them can be found in the book by Heineke and Meile (1995).

Figure 2 illustrates a more tactical-level view of part of a supply chain.

![Generic Supply Chain Diagram](image)

Figure 2. Model Segment of Generic Supply Chain.

Companies that successfully achieve supply chain excellence typically do so by organizing the key managers responsible for the various elements of the supply chain into a formal group, sometimes called a supply chain steering committee. This is analogous to the high-level, cross-functional approach used to manage many of the more successful quality efforts. The responsibilities of this group are to:

- Make policy-level decisions about the supply chain.
- Create, track, act upon, and update the supply chain metrics as needed.
- Identify planning and improvement projects with respect to the supply chain.
- Select and provide resources to teams to carry out the projects.

- Assure that the solutions generated by the teams get implemented.

**Performance metrics**

How can one assess how well a supply chain performs with respect to meeting customers' needs, while at the same time providing some sort of competitive advantage for the organization? How can the performance of individual managers and employees be linked to the accomplishment of system-wide goals? How does the supply chain steering committee organize and prioritize its responsibilities?

The answer to these questions lies in the establishment of quantitative measures of performance for the supply chain and its components. These measures ought to reflect how actual performance corresponds to system requirements; understanding and being able to quantify these requirements goes to the heart of any assessment and subsequent improvement effort.

In our experience, thinking about supply chain performance metrics is easier if we consider two broad classes of measures, defined by considering the viewpoints of (a) the external customers and (b) the internal organization. The external dimensions of performance are timeliness (Does the supply chain deliver orders at the time needed?), accuracy (Are the orders produced and delivered error free?), and product quality (Does the product quality meet the needs of the end user?). We define these to be measures of supply chain *effectiveness*; inadequate performance with respect to these metrics is associated with customer dissatisfaction, loss of market share, and deteriorating revenues.
The second class of supply chain performance measures centers on efficiency\(^1\). This is a set of measures of concern to the internal organization and the supply chain’s intermediate customers. One can evaluate efficiency in many ways, but we have successfully used the analytical structure of “cost of poor quality” developed by J. M. Juran. This type of analysis can be designed to include production costs, inventory costs, and distribution costs. Inadequate performance with respect to these metrics is associated with excessive costs of production and distribution, excessive investment in both work-in-process and finished-goods inventory, and deteriorating profitability.

Each measure ought to be carefully defined, with consideration given by the steering committee to several key issues:

- Is the measure linked to the strategic goals of the supply chain?
- Is the measure operationalized in such a way that data can be easily collected, presented, and interpreted?
- Who is responsible for collecting the data?
- What is the organization's goal with respect to this measure?
- Who is responsible for maintaining or improving performance with respect to the goal?

Inevitably, as the various responsible managers attempt to achieve these performance goals, conflicts emerge. Even in the most amicable organizations, legitimate disagreements develop.

\(^1\) We have defined the terms efficiency and effectiveness here slightly differently from their usual conversational meanings in order to provide a simple lexicon for two broad sets of performance measures.
because some of the organizational goals naturally conflict with each other. For example, a common effectiveness goal is to improve the "fill rate" (the proportion of orders that are filled immediately from finished-goods inventory), and a common efficiency goal is to reduce finished goods inventory. A high fill rate can become increasingly difficult to achieve when finished-goods inventory levels are reduced, leading to a "cross-cutting" issue that needs to be resolved at the steering committee level.

In our experience, four cross-cutting issues emerge as the organization begins to rationalize its supply chain management activities. In the next sections of this paper, we identify and discuss these four issues with respect to training employees to understand them and their linkages to other supply chain processes, as well as measuring and improving performance. The four issues are:

- Efficiently utilizing finished-goods inventory across multiple distribution centers,
- Keeping production reliable and responsive to variable demand,
- Spreading production smoothly over resources, and
- Effective production planning (either through pull systems or accurate forecasting).

Failure with respect to any one of these will negatively affect supply chain performance. Our training programs have focused on achieving an understanding of each of these four elements, first in isolation, and then as an integral part of the larger supply chain.

Visibility of Inventory

The theorists have performed a great deal of useful work on the so-called transshipment problem (e.g. Krishnan and Rao, 1965, and Karmarkar and Patel, 1977). Essentially, the transshipment problem is concerned with how to manage the inventory-control aspects of a
supply chain using techniques of mathematical programming. One common assumption in the transshipment literature is that the inventory in a supply chain system is "visible".

We use the term "visibility" to mean that the organization has (1) the ability to keep real-time track of finished-goods inventory in all of its various distribution centers (or other facilities in which finished-goods inventory is stored), and (2) the ability to rapidly and cost-effectively transfer inventory between these facilities in response to variable demand. While mathematical modelers often assume visibility, it is not always a realistic assumption in practice. In a large supply chain, visibility can have a very powerful effect on both inventory levels (the reduction of which are typical efficiency objectives) and backorders (the reduction of which are typical effectiveness goals).

Some measures of visibility include (1) the proportion of total finished-goods inventory that is known and available to all distribution centers in real time, and (2) the time and/or cost involved in transshipping inventory between distribution centers.

One of the significant academic contributions to supply chain management is the rich literature on inventory theory. In particular, practitioners can gain a great deal of insight from studying inventory as it relates to specific managerial problems that can be solved through the judicious use of inventory. While managers are certainly accustomed to thinking about inventory, they are not always clear as to why inventory exists in the first place, or what principles can guide them when the time comes to reduce inventory intelligently.

In our view, the most effective initial reduction of finished goods inventory is achieved by reducing safety stock (as opposed to other kinds of inventory, such as cycle stock, pipeline
inventory, decoupling inventory, or anticipation inventory). Safety stock is the term used to describe inventory that exists because of uncertainty. Inventory managers build up and hold safety stock to protect themselves against the effects of uncertain demand or uncertain production. If these root causes of uncertainty can be reduced or eliminated, safety stock can similarly be reduced.

While uncertainty in demand is frequently beyond management's control, we will describe certain structural techniques for reducing the *effects* of demand uncertainty on the supply chain. Later in this paper, we will discuss the reduction of uncertainty in production times.

Safety stock can be reduced when demand is effectively "pooled" across the distribution centers, reducing demand uncertainty. Similarly, a reduction in backorders can be achieved by effectively "pooling" the inventory at all distribution centers. While the inventory at the various centers is not all physically in the same location, visibility allows it to be used almost as though it were. This is not a very new concept; it is the rationale behind financial diversification, product portfolios, and other managerial techniques for reducing risk.

We have found it useful to illustrate this concept through the use of the following graphs, based on a computer simulation of a single SKU system with three distribution centers. In this scenario, each of the three distribution centers receives a steady, deterministic supply of 100 units every period. Demand at each center is random, but averages 100 units. The simulated demand patterns at the distribution centers over fifty periods are presented in Figure 3. (The details of our complete simulation models are tangential to the purposes of this paper; interested parties are encouraged to contact the authors for specifics.)
Figure 3. Variable Demand Pattern, 3 Distribution Centers.

In the following chart (Figure 4), we can see that this system, simple as it is, has serious problems with respect to inventory and backorders. During most of the fifty-period scenario, customers are waiting for products at one distribution center, while at the same time there is excess inventory at another distribution center. This, despite the following facts: (1) production is constant, (2) production, in the aggregate, is sufficient to meet demand, and (3) there is only one SKU. This paradoxical result stems from the fact that inventory is "invisible"; there is excess inventory at one center and excess demand at another center.
In the final chart (Figure 5), we see what could have been the performance of this same system if the distribution centers had been able to transship goods between themselves as needed. With the same demand pattern and the same total production, the system operates with very few backorders and a much lower level of inventory.

Figure 5. Visible Finished-Goods Inventory.
In our experience, this simulation is a useful learning device for several reasons. First, it removes blame for backorder problems from the production department (at least in this scenario). We can see that backorders and inventory build-ups are entirely possible, even if manufacturing is doing its job perfectly well. This is not a trivial result; organizations embarking on efforts to improve their supply chain performance are often plagued with counterproductive pre-conceived notions as to root causes of their problems. These notions are a serious barrier to rational decision making and improvement programs.

Second, this example reveals the often hidden potential for improved supply chain performance that might be realized if inventory were more visible. The intelligent pooling of supply and demand across multiple distribution centers is one of the most important principles of supply chain management.

Finally, the simulation suggests how the potential improvements in both inventory reduction and backorder reduction might be very large indeed in a more complicated system. This example illustrates significant improvement in a very simple system, resulting from pooling inventory across three distribution centers. Presumably a larger system with more SKUs and more distribution centers could achieve even greater improvements.

**Measuring and Improving**

Obviously, even a visible system can't transship inventory instantaneously or for free. Trade-offs need to be made by the supply chain steering committee as to what level of visibility is cost-effective. Not every organization will want to invest in the considerable information technology required to create a truly global awareness of all of its inventory and backorders on a continuous real-time basis. Nor will every organization decide to transship goods from
distribution center to distribution center to achieve very small improvements in backorder performance.

However, the management faced with these issues will perhaps make better decisions if they are informed with the sort of intuition that comes from studying a simple system such as the one illustrated above. Investment in information systems aimed at creating inventory visibility can be made with a more accurate idea as to the costs and benefits of such an investment. What will be the expected reduction in finished goods inventory as a result of the investment? What will be the expected reduction in customer backorders? Do these expected benefits justify the costs of visibility?

Predictable Production

We use the term "production predictability" to refer to how well actual deliveries of finished goods into the distribution system comply with the production plan as originally scheduled. This concept, like the concept of inventory visibility, is related to reducing uncertainty and, consequently, reducing safety stock.

Typical measures of predictability are (a) the standard deviations of lead-time within particular production departments or cells, or (b) the proportion of orders (or units) actually delivered into final stock in accordance with the production schedule.

There are several difficult concepts involved with understanding production predictability. It isn't always easy to see why lead-time variability is a problem as long as a production department produces according to plan on the average. In particular, production managers sometimes find it difficult to understand why it is undesirable to deliver orders early.
Using the same fifty-period, single SKU scenario employed previously, we can illustrate the effects of lead-time variability. In Figures 6 and 7, we see the same scenario as before; each distribution center receives a deterministic quantity of 100 units per period. In Figures 8 and 9, production varies moderately; each distribution center receives a random quantity between 95 and 105 units per period. Note that inventory control deteriorates as lead-time variability is introduced, even with visibility of inventory.

In Figures 10 and 11, lead-time variability is more pronounced; the quantity delivered to each distribution center varies between 75 and 125 units per period. The finished goods inventory level fluctuates even more wildly, with or without visibility.

Most production managers can intuitively see why longer-than-expected lead-times are a problem: goods aren't available to customers, causing a backorder. It is less intuitive to see why delivering an order early is also a problem for the supply chain. In fact, an order received before it is expected occupies space in the supply chain, and space is a scarce resource.

The negative effects of early orders can compound themselves in a more complex system, in which production consists of numerous process steps in various departments or cells. If downstream operations (e.g. inspection, packaging) are accustomed to processing orders as they are received, an order received early might get into the process and pre-empt a more urgent order arriving later.

Avoiding this situation requires discipline at all stages of production: upstream processes need to be careful not to move orders early, and downstream operations need to keep early-arriving orders from disrupting the overall production plan.
We have learned to approach the measurement and improvement of production predictability in several phases. In the first phase, we begin measuring the average and standard
deviation of lead-time within the various production processes in a supply chain, with the implication that the responsible managers will eventually have the performance of these metrics included in their own incentive systems. Simply measuring and reporting these statistics is a powerful tool for creating awareness of lead-time variability. It will provide the steering committee with information as to where in the supply chain time is being lost, and will expose opportunities for safety stock reduction through the reduction of lead-time variability.

Another useful metric can be created by studying the proportion of orders in a department that are delivered within a certain interval around the target in the production plan. For example, we have created a target such as "deliver all orders within two days before or after the due date", and tracked the percentage of all orders passing through a cell that meet this target. This sounds like a fairly low hurdle, but our experience has shown that many processes have difficulty meeting this target. These processes are revealed through this metric, and they can then be the focus of improvement efforts.

Some debate is likely to develop as to how these statistics are calculated; it is tempting for those who collect the data to throw out "outliers" from the data that seem to unfairly punish a particular department. For example, an order might sit in a packaging cell for several weeks pending resolution of some quality issue. The packaging manager may object to having this order included in the lead-time statistics for his/her department, because it increases both his/her average lead-time and standard deviation of lead-time. There will be a strong (and legitimate) objection to linking one's reward and recognition system to metrics that are beyond one's control.

In this phase of implementation, the focus ought to be on problem identification and solution, not on assigning blame or punishing people. (Keep the outliers in the data; they may
well be symptoms of the extreme events that cause the supply chain to perform poorly! Find their root causes and eliminate them.)

As improvements are made and the capability of production processes to meet desired predictability targets is established, production departments can be put into a state of "self-control", and performance with respect to these targets can legitimately be linked to the organization's reward structure.

Smooth Production

As production departments become increasingly skilled at avoiding lead-time variability and become increasingly responsive to demand, the organization begins to be faced with some critical issues regarding production flexibility\(^2\). We use the word flexibility here to mean the ability to respond to customer needs by changing the rate of production. In our experience, the fundamental trade-off involves this form of flexibility and the concept of production predictability, as discussed in the previous section.

Ideally, we would like to see production employees become proficient at delivering orders according to plan, with little or no variability. In addition, we would like to have the manufacturing system closely linked to demand, so as to avoid backorders and excess inventory. Unfortunately, these two ideals tend to conflict with each other, at least in the early stages of supply chain improvement.

The problem arises as the result of the activities required for making production cells flexible. These activities typically involve cross-training workers (so they can switch from one
task to another as needed), installing new machinery and equipment (so set-up times can be reduced and change-overs performed less expensively), and the periodic hiring and laying-off of temporary workers (so that the manpower levels can be inexpensively adjusted to match demand).

These activities can be very effective at achieving their desired outcomes, but can also be disruptive to the production process. In our experience, the effort to improve predictability ought to take precedence over the effort to improve flexibility. Activities aimed at enhancing flexibility should flow from and be consistent with efforts to establish predictability.

For example, the goal of delivering all orders within two days of the production plan may lead a manager to request additional workers from other departments on certain occasions when his/her workload gets especially heavy. This presents an opportunity for cross-training that is consistent with production predictability, not in conflict with it. Similarly, investment in equipment ought to be driven by the need to improve lead-time predictability.

Finally, we suggest that organizations resist the temptation to employ large numbers of temporary workers to achieve flexibility. In a useful study of paper manufacturing, David M. Upton (1995) concluded that the most effective form of flexibility comes from having managers who emphasize the importance of being flexible, and from workers who practice being flexible. If these workers are "temps" who are hired for short periods, they will find it difficult to attain the level of practice necessary to support the organization's goals with respect to flexibility.

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2 The word flexibility is burdened with numerous meanings; here, we are concerned specifically with production rate flexibility.
Cycle stock is inventory held because goods are produced in batches; goods that are produced in relatively large batches will be associated with relatively high levels of cycle stock. As production departments become more flexible, they are increasingly able to produce in small quantities, thereby allowing for the reduction in cycle stock.

We caution against the aggressive targeting of cycle stock for reduction until safety stock has first been addressed. Put another way, we have found that reducing uncertainty in production is initially more important than reducing batch sizes. It will be useful to maintain some level of cycle stock while the organization learns the techniques of production control; attention can be shifted to reducing cycle stock when the organization is at a more mature phase of supply chain improvement.

This means using the "production smoothing" feature available with most production planning systems to "protect" the production cells from overly wild swings in production rates and too-frequent product changeovers. In the short term, this may require a higher level of cycle stock.

Because of the previous discussion, we suggest that metrics for assessing production flexibility not be introduced until the organization has achieved control over its existing processes with respect to predictability. When appropriate, the steering committee can implement targets for batch sizes, changeover times, cycle stock, and cross-training of workers.
Forecasting of Demand

Ever since the "discovery" of "lean production" (documented in the 1990 book *The Machine that Changed the World*, by Womack, Jones, and Roos³) many organizations have moved away from old-fashioned "push" systems, in which production is targeted toward some forecast of demand. The lean paradigm is based on the concept of a "pull" system, in which production is directly responsive to demand, and forecasts are largely unnecessary.

Although some organizations have achieved pure pull systems, we have found that most manufacturing operations rely on some form of production planning based on demand forecasting. Moreover, a move to implement a true pull system is frequently unrealistic until the organization acquires a level of manufacturing discipline as discussed above. For that reason, it is useful to discuss forecasting in the context of an overall supply chain improvement effort.

Typically the demand forecast is the result of some statistical time series method (e.g. moving averages, exponential smoothing, or linear trend lines with seasonal adjustments), and is built into the production planning system to some degree. The specific method and the level of integration vary across organizations, and are not critically important for this discussion.

The critical forecasting issue for supply chain management is the *accuracy* of demand forecasts, which is the aspect of forecasting that has a practical effect on production and distribution. Poor forecasts lead to poor utilization of production resources, which in turn cause build-ups of unwanted inventory and shortages of desired finished goods. This linkage crosses

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³ While JIT and kanban systems predate the 1990 book by Womack et al., general awareness of their applications sharply increased following that book's publication.
organizational boundaries, and it is important for those who bear responsibility for the forecasting process to understand the ramifications of inaccurate forecasts.

Forecast accuracy can be assessed with metrics such as mean absolute deviation (MAD) or total cumulative forecast errors. The forecast error can be the subject of a traditional control chart, so that random fluctuations in the forecast accuracy are monitored and action is taken when unacceptably large errors occur. These processes (the forecasting process itself and the process of evaluating the accuracy of the forecasts) should be integrated into the organization's information system.

To illustrate, Figures 12 through 16 show the effects of three scenarios based on the supply chain segment portrayed in Figure 2. These scenarios were created using computer simulations of a simple system of demand, production, and inventory with a single production facility, a single distribution center, and three SKUs, and have been very useful in teaching the fundamental concepts by which these three variables are linked.

In each of these scenarios, demand for each of the three SKUs is random, but on the average falls within the capacity limitations of the production facility. The scenarios differ from one another in how accurate the demand forecast is; it is assumed that the production facility will produce to meet the demand forecast while staying within its capacity constraint.

In Figures 12 and 13, we can observe the effects of poor forecasting on inventory and backorder levels. Both metrics deteriorate as the forecast accuracy gets worse. In Figures 14, 15, and 16, we can observe how increasing forecasting inaccuracy is associated with increasingly wild fluctuations in the production rates of the three SKUs. Using this simple example, we can
illustrate the importance of forecasting accuracy to the achievement of strategic supply chain performance targets (e.g. inventory levels, backorder levels) as well as intermediate-level targets (e.g. smooth production levels).

Figure 12. Inventory Levels and Forecast Accuracy

Figure 13. Backorder Levels and Forecast Accuracy

Figure 14. Production Level of SKU 1

Figure 15. Production Level of SKU 2
Improving the Total Supply Chain

Improving supply chain performance means improving (and controlling) the performance of all the elements of the system, from planning to distribution. Managerial improvement follows the fundamental structure of process improvement described decades ago by J. M. Juran. Juran’s process improvement roadmap is, in essence, the Cartesian scientific method of hypothesis and test cast in a management context. We will briefly outline here the steps of this structured improvement process as they related to one recent example.

Symptoms

In our case example, interviews with customers, company executives, and sales people in the field revealed that the key issues with respect to the supply chain were backorders and excess inventory. Backorders contributed to customer dissatisfaction while excess inventory contributed heavily to cost of poor quality.

Data were collected to validate these statements, leading to the discoveries that backorders occurred in about 20% of orders, and that excess inventory accounted for almost 50% of internal failure costs (i.e., costs of poor quality). On the other hand, errors in shipping and product defects were minimal.

This analysis allowed the steering committee to focus its resources on the most significant problems, namely frequent backorders and high inventory costs.
Theories of Cause

It is necessary to recognize more than just deficiencies within organizational functions. One must also recognize how such deficiencies feed back and distort other functions. The high level cause-effect diagram of Figure 17 attempts to capture some of these phenomena.

Figure 17. Cause-Effect Diagram.

The interesting thing about this diagram is that it does not focus exclusively on the portion of the supply chain normally associated with production or warehousing. Since the organization under study makes products available to end users through multiple distribution points, the diagram also captures their influence on performance. The fundamental hypothesis is that deficiencies in the production process (above the line) and defects in the management of inventory at distribution points (below the line) feed back into each other creating a vicious loop that, simultaneously, produces product backorders and surplus inventory.
Over/Under Production is a result of unreliable forecasts coupled with a manufacturing facility and culture unused to producing according to plan. (It is easy to see how these two factors alone could be self reinforcing, to the detriment of supply chain performance.)

Below the line, Lack of Control Over Field Inventory is a result of the organization’s lack of inventory visibility. In addition, a wide variability in skill levels was found among the various distributors with respect to inventory management. The effect of these deficiencies creates what Peter Senge calls the “Balancing Process with Delay” or the “Beer Game”. This organization had developed a cultural behavior pattern of over-ordering and hoarding goods in the field as a way of compensating for an unpredictable production process.

Root Causes

Supply chain dysfunction is rarely traceable to one root cause. Rather, one often finds a constellation of causes. Such was the case here. During the assessment, all the “bones” of the cause-effect diagram were verified with hard data.

To illustrate, the factory in question had a 60% to 70% failure rate in terms of its ability to deliver goods to final stock as planned. There were many reasons for this, some technical and some cultural. Meanwhile variability among distributors was so great, with respect to inventory management, that about one third of backorders were a result of hoarding. This pattern was a result of the distributors' long and painful experience with factory backorders. One root cause reinforced the other.

Another interesting group of root causes in this case dealt with the planning process. Detailed analysis of customer backorders at a point in time revealed that almost half of the items
on backorder were for products that had never been planned for production. In some cases these were for new products. These were anticipated by distributors, ordered by them, but never included in the production planning process.

**Remedies**

Remedies must flow from causes, otherwise there will be no improvements. As may be seen from the cause-effect diagram, there was no single “silver bullet” for correcting these supply chain deficiencies. Performance improvement requires addressing all of the critical “bones” in the cause-effect diagram. This meant, for the case under study here, undertaking projects to: improve forecasting, change manufacturing methods to foster producing according to plan, correct technical problems in the factory, and improve the management of field inventory.

This complicated situation illustrates a point made earlier, regarding the need for an overall theoretical structure for jointly managing systems with multiple measures of performance. This presents an opportunity for academic scholars to make a significant contribution to supply chain management practice.

**Holding the Gains**

Supply chains are complex, and in many ways fragile, systems. One-time improvements will not hold for very long unless the system is carefully managed and monitored. This requires new organizational responsibilities plus a panel of metrics that continuously evaluates performance, both internal and external.
Conclusions

A supply chain system is a complex and non-linear system, and there may well be multiple reasons for poor performance. Supply chains can be victims to feedback loops that reinforce negative actions and behaviors. One cannot expect to solve such problems by “buying” a solution off-the-shelf. Improving a supply chain requires understanding functional deficiencies and, also, how such deficiencies interact with each other to degrade overall performance. Eventually, all such deficiencies must be corrected and the vicious loops broken to achieve performance improvement.

Identifying and correcting these deficiencies requires putting the elements of the supply chain into the context of the organization’s strategic goals, mission and vision, using multiple levels of perspective from the “satellite view” to the “ground level”. In this context, organizations can productively employ the familiar tools of quality management (e.g. strategic planning, process planning, process control, and process improvement). They can also draw upon the considerable expertise of academic experts in the specific fields of forecasting, scheduling, inventory analysis, and queueing theory.

Going forward, we will also require the development and implementation of new guiding principles for solving specific supply chain assessment and improvement problems. Some of these principles are proposed here, such as focusing on reducing production uncertainty before attempting to develop production flexibility, and the efficiency/effectiveness assessment model. Other principles remain to be developed as the study of supply chains continues, which will create new opportunities for mutually-beneficial collaboration between management practitioners and scholars as these emerging principles are tested and refined.
References


