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Building Operational Excellence in a Multi-Node Supply Chain

by

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Submitted to the Sloan School of Management and the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration and
Master of Science in Mechanical Engineering

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Abstract

This thesis shows how a combination of macro-economic, business, and organizational factors can lead a well-run company to adopt a "launch-and-expedite" behavior with detrimental effects on operational efficiency. It also demonstrates how it is possible, for an organization that finds itself in such a state, to apply basic operations principles and a data driven approach to systematically get out of the "launch-and-expedite" mode.

The thesis presents a method to characterize a real, functioning supply chain in the context of changing conditions and in the absence of perfect data. It shows the analysis, recommendations, and results from a particular supply chain case study at Agilent Technologies, Inc. The project first analyzes and maps the current supply chain to characterize demand and supply variability. A selected menu of operational building blocks is then recommended to improve overall supply chain performance by reducing the internal bullwhip effect and improving on-time delivery. The recommendations are implemented in a successful pilot study and key operational metrics are recorded such as supply chain inventory, on-time delivery, variability of lead-time, and number of expedite/schedule change requests. The particular organizational context of the project and its affect is also considered.

Although this thesis provides a case study of the Colorado Springs Technical Center operations and supply chain, results and lessons learned are applicable to other component suppliers or component buyers within multi-node supply chains, particularly those in the capital equipment business.

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Chapter 1: Introduction

1.1 Project motivation

The cyclic nature of the high-tech industry is well known in business. In particular, the capital equipment manufacturers that supply the high-tech industry are subject to an even greater volatility than that driven by the end consumer. These equipment manufacturers, as a result of their upstream position in the supply chain are subject to an amplification of demand variability often referred to as the bullwhip effect (see Figure 1.1). The bullwhip effect has been widely studied in supply chains and discussed in the literature (Felch 1997; Coughlin 1998; Blake 1999; Anderson 2000; Spearman 2000; Sterman 2000; Blaha 2002; Simchi-Levi 2003).

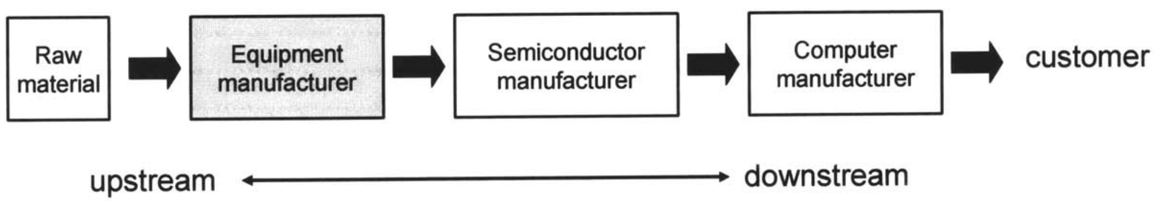

Figure 1.1: Supply chain for high-tech capital equipment manufacturer

However, it is important to make a distinction between the variability amplification experienced by the manufacturers of finished goods and that faced by capital equipment manufacturers. For equipment manufacturers, the increased demand volatility is experienced as demand driven changes in the desired manufacturing capacity (Anderson 2000). For example, a small percentage change in the demand for computers will produce a much larger percentage change in the demand for equipment to make the microprocessors that are inside the computers. In macroeconomics this effect is known as the investment accelerator (Samuelson 1939).

To fully comprehend the extent of the volatility faced by equipment manufacturers in the semiconductor and electronics business, consider Figure 1.2 (Fine 2005).

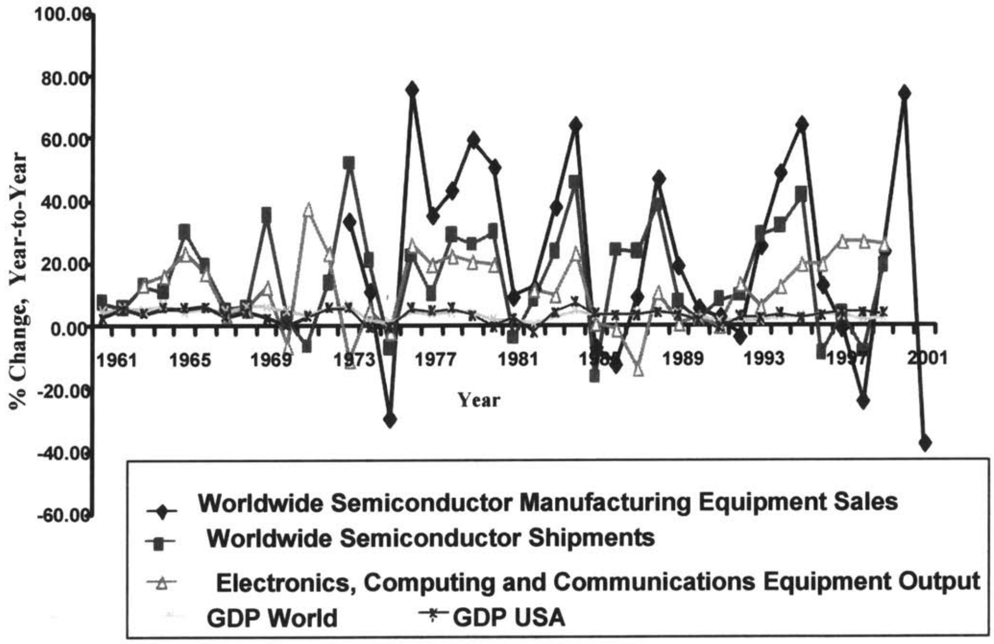

Figure 1.2: Variability in the semiconductor and electronics supply chain

This figure plots data from the US economy over the period of 1961 – 2001. Five time series are plotted: (1) year-to-year percent changes for semiconductor equipment sales; (2) semiconductor shipments; (3) electronics, computing, and communications equipment output; (4) gross domestic product (GDP) USA; and (5) GDP World. Note the extent to which the equipment sales overshoot both the bull and the bear markets throughout several decades of data. It is also important to note that in this industry, the pattern repeats every 4-7 years. Experienced leaders of such firms are familiar with the pattern, as expressed in the following quote (Barnholt 2003):

> *"This is my seventh business cycle in my 37 years with HP and Agilent, and one thing I know is business cycles do end. But markets are always different when cycles end than when they started. The challenge is to understand the structural changes that are going on in our industry to be ready for the new opportunities as they come along."*
>
> – Ned Barnholt, Agilent Technologies Chairman and CEO

The macroeconomic trends and bullwhip effect on high-tech capital equipment manufacturers highlighted in Figure 1.1 provide the external context and motivation for this thesis. However, this thesis focuses on the internal concerns relevant for the management of such firms including:

(1) What should the operations strategy be for a capital equipment manufacturer in a high-tech and highly cyclical industry?

(2) How can a typical company that desires to recover from a downturn restructure its operations to perform well not only in the next upturn but also to survive the next downturn?

(3) What data should be collected to characterize the current situation?

(4) What specific actions can be taken to begin a change towards a new, more robust operational structure?

This thesis will examine these fundamental operations questions in the context of the semiconductor and electronics equipment business based upon applied research conducted on-site at Agilent Technologies in the Colorado Springs Technical Center, but the results and findings can be generalized as applicable to other high-tech equipment manufacturers, who aim to strengthen their operational competitiveness.

1.2 Agilent

Agilent Technologies became an independent company from Hewlett-Packard in 1999, focusing on the test & measurement, automated test, semiconductor, and life sciences parts of the business. In the short time since independence the company has weathered many changes from a spectacular market upturn to an abysmal downturn and a subsequent on-going recovery.

Additionally, with growing competition and maturation of its product architecture, Agilent has been shifting from historically vertically integrated businesses to increasing use of external suppliers, contract manufacturers, and low-cost labor regions for final assembly of products. During this transition, much attention has been focused on Agilent final assembly and test site operations while less attention has been given to manufacturing organizations within the firm. This thesis considers the role of key internal component manufacturers and their new supply chain relationships within the firm.

1.3 Global Supply Chain Engineering (GSCE)

The Global Supply Chain Engineering (GSCE) group at Agilent sponsored this research in order to better understand the role of key internal component suppliers in the new Agilent supply chain.

The initial goal of this work was to model and analyze an Agilent supply chain that included an internal Agilent component supplier, as well as an Agilent final assembly site. This model would then be used to simulate and quantify the effects of different operational policies, such as safety stock levels or scheduling rules, on operational efficiency. The ultimate project goal was to improve operations within an Agilent supply chain by understanding the unique characteristics of internal component suppliers within the chain and designing an operations strategy to best capitalize on this understanding.

1.4 Chapter overview

This thesis is organized into seven chapters. Chapter 2 introduces the Colorado Springs Technical Center (CSTC) in terms of its structure, objectives and strategy within the larger context of Agilent's Electronic Products and Services (EPSG) division. Chapter 3 characterizes the current CSTC operations within the Agilent supply chain and a computerized ERP system. Chapter 4 recommends the application of specific operations principles based on a data-driven analysis in order to drive improvements in CSTC performance. Chapter 5 presents the challenges, learning, and data from a pilot implementation of the recommendations at the CSTC. Chapter 6 addresses the specific organizational context and its influence on further operational improvements at CSTC. Finally, Chapter 7 summarizes the conclusions of this research and the lessons learned. In addition, opportunities for further work as well as the applicability of the conclusions to other companies or industries are discussed.

Chapter 2: Colorado Springs Technical Center (CSTC)

2.1 Organizational structure and background information

HP purchased the site of the current CSTC operations in 1962 and micro-circuit work began on the site in 1969. The CSTC was formally created in 1975 to manufacture key components in support of Hewlett-Packard's growing test and measurement business. Historically, the CSTC was part of the Colorado Springs Group, which functioned as a stand-alone profit center within the larger company. Ownership of CSTC was officially transferred to Agilent when the company spun out of HP in 1999. Currently, the CSTC functions as a cost center within the Multi-Industry Business Unit (MIBU) of Agilent.

The CSTC manufactures low-level components which are used in Agilent products across all four divisions: (1) Test and Measurement; (2) Semiconductor Products; (3) Automated Test; and (4) Life Sciences and Chemical Analysis. Per a company policy aimed to preserve Agilent's competitive advantage, CSTC does not sell its components on the open market. The majority of CSTC components (93%) are used in products for the Electronic Products and Services Group (EPSG) part of the Test and Measurement Division. Within EPSG, the two major internal customers for CSTC are the Multi-Industry Business Unit (MIBU) and the Computing and Networking Solutions Business Unit (CNSBU). The shaded organizations in Figure 2.1 will be the focus of the work described in this thesis.

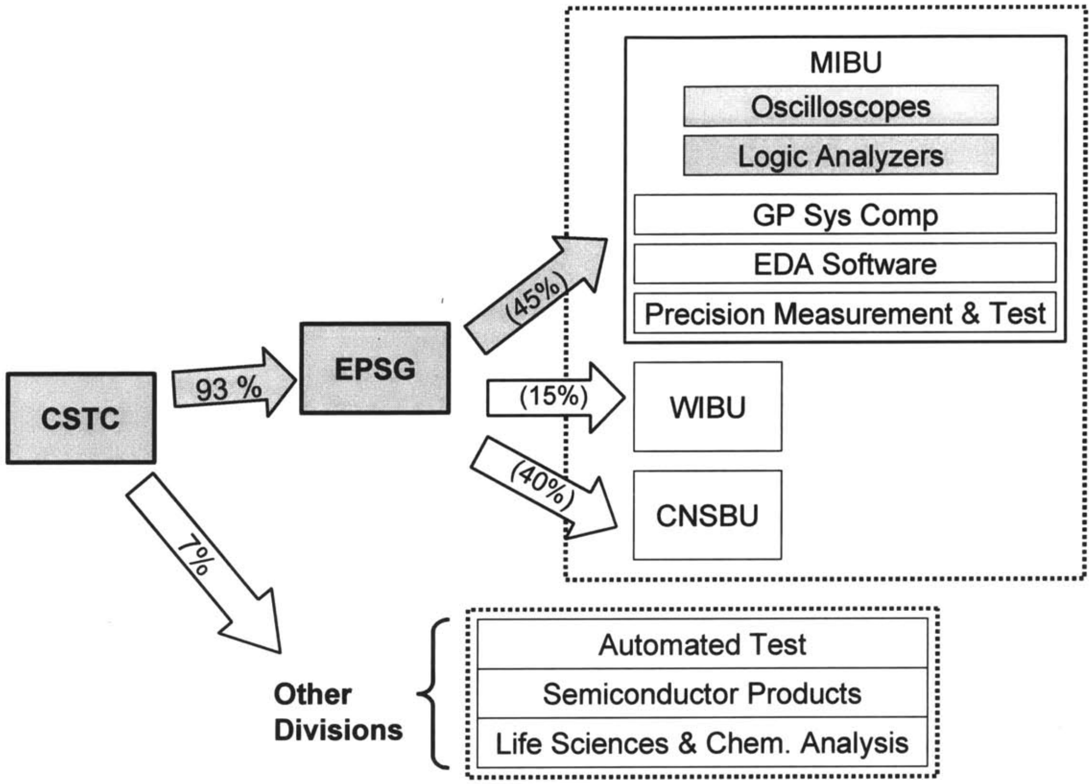

Figure 2.1: Distribution of CSTC products to product organizations at Agilent

Discussion of CSTC components in this case study will be limited to those made for MIBU products, which are a $2.1B market for Agilent annually. This represents the largest CSTC customer when the products are dollar-weighted. Although it won't be addressed specifically in this thesis, the diversity of customers and markets served by the CSTC does complicate its strategy and objectives. Oscilloscopes and logic analyzers are examples of MIBU products which are sold to other electronics firms for test and measurement applications, representing a $650M annual market size for Agilent. Typical examples of these products are shown in Figure 2.2.

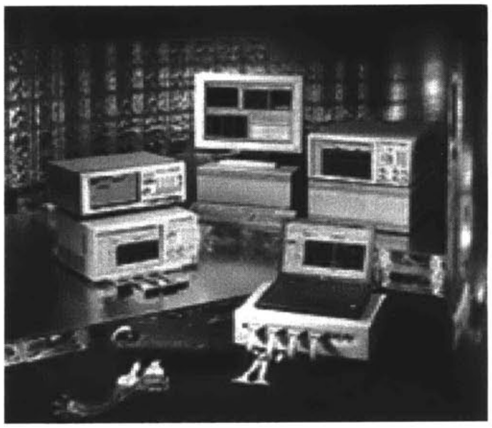 

Figure 2.2: Logic Analyzers (left) and Oscilloscope (right)

Some examples of components manufactured by CSTC include: hybrid integrated circuits and probe tips with integrated logic. However, the CSTC is most often recognized in terms of its process capabilities, not the specific products it manufacturers. These process capabilities include:

- Thick film, thin film (wet), and laser
- Chip and wire bond
- Final assembly (solder, encapsulation, lid bond, etc.)
- Test (included several custom Agilent automated test equipment systems)

The CSTC is at the forefront of developing new process technologies and using these technologies in production. As such, the manufacturing processes performed at the CSTC are complex and often rely on the skill and tacit knowledge of technicians, operators and engineers at the site.

CSTC is currently run as a cost center and led by the plant manager. The types of personnel included in the CSTC organization are process engineers, quality engineers, equipment operators, planners, buyers and various supervisors and project leads. In 2004 there were approximately 90 associates working in the CSTC. Due to the market slowdown, only one shift was run on most equipment and two shifts were only used if necessary to meet scheduled output requirements.

2.2 Organizational goals

"New products are the life-blood of our company... It's important to recognize that when we talk about innovation, we're not just talking about product innovation. We're talking about innovation in process [too]..." – Ned Barnholt, Agilent Chairman and CEO

The overarching goal of CSTC and Agilent is to increase market demand for Agilent products through innovation – including creating demand through obsolescing and cannibalizing demand for its own products. As a process center, the CSTC supports Agilent's corporate strategy and culture of innovation by leading the industry in process innovations. These process innovations enable the products designed by Agilent development engineers to reach the marketplace ahead of the competition. While cost pressure has increased in importance of late, developing process capabilities for low-volume, high-mix production remains the primary goal for CSTC in order to satisfy the unique needs of its internal customers.

Additionally, the unstated goal of any firm is self-preservation, and the goal of CSTC is no different. Following the market downturn that began in 2001, the CSTC was challenged to re-position itself competitively in relationship to potential external suppliers. Despite increased outsourcing of higher volume products, the CSTC continues to occupy a key strategic position in the Agilent supply chain by providing manufacturing for prototyping, process development, new product launches, spares, and other low-volume products.

2.3 Market based view

Agilent and CSTC have typically led the market in the introduction of new products and product features. For example, the Colorado Springs Group originally created the entire market segment for Logic Analyzers. Before introduction by Agilent, this product category did not even exist. Agilent products represent the highest quality products available in terms of features, options/customization, service and support. These high quality products are sold at a significant price premium in the marketplace. The high-end customer needs for the electronics test and measurement market can be distinguished from other customer segments. In the high end, there is little elasticity of demand. Customers require the highest performance products and are willing to pay what is necessary to acquire these products. Customers, in exchange for this price premium, also expect responsiveness on the part of the manufacturer as well as excellent service and support. Moving only slightly down-market in product performance can have a significant influence on the basis of competition. In the mid to lower-end segments, price is a significant consideration and many suppliers compete for this business. Typically, Agilent does not develop new products for the lower-end market segments, but instead sells its more mature products to meet the needs of these segments.

Although Agilent (HP) initially created many of the markets it serves, over time competition has developed and increased. As more of the electronic components necessary to build the equipment Agilent produces become commodities, competitors have been able to move up-market in quality while still offering low-priced products. This has led to increasing competition and pricing pressure in Agilent's traditional markets (see Figure 2.2).

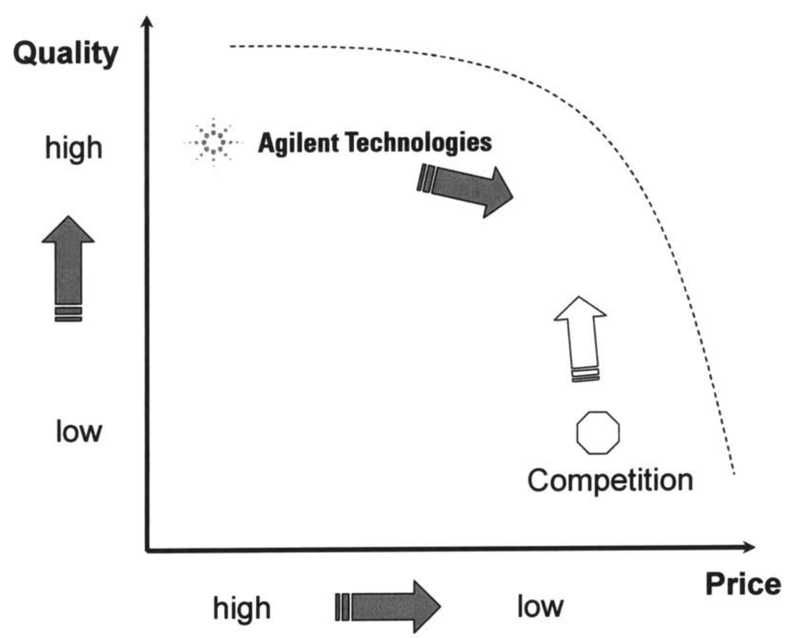

Figure 2.3: Competitive positioning of typical Agilent and CSTC products

Agilent's CEO Ned Barnholt highlighted this shift in the nature of competition during his speech at SEMICON West in 2003:

> *"We're in a period of lots of price pressures, continuing excess capacity, and pressure for time-to-market, bringing new technologies and products to market. These aren't going away, and the focus on operations improvement and cost reductions is much greater now than when we went into this downturn three years ago. ... We're in a market-share battle – all fighting for a limited piece of the pie as opposed to the capacity-expansion battle where we were all trying to keep up with the growth rate of the industry. That means there has to be a lot of improvement in operations, whether in the way we run fabs or in the way we run our equipment businesses for minimum costs and competitiveness. There's just a lot more cost pressure across the industry, all the way from the component to the equipment providers."*

2.4 Resource based view

The resources of Agilent, including the CSTC, are designed to support the primary goal of the firm as noted in section 2.2 above. As a result, the CSTC production objective is to lead the world in prototype, new product introduction and low-volume high-mix manufacturing. In addition, since engineering innovation is central to Agilent's competitive advantage, product and process innovation are tightly coupled. For the CSTC this link between product and process innovation is a key resource in development and delivery of oscilloscopes and logic analyzers because the engineers are co-located.

Overall, however, the goal of the company is to remove manufacturing from the critical path of delivering innovative products to high-end customers. Recently with the market softness, there has also been an emphasis on limiting manufacturing costs; however, this is not historically a primary business concern for Agilent. In general, Agilent cultivates world-class engineering innovation, while manufacturing operations are a lower priority.

Because of the significant first-mover advantage for an innovation-based strategy, the capacity strategy for the organization has been to lead demand. That is, the CSTC aims to have more manufacturing capacity than the market requires, so capacity does not become a "bottleneck" for the company (Goldratt 1984). With such a strategic design, marketing and sales are usually the bottleneck, not the factory. During the boom of 1999, however, total industry capacity, as well as capacity at Agilent, lagged market demand and this re-positioned manufacturing as a bottleneck. Thus the boom of 1999 shows that it is possible in a highly cyclic industry despite a capacity strategy to lead demand, to end up lagging demand at the peaks of business cycles.

Policies of Agilent corporate and the macro-economic environment influence CSTC resources in several ways and thus must be considered in any future operations strategy development. The company is continuing to lower its cost structure by converting previously fixed costs to variable costs. Following this emphasis, managers are encouraged to outsource as much as possible. While management at CSTC supported this corporate initiative, they found that some products could not be made outside and after several tries were forced to bring the products back in-house for manufacturing.

Although previously the CSTC had been part of the Colorado Springs Group profit center, the CSTC is currently organized as a cost-center. Measures of success for CSTC management include: on-time delivery, warranty rates, injury/illness rates, variance in controllable spending, variance in cost of sales, variance in price of purchased goods, and variance in inventory dollars. Because of the cost-center mentality, one can see that most of the management metrics are focused on variances with the plan or budget for the quarter. The only management metrics that are absolute are on-time delivery, warranty, and injury/illness rates. This is an important consideration for a new operations strategy that will be revisited in the implementation section (Chapter 5).

2.5 Chapter summary

This chapter presented the current strategy of Agilent and the Colorado Springs Technical Center in terms of the value proposition, the capabilities, the processing network and resources of the firm. As indicated by the CEO, Ned Barnholt, in his speeches, the nature of competition for Agilent and CSTC is changing, so the company must respond by re-considering its strategy.

This chapter highlights the importance of articulating an operations strategy even in a high-margin, low volume business like electronics test and measurement. An operations strategy provides cohesion between the high-level business strategy of the CEO and the daily decisions that must be made by line managers. In addition, it helps unify decision-making amidst pricing pressure, as a sector matures or under cost rationalization pressure during a market downturn.

Often a clear operations strategy that integrates with the financial and overall strategy of the firm has not been articulated. This was the case at CSTC at the beginning of the applied research project. The management's operations strategy was primarily reactive as is often the case in a rapid market downturn. One of the goals of this work was to encourage CSTC management to articulate a proactive operations strategy based on the market realities and resources of the division in order to clearly define the means to achieve the firms' performance objectives.

Chapter 3: Direct observation of the current reality

This chapter introduces the CSTC role in the supply chain and provides both a qualitative and quantitative description of the current state of operations in this supply chain from the perspective of the component supplier. Although industry cycles in the electronics test and measurement business are outside of the control of Agilent management, internal sources of variability can be minimized. This chapter presents sources of internal variability in the CSTC supply chain by examining internal data from forecasting, planning, and customer order flow. In addition, it considers other operational practices regarding capacity, job scheduling, inventory management, and metrics which also contribute to the internal bullwhip effect as it applies to the CSTC – at the tail end of the internal Agilent supply chain.

Whereas Figure 1.1 from the introduction illustrates Agilent's position in an external supply chain relative to electronics consumers, Figure 3.1 illustrates the position of CSTC within the internal Agilent supply chain, relative to direct customers of Agilent – typically other electronics and semiconductor businesses.

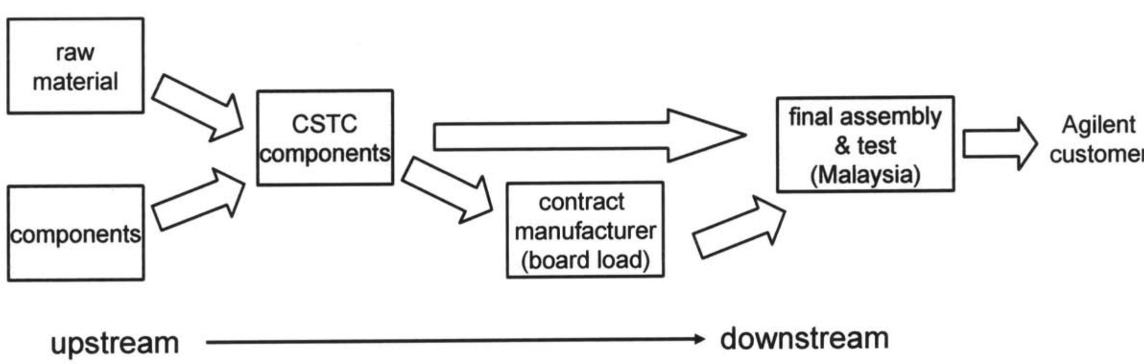

Figure 3.1: CSTC supply chain material flow

The CSTC and the final assembly and test site in Malaysia (officially known as PIMO – Penang Integrated Manufacturing Operations) are facilities owned by Agilent, but lower-level components can be sourced from either internal or external suppliers depending on the part. In today's supply chain design printed circuit boards (PCBs) are almost always loaded for Agilent by a third party contract manufacturer (CM). The data presented in this section will focus on the shaded supply chain nodes which are wholly owned and controlled by Agilent. In the future, the same type of analysis and supply chain mapping could be extended to include the other nodes of the Agilent supply chain.

3.1 Forecasting and planning

"In our business, we look at technology waves. In the communications industry, storage industry and computer industry, new standards come along at a fairly rapid pace. If you don't catch that wave, you've missed the market. These waves generally are not very long, so you have to be there right at the front edge to be able to capitalize on them."(Barnholt 2003)

Demand planning and forecasting of product sales is a sophisticated and complex process at Agilent Technologies. The company strategy of innovation dictates that Agilent is constantly pushing the "clockspeed" of the industry faster (Fine 1998). This makes it very important to effectively manage the ramp-up and ramp-down of products as typical life-cycles for high-end oscilloscope products have shrunk from 15 years to less than 3 years, with under one year of sales at peak margins before a higher performance product will begin to cannibalize the market.

Product family forecasts are developed and updated monthly by demand planners who work for a marketing group in a specific division. Detailed internal statistics are kept by the marketing organization on the historical accuracy of the forecasts, forecast bias, confidence intervals, etc. A product within a family may originally be forecast as a percentage of the total family demand. As the product family begins to sell and more information is available about customer preferences, this planning percentage is often adjusted to reflect actual customer demand. Although significant adjustments are common for individual products, or product options, forecasts for aggregate product families are quite accurate.

Figure 3.2 shows graphically the way in which forecast information is propagated throughout the organization to lower level component suppliers, such as the CSTC, through the ERP system.

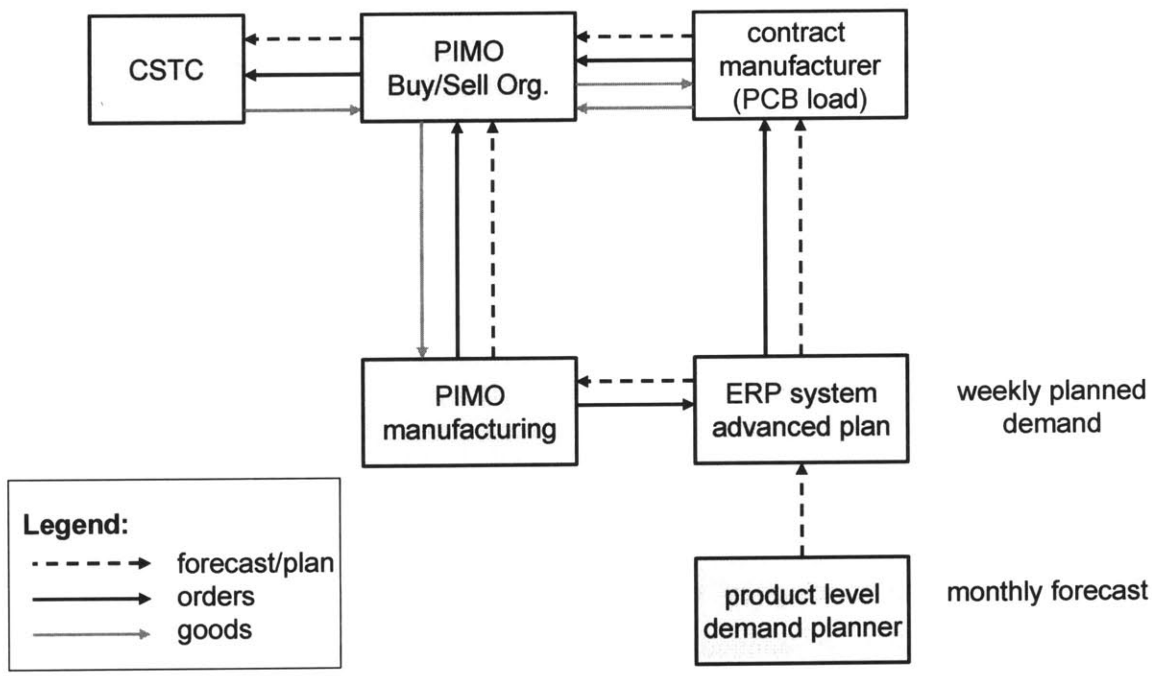

Figure 3.2: Flow of information and parts through the supply chain

A typical monthly forecast predicts 18 months into the future and is first entered into the computerized ERP system and then translated from calendar months to ERP system weeks. If necessary, forecasts can be updated by the demand planner, but only for time periods two months out in the future or greater. Although the conversion of the forecast from calendar months to ERP system weeks introduces some additional variability into the system, it can be shown mathematically that the additional variability is not significant (see Appendix A). However, this additional variability can cause some confusion to planners who review the weekly planned orders and see the production rates changing, when in fact they are not changing.

Once the forecast is in the computer system as "planned demand", the forecast is "exploded" down to lower level components of the forecasted product based on the product bill of materials, options, and planning percentages. For components that the CSTC sells directly to PIMO via the buy/sell organization, the planned demand seen in the ERP system by CSTC contains both demand that might be manually entered by PIMO (special orders, big sales, yield loss issues at PIMO) and demand that is derived from the original product forecast. Because the plan is "run" weekly, the propagation of changes to lower level components happens weekly between internal organizations. The weekly planned demand is changed often as production schedules for final assembly and actual customer demand patterns change.

One surprising observation is that it was not possible for a planner at the CSTC to use the centralized ERP system to view the original upper-level forecast data entered by the division demand planner for his or her assigned products. Permission settings in the ERP system restricted planners in one Agilent organization from accessing information in another Agilent organization, because the ERP system treated each organization code as a separate entity. This was a change from previous IT systems used by CSTC which had developed organically at the division level and allowed information sharing within a division, but not necessarily across divisions.

Planners in the CSTC employed several coping strategies to improve information transparency. First they had almost daily phone calls with the buyers in Malaysia to confirm orders and to understand the relative importance of orders in the ERP system. Additionally, when demand seemed very strange, planners at CSTC would sometimes speak directly with the product level demand planner. Although this practice was acceptable in the past within the Colorado Springs Group, management in Malaysia very much discouraged this information sharing.

Another less surprising observation is that despite the sophistication of the original forecast information produced, the only information that gets propagated through the

ERP system to lower level suppliers is a point forecast – not the forecast with bands of confidence or certainty. For example, a forecast that was highly accurate and one that was known to be much less accurate by the demand planning organization would both be translated by the ERP system to a supplier as a single point forecast. Therefore, much of the important information contained in a forecast could be lost as it was "exploded" through the bill of materials. (Note: Agilent is actively pursuing methods to include this information such as structured contracting. However, this relatively new approach is not pervasive within the company and not used currently with internal suppliers (Schmidt 2003).)

In the case of an external supplier, such as a PCB loader, the supplier can access a website that provides the weekly planned demand for the supplier's parts. This information is updated weekly. The PCB loader takes this weekly planned demand information and generates its own forecast. If the PCB uses parts which are supplied by an Agilent internal organization such as CSTC, the new forecast of the PCB loader is then entered manually on a website for the Agilent buy/sell team. The buy/sell team then translates the information back into the ERP system for the CSTC.

This additional translation requirement adds a minimum two-week delay to the demand planning process for externally processed parts when compared with the internal process. For example, for an externally loaded PCB in week one, the demand is shared with the contract manufacturer (CM). In the second week, assuming no data accuracy issues, the new demand is shared from the CM to the Agilent Buy/Sell team. In the third week the information is updated in the plan seen by the CSTC. In addition, Agilent employees often referred to the forecast being "broken" when it was sent to outside contract manufacturers. This is because once a part had gone outside the ERP system and required manual entry of lower level demand information, it was not possible to trace the demand signal back to the original forecast for a part (although theoretically it should be).

Within the division that makes oscilloscopes and logic analyzers, the demand planner who generates the monthly forecasts is measured on three qualities: bias, forecast error and stability. This information is also used to improve the monthly product forecasts in the future. An interesting observation is that beyond the monthly forecast, there is no formal measure of weekly demand plan accuracy. In addition, the weekly demand plan, which is updated weekly, is not archived, so it is not possible to determine its bias, error, or stability in comparison with actual orders. Currently there are no metrics focused on the weekly demand plan, so information about it is not monitored.

Several meaningful conclusions can be made from this high-level treatment of Agilent's demand planning and forecasting process.

1. The traditional role of demand planning in Agilent is to serve the sales and marketing organization, not production and operations.
2. Lower-level internal component suppliers, such as CSTC, do not have access to end customer demand data, despite an integrated ERP system.
3. Lower-level internal component suppliers, such as CSTC, receive different demand information than final assembly and test sites because of delays in propagation of the forecast (~ 2 weeks) and various built-in order modifiers in the ERP system.
4. The conversion of monthly forecasts to ERP weeks does not significantly affect forecast variability (see Appendix A).

3.2 Customer order flow

Given the uncertainly in much of the supply chain data as well as the lack of archived information on forecasts and demand in particular, one method which proved valuable in characterizing the supply chain was to map the flow of customer orders. The following example illustrates this useful methodology.

3.2.1 Determine true customer demand at final assembly factory

First, a component manufactured by CSTC is chosen. Using bill-of-materials data all the upper level assemblies which use the component are identified as well as the quantities of each component per upper level assembly.

Next, historical order data is collected for each of the final customer-purchasable products identified. There are many dates associated with a customer order in the ERP system, such as order-ordered date, order booked date, customer request date, order ship date, etc. This example uses the customer request date, which represents the date the customer would like to have the product, minus the average shipment time in days from the final assembly plant to the customer location. The product order history data is then aggregated based on the BOM structure quantities previously identified. This transformed and aggregated data represents what we will call the true demand for a given CSTC component at the final assembly site.

While the customer order data was recorded daily, internal orders between organizations were only placed weekly so it is logical to aggregate customer order data into weekly buckets. Monthly buckets were also considered. However, with high-end products having a maximum life cycle of three years, a product in production was likely to have less than 15 monthly data points available so weekly data aggregation was selected as the preferred method. Figure 3.3 shows aggregated customer demand for Component A.

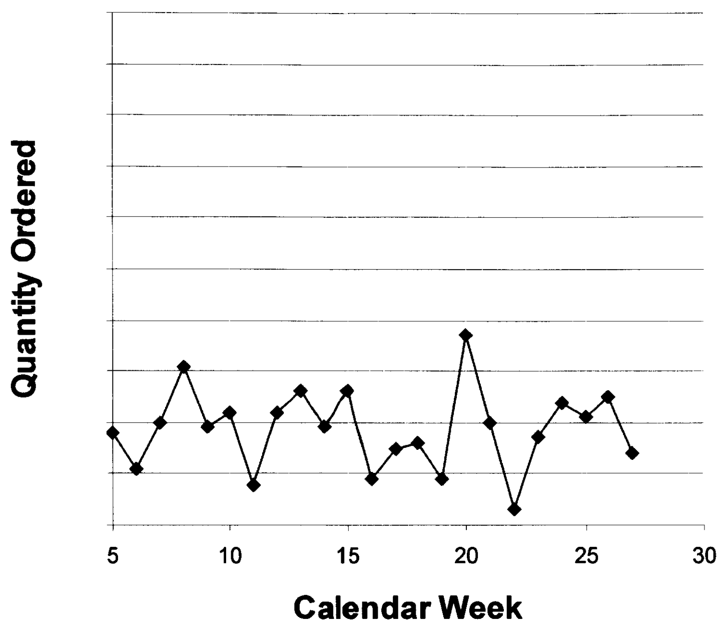

Figure 3.3: Component A weekly customer demand data[1]

For example, if this demand was approximately normally distributed with a mean, $\mu_D \approx 40$ and a standard deviation, $\sigma_D \approx 20$, customer orders as seen from the perspective of final assembly would have a coefficient of variation (COV) as follows:

$$COV_{finalassembly} = \frac{\sigma_D}{\mu_D} = 0.5$$

3.2.2 Determine order history between final assembly and component manufacture

Shipment requests (i.e. orders) are placed weekly between the buyer at the final assembly site (PIMO) and the planner at the component manufacturing site (CSTC) via the computerized ERP system. This is a semi-automated process in which the computer will recommend the order, but the buyer and planner must both electronically approve the

[1] Throughout this thesis y-axis numerical values are blank in order to protect the confidentiality of the sponsoring organization. In some cases specific numerical results are provided for the purposes of example and should not be construed to be actual results of the sponsoring organization.

order before it will ship. The size of the order is determined by the demand forecast for the next week at the final assembly site, any yield loss in final assembly, and any order modifiers which restrict the minimum, maximum or multiple size of the order. For example, if electronic chips supplied by the component manufacturer are delivered on a reel with 100 units per reel, this would be the multiple required by the order modifier. Figure 3.4 shows an example of the order history for a product between the final assembly site and CSTC.

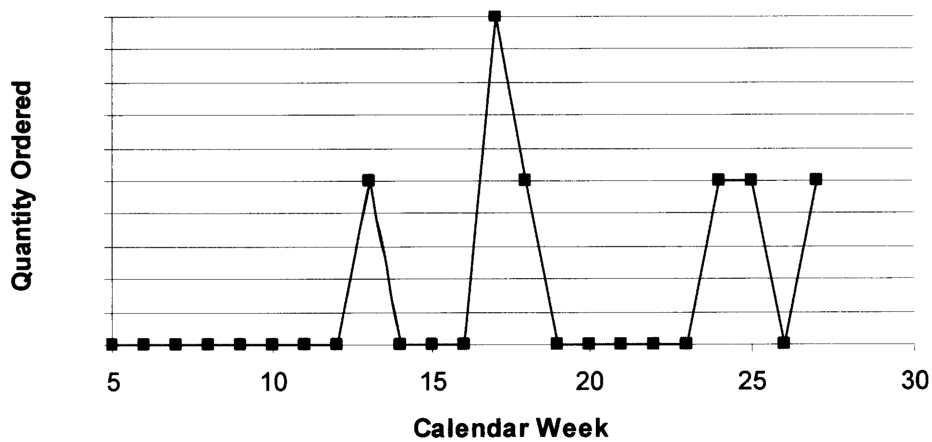

Figure 3.4: Component A weekly order history between final assembly and CSTC

Note that because of order modifiers in the system for this component, the final assembly site is ordering in groups of units. For example, if we let each order be for 50 units and consider an order an event, this data can be approximated by a Poisson distribution with mean $\lambda = 0.52$ and variance $\lambda = 0.52$. The coefficient of variation (COV) for the order history in Figure 3.4 can then be calculated (See Appendix B for additional calculation details).

$$COV_{component} = \frac{\sigma_D}{\mu_D} = \frac{\sqrt{\lambda}}{\lambda} = 1.4$$

3.2.3 The internal bullwhip effect

With a mathematical representation of the true customer demand and the internal order history between final assembly and the component manufacturer the variability can be compared between the two nodes of the supply chain using the coefficient of variation.

$$Variability\ Amplification = \frac{COV_{component}}{COV_{finalassembly}} = \frac{1.4}{0.5} = 2.8$$

This means that given a certain variability of customer demand, the structure and system of propagating orders from final assembly to component manufacturing is amplifying that variability by 2.8 times. This phenomenon of increasing variability as we move upstream in the supply chain is known as the bullwhip effect and the comparison of COVs between nodes of a supply chain is one way to quantify the bullwhip effect (Simchi-Levi 2003).

3.3 Capacity management

Manufacturing capacity at a firm can be considered in terms of human resources, machine resources, and contracted/purchased resources. Each type of capacity possesses unique aspects to be considered in operations planning and strategy.

For physical resources, the CSTC facility had excess machine capacity. It was originally designed for three shifts of almost 24 hours a day operation, but was currently only running one or at most two eight-hour shifts per day. The equipment supported both low and medium volume production processes for Agilent. Prior to the downturn in 2001, the CSTC produced some high volume thick-film products, so it also had some automated equipment alongside the semi-automated and manual process equipment typically used for lower volume products and prototype production.

Although in 2004 there were sufficient machine resources in aggregate, it was possible at times that due to the high mix of product a particular machine in test could be overutilized. Manufacturing at CSTC is divided into three areas: (1) thick film; (2) wire bond, die-attach and laser; and (3) assembly and test. While the equipment in the thick-film, wire bond, die attach, and laser areas was primarily flexible and could be used to manufacture a variety of products, the equipment in test was specialized. For example, Component A could only be tested on Test Equipment A. Therefore, if demand was high in a particular week for multiple components that all required final test on Test Equipment A, this could lead to Final Test being a constraint on throughput for CSTC.

The second determinant of CSTC capacity is human resources. The typical response by management, if test was becoming a bottleneck due to uneven distribution of work between test equipment, was to shift some test operators to second shift. In addition, most operators were cross-trained in order to increase human resource flexibility, thus improving the responsiveness of CSTC to mix variability.

Reducing variability or "smoothing" demand on human capacity was a significant concern of management in the CSTC. During the downturn, the total number of operators had been reduced from a peak of 110 to 14. This weighed heavily on management's mind as demand for CSTC products picked up. Management preferred to contract temporary workers to support peak demand periods rather than to hire Agilent employees. This was also due to the corporate emphasis on reducing fixed costs. Total operator hours were closely tracked by manufacturing planning. During this six-month project, operators were typically over 100% utilization according to the plan; however, management was still cautious about bringing on more operators. Only when the plan going forward showed a period of greater than 100% operator utilization for longer than two quarters did management work to bring on additional operators.

The theoretical implication of this approach to human capacity is that as utilization approaches 100%, queueing times for work orders in the CSTC shop will approach infinity. However, since this is not an acceptable outcome, other actions will be taken by management before the actual queueing time reaches infinity. These measures will likely include overtime, productivity enhancement efforts, and expediting of late jobs.

Another proxy for human resource capacity at CSTC is process engineers or technicians. Although this type of information was not tracked by the ERP system, skilled technicians or process engineers were regularly needed to assist with set-ups for manufacturing. These setup times represented about four to five times the per unit processing time for components made at CSTC. Sometimes operators would have to switch to work on another work order, while they waited for a skilled technician or engineering to assist with a setup.

The CSTC was increasing its use of outside vendors as part of the Agilent strategy to reduce fixed costs. In general, this strategy was effective in reducing fixed costs for the company; however, as CSTC was a low volume customer for these vendors, the CSTC could not exert much buyer power over the vendors. Often this led to delays in material availability for key CSTC components, which delayed the start of work orders according to the plan. As a result, CSTC management was considering the possibility of reserving some capacity at key vendors in the future.

3.4 Job scheduling and WIP management

"WIP is what it is. WIP is not something we can control. We have to report on it, but I really don't focus on it because it is not determined by us." – Planning manager at CSTC

Work orders at the CSTC are scheduled for release into the shop by the centralized ERP plan. They are released based on the lead time for the component, as long as the planner for the item has verified that the material is available to complete the job. Capacity of the shop is not considered when releasing jobs according to the plan.

An important relationship between WIP, throughput and cycle time is expressed by Little's Law (Spearman 2000):

$$(\textit{Inventory in WIP}) = (\textit{throughput}) * (\textit{flow time})$$

$$I = R*T$$

Consider the status of WIP at the CSTC. At current production levels there were on average 300 work orders in WIP in the CSTC shop at any given time. These 300 work orders were made of 124 different part numbers on average. Each work order would take an average 80 hours of processing time to complete (not including queueing time). Therefore we have I = 24,000 hours of work. On average there were 12 operators working on first shift and 4 on second. The rate of work completion is then R = 128 hours per day. From Little's Law we get an average 187 days completion time!

While the above estimate is extremely rough, it can certainly be concluded that there were significantly more jobs in the shop than could be expected to be worked on in a given day or week. This rough estimate was confirmed by conversations with operators who estimated on average each operator would work on 1-2 jobs per shift, i.e. about 32 jobs would be worked on in a given day or about 10% of the 300 jobs in the shop.

With so many jobs to choose from, scheduling and prioritization of jobs was very important and challenging. Every morning, CSTC lead operators, planners, and managers would meet to determine priorities for the day based on shipment requests in the ERP system and phone conversations with customers. Because of the limited human capacity of the shop, this method of job scheduling resulted in the use of CSTC WIP as a (un-intentional) buffer or shock absorber. This shock-absorber is a coping mechanism that was developed by the CSTC management in order to meet the variability in demand they saw from internal customers. In the current situation, the supply chain shock absorber requires the CSTC to accelerate and decelerate work in process in an attempt to meet material transfer requests via a highly manual process. Figure 3.5 illustrates this principle.

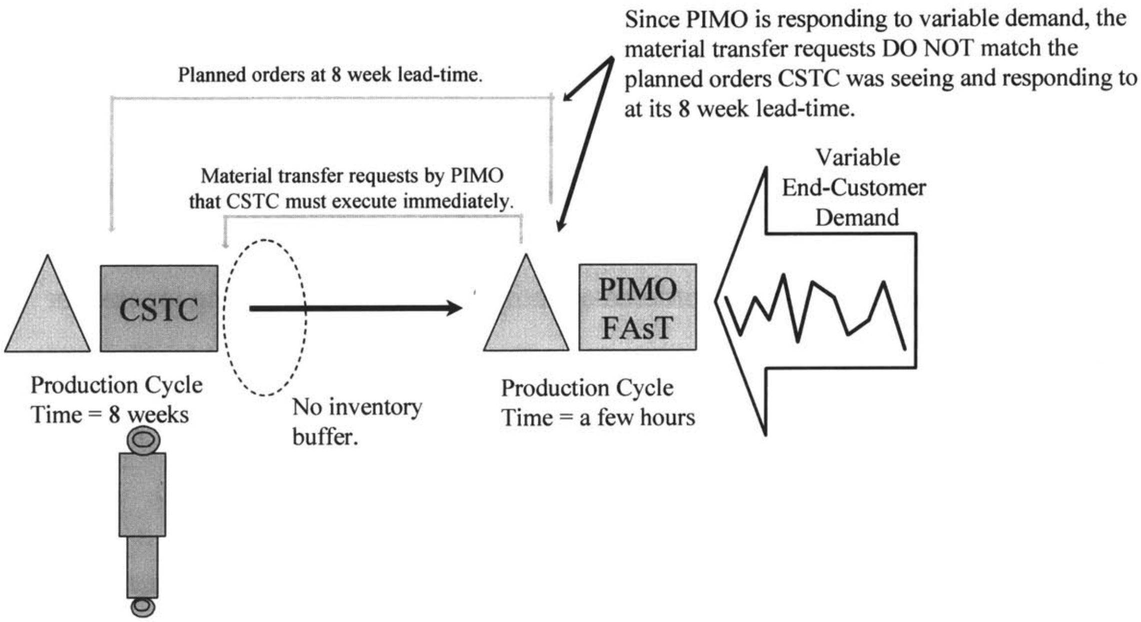

Figure 3.5: WIP used as a shock-absorber for demand variability

3.5 Inventory and safety stock management

CSTC had an official "no inventory" policy which was originally implemented during the downturn of 2001 in order to flush cash out of the supply chain. Another way to describe this policy is that CSTC would only complete a work order from WIP if it had a shipment request from a final assembly site for that component.

Because a typical component manufactured by the CSTC took between 2 and 8 weeks to manufacture, the "no inventory" policy significantly hampered the ability of CSTC to deliver product on-time to the final assembly site in Malaysia. Consider the best case scenario in which the forecasted demand is normally distributed with the same mean (μ) and standard deviation (σ) as the actual demand – i.e. the forecast is perfect. Even in this perfect world, CSTC would meet or exceed actual demand only 50% of the time. Put another way, although CSTC management had metrics that assessed on-time delivery to CSTC customers with a target of 90% or better on-time delivery, the current system structure had set up the facility for failure to meet this metric.

As a side note, actual on-time delivery performance ranged from 55% - 65%. In addition to the accumulation of partially completed product in the form of WIP (see section 3.4), one coping strategy developed by CSTC in order to improve on-time delivery performance was to use the effect of manufacturing lot-sizes as an advantage. In reality, CSTC did not have zero inventory; instead the facility accumulated limited inventory as a result of the difference between the ordered quantity and the manufacturing lot size for the component.

3.6 Internal on-time delivery

On-time delivery between the CSTC and its internal customers was an important metric for the organization. A minimum acceptable on-time delivery (OTD) target had been set at 90%. In order to report performance against this goal, the planning manager considered the information he could obtain from the new centralized ERP system and decided to use shipments. Because of international import/export regulations for high-end electronics and accounting rules, each shipment leaving the CSTC contained only one type of component. As the parts were small and lightweight, all shipments were made by air and the overwhelming majority of shipments arrived at their destination on schedule based on the ship date. Using this information, the organization currently compared the required ship date for on-time delivery to the actual ship date and compiled all shipments for the month to determine an aggregate on-time delivery percentage for the organization.

While this method for reporting OTD was convenient, because the information about shipments could be exported directly from the ERP system to a spreadsheet, the data is not particularly useful for decision making or control. It seemed instead to be collected for the purpose of reporting on the metric of OTD. Consider the following example which shows why the shipments measure does not provide consistent and useful data for decision making.

The final assembly site places two shipment requests for Component A from the CSTC. One shipment should be completed today (Week 0) and one should be made on Week 8. Each shipment request is for a quantity of 50 units of Component A. Let us suppose the CSTC only has 10 units available in Week 0 and ships these. Then each subsequent week, the CSTC continues to ship 10 units as the component manufacture is completed until the first order for 50 is satisfied. In Week 8 the CSTC has 50 units available and ships them as requested. Table 3.1 summarizes this simple example.

			Metrics		
Week	Requested shipment	Actual shipment	On-time shipment? (current)	On-time % (fill-rate/Type II)	Weekly stock out? (Type I)
0	50	10	Yes	10	Yes
1		10	No		
2		10	No		
3		10	No		
4		10	No		
5					
6					
7					
8	50	50	Yes	50	No
Reported on-time delivery:			*33%*	*60%*	*50%*

Table 3.1: On-time delivery metrics example

Note that under the current reporting method, 33% OTD would be reported while under a more traditional service metric called fill-rate, the percentage of units shipping on-time would be reported. Using fill-rate in this case we would report 60 units on time out of 100 units ordered for an on-time delivery or fill-rate of 60%. Fill-rate is commonly referred to in the literature as Type II service (Nahmias 1997; Spearman 2000). Another commonly used measure of service level in the literature is called Type I service. It measures weekly if a stock-out has occurred. This metric is captured by the third column in Table 3.1. While a metric based on a Type II service level definition will always be higher than Type I, it more typically represents the type of information management in an organization desires.

Note that the current metric discourages a practice that may be in the best interest of the organization – that is shipping partially complete orders. In the example above, if the CSTC had simply waited until all 50 units for the first order were complete and shipped them as one shipment, the OTD would actually increase to 50%, according to the currently used metric, although the result may be less desirable for the customer.

A second concern applies to all the commonly used metrics for on-time delivery performance – they equally penalize an order that is one week late and an order that is 8 weeks late. Certainly the effect of this difference on the customer is significant and should be considered in any newly proposed system.

No matter the definition of the metric, however, OTD for the same Component A as described in Figure 3.3 and 3.4, averaged 50 – 65% during the past 9 months which was significantly below the minimum management target of 90% and all parties conceded that improvement was necessary in the realm of OTD to CSTC customers.

3.7 Chapter summary

The primary take-away from this chapter is that the current reality of operations at the CSTC can be characterized as "launch-and-expedite". In other words, work orders are launched into the process based on the plan. These planned orders continue through manufacturing until a shipment is requested by the corresponding internal customer. Then the responsibility of a planner or manager at the CSTC is shifted to expedite mode. The work order is prioritized in a morning team scheduling meeting and expedited to the customer in order to achieve an on-time shipment for the organization.

It is important to note that this system of "launch-and-expedite" was not part of an operations strategy articulated by the firm, but instead a coping mechanism developed by the planners and production managers for dealing with the "no inventory" edict and the extreme demand variability they experienced at their node in the supply chain. Chapter 4 will explore other strategies for mitigating the demand variability seen at the CSTC supply chain node. The trade-off is that the strategies recommended in Chapter 4 will require coordination and communication across organizations, while the coping strategy of using WIP as a shock-absorber focused on what was immediately controllable by the planning manager at CSTC.

The quantitative data presented in this chapter on order flow or on-time delivery represents the simplest case – a component that passed directly from CSTC to PIMO without an intermediary step at an outside contract manufacturer. Certainly a process that requires this additional step would experience even greater variability amplification and internal bullwhip effect from the actual customer orders to the demand experienced by the CSTC. Approximately 50% of component types manufactured by the CSTC went on to a contract manufacturer prior to final assembly while the other half went directly to final assembly.

In addition, it should be understood from this chapter how current metrics for specific organizations (marketing & sales, product line inventory manager, planner, etc.) drove a focus on specific outcomes. It did not seem that any person or organization was responsible for the operations system as a whole. This is often the case in a corporation, where in the nature of efficiency job tasks are split and work is specialized. While it makes sense that the majority of a corporation should be engaged in work tasks in this manner, it is equally important that some portion of an organization consider the big picture and system as a whole. Otherwise, as in the case of CSTC, many small independent operations decisions can combine to create a significant operations performance shortfall.

While a well articulated operations strategy can help guide dispersed decision making, there are also tactical steps and processes which can be put in place to help support system level operational excellence. Chapter 4 will examine a variety of such tactical steps that could be implemented by an organization like the CSTC in conjunction with its customers and suppliers. Chapter 5 will reflect on a limited scale, actual implementation of the recommendations from Chapter 4. Chapter 6 on the other hand will address more strategic operations concerns and the organizational fit of these at Agilent and the CSTC.

Chapter 4: Hypothesis for change towards the ideal state

Hypothesis: Implementing safety stock as a buffer to decouple the demand variability of end-customer orders from the planned work orders for components would significantly improve operational performance and, in particular, on-time delivery of components within the Agilent supply chain without incurring additional costs.

Figure 4.1 below illustrates the decoupling effect of the buffer safety stock between the two supply chain nodes.

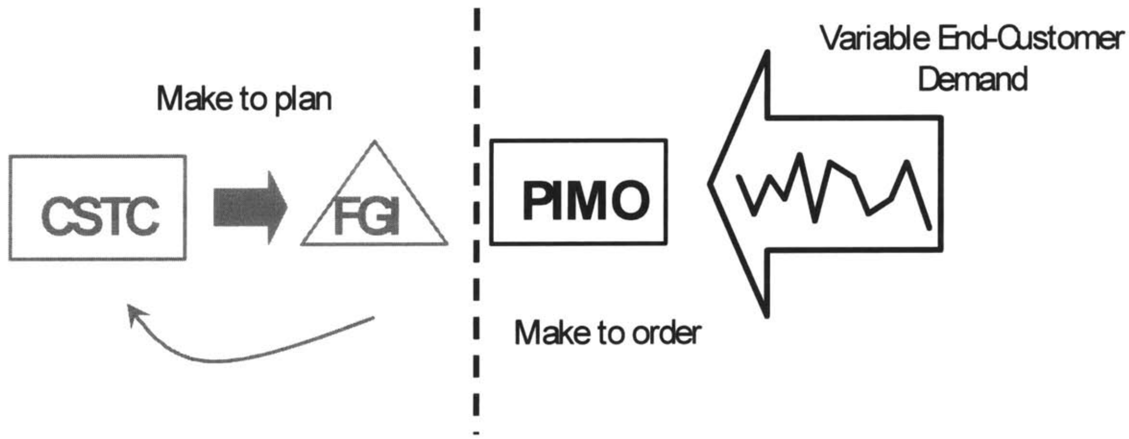

Figure 4.1: Decoupling statistical safety stock buffer (FGI)

In order to test the hypothesis above, a mathematical model was used to quantify the effects of the proposed change (adding statistically-sized safety stock) on inventory levels throughout the supply chain in conjunction with on-time delivery performance, as well as plan stability. Statistically determining optimal safety stock levels for the decoupling buffer required multiple inputs including those shown in the figure below.

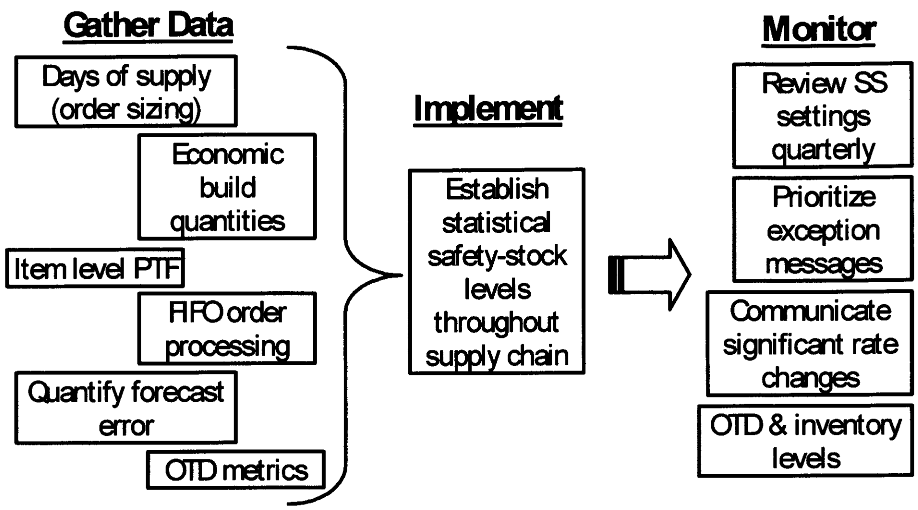

Figure 4.2: Building blocks for operational excellence

This chapter focuses on gathering the proper input data in order to calculate statistical safety stock levels for the proposed buffer and on determining which settings in the ERP system must be adjusted in order to implement a safety stock buffer as proposed in Figure 4.1 above.

4.1 Order sizing

The size of orders placed between the final assembly organization and the component supplier organization can significantly alter the magnitude of the bullwhip effect experienced by a component supplier (Spearman 2000). Section 3.2.2 plotted data for orders for Component A between a final assembly site in Malaysia and the CSTC and it highlighted the effect of a minimum order quantity of 50 on order variability. According to their own admission, planners at the CSTC set current order sizes somewhat arbitrarily at the beginning of a components life, in order to prevent too high an order frequency from the final assembly sites. Therefore, order sizing was identified in this study as an opportunity to reduce the internal bullwhip effect.

When there is an explicit cost to placing or shipping an order between organizations, an economic order size can be calculated using standard formulas (See Appendix C). In the example of the CSTC, however, ordering costs are implicit. Orders are suggested automatically via the ERP system, and shipping costs are allocated by the Colorado Springs site in aggregate back to the CSTC based on quarterly spend. These costs are allocated back to CSTC products as part of the overhead burden rate. CSTC products, as custom semi-conductor components and chips, have a very high cost-to-weight ratio. As such, they are always air-shipped, and shipping costs do not vary significantly depending on the quantity of parts shipped. With ordering costs approaching zero, the economic order size formula suggests a minimum order quantity of one unit.

In this case, there were two practical limits on order frequency. First, any reduction in order quantities could not require such a large increase in the number of shipments that the shipping department required another employee to meet the increase in workload. Second, the planning cycle of the ERP system was run weekly, which limited standard order frequency to weekly periods.

An investigation of the ERP system revealed that it could leverage information about future planned demand and automatically adjust order size parameters as a result. This method of order sizing, called days-of-supply, would prevent multiple orders for the same components in the same weekly period, while providing the flexibility to automatically adjust order sizes as demand patterns changed. For example, setting the order modifier to five days of supply would allow the final assembly and test site to order one production week's worth of material per week. Another benefit of this feature is that it is based on forward-looking demand patterns, so if there is a predicted spike in customer orders (known as a "big-deal" within the company), the final assembly site is capable of ordering larger quantities for that specific week, but not all other weeks.

Recommendation: Use the "days of supply" order modifier to regulate order quantities.

4.2 Manufacturing lot sizing

Aside from direct labor hours, lot size is the most significant driver of part costs for component production at CSTC. Higher part costs earn more "recovery dollars" for CSTC in the short term since it is a cost center, but high part costs also encourage the

CSTC's internal customers to look elsewhere for components in the future, threatening the long term viability of the operation.

Although lot sizes were not critical to implementation of the project, lot sizes are an input for the statistical safety stock calculation formulas used in the project. Revisiting lot sizes depending on the life-cycle position of a product (ramp-up, maintenance, or end-of-life) was a potential value to the organization from an operations cost and efficiency standpoint. Currently lot sizes were set during the new product introduction phase and often not changed, even when actual demand patterns differed significantly from original forecasts. Management at the CSTC had initiated a project to consider formalizing lot sizing methods. My involvement with the project was a way to build currency with the CSTC staff and management for my own proposal.

Therefore, as part of the project, I developed a tool to allow planners at the CSTC to calculate the optimal lot size based on the Economic Build Quantity formula. According to the formula, optimal lot size is achieved at the point where the incremental set-up costs per unit time are equivalent to the incremental inventory holding costs per unit time. This standard formula is explained in more detail in Appendix C. The spreadsheet-based tool that was developed also plotted the results, so that the CSTC planners and process engineers could see visually if the current lot size was in an acceptable range. Figure 4.4 shows an example of the output from the tool for a typical CSTC product. Note that there is a "knee" in the curve, beyond which incremental changes in lot size do not significantly affect unit costs.

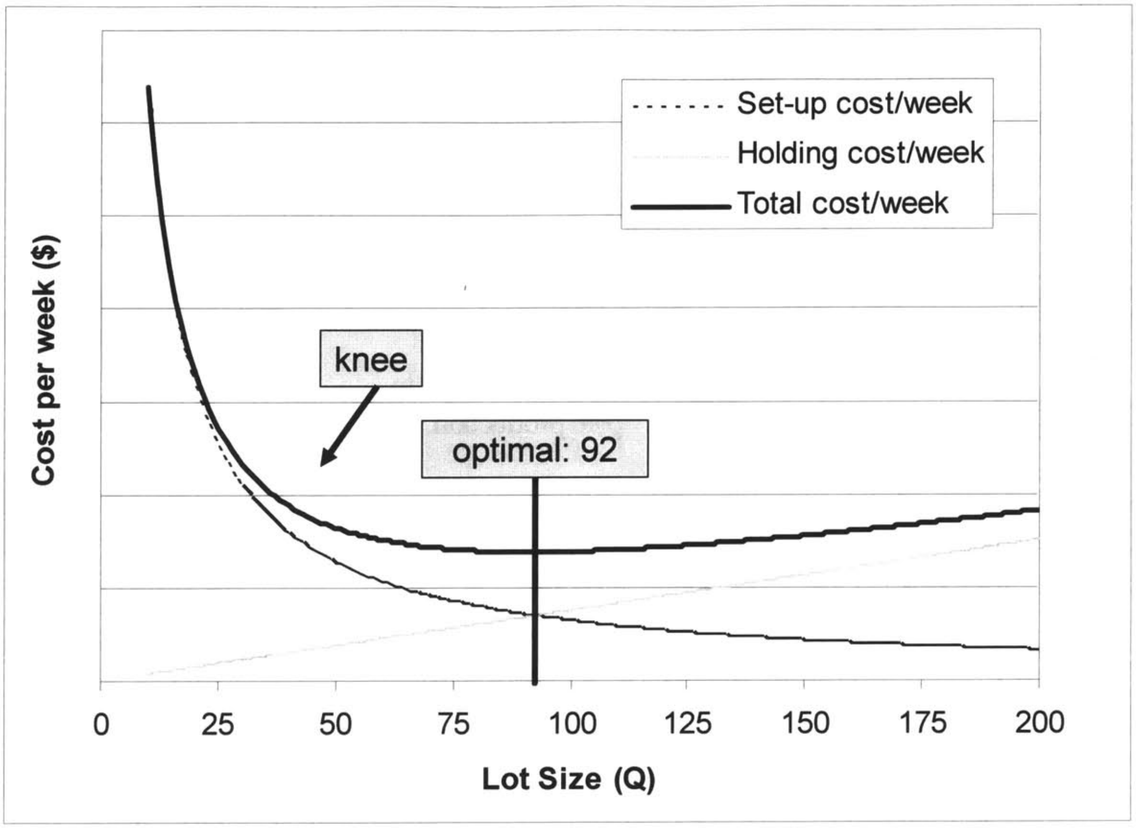

Figure 4.3: Example trade off between set-up cost and inventory holding cost

In addition to helping planners determine optimal lot size ranges for their components, the tool also helped support decision making for process engineers. For example, the tool highlighted components with lot sizes that were far to the left of optimal due to other processing limitations (where set-up costs were extremely high per part) as candidates for set-up time reduction by process engineers.

Recommendation: Use the economic build quantity calculation to identify opportunities for significant cost reduction through set-up time reduction.

4.3 Job scheduling and WIP management

Like many manufacturing organizations with long lead times, the CSTC found itself stuck in the "planning loop" (Stalk 1988). That is, long lead-times for manufacturing processes necessitated use of sales forecasts to guide planning. However, as lead-times lengthen the accuracy of sales forecasts declines. With increased forecasting errors, inventories increase and the need for safety stock at all levels increases. Errors in forecasting also lead to more unscheduled jobs that must be expedited, commanding capacity originally designated for scheduled jobs. As WIP increases, the lead-time required to complete a job increases and the cycle continues, expanding the planning loop. The reinforcing nature of the planning loop is illustrated in Figure 4.4 below.

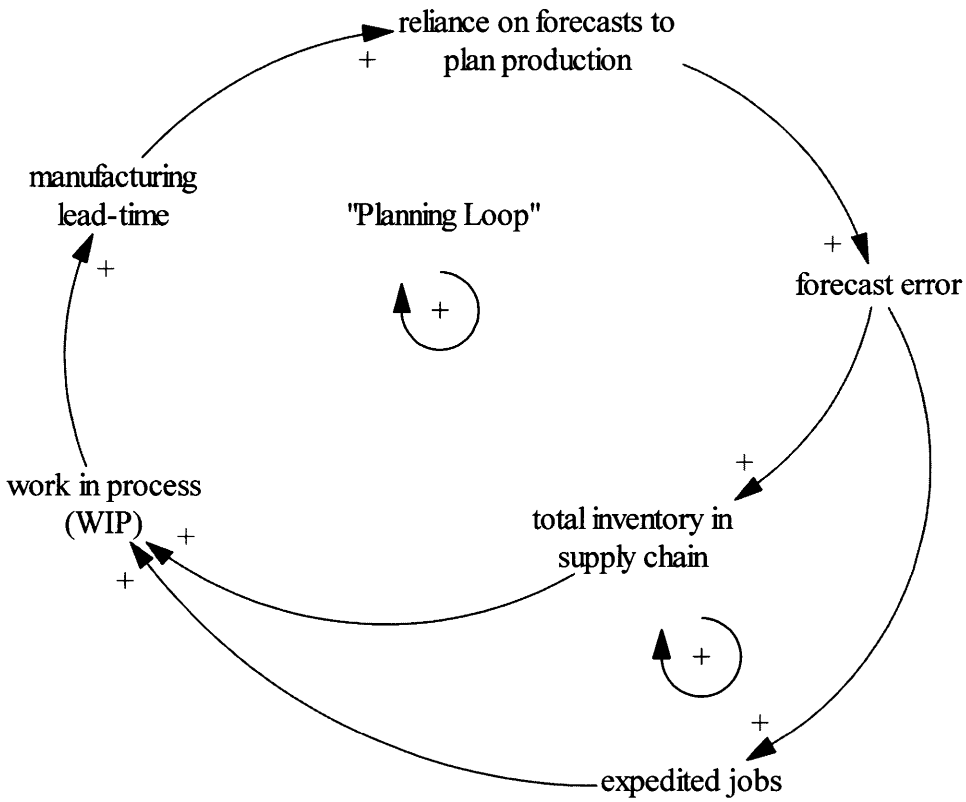

Figure 4.4: Simple system dynamics model of the planning loop

In order to implement a safety stock buffer without increasing total inventory dollars in the supply chain, this "planning loop" needed to be broken. There are two approaches to reversing the planning loop (Stalk 1988): producing to forecast (i.e. reducing expedited jobs in the above diagram) and reducing time consumption (i.e. manufacturing lead-time in the above diagram). Both must be addressed in order to effectively reverse the planning loop.

The first recommended step is to produce to forecast. In other words, once an order has begun processing in the CSTC shop, it should be completed. Conversely, expedited jobs should be limited. Instead of constantly altering the schedule of jobs in WIP in order to match actual orders, the statistical safety stock should be the buffer. Within the ERP system used by Agilent, producing to forecast is enabled by the item-level planning time fence. The time fence can be set to the processing lead time for a given component. Once this is done, the ERP system will not try to re-schedule jobs that have already begun processing. Implementation of the item-level planning time fence also ensures only jobs that the firm intends to complete enter the work queue and the work queue will more closely follow first-in-first-out (FIFO) scheduling rules.

The second recommended action to break the planning loop is to reduce lead times in the system. The easiest way to reduce lead times is first to reduce WIP, such that actual processing times fall (according to Little's Law) and then to reduce the queueing time assigned to parts to reflect the new reality. According to Stalk (1988) products only receive value added work for 0.05% to 2.5% of the time they are in the factory. More recent "rules of thumb" from (Weiss 2004) estimate that in a high-tech manufacturing process, products receive value added work for 1/6th of the time, or roughly 17%. For most components manufactured at the CSTC, value added time represented 15 – 25% of scheduled lead time, with queueing time representing the remainder. While improvements in process engineering could certainly reduce lead times, the reduction in queueing time allocated a component, as supported by reductions in factory WIP levels, represents a stronger management lever.

<u>Recommendation</u>: Set the item-level planning time fence in the ERP system to the processing lead time. Monitor WIP levels in the shop and compare with forecast demand. Monitor actual work order starts and completion dates. When these are consistently shorter than processing lead time, gradually decrease built-in queueing times.

4.4 Quantify forecast error

Forecast error is one of the most influential, yet least accurate inputs to a statistical safety stock calculation formula. As noted in section 3.1, historical forecast information was not archived by the ERP system, so securing this information required data sharing between the product level demand planner and the component supplier (CSTC). Product level forecast data was manually exploded down to the component level and then recorded at the corresponding component lead-time. These forecast data were then paired with actual order data to calculate the historical standard deviation of the weekly forecast error.

Although this manual process was feasible for a limited number of components, it was time-consuming and not clear that repeating it for numerous components of the same types of products would add significant value. Therefore, a second simplified process was also proposed for use until a new module of the ERP system (called inventory optimization) that will archive and calculate forecast error, is available. The simplified method used the demand planner estimate about future forecast accuracy directly to estimate forecast error. For example, during a new product introduction, the demand planner expects the forecast to be less accurate (higher standard deviation of error) than during product maturity. Since the demand planner is already tracking and capturing this information, the component level planner could benefit from a sharing of this information not currently contained in the ERP system.

There are two primary differences in the simplified method. First, it estimates the forecast error at the forecast date, not at the component lead time when the forecast must be used. Although this simplified method might make the forecast look more accurate, since Agilent froze forecasts two months in advance, lead time considerations on forecast accuracy were negligible. Secondly, the simplified method is forward-looking depending on the product life-cycle, while the original method is based completely on historical data. As product life-cycles continue to shrink, this second difference becomes more important to consider. It is possible that forward-looking expectations of forecast error will be more accurate than ones based on historical data.

Recommendation: Coordinate with the product level demand planner to obtain historical forecast data until the new ERP module is implemented. Information transparency across multiple organizations within the same company is a significant benefit of a large connected ERP system. The company should also consider changing permission settings in the system, such that it is possible for planners in the CSTC to view upper-level forecast data.

4.5 On-time-delivery measurement

The fill-rate metric, or type II service level (see section 3.6 for details), is recommended for use by the CSTC because it most accurately represents the concern of its customers. Customers of the electronics products and services division of Agilent most often order single units of product – therefore any increase in product availability should reflect positively on component suppliers, and the fill-rate metric aligns incentives to encourage incremental increases in product availability. In addition, fill-rate is straightforward for planning management to calculate by reporting on data extracted directly from the ERP system. Since management at CSTC had agreed to a goal of 90% on-time delivery or better, the first target was set at 90%.

If the CSTC supplied components to its internal customers with 90% OTD, one might wonder, would the end customer also experience 90% OTD or would it be different (See Figure 4.5).

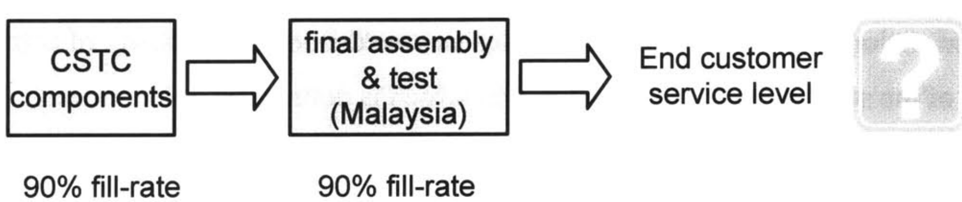

Figure 4.5: Service level in a multi-echelon supply chain

One practical solution to the problem of setting service levels in a multi-echelon supply chain is to make the assumption of bounded demand as introduced by Simpson in 1958. That is, in the case where demand exceeds the maximum demand a company wishes to satisfy from safety stock, we assume that management at that node will resort to extraordinary measures. For example, a manager might use expediting, overtime, or subcontracting to handle the excess demand (Graves 2000; Graves?). Such actions would be beyond the scope of the proposed statistical safety stock model, so they will be disregarded when considering service level targets.

Recommendation: Use the fill-rate on-time delivery metric with an initial target of 90%.

4.6 Statistical safety stock setting

Once the necessary input data is collected, a standard statistical model can be used to set the target safety stock level between the component supplier and the final assembly site. The proposed system is make-to-stock with periodic review (weekly due to the ERP system design) and a fixed manufacturing lot size. Thus, the recommended safety stock model is called the base stock model. Safety stock targets for a 90% fill-rate can be calculated according to the base stock (Q, r) model following the procedure in Appendix D.

When the base stock model is used in conjunction with a type II service level definition or fill-rate, traditionally, safety stocks are calculated according to an approximation formula (Brown 1959; Parr 1972; Kruger 1997) or looked up manually from a table found in the appendix of many operations or statistics books (Nahmias 1997). The need for approximation functions and look-up tables stemmed from the difficulty of computing the value of the standardized loss function $L(z)$ which is defined as:

$$L(z) = \int_z^\infty (t - z)\phi(t)dt$$

where $\phi(t)$ is the standard normal density. The approximation formula, which is a polynomial curve fit based on the function above, is given in Appendix D. Although this curve-fit has been used in practice for some time, with modern computing and built-in spreadsheet capabilities it is possible to directly compute the standardized loss function. As long as targeted service levels are greater than 85%, either method should be equivalent, but for lower service levels the approximation formulas are not recommended (Johnson 1993). If possible direct computation should be used.

The original intention of the project had been to design one inventory buffer located physically either at the final assembly site or the CSTC. However, the structure and capabilities of the centralized ERP system constrained the proposed solution implementation. Although the ERP system provided options for vendor-managed inventory solutions at final assembly sites, it did not allow for the same practice when the supplier was internal. In other words, the ERP system design governed the process of interactions between organizations within the same company.

Without investing significant time and money in customization for the ERP system, the existing software required designating two inventory locations – one at each site in order for the buffer concept to function. Although two inventory locations in sequence would require more total inventory in the system than one, it provided an opportunity to leverage the existing IT infrastructure and to implement the proposed changes by simply "adjusting knobs" in the existing system. The two options are summarized in the figures below.

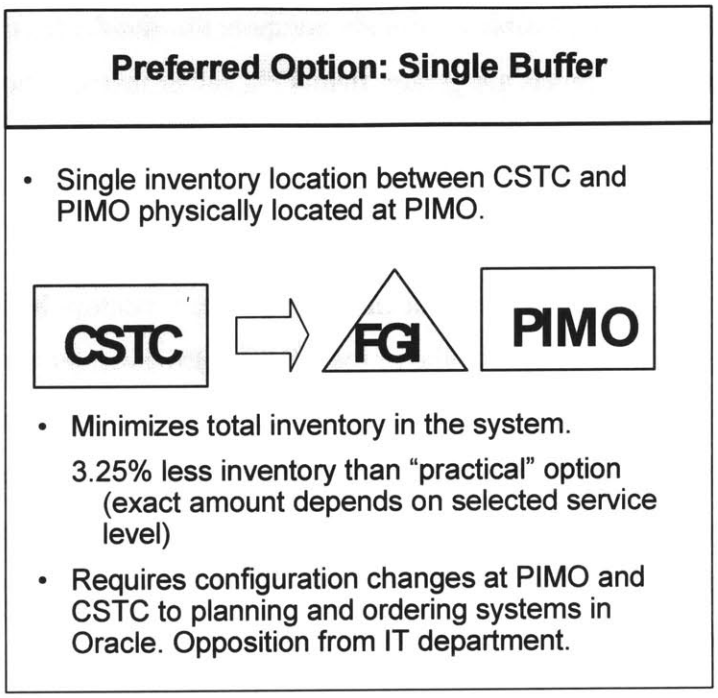

Figure 4.6: Preferred Safety Stock Configuration

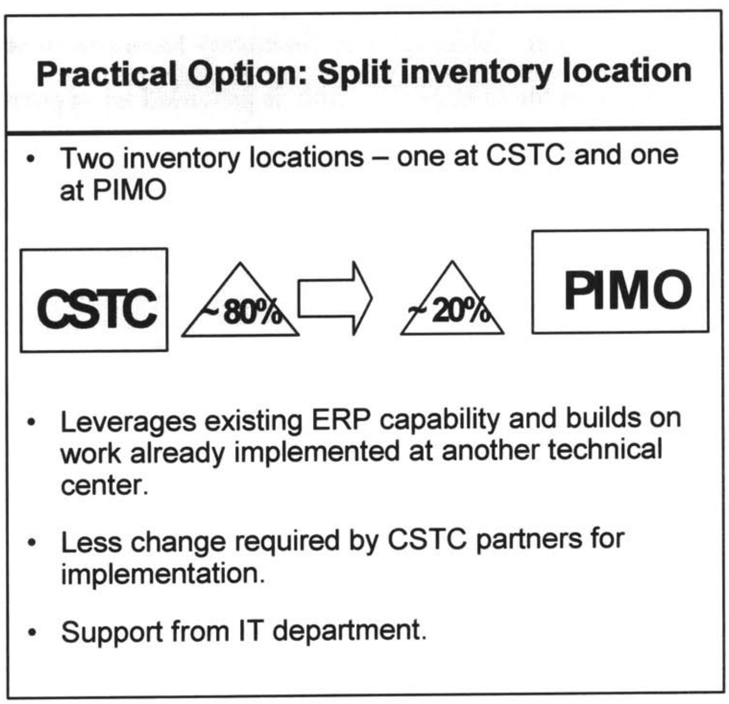

Figure 4.7: Practical Safety Stock Configuration

In either option, it was calculated using the base stock formula that the total amount of inventory required in the supply chain to achieve a 90% or greater service level would be equal to or less than the current amount of inventory dollars in the supply chain for Component A. Also note that selecting the practical option does not eliminate the possibility to implementing the preferred option at a later time when resources are available to customize the ERP system. Therefore, after considering implementation barriers, the clear choice was to propose a split inventory buffer location.

As mentioned previously, manufacturing lot sizes can change the recommended safety stock setting (Kruger 1997; Nahmias 1997) and this is included in the calculations in Appendix D. Conceptually, consider the following example. Component A is manufactured in lot sizes of 50 units. The average demand is 10 units per week. When a lot of 50 units is completed the parts are put into stock. During the next few weeks the stock of 50 units is depleted. It is really only in the last week or so prior to replenishment that there is a danger of stocking out. If we do not take manufacturing lot sizes into consideration when calculating safety stock levels, we will be overly conservative about stock-out potential and end up with too much inventory in the system.

In the specific case at Agilent, due to the historically low service level provided by CSTC to Malaysia, buyers in Malaysia were somewhat skeptical that CSTC could achieve 90% OTD under any sort of operations policy. This history influenced the recommendation, and the team chose to not include manufacturing lot size in the safety stock calculation, so that they could under-promise and over-deliver on this product to their partner, with the hope that over time as trust was built between the organizations, important factors like lot size could be included. Another reason, beyond the history, is that buyers in Malaysia were familiar with the concept of statistical safety stock. However, in Malaysia they don't have manufacturing lot sizes – so essentially their lot sizes are always one. Neglecting lot size was also a way to use formulas more familiar to the associates in Malaysia for the team project.

Recommendation: Use two inventory buffers at first to speed implementation, but retain the option to switch to one if this option becomes more attractive and easier to implement in the ERP system in the future. Initially also neglect the effect of manufacturing lot size on safety stock calculations until trust in the organization's ability to deliver is established. Again later, the effect of manufacturing lot size can be introduced to further reduce total inventory in the system.

4.7 Future state predictions

The first few building blocks proposed (setting order quantities, lot sizes and review periods) are all techniques to reduce the bullwhip effect between organizations within a firm. Lee, Padmanabhan, and Whang divide causes of the bullwhip effect into four categories: batching, forecasting, pricing, and gaming behavior (Lee 1997a). The recommendations above address batching and forecasting issues, which are primarily internal to the firm. Pricing by the firm, such as end-of-quarter discounts offered by the sales department and gaming behavior by customers are not addressed, but could be considered in future studies.

Once the internally controllable causes of the bullwhip effect have been addressed, statistical safety stock can be calculated and implemented without significant increases to total supply chain inventory. This safety stock will enable the CSTC to achieve the service levels demanded by its customers. The figure below compares total inventory levels in dollars required in the supply chain for Component A currently (horizontal line) with that required for a variety of service levels.

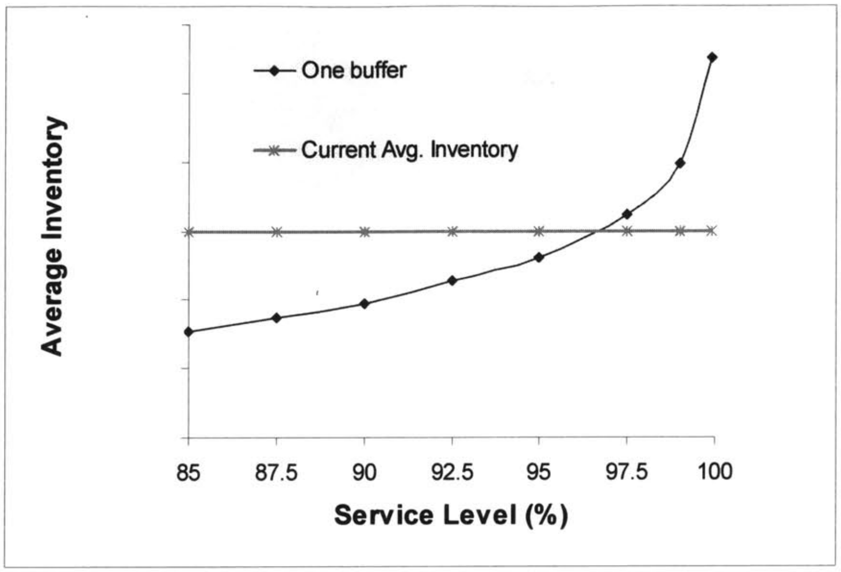

Figure 4.8: Current vs. future supply chain inventory and service levels

Note that the current total inventory dollars in the supply chain should be able to support > 95% service level; however, the firm is only able to achieve 60% at best with the current system design. The goal of the combined recommendations here is to alter the system design such that it is possible to achieve the desired service level.

Finally, after the building blocks are in place and the safety stock has been implemented along with FIFO order processing in the component manufacturing area, we expect that less WIP will lead to shorter actual lead times. This result will effectively break the "planning loop" and allow continued improvements by decreasing built-in queueing times, therefore reducing the total safety stock inventory required by the supply chain.

4.8 Chapter summary

This chapter recommended specific actions in order to improve CSTC operational performance. These actions, when combined will improve on-time delivery to CSTC customers, while simultaneously stabilizing CSTC processes and reducing WIP at CSTC. The next chapter studies a pilot implementation of these actions focused on improving on-time delivery (OTD) from the CSTC to its internal customers and considers the lessons learned from the pilot project.

Chapter 5: An implementation case study

Chapter 3 showed that the CSTC was currently performing below its objective of 90% on-time delivery to its internal customers. In fact, OTD provided by CSTC to its customers in the past nine months had been 60% based on the fill-rate metric. Chapter 4 proposed how this situation could be changed within the resources currently available to management. After thorough discussion and consideration by all stakeholders involved in the supply chain, support was provided to the proposed project. The project was also listed by CSTC plant management on the plan of record as a method for remedying on-time delivery problems. Management support for the project was conditional upon successful completion of a pilot implementation of the recommendations discussed in Chapter 4 with a limited set of products. At this point work on the project accelerated and a multi-disciplinary, multi-organization task force was formed to implement the recommendations.

The following section will discuss the implementation of the recommendations with an emphasis on what other organizations might learn from Agilent's experience. Implementation results including challenges, learning, and data will be presented from an on-going pilot experiment in CSTC operations. In addition, the methods of implementing standard operations principles in order to improve on-time delivery from CSTC to partner organizations will be described.

5.1 Pilot implementation objectives

It is important to understand that the objective of the pilot implementation was not to determine the costs or benefits of using statistical safety stock as a buffer, since this principle is well known and has been documented in the literature as well as in practice. Instead, the objective of the pilot implementation was to prototype the new production process specifically by:

1. Validating all ERP mechanics necessary to implement OTD improvements.
2. Developing planner knowledge to manage the transition from current state to future state for multiple future products.

In addition achieving the objectives stated above, deliverables from the pilot project included:

1. An Excel-based tool that calculated, via queries to the ERP system,
    a. Economic Build Quantity ranges
    b. Safety Stock levels for CSTC and partner locations
    c. Average inventory levels and expected variation
2. An Excel-based tool that filtered and prioritized exception messages generated by the ERP system for planners
3. A summary of lessons learned that should be considered in the transition to a full-scale roll out
4. A written plan for full-scale roll-out that included a transition plan and designated which items should be excluded

Throughout the pilot phase and during the transition to a full-scale roll-out, the pilot team also monitored and recorded weekly metrics for each of the pilot items including:

1. Total inventory value and location (at each supply chain node)
2. Number of ERP system exceptions that require action (schedule in/out, etc.)

On-time-delivery (OTD), number of days late if late, and variability of processing time at CSTC were also recorded and compared to historical data as work orders completed.

5.2 Pilot implementation results

The official pilot implementation project at Agilent ran for six weeks and was successful at implementing and integrating all of the elements noted in Chapter 4 for Component A, through the centralized ERP system. For example, one of the building block elements implemented for the first time in the pilot project was use of the item level planning time fence (PTF). Within the CSTC, use of the PTF eliminated requests from the ERP system to schedule-in or schedule-out jobs for Component A that had already started processing. This helped to stabilize work in the CSTC shop during the pilot project beginning with Component A. In addition, the fixed days of supply order modifier supported weekly orders of components between Malaysia and the CSTC as anticipated. Instead of orders occurring in groups of 50, as in the example for Component A in Chapter 3, weekly shipment requests from Malaysia were in smaller groups according to the weekly demand of the end customer.

The manufacturing lot size, or build quantity, was also adjusted to approach the ideal lot size for Component A as part of the pilot project. For Component A, the build quantity was changed from a quantity representing 1.83 sheets of substrate, to one representing 4 sheets of substrate. This change took into account both the physical process constraints, i.e. there are X parts per sheet of substrate, and the EOQ formula calculations (see Appendix C). The primary purpose of the lot size change was to test the change method in the ERP system, should it be necessary to increase or decrease lot sizes in the future.

Statistical safety stock targets were also set for CSTC as well as Malaysia, according to the recommendation of an Excel-based tool which drew input data directly from the ERP system. Beyond the six-week pilot project, data continued to be collected on inventory and OTD performance for Component A, as part of the CSTC organization's efforts to improve OTD to its partners. A summary of the actual vs. predicted supply chain inventory levels for Component A during the pilot (first 6 weeks) and several months beyond is shown in Figures 5.1, 5.2 and 5.3.

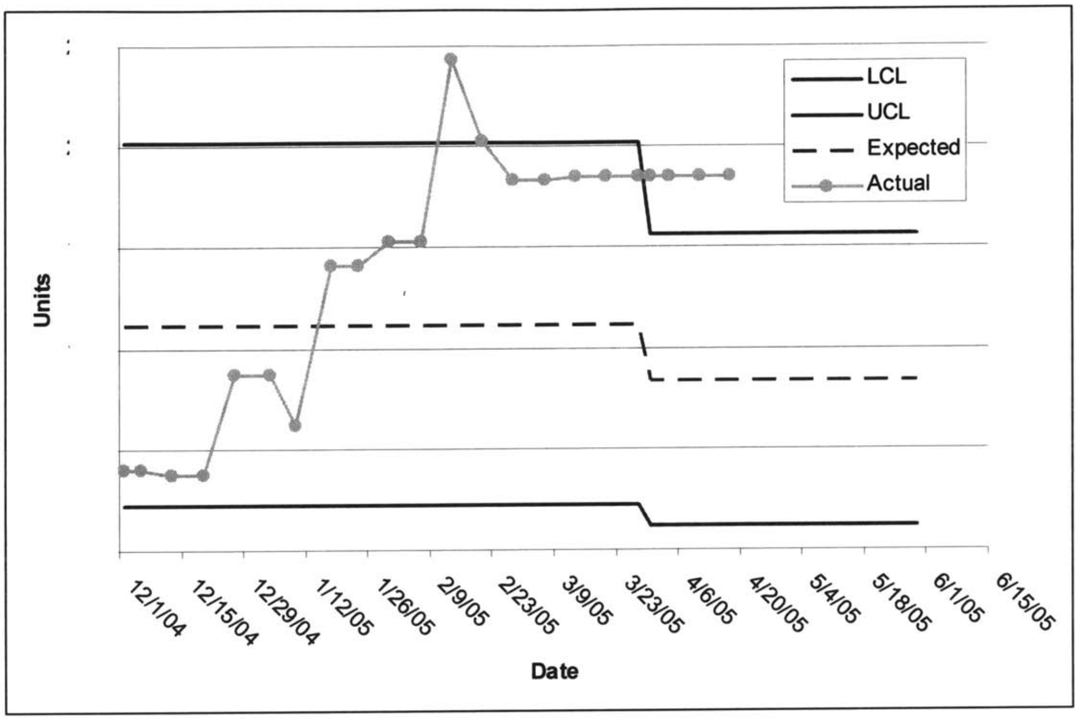

Figure 5.1: Component A inventory control chart for CSTC site

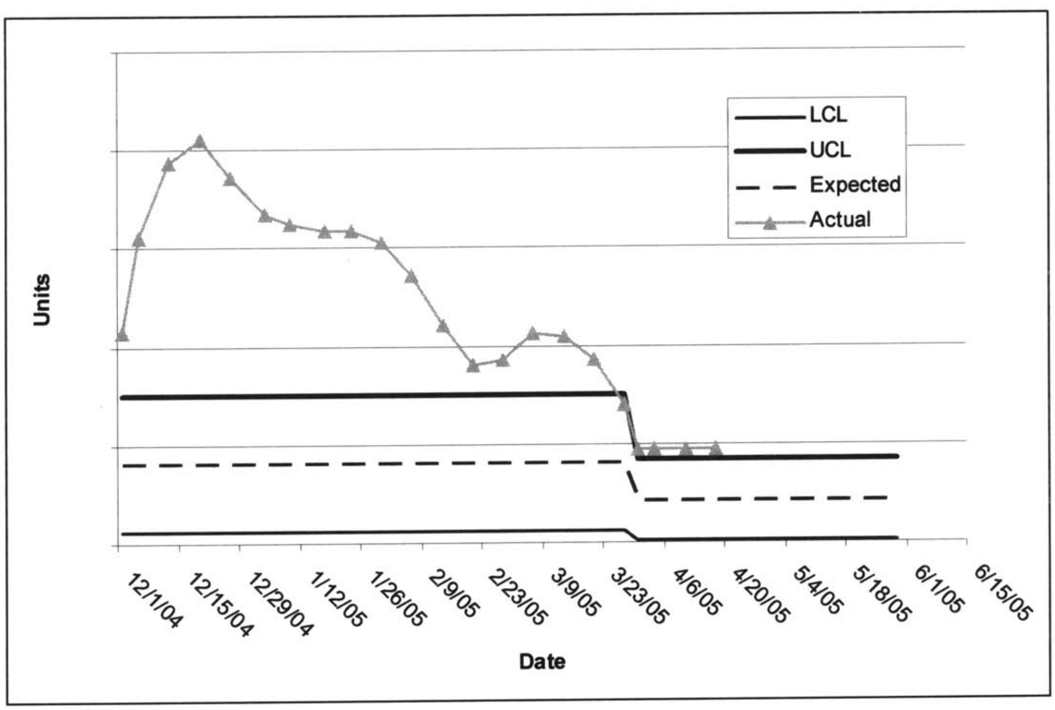

Figure 5.2: Component A inventory control chart for final assembly site

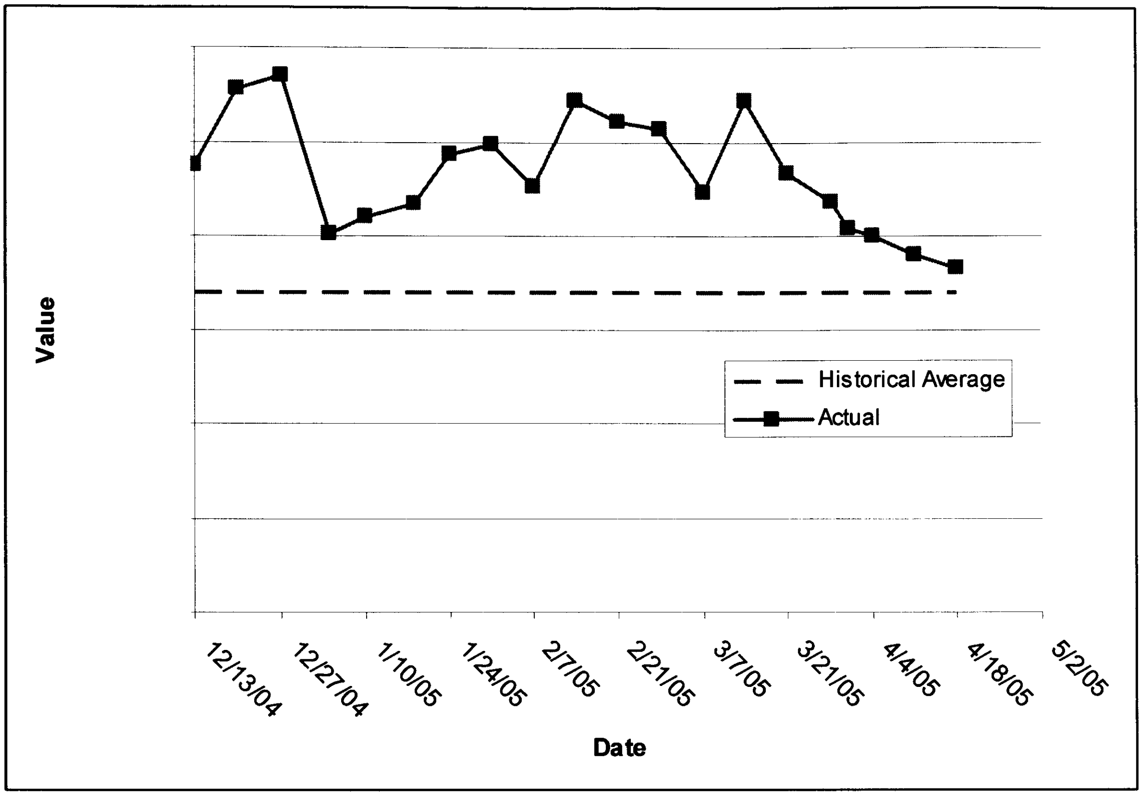

Figure 5.3: Historical vs. current average supply-chain inventory level component A

The dashed horizontal line represents the predicted average inventory level, while the solid horizontal lines represent two standard deviations above and below the predicted average inventory level. The plots are a type of inventory control chart for planners and the team task force which suggest they review more details about a component if actual inventory levels at a specific node are outside of the two sigma zone. Note in the figures above that the actual inventory at CSTC was primarily within the expected zone, while inventory at the partner organization remained much higher than statistical models would predict. As a result, total inventory in the supply chain was above average historical levels (see Figure 5.3). This unexpected system behavior triggered an investigation during the pilot project, the results of which are discussed in more detail in section 5.3.

OTD for Component A was at 100% for shipment requests during this same time. Although the target OTD was only 90%, the result is logical for two reasons. First, a bug in the ERP source code caused extra orders for Component A to be placed from the final assembly site to the CSTC (more details in section 5.3). Second, aside from one single "big order" at the beginning of the pilot project, average weekly demand was only 80% of the forecasted demand for the period. Therefore, there was more than sufficient inventory to meet demand. Eventually, the forecast and work plan were adjusted. As a result the safety stock targets and predicted average inventory levels for Component A were reduced for Q2 of 2005 by the planner. This shift in targets is also shown in Figure 5.1 and 5.2. The planner taking initiative to adjust settings in the ERP system for Q2 of 2005 provides evidence that the planners at CSTC are becoming comfortable with the new process and the statistical setting of the safety stock.

While the overall pilot was successful, it also highlighted several concerns which needed to be addressed by Agilent and the CSTC in the future. These are discussed in the lessons learned and next steps sections.

5.3 Implementation surprises and lessons learned

Although the primary purpose of the pilot project was to prototype the changes necessary in the ERP system, the task force leading the implementation did not anticipate the breadth or the depth of ERP issues that the project would uncover. Despite extensive documentation about the ERP system and the support of internal and external ERP experts for the project, the implementation team discovered field interactions, synchronization issues and a source code "bug" that had not been previously documented.

With ERP fields and settings that are so intricately connected, it is possible that no one (even the provider) knows exactly how each field is connected to all other fields and how they may or may not update each other over time. In other words, the effects or consistency of changes made in one field of the ERP system often could depend on settings that populate other fields. While this is expected of a complex integrated system, it is very possible that within the firm, each of these fields that interact with each other is controlled by different associates under different management.

For example, in the Agilent ERP system, when the design engineer creates a bill of materials for a product, he or she may also select component suppliers from the approved supplier list in the ERP system. Because the rules were not clear, on some internally sourced parts, such as those from the CSTC, the approved supplier list field was populated, while on others it was not. The implementation team discovered that when manufacturing lot sizes within the CSTC were changed by a planner or process engineer, the effect on the calculated processing lead time by the ERP system differed depending on the setting by the design engineer in the approved supplier list field. The benefit of building in advance an interdisciplinary and multi-organization team or support network in order to resolve such ERP system interaction issues in a timely manner can not be overstated.

The second major lesson learned was about the importance of synchronizing and understanding the timing of various changes made in the ERP system between the supplier and buyer organizations. For example, in order to see the effects of changes to the ERP system in the next weeks' plan, instead of waiting until all outstanding orders had been filled (approximately 8 weeks) existing Internal Sales Orders had to be deleted concurrently by both CSTC and the partner organization. Then the weekly plan had to run and generate the "new" planned orders. Next the partner organization had to issue internal requisitions for the parts in the system, which would finally cause the ERP system to generate new Internal Sales Orders. It is important that the deletion and re-insertion of the orders is well coordinated between the two parties involved, because even with daily phone calls the implementation team experienced some hiccups in this process and it took more than one week for the system to properly generate new sales orders based on the updated parameters.

In addition to the previous issue that can be relegated to the category of human error, there are inherent synchronization issues built into any ERP system design. Although every effort was made to synchronize changes for the pilot part across organizations, certain fields in the ERP system were updated based on other fields on different schedules. The most important timing to coordinate was to make all changes before the weekly plan began collecting data. In the case of CSTC, cost information was updated quarterly, while processing time was updated monthly. Because of these synchronization issues, it was important to monitor "implemented" parts for about a quarter after the changes had been made in order to avoid any surprises.

The most significant discovery during the pilot implementation was a bug in the ERP source code. Like other software bugs that escape early detection, this one required a certain sequence of events in the ERP system in order to be manifested. First, actual customer orders had to surpass the planned orders in the ERP system. Next, the partner organization had to request shipment of an internal order prior to the original scheduled ship date. Finally, the CSTC had to ship the order in advance of the original planned ship date, per the ERP system request. When these events occurred, the order would be "lost" from the ERP system while in shipment and additional expedited orders would be generated by the system to meet the demand and cover for the lost units. Once the "lost" shipment was received by the partner organization, logged into the ERP system and the weekly plan was run, the additional expedited orders would be cancelled leaving CSTC with excess inventory.

The unfortunate consequence of the bug was automatic double-ordering by partner organizations when customer orders were greater than the original forecast followed by subsequent under-ordering or canceling of orders when shipments arrived. This ERP bug effectively increased the bullwhip effect for internal component orders. This bug was also identified as a major source of the higher than expected inventory level at the partner organization during the pilot.

During the pilot project, the bug was documented by the team and acknowledged as an issue by the ERP system vendor. Because it involved the source code, however, the issue could not be resolved by Agilent alone, it had to be addressed by the vendor. Although the initial estimate for a release that fixed the bug was two months from the date of discovery, four months have passed without a fix from the ERP system vendor. In the meantime, Agilent has by necessity continued operations under the current system.

This bug was important not only for the pilot project results, but for all components shipped by CSTC to partner organizations. However, it might not have been discovered had the extra resources of an MIT student not been allocated to the project implementation team. This discovery highlighted an important lesson for future projects – that someone on the team must have the bandwidth to investigate and follow up with seemingly illogical results from the ERP system in order to discover the root cause. Usually, the result won't be a bug, but instead a misunderstanding by the team of certain ERP system fields. Still, it is possible that the ERP system contains additional undocumented field interactions or bugs, so it is important that users of the system try to understand what the system is doing and how it is making its calculations.

5.4 Continuation and expansion of work

Despite the complications, overall the results of the pilot project were successful and it provided an excellent learning environment for the entire interdisciplinary team. Since the official completion of the pilot project, the program to reduce the bullwhip effect and implement statistical safety stock has been expanded to multiple additional CSTC products. The comfort level of the CSTC associates with the recommendations has greatly increased due to the results of the pilot program. CSTC planners have become strong advocates of the program because even with this limited set of parts implemented the item-level planning time fence, which limited rescheduling inside of lead times, in combination with the safety stock buffer has significantly reduced their time spent rescheduling and expediting work orders.

Orders for Component A have achieved 100% on-time delivery during the five-month period since implementation. In addition, manufacturing jobs for Component A have completed processing in the CSTC shop in four weeks, instead of the eight weeks allowed for with queueing time. This performance has led to discussions to gradually reduce the queueing time built into the ERP system for the part, thus allowing a reduction in overall safety stock and supply chain inventory levels.

Surprisingly, even with 100% OTD, due to personnel turnover at the Malaysia final assembly site, a new buyer was discovered to have increased the safety stock level settings in the ERP system without notifying the rest of the team. When this issue was raised, the buyer commented that he was "not comfortable" with the safety stock level the team had set. Presumably, because the employee was new, he or she did not know that Component A had sufficient safety stock at CSTC to actually deliver to the one-week lead time for shipments that the system promised, as opposed to other components which the buyer managed where suppliers were not really able to deliver in the one-week allotted time. It is important to remember that despite any analytical optimizations, this human intervention in the supply chain can also have significant effects on the achievable results.

Finally, work by the firm on the ERP inventory optimization module, which could automatically calculate statistical safety stock settings, continues and the team is hopeful that it will be implemented throughout the company within the next year.

5.5 Chapter summary

Overall, the pilot implementation project was successful and as a result, the task force has continued to expand the changes to additional products. All parties continue to support the implementation and planners at CSTC have acknowledged a significant reduction in the rescheduling chaos of their jobs when this new system has been implemented on a component they oversee. The organizations involved are beginning to experience some positive results of the project such as improved on-time delivery and sanity of processing schedules. However, some of the major improvements promised by the project, such as lead time reduction and lower total supply chain inventory, have yet to be realized. Finally, the efforts of the task force have set the stage for the CSTC to transition smoothly to the ERP system Inventory Optimization module, which is proposed to be adopted by Agilent in one year.

The pilot project proved that the implementation of a seemingly simple, previously-proven change in a complex system, like a modern state-of-the-art ERP system, can have far reaching and sometimes unintended effects. The pilot project demonstrated that it is important to prototype the change process within the actual ERP system, not just a theoretical or simulated ERP system. In addition to some unexpected behavior from the ERP system, actions taken independently by individual members of the supply chains also had a significant effect on the project results.

While this chapter focused on the technical challenges and results of the implementation, Chapter 6 will consider the organizational context and its role as the people of Agilent strive towards building operational excellence in the Agilent supply chain.

Chapter 6: Organizational context and impact

In this chapter anecdotal data from the solution development and implementation will be provided to depict the organizational context. The chapter then considers the relevance of the organizational context for further operations improvements. The challenging part of supply chain management is that it must span across many disparate entities of an organization structurally, politically and even culturally. In order to develop an efficient supply chain these three areas must be in alignment across all supply chain nodes. For this project at Agilent it is interesting to examine the CSTC in the context of its changing supply chain relationship with other organizations in the company.

6.1 Structure: Recent changes disrupted the CSTC

The structural design of Agilent is best characterized as a loose collection of decentralized groups. While this organizational design had been effective in the past, recent structural changes were straining the system.

<u>Decentralized groups</u>

In the context of a supply chain project, the decentralized division-based structure at Agilent posed a challenge in trying to coordinate and implement changes across divisions and groups. Although there were some examples of individuals "moving up the ladder" of management from centralized groups, it was clear that power and upwardly mobile career paths began in the divisions, not corporate functions. Therefore, as a member of a central corporate organization in a decentralized company, it was important to develop my influence skills, as neither I, nor other members of my group, had any official structural power to implement our projects.

<u>Recent structural changes</u>

In an effort to recover from the downturn, many structural changes were instituted and the CSTC was trying to cope effectively with these changes during my tenure. For example, the CSTC was changed from a profit center belonging to the Colorado Springs Group, to its own cost center. Structural changes such as this one had significant operational effects, as management focused on achieving new metrics important to the cost center. For example, the cost center structure encouraged planners to release more material into the shop than the available capacity, because on the books, the organization got credit for this operational step. Conversely, as a profit center the same planners had worked diligently to ship product at the end of a quarter, but as a cost center shipping was considered overhead. Since there was no longer value-add credit for shipping in the new structure, incentives to ship at quarter-end, despite potential customer needs, lagged.

The second significant structural change following the downturn was the increasing role of Agilent Malaysia in CSTC operations. Now that the final assembly and test site for the majority of CSTC products was not part of the same P&L group nor the same physical facility, it led to a greater need for supply chain and other cross-organization coordination. High turnover in Malaysia, the time difference, and cultural expectations, as well as lack of geographic proximity, hampered the development of linking mechanisms between these decentralized groups that had served the company well in the past. For example, during a period of six months, the buyer in Malaysia for a particular component the CSTC supplied changed three times.

In addition, Agilent Malaysia had its own structure, which was different than Agilent facilities in the States. There were more hierarchical levels for associate positions in Malaysia than in the States, and this was coupled with a strong functional emphasis in Malaysia. Job titles were also more important in Malaysia than in the States. Because of the growing importance of the relationship between Malaysia and CSTC, several task forces were formed to improve communications and alignment.

Finally, and most significantly, the CSTC had recently weathered its first layoffs in company history and during this project the layoffs continued. These layoffs eliminated 60% or more of the workforce at the CSTC. Many of those who did stay with the company were re-assigned to new tasks. The organizational result was a structure with many holes in knowledge and responsibility, as well as disrupted informal links between groups.

The recent layoffs also challenged the ability of the Agilent organization to develop a coherent culture across all sites.

> *"As we've become larger, we really spread the people who have the ability to pass along the HP Way in subtle kinds of ways…We, as a company, still depend on those leaders who have these characteristics to continue to pass them on to the current management structure which is very diverse, very matrix-oriented, with a lot of dotted lines.*" HP Manager (vonWerssowetz 1982)

The next section will discuss some observations of localized divisions in the strong Agilent culture.

6.2 Culture: Friendly and loyal

The Agilent culture is a supreme and ubiquitous testimony to the "HP Way". So dominant is the HP Way, that a casual observer might think Agilent was HP. Many Agilent employees told me that they got the "real" part of HP in the split, despite the change in name. Several aspects are critical to understanding the strong Agilent (HP) culture including: innovation, engineering, individuals, history and respect.

<u>Innovation</u>

Innovation is at the heart of the Agilent culture. Displayed on banners and posters throughout the site was the mantra "Agilent: Innovating the HP Way". Dominating the interior décor were the recent patents from CSTC employees. These cultural artifacts were so important to Agilent that they were embossed on plaques which were installed inside glass display cases throughout the hallways.

This strong culture of innovation posed a significant challenge for managers and those striving for the type of standardized processes, rules and consistency typically associated with operations. The challenge for the manufacturing leadership within the company was to develop a culture that could successfully marry free-wheeling engineering innovation with operational excellence. For example, when the CSTC plant manager was asked "Of which projects from the past year are you the most proud?" his response included the development and invention of new physical manufacturing processes, but no strictly operational improvements were mentioned.

<u>Individual based relationships</u>

Agilent is a company built upon the integrity of many individuals, and central to an individual's success at the company is his or her cultivation of relationships with others. While the relationship-based culture can be rewarding for long-time employees, it can make obtaining information difficult for newcomers.

> *"People find out about individuals here by direct contact. There is a lot of that here, and people recognize those that are sharp, that they feel comfortable with, that have the skills. There is a lot of informality..."* HP Employee (vonWerssowetz 1982)

One symbol of this relationship-based culture was the coaching I received on approaching new contacts. E-mail was deemed too impersonal for initial contact with another employee. Phone calls were acceptable for those employees at another site; however, face-to-face contact was always preferred. Thus my mentor took great efforts to walk me around the buildings and to introduce me to his co-workers - often we would stop by an empty cube several times before resorting to a phone call.

Given current business realities at Agilent and CSTC, one might expect an environment of mistrust, or hostility, but that was not the case. The strong culture dictated a basis of respect for every person. Even cooks in the cafeteria made an effort to know each and every employees name and to greet them with a friendly smile. I have never worked at a company where the people were as cordial and respectful as at Agilent.

History & respect

The strong individual relationships and maturity of the workforce also produced an environment of trust. The majority of my team worked from home, and each member of the team was physically based at a different Agilent site. This was not a problem for GSCE management, which trusted each individual employee to get his or her work done and to make independent decisions. This trust between management and employees extended to me, even as an intern. My supervisor did not get involved in my project unless I called a meeting or asked him for specific advice. Even then, he saw his role as reducing bureaucratic obstacles to progress, not becoming involved in recommendations or decision making.

At Agilent, employees are often introduced by their length of service with the company. For example, "This is Amy. Amy has been with the company for 22 years." The length of service is typically mentioned in introductions prior to a job title or current responsibilities, if these are mentioned at all. Loyalty to the company is a source of pride and respect is commanded by those with the longest service. In fact, it is more common to know a fellow employee's start year than it is to know his or her official position in the organizational structure. The average length of service at the CSTC was over 15 years.

In contrast, the maximum length of service at the Agilent Malaysia final assembly and test site was under 10 years. This generated unspoken tensions, as the CSTC employees, due to the traditional Agilent culture, felt they should engender much more respect than they received from Malaysian employees due to their length of service. Service years were not the only cultural discrepancy. In Malaysia, an employee's title and position on the organization chart was also very important, which conflicted somewhat with the importance of personal networks in the States.

Along with the respect for length of service and loyalty to the company was an unspoken requirement of humility. Employees would often compliment others by degrading themselves. For example, "I've only been here for 15 years, but Dave knows much more, he's been here for 22." Employees who had PhDs, MBAs or Six Sigma Black-Belt certifications did not go around proclaiming these qualifications. Likewise, I was encouraged to be humble and not mention that I came from an east-coast school unless asked. Often in preparation for a meeting, my mentor would coach me on proper socialization and the interpretation of norms at Agilent. He would begin with, "From what I know about the way we do things around here…" and as I continued my experience I would add each nugget to my Agilent cultural cache.

6.3 Politics: Shifting basis of power

In the Agilent that was rebuilt after the downturn and following separation from HP, players were still working to find their new sources of power in the organization. Although the engineers still dominated, in order to save the company from bankruptcy they had been forced to share some power with their business counterparts.

Engineering

Agilent was a company of engineers who design and develop products to sell to other engineers. The engineers led the company. Within engineering, there was a clear pecking order defined (Sheinbein 2004). My mentor explained to me that EE design engineers ranked above all other types of EE, followed by software engineers, other engineers, and finally non-engineers. However, at the end, he added that in today's new economy the cost accountants just might need to be moved to the top of the list, because "They seem to control everything nowadays." His comment highlights a transition happening within Agilent. Prior to the split of Agilent from HP, PC's and peripherals dominated revenue; hence analysts focused on that part of the company. Test and measurement was largely left alone as a "cash-cow" run by a bunch of engineers. As the newly formed stand-alone company struggled to return to profitability from the downturn of 2001, some power was shifted to those in business roles. The growing role of accounting in the new company highlights the shifting basis of power and also the relative importance of the financial performance of the test and measurement division to the new company.

It is interesting to note that even my home organization, Global Supply Chain Engineering, had the word engineering included in the name of the group although the majority of its members came from accounting, finance, statistics, manufacturing and other business areas. Officially, this group put engineering in the team name to differentiate it from other supply chain groups in the company, which, for example did not develop mathematical models. However, this is still a testament to the continuing power of engineering in the Agilent organization.

The engineering power base is reinforced by hiring practices. Entry level engineers are recruited from top schools nationwide via a rigorous and competitive selection process. Conversely, entry level business employees tend to be recruited from local colleges or work their way up from manufacturing, facilities, and other line jobs. While very high level business positions may be recruited from top sources, it is possible that employees in business and operations functions do not have a formal college education in business or operations subjects.

Inter-organizational politics

In light of recent corporate restructuring, the CSTC was finding it difficult to make the transition to a potentially less powerful role in the company. Technical centers like CSTC had been shrinking over time as some capabilities they provided became commoditized and could be outsourced. As they got smaller, they lost power in the organization, and some individuals within the technical center wondered if it was just a matter of time before the entire CSTC would be dissolved.

Additionally, the new final assembly and test site in Malaysia (PIMO) was trying to exert its power over CSTC in the relationship. Buyers and planners in Malaysia were infamous for quotes such as "They are just a supplier," or "The suppliers must respond". This inflexible attitude towards suppliers by relatively new employees of the company in Malaysia frustrated those in the CSTC. CSTC process engineers found it difficult to view themselves as similar to commodity suppliers to final assembly. "We make the money parts. Without us, they would be assembling a box of little or no value," CSTC process engineers would claim.

Certainly, had CSTC been an external organization to the company, it could have exerted significant supplier power to "hold-up" its customer (PIMO) as CSTC produced unique products that no-one else in the world could make. However, as part of the larger organization and same company, CSTC lost some of this power and the management and engineers at CSTC resented it.

As I progressed with my internship, I was conscious to develop my basis of influence as much as possible in order to form coalitions that could make the implementation of my operations recommendations a reality. In forming coalitions to support the project recommendations, I had to be mindful of strong existing individual loyalties in the organization. Eventually, I gained the respect and support of senior level plant management and division leadership because I had the ability to get information they could not, and I was able to apply this information in order to address some metrics on which they were lagging. As a result they included my project in the FY05 Plan of Record when presenting to their superiors. I also developed an alliance with the corporate IT group which eventually viewed implementation of my project as "what we had originally intended for the ERP system, before we ran out of time and budget and had to just implement what we had."

6.4 Leading change in the organization

Leading the change process at Agilent CSTC required me to learn two important lessons. First, I needed to exercise more effective use of the power of influence, and second, I needed to embrace the role of a "satisfier" over that of a "maximizer" (Wheeler 2004).

One feature of the communications style at Agilent is not only the ability to seek the advice of anyone in the company, but also the expectation that those who can contribute will be sought out (vonWerssowetz 1982).

"I guess one of my first reactions was seeing how many people I had to check things with before I went ahead and did something. And it wasn't the tone of saying, "Look, you have to get their approval." It was in the tone of saying, "here are some people that probably really have something to say about what you are doing, you really ought to talk to them." It was that kind of subtle difference, but it really ended up in getting approval.

It comes across as, "There are some people that you really ought to check bases with and if you've got a reasonable proposal, they'll support it." I thought several times that if somebody said you <u>have</u> to do this before you can do something, I would have said forget it! But it's more of selling the idea. And you do that on a very personal basis. Not very many times does anybody come along and say you can't do something. It's a subtle influence process." HP Engineer (vonWerssowetz 1982)

Internalizing what is expressed in this quote was critical to the success of the pilot project implementation. As an outsider, I didn't comprehend the extent to which each and every individual needed to be consulted and enthusiastically embrace the project in order for it to move forward. Initially, I relied too much on obtaining structural approval for the project from the official leaders of the organization. In addition, I did not allow enough time for selling my proposal in my initial project plans. Understanding this cultural reliance on the powers of influence and driving decisions to the lowest level in the organization up-front would have helped me to develop a more realistic original project timeline. While my initial timeline allowed less than a week for the selling activity, in the actual timeline of the project this process took almost two months (see Figure 6.1).

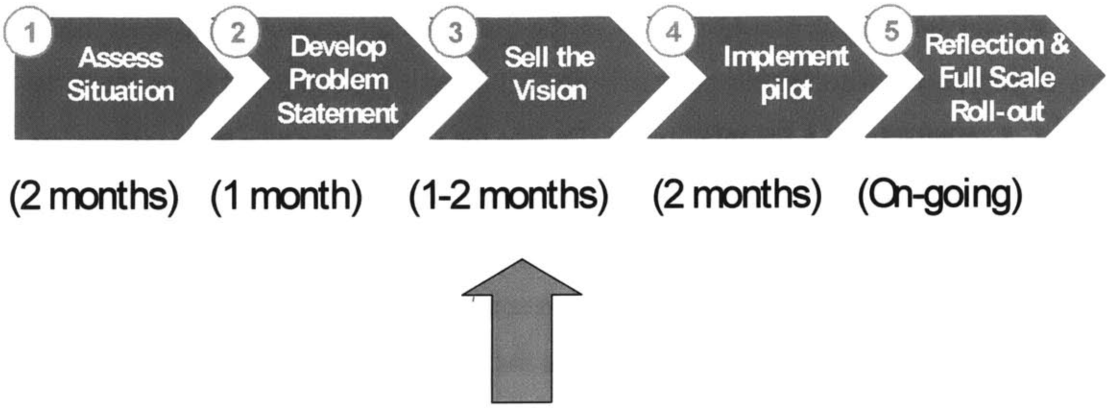

Figure 6.1: Actual project timeline

The second key take-away from my experience leading change on my internship was learning to embrace the role of a satisfier over that of a maximizer. In engineering school students are all taught to be "maximizers" – that is seeking the optimal solution to a given problem. However, it is important in business that the perfect solution doesn't become the enemy of the good (Wheeler 2004). For example, following the analysis of the CSTC supply chain there were two options for implementation. One was the maximizer solution – the theoretical optimal configuration. After further investigation, it became clear that Malaysia and the information technology organization would object to the optimal solution. Therefore, I proposed we implement a near-optimal solution.

The proposed solution required 3% more inventory in the supply chain than the optimal one; however, it was still below the inventory levels currently and would provide a 90% or greater on-time delivery compared with the current 60% results. In her article on negotiation, Wheeler asserts that satisfiers are often more satisfied themselves because they are able to achieve their objectives without requiring a monumental effort to launch changes. This was certainly the case with my project at Agilent which would not have been implemented without the full support of the corporate IT organization or the planners in Malaysia.

This maximizer vs. satisfier framework can also be applied in regard to the influence process described above. It order to get the project approved, many different organizational sub-cultures needed to align. For example, the IT group which supported the ERP system operated in one world, where the timelines for projects were described roughly in years and estimates for particular project completions might shift on the order of months. Conversely, at a manufacturing site like the CSTC, changes were conducted by the hour and the day. This temporal mismatch between two organizations which required cooperation for the implementation of the project was a problem. It was addressed by proposing a staged implementation strategy. Realizing that the optimal ERP solution could take a matter of years, while the CSTC required an immediate solution for OTD issues, the implementation team proposed a staged implementation that allowed both parties to agree to take action today while making sure those actions could be leveraged by future longer-term projects.

6.5 Implications for the future of operational improvements at CSTC

Increasing training for operations personnel is fundamental to driving further improvements at CSTC and throughout the Agilent supply chain. Training is necessary both for those who will be leading the efforts and those who will be doing the actual implementation. Agilent relies heavily on the HP practice of management by objectives (MBO). MBO means that a manager, supervisor, planner or machine operator when given the proper guidance (objectives) is probably better able to make the right decisions about his or her work than some executive. This system places great responsibility on individuals and drives decision making to the lowest levels of the company. As such, all associates must be highly skilled in their disciplines.

With all the turnover and shuffling of jobs in the downturn, some of this skill, particularly in operations, has been lost. The standards for operational efficiency in the industry have also risen over time. Not taking full advantage of standard operations practices means an organization is leaving money on the table, something that no firm in today's competitive marketplace can afford to do.

The return on investment (ROI) for additional training in operations should be reasonable for an organization within Agilent like the CSTC to justify. Consider that other manufacturing organizations are able to increase productivity year over year by up to 10%. It would be reasonable to expect a 5% increase in productivity at CSTC as a result of additional operations training. Any bottom-line cost savings due to productivity enhancements translate directly into the firm's profits, whereas top-line sales revenue increases are reduced by COGS before adding to firm profits. For example, a firm with 50% profit margins that increases total sales revenues by $1, will see an increase in total profits of $0.50. Instead, if the same firm reduces total costs by $1, the firm will see an increase in profits of $1.00. For products with smaller profit margins, the multiplier effect of cost savings is even greater.

Additional operations training would also ease the difficult role of the middle manager. A middle manager at Agilent, like most other companies, must be skilled at translating from the language of things (operations) to the language of money (finance) and back again (Goldratt 1984; Fine 2005). Such bi-lingual abilities require significant skill development which can also benefit from continued training.

6.6 Chapter summary

Implementing this project across multiple decentralized groups required a central focus. For this project, the method was to concentrate on on-time delivery as a unifying metric. In this case OTD resonated with multiple individuals in the supply chain because it already had management attention as a below-target metric, and this helped create a sense of urgency. With the significant premiums Agilent can charge for its high-tech products, the firm doesn't want operations to be the bottleneck. When OTD is too low, operations is a bottleneck costing the firm by delaying incoming cash flow from customers and potentially encouraging customers to switch to competitors products.

This chapter highlighted the implications of the pervasive Agilent culture and organizational context on implementing change in this firm. The chapter also illustrated some methods which were successful for bridging the decentralized groups in the company, such as staging implementation of changes and promoting less than optimal, but better than status quo, solutions in order to gain support from all parties. Finally, the chapter asserts that innovation in operations should not be an oxymoron, and it encourages further training in operations principles and practices for Agilent associates in order to drive additional productivity enhancements.

Chapter 7: Conclusions and follow-on work

7.1 Introduction

This thesis presented a method to characterize a real, functioning supply chain in the context of a changing economic environment and industry structure, as well as in the absence of perfect data. It showed the analysis, recommendations, and results from a particular supply chain case study at Agilent Technologies Inc. It demonstrated how classic text-book operations principles can be applied in practice and highlighted specific roadblocks to be mindful of during operations improvement project implementation. It also discussed the organizational behavior of the firm and the impact of this on the project. This chapter will review the supply chain project and give recommendations for next steps.

7.2 Summary of analysis and recommendations

Although industry cycles in the electronics test and measurement business are outside of the control of Agilent management, internal sources of variability can be minimized. Chapter 3 presented sources of internal variability in the CSTC supply chain by examining internal data from forecasting, planning, and customer order flow. Chapter 3 also considered operations practices regarding capacity, job scheduling, inventory management (raw material, work-in-process and safety stock), and on-time delivery performance. The analysis showed how a system of "launch-and-expedite" had developed in the organization as a coping strategy for demand variability, in the absence of a clear unifying operations strategy.

Recommendations focused on improving on-time delivery. This unifying metric was leveraged to promote implementation of several basic operations principles. Suggestions centered on (1) reducing the amplification of variability due to the supply-chain design and ERP system settings and (2) implementing statistical safety stock as a buffer for demand variability between the CSTC and its internal customers. Specific practical and actionable recommendations were given in Chapter 4.

The current state analysis and recommendations sections of this thesis highlight the importance of understanding basic operations principles. Sophisticated techniques were not necessary to significantly change the outcome and performance of the supply chain studied. In addition, it was important that these basic operations building blocks be put in place prior to implementing more sophisticated methods.

7.3 Results and caveats

Implementation of the recommendations focused on testing the necessary changes for a limited number of parts in the ERP system. The pilot implementation was successful, though as expected, the ERP system was the primary cause of implementation surprises and lessons learned. The results from the pilot project were very important in expanding the use of internal variability reduction and statistical safety stock to additional product lines. Although total supply chain inventory levels during the pilot project suffered from some hiccups in the ERP system and some human errors, project team members understood that the specific results were not statistically significant. Thus, the pilot project served to inspire team members to believe that changing the current state of operations was possible and that they could comprehend and lead this change themselves.

Some cautions about the liberal application of these principles to all products at the CSTC and other Agilent technical centers should be noted. This project focused on those components which represent the largest dollar value percentage of CSTC business. For CSTC they also represented some of the highest volume components. Internal empirical data suggested that for components with a monthly demand below 15 units, order variability increased significantly and would be too high to economically support a safety stock system like the one described. For such components, a make to order system or a safety stock system with a much lower target service level may be preferred. The methodology presented here should be used for 'A' parts, when following traditional operations practice of designating 'A', 'B' and 'C' parts (Spearman 2000).

7.4 Recommended next steps

While associates at Agilent have begun to see a change in operations due to implementation of these operations building blocks to their supply-chain, expansion of this program and follow-on operations work promises to bring more significant improvements. Recommended follow-on work includes[2]:

- **Expansion of the pilot program**
  - Implement recommendations on all 'A' components
  - Expand variability reduction efforts to the contract-manufactured parts (PCBs) supply chain
  - Include effect of lot size to reduce safety stock buffer at CSTC
  - Reduce built-in queueing time in the ERP system for parts, using data recorded for which jobs typically are completed prior to scheduled completion date
  - Set CSTC raw-material inventory levels statistically for key components, such as custom ASICs
  - Work with process engineers to target specific set-ups for time reduction based on economic build quantity analysis
  - Work with ERP experts to eliminate the double buffer between CSTC and partner organizations
- **Improve training programs for operations personnel**
- **Quantify the cost of a stock-out**
  - How many days late is okay? For which products?
  - Is 90% OTD a good target? For all parts?
- **Explore additional bull-whip reduction methods**

[2] Not listed in any particular order

- Consider if pricing behavior by the firm, such as end-of-quarter discounts offered by the sales department, is amplifying variability of orders and quantify this effect in terms of total cost to the firm
- Consider if customers exhibit gaming behavior when placing orders and quantify the effect of this on variability of orders

7.5 Summary

In conclusion, this thesis showed how a combination of macro-economic, business, and organizational factors can lead a well-run company or technical center to adopt a "launch-and-expedite" operations behavior with a negative impact on operational performance. The thesis also showed how it is possible for an organization that finds itself in such a state to rely on basic operations principles to systematically get out of the "launch-and-expedite" system. As such, those involved with the project hope that the insights and lessons learned from this work will be of interest to the general population of manufacturing and operations managers, particularly those in the capital equipment business, who are confronted with increasingly complex supply chain issues.

Appendix A: Effect of forecast translation from months to weeks

We show here that although the translation of the forecast from months to weeks adds to the standard deviation of the forecast error, this effect is not significant in comparison to the magnitude of the typical coefficient of variation for Agilent and thus can be neglected.

In the ERP system used by the CSTC, 2/3 of the months have 4 weeks per month and 1/3 of the months have 5 weeks per month. In other words, each year has 32 weeks that are part of 4 week months and 20 weeks that are part of 5 week months. How significant is the additional variability caused by the system when it translates the demand planners monthly forecast into a weekly one? Consider the following example.

The monthly forecast is for 55 units per month for the entire next year. Then, the weekly plan is for 11 units for 20 weeks or 13.75 units for 32 weeks. For the weekly plan, over the course of the year, we have:

$$\sigma_W = 1.35$$

$$\mu_W = 12.69$$

Normalizing this information so that it is applicable to other monthly forecasts, the coefficient of variation is:

$$COV = \frac{\sigma_w}{\mu_w} = \frac{1.35}{12.69} = 0.1064$$

While this COV is significant for a final assembly site in the Agilent supply chain, given that the CSTC currently sees a COV of 1.4 on weekly orders, the additional 0.1 COV due to the ERP system forecast propagation process is not significant. As can be seen in the following table, the effect on COV will not change depending on the magnitude of the particular monthly forecast, although the absolute value of the variance scales with the magnitude of the forecast.

Forecast	5.5	55	550	5500
Std. dev	0.135	1.351	13.509	135.094
Mean	1.269	12.692	126.923	1269.231
COV	0.106	0.106	0.106	0.106

Table A.1: Effect of magnitude on monthly to weekly forecast translation variability

However, this opportunity to change to weekly forecast data input should be examined as an opportunity for future internal supply chain variability reduction.

Appendix B: Coefficient of Variation for a Poisson distribution

Consider the example from Chapter 3 where each Poisson "event" is an order for 50 units. We show here that the coefficient of variation (COV) is independent of the number of units per event for a Poisson distribution as long as the number of units per event is a constant.

Let $y = 50 * Poisson(\lambda)$

For a Poisson distribution we know:

Mean $\mu = \lambda$

$$\mu_y = 50 * \lambda$$

Variance $\sigma^2 = \lambda$

$$V(y) = 50^2 * \lambda$$

Standard deviation $\sigma = \sqrt{\lambda}$

$$\sigma_y = 50 * \sqrt{\lambda}$$

Therefore, the Coefficient of Variation for the Poisson distribution will simply be:

$$COV = \frac{\sigma_y}{\mu_y} = \frac{50 * \sqrt{\lambda}}{50 * \lambda} = \frac{\sqrt{\lambda}}{\lambda}$$

Appendix C: Economic Build Quantity

Let Q^* represent the optimal manufacturing lot size that minimizes the total cost associated with manufacturing the items. Optimal lot size will be achieved at the point where the incremental set-up costs per unit time are equivalent to the incremental inventory holding cost per unit time. This can be expressed as follows:

D = demand per unit time

K = fixed "set-up" cost per lot

h = inventory holding cost per item per unit time, also known as inventory carrying cost

$$\frac{KD}{Q} = \frac{hQ}{2}$$

$$Q^* = \sqrt{\frac{2KD}{h}}$$

* Note that the same formula applies to calculating the economic order quantity (EOQ), except *K* is the fixed cost per order placed.

As a lower bound, *h* can be set equivalent to the cost of capital for the organization. For inventory that has spoilage costs or significant warehousing costs, the inventory holding cost should be increased to reflect these realities. Although there will always be debate in a firm as to the true inventory holding cost, a bounded estimate should suffice for most practitioners.

More significant to the operations professional is the effect of changes in set-up cost or future demand per until time on the economic build quantity. Therefore, in a high-mix low-volume shop like the CSTC where these numbers are likely to change, it is best to perform a sensitivity analysis and determine an acceptable range for the economic build quantity, rather than a single target figure.

Finally, physical limits need to be considered when setting the EOQ. An example, at the CSTC was images per snap. Each snap might have 24 images of a component. These images would not be separated until mid-way through the manufacturing process. As a result, any specified lot size needed to be in multiples of 24. Another type of physical limit might be an oven, which is a single resource and can only fit a maximum of X units. In this case, set-up costs would be non-linear when the capacity of the oven is reached. In addition, the effects of any process yield being < 100% should also be taken into account when setting lot sizes.

A more complete treatment of traditional economic order quantity calculations can be found in most operations textbooks (Nahmias 1997; Spearman 2000; Simchi-Levi 2003).

Appendix D: Statistical safety stock determination

This appendix provides the statistical safety stock calculation formula for a continuous review, fixed order quantity, fixed lead time system (Q,r model) with a Type II (fill-rate) service level metric. It shows how safety stock settings can be calculated using either common spreadsheet functions, a look-up table or an approximation formula. For a more complete explanation of this formula see a productions and operations management textbook such as the one by Nahmias (1997).

Key assumptions:

- Demand over the lead time can be approximated by a normal distribution with mean (μ_D) and standard deviation (σ_D)
- Demand is independent in non-overlapping time increments
- Forecast errors are also normally distributed with mean (μ_e), standard deviation (σ_e), and they are independent and non-overlapping in time
- Lead time is fixed (L). In practice this assumption can be relaxed and a normal distribution can be used to approximate lead time (Kruger 1997) if again we assume that successive lead times are independent and orders are not allowed to overlap

Note that while any applicable time period can be used (days, weeks, months), in this project weeks were used, as most of the available data was weekly.

Variable definitions:

fr: desired fill-rate (service level percentage) expressed as a decimal

f (k): unit normal partial expectation; also known as the unit normal partial loss function; noted as L(z) in Nahmias (1997)

k: the 'safety factor' as referred to by Brown (1959)

L : lead time in weeks

Q : replenishment quantity (i.e. manufacturing lot size or economic order quantity)

μ_D : average weekly demand during the lead time

σ_e : standard deviation of weekly forecast error

Calculation of safety stock:

$$f(k) = \left(\frac{Q}{\sigma_e * \sqrt{L}} \right) * (1 - fr)$$

Once *f(k)* is known, the value of *k* can be either looked up manually from a chart, like the one on page 109 of Brown (1959) or in Table A-4 of Nahmias (1997). Since manual look-up is not plausible for an automated tool, as developed for calculating safety stocks in this project, two other methods for determining k can be used.

(1) Spreadsheet calculation:

Note that *f(k)* can be broken into two functions and written in terms of *p(t)*

$$f(k) = \int_k^\infty (t - k) p(t) dt = p(k) - k \int_k^\infty p(t) dt = p(k) - k(1 - c(k))$$

where *p(k)* is the normal probability density function and *c(k)* is the cumulative distribution for the standard normal distribution. In this new format, *f (k)* can be directly calculated via standard spreadsheet tools. For example, in Microsoft Excel *f (k)* is:

$$-k * (1 - NORMSDIST(k)) + NORMDIST(k,0,1,0)$$

Since $f(k)$ is known, k can be solved for in Microsoft Excel using the Goal Seek or Solver method to satisfy the function above.

(2) Approximation formula:

k can also be solved for using the natural log approximation formula given by Parr (1972) and Kruger (1997) where:

$$f(k) = e^{\left(-0.92-1.19k-0.37k^2\right)}$$

This is the formula for a quadratic approximation of the unit normal partial expectation, which represents the average quantity backordered, measured in standard deviations.

The following plot shows how these two methods give the same results.

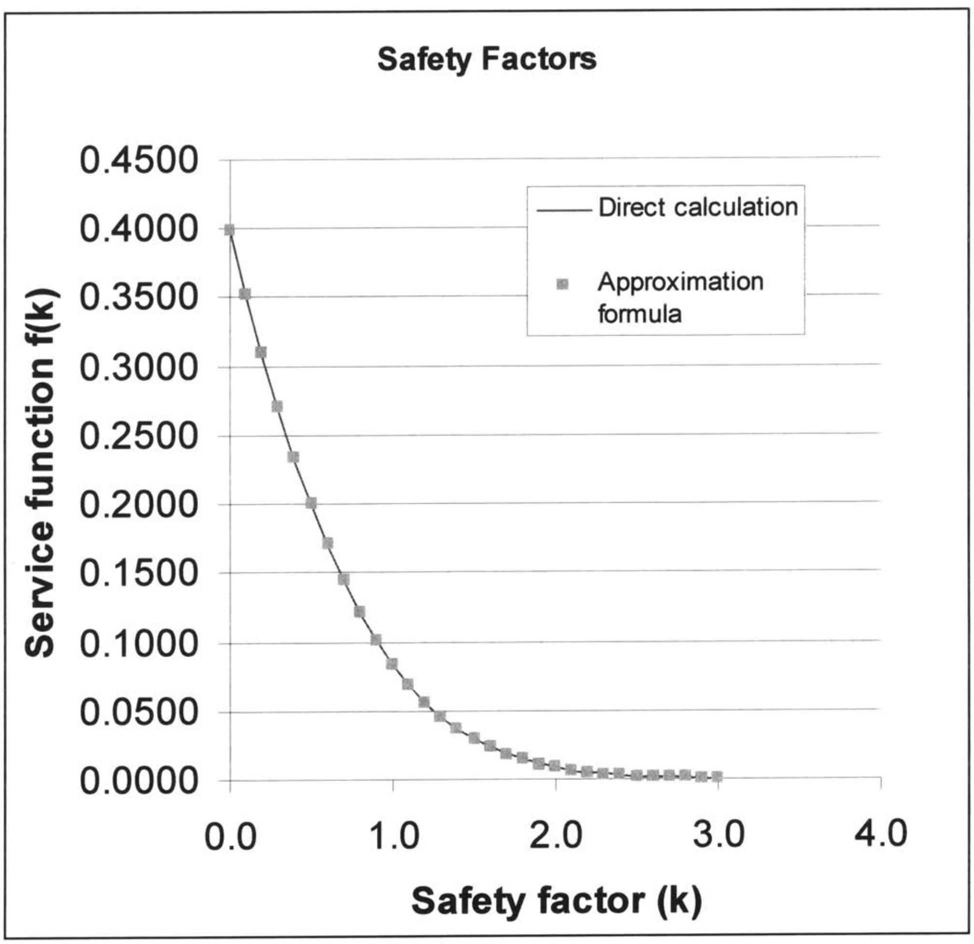

Figure E.1: Comparison of service function calculation methods

Determine safety stock:

Once k has been determined by any of the methods listed above, safety stock will be:

$$SS = k * \sigma_e * \sqrt{L}$$

Aside:

One calculation of interest to management may be to determine what percentage of demand will be filled for a given component simply based on the replenishment lot size, with no safety stock at all.

The value of $f(k)$ for $k = 0$ is 0.3989. Therefore, the fraction of demand filled from stock without delay will be:

$$fr = 1 - 0.3989 * \left(\frac{\sigma_e * \sqrt{L}}{Q} \right)$$

From this simple calculation, management can compare the current position to the increase in inventory (i.e. cost) to achieve a greater service level. Note that for smaller lot sizes, more safety stock will be needed to achieve a given service level.

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