Analysis of New Approaches to Improve the Customer Responsiveness of Intel's Microprocessor Supply Chain

by

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B.S. Civil Engineering, Massachusetts Institute of Technology 1993
B.S. Management Science, Massachusetts Institute of Technology 1993

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

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Master of Science in Civil and Environmental Engineering

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Abstract:
Intel Corporation is looking to strengthen its long-term competitive armor by engaging in new initiatives to develop world-class customer service and build strong customer loyalty. A company's supply chain design and processes often hold the key to how well the company can serve its customers. This thesis looks to unlock new approaches for Intel to improve the customer responsiveness of its microprocessor supply chain. The primary approaches examined include (1) the identification and implementation of customer-focused supply chain metrics through a metrics framework and (2) the application of traditional inventory models and service level to determine optimal microprocessor inventory levels for Intel's die and finished goods inventories. The base stock inventory model is used along with extensions to the model based on work by Graban (1999) and Levesques (2004) that include two-stage inventory analysis along with supply variability inputs. The results of the inventory models are then compared with Intel's current inventory strategy based on heuristics. Next the application of the inventory models are extended to examine the possibility of setting service levels by product segment and the resulting impact on overall inventory mix and inventory levels. Finally, other approaches for improving the customer responsiveness of Intel's microprocessor supply chain are discussed at a high level as potential areas for future research. Many of the frameworks, learnings, and insights from the research done at Intel are transferable to other corporations which seek to make similar improvements to the customer responsiveness of their supply chains.

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Chapter 1. Introduction and Thesis Overview

"The ability of the supply chain to support exceptional customer service
is a differentiator and one of the business battlegrounds for the foreseeable future."[i]

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Chapter 1. Introduction and Thesis Overview

"The customer is always king."

Or so they say. For Intel, the world's largest and most successful semiconductor company, the customer has not always been king. Technology innovation and manufacturing are viewed as king internally as the company's primary core competencies. However, as the high-tech landscape continues to evolve at a rapid pace and as Intel moves more aggressively into new business areas, Intel realizes that its technology and manufacturing advantages may not last forever. Intel recognizes the importance of serving its customers better to build customer loyalty and strengthen its long-term competitiveness. A critical part of becoming more customer-focused is designing and managing a supply chain that is highly responsive to customer needs.

This thesis will analyze the customer-impacting aspects of Intel's microprocessor supply chain and will provide detailed frameworks, analysis, and recommendations on how Intel can increase its responsiveness to customers through the supply chain. The main approaches will focus on (1) company-wide implementation of customer-focused supply chain metrics and (2) optimization of inventory levels and inventory placement by applying traditional inventory models and the concept of "service level." The thesis will also provide preliminary exploration of other potential strategies to improve customer responsiveness based on current understanding of Intel's processes and systems. These approaches provide potential areas for future research to continue improvement of supply chain responsiveness to customers. Many of the frameworks, learnings, and insights from the research done at Intel are transferable to other corporations which seek to make similar improvements to the customer responsiveness of their supply chains.

Customer Service and the Supply Chain

What do customer service and supply chain have to do with one another? As Kevin O'Brien and Mike Schickedanz, supply chain management consultants for MidWest Group explain, "How you design and manage your supply chain can significantly affect your ability to provide the levels of service your customers demand."[ii]

A company's supply chain design from its customer order processes to its manufacturing and inventory systems to its logistics operations to its supply chain metrics all impact how well a company can service its customers.

By examining a company's supply chain operations and making improvements to it, a company can transform its ability to serve its customers. Companies like Gillette serve as real-world case studies as to how changes in a company's supply chain operations can drive dramatic improvements in its ability to service its customers (Duffy, 2004). This was the exact philosophy behind the research conducted at Intel Corporation in the Microprocessor Marketing and Business Planning (MMBP) group from June 2003 to January 2004 in Santa Clara, CA as part of the LFM internship.

Customer Service and Customer Responsiveness

"Customer service" appears to be one of the most ambiguous terms used in business. Its meaning often depends on the context in which it is used. The most common dimensions of "customer service" as it relates to supply chain are summarized in the table below.

Dimension of Customer Service	**Description**	**Example**
Promptness	How quickly were we able to respond back to the customer's request with an answer?	24 hour response to a product request
Availability	Did we have exactly what the customer wanted when they wanted it?	Confirming to the customer that we can meet their requested delivery date and requested quantities
Quality	Did the quality of our product or service meet the expectations of the customer?	All products shipped to the customer were defect-free and excellent quality
Execution	How well did we execute and meet our promises to the customer?	We met the delivery date we promised to our customer for this order.

Consistency	Does the level of service we provide customers vary greatly or is it usually consistent?	We are able to meet a customer's weekly requests exactly as requested 95% of the time with 2% standard deviation.
Flexibility	How well are we able to support customer requests that are exceptions out of the normal expected service?	We are able to immediately support a sudden 20% upswing in demand from a customer with no additional investment.

When one speaks of a company being "customer responsive," these supply chain-related dimensions of customer service come to mind primarily:

1. Promptness: Responding quickly to questions or requests. (Example: "They were very responsive in answering my question.")
2. Availability: Satisfying requests for product exactly in the timing and quantity needed. (Example: "They were very responsive in meeting my needs for 100 units to be delivered by Tuesday.")
3. Execution: Acting to get products quickly to customers. (Example: "They were responsive in getting products shipped to us very quickly.")

A simple customer service framework (the "Customer Responsiveness Framework") was developed for Intel to effectively communicate these three dimensions of customer service which are crucial to Intel's microprocessor business from a supply chain standpoint. (Figure 1-1)

This framework breaks down a typical customer order into the three customer responsiveness elements discussed (Promptness, Availability, Execution) and will act as the common mental model for the rest of the research discussed in this thesis:

- The supply chain metrics approach to improving customer responsiveness looks at all of these three elements and ensures that proper customer-focused metrics are in place to measure and provide visibility for these three areas.
- The inventory modeling approach primarily addresses the Availability dimension and provides models and analysis to recommend optimal inventory levels that balance desired service level to customers and inventory cost.
- Other approaches to increase customer responsiveness discussed in this thesis also touch all the 3 areas of the mental model.

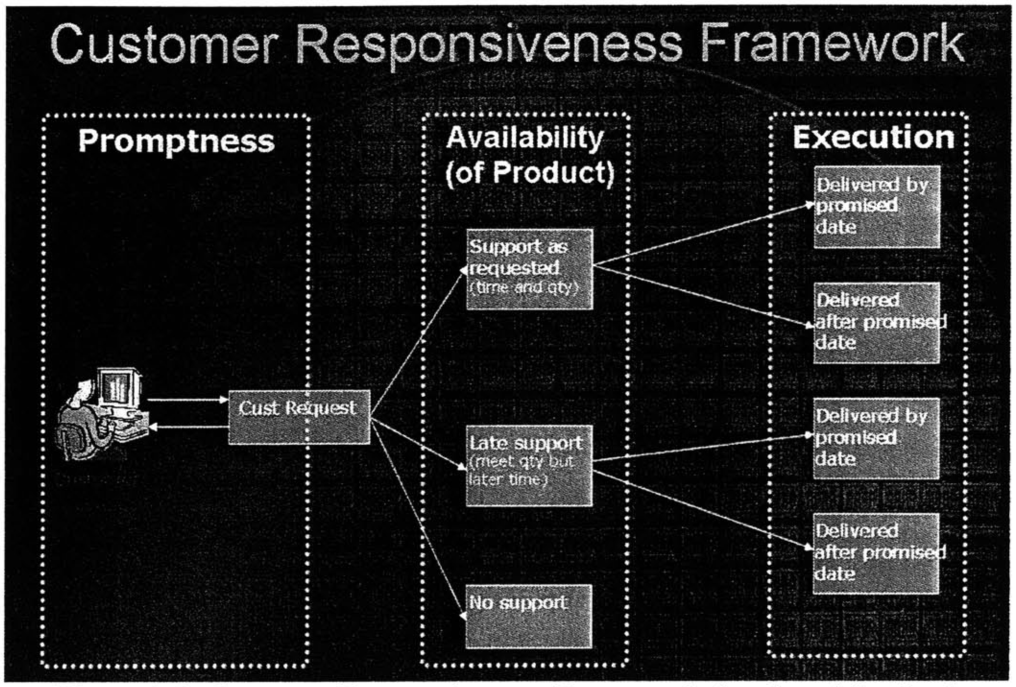

Figure 1-1. Customer Responsiveness Framework developed for Intel

	Customer Responsiveness Dimension		
Summary of Thesis Research Areas	**Promptness**	**Availability**	**Execution**
Implementation of New Customer-focused Metrics (Chapter 4)	X	X	X
Application of Quantitative Inventory Models (Chapters 6-7)		X	
Other Approaches for Improving Customer Responsiveness (Chapter 8)	X	X	X

Thesis Overview

This thesis is divided into ten chapters. This chapter (chapter 1) provides a brief background and introduction to the research discussed in this thesis. Chapters 2-3 examine Intel's microprocessor business today as well as provide an overview of Intel's supply chain and manufacturing processes. These processes provide the background and foundation for much of research discussed in this thesis. Chapter 4 discusses the implementation of relevant customer-focused supply chain metrics, one of which will support Intel's desired direction towards using quantitative inventory models and service levels to achieve optimal inventory levels and inventory mix discussed in Chapters 5-7. Chapter 8 explores other potential ways that Intel can look into improving the customer responsiveness of its supply chain. Chapter 9 examines some of the key considerations in implementing the two main approaches discussed in this thesis from strategic, political, and cultural perspectives. Chapter 10 provides final thoughts and recommendations.

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Chapter 2. Intel's Microprocessor Business

"For the foreseeable future, our core business of microprocessors and chipsets for PCs and servers will produce the majority of our revenues."[iii]

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Chapter 2. Intel's Microprocessor Business

Incorporated in 1968, Intel Corporation is the world's largest semiconductor chip maker supplying advanced technology solutions for the computing and communications industries. The company's major products include microprocessors; chipsets; boards; flash memory; application processors used in cellular handsets and hand-held computing devices; cellular baseband chipsets; networking and communications products, such as ethernet connectivity products, optical components and network processing components, and embedded control chips (microcontrollers).

Intel's Main Business Divisions

Intel is split up into two main businesses: Intel Architecture (IA) and Intel Communications Group (ICG). The IA business provides the advanced technologies to support the desktop, mobile and enterprise platforms. IA's business includes Intel's microprocessor business which constituted about 73% of Intel's consolidated net revenue in 2003. The ICG business focuses on wired and wireless connectivity products and provides key components for networking and communications infrastructure devices. ICG's business also covers component-level products and solutions for the wireless hand-held communications market, which were previously part of the WCCG group merged into ICG at the end of December 2003.

This thesis will focus on the IA part of Intel's business, particularly around Intel's microprocessor products.

Intel's Microprocessor Business

Intel's microprocessors function as the central processing units (CPUs) of computer systems. These microprocessors process system data and control other devices in the system, acting as the "brains" of computers. For many years Intel has been the dominant

CPU manufacturer and is the market leader in many segments of the market. Intel has primarily accomplished this through its strengths in microprocessor design, manufacturing, and marketing.

Intel's microprocessor products are segmented into three main categories:

1) Desktop – desktop computers and entry-level workstations
2) Mobile – notebook computers
3) Server – high-end servers and workstations that often have multiple microprocessors working together.

Intel's main customers in the CPU space are OEMs (Original Equipment Manufacturers), ODMs (Original Design Manufacturers), and channel customers that include distributors, resellers, and retailers all around the world. Figure 2-1 is a diagram of Intel's Value Chain (Rassey, 2003) extended to include ODMs.

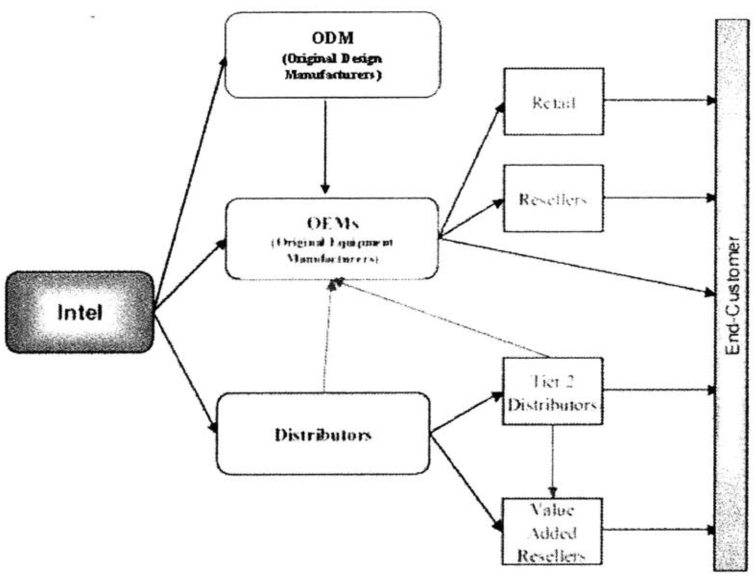

Figure 2-1. Intel's Value Chain

Most of the power in the value chain resides with the OEMs which make up the majority of Intel's total revenues. However, channel customers like distributors, resellers, retailers (generally categorized as "distributors" in the diagram) are extremely crucial in helping Intel reach customers in developing countries like Russia and India. Another group of customers growing in influence and size are ODMs. ODMs build and design products (such as PCs and other electronics devices) for OEMs which then market and sell the products under their own brand names.

Intel's microprocessor business generally has followed seasonal demand trends. For the past five years, the company's sales of microprocessors were higher in the second half of the year, primarily due to back-to-school and holiday demand.

Intel Microprocessor Customer Sales Process – CCP Process

Customers (direct OEMs or channel customers) who wish to order CPUs from Intel typically do not encounter the common first-come, first-served process that most other high-tech companies have. Nor are they given a standard lead time like electronics component manufacturers give to their potential customers. Instead, Intel's CPU customers go through a sales process that is more similar to an allocation-based sales process that other high-tech companies adopt only when supply is limited.

Instead of a first-come, first-served customer service model, Intel uses what is called a "corporate commits process" (CCP) to address customer requests for CPUs.
The primary goals of CCP are to (1) ensure fair and adequate distribution of CPU supply across all customers and geographies and (2) ensure that Intel does not make supply commitments greater than the available capacity of its semiconductor fabrication plants ("fabs") since the cost of additional fab capacity is extremely costly in the billions of dollars for each fab.

Without the CCP process, some customers may try to game available CPU supply in situations where there is an anticipated product shortage or current shortage to ensure supply for themselves and/or keep competitors from getting supply. For example, in a scenario where there is a short supply of hot CPUs in high demand, Customer A might want to buy as many as possible to ensure their own supply as well as to prevent Customer B from getting the quantities that they need, and vice versa. The CCP process minimizes the risks to companies from such possible gaming. CCP also keeps internal

Intel sales groups honest. For instance, in a CPU shortage scenario, one of the four geographies might ask for as many CPUs as possible to maximize its own sales regardless of whether this may hurt sales in other regions. Finally the CCP process keeps Intel from promising more product that it can provide based on its anticipated fab capacity.

Figure 2-2 provides a simplified high-level map of the CCP process:

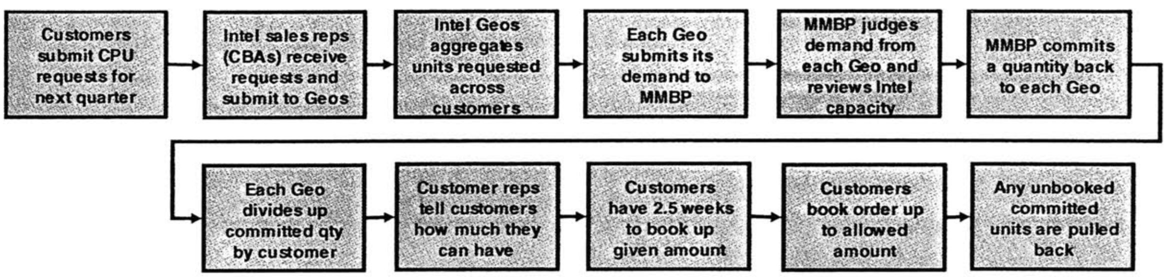

Figure 2-2. Intel Corporate Commits Process (CCP)

With CCP, at the beginning of every quarter customers submit to Intel what quantity of CPUs they expect to buy in the next quarter. Then each of Intel's 4 Geos (geographies: ASMO, APAC, IJKK, EMEA) rolls up the quantities from each customer and reports this to MMBP (Microprocessor Marketing and Business Planning). MMBP then "judges" the demand based on Intel's current strategy, future price moves, supply, and capacity and communicates a committed quantity back to each Geo. The GBA (geo business analyst) at each Geo divides its geographic committed units across the customers in that Geo and alerts all the Intel CBAs (customer business analysts). The CBAs then give the commits to customers and customers have 2.5 weeks to place orders or "book" orders up to their committed amount. Customers place their orders through WOM, Intel's Internet-based web order management website, or through their CBAs. After the order booking deadline for customer commits, Intel "pulls back" any remaining committed units that were not booked and puts those units back into the general inventory pool. Customers are not required to book all the units that were committed to them and there is no penalty for unbooked units.

Although the CCP process is disliked by some of Intel's customers because of the extra steps and because customers cannot order the amounts they want anytime they want, overall the CCP process has worked well to ensure a fair and equitable supply across all customers and geographies. It also has given customers assurance that they will not be shut out of supply in times of product shortages. However, CCP introduces slower customer response and more complexity than traditional first-come, first-served customer sales processes such as available-to-promise (ATP). The CCP process also requires significant human intervention across a number of groups every quarter to confirm product availability and determine how much of a customer's requested quantity can be supported. In many companies with Internet-based order interfaces that connect with internal ATP inventory systems, customers can get automated and immediate product request grants and order confirmations. There might be better approaches than CCP that may achieve the same goals but increase responsiveness and flexibility for Intel's customers. This is not within the scope of this research but may be a valuable topic for future research.

Intel Microprocessor Customer Sales Process – Hotlist Process

For changes to existing booked orders ("bookings") or additional requests for product 0-13 weeks in advance, customers go through Intel's "hotlist" process. The hotlist process allows customers to submit changes to what they had ordered already for the next 0-13 weeks and get an answer back from Intel. Today hotlist response time (from the point a customer submits a hotlist request to the time the customer gets a response) ranges anywhere from 1 day to 1 week.

There are 4 common types of hotlists:

Hotlist Request Type	**Description**
Upside	A customer request for additional units of product in a given workweek (WW). This is the most common type of hotlist request.
Swap	A customer request to cancel already booked units in exchange for additional units of another related product.
Pull-in	A customer request to receive product booked for a future date to be delivered in a WW earlier in a quarter.

Push-out	A customer request to push out in time the delivery of product that has been committed and booked.

Figure 2-3 provides a simplified high-level map of the hotlist process:

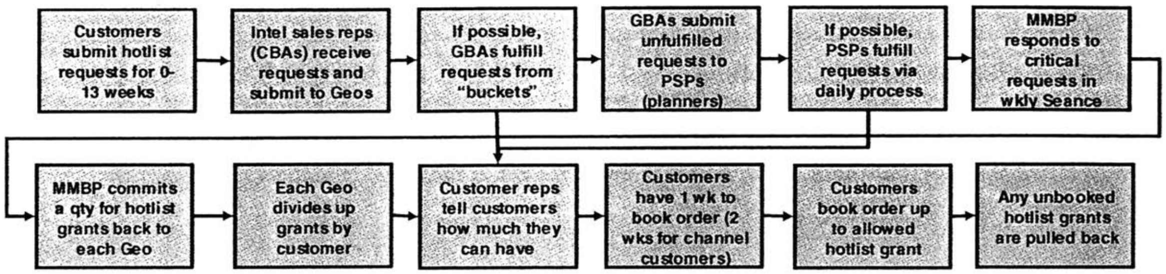

Figure 2-3. Intel hotlist process.

Within 13 weeks of desired product delivery, customers submit hotlist requests to the CBAs at Intel. CBAs then submit these requests to the GBAs at their respective Geo. The GBAs first check their sustaining buckets (units of active SKUs with excess inventory that have been committed to each Geo) and fulfill any hotlist requests from these buckets and let their CBAs know. Next the GBAs escalate the remaining unfulfilled hotlists to PSPs (product supply planners) in Division. If there is sufficient inventory, the PSPs give the GBA a hotlist grant in the form of committed units for that Geo. For critical hotlist requests which are still unfulfilled, they are escalated to the weekly Séance meeting for resolution by MMBP. Out of the hotlist requests granted during the Séance meeting, the PSPs grant each Geo a number of committed units that the Geo can then divide up across its customers. Customers find out the number of units that they have been committed to them from their CBAs and have 1 week to book the orders (2 weeks for channel customers). After the hotlist booking deadline, Intel "pulls back" any remaining committed hotlist units that were not booked to support future hotlists. Customers are not required to book all (or any of) the units that were committed to them through hotlist requests and there is no penalty for unbooked units.

The hotlist process is valuable to Intel and its customers in that it allows customers to submit "last-minute" requests to respond to unexpected market changes or forecast error. However with the current process, customers, who often have urgent requests and would like prompt responses, have to wait anywhere from 1 day to 1 week for Intel's response to their hotlist requests. Like the CCP process, the hotlist process today requires significant human intervention and cannot provide customers with quick immediate response. Other companies with Internet-based order interfaces that connect with internal ATP inventory systems can provide customers with automated and immediate responses even for change requests. This is also an area that possibly can be re-engineered to require less human involvement and quicker customer response. One current pathfinding initiative to address these issues specifically is the WICIT project. WICIT is attempting to build tools and automation to empower Geos with more real-time information to reduce the need to escalate requests to Division and MMBP so Geos can provide rapid response to customer hotlist requests.

One challenge with the hotlist process today is that it does not provide incentives to deter gaming by customers. Customers can submit hotlist requests, be granted additional units, and end up booking no additional units without penalty. This gives customers no cost safety blankets a week at a time (and channel customers two weeks) since unbooked units are pulled back after a week for direct OEM customers and after two weeks for channel customers. This potentially hurts other customers who may have real needs and are intending to book orders for units granted to them via hotlists.

Another common way of gaming supply using hotlists is to request and book up as many hotlist units as possible with no specific intention of using these units. Because of Intel's apparent generous and no-penalty cancellation terms with large customers, often large customers will book up a number of extra units granted from the hotlist process and then cancel these units at the end of every quarter without penalty. To customers, this provides a valuable and no-cost insurance policy for CPU supply every quarter. However, this potentially takes units away from other customers who have real demand for these units and reduces revenues for Intel.

Customers also game supply and potentially cause problems in quarterly production schedules in the following way: to hedge demand uncertainty, customers might submit hotlist requests and book up much more than needed in the first weeks of a quarter. Then as weeks pass in the quarter, customers do not end up needing the units and then request "push-outs" to push these units to later in the quarter. Since these units have already been built and committed for these customers, customers are guaranteed supply availability later in the quarter (as compared to booking up more than needed at the end of quarter and not having pull-in requests fulfilled). And once the end of quarter approaches, customers can cancel the orders with little or no penalty. This is another way customers can game the system and get an insurance policy on supply.

One final way customers are noticeably gaming supply through hotlist requests is by requesting additional upsides without canceling other existing orders until the end of the quarter in swap situations. Especially in cases where Intel's customers are not certain which of several products will resonate best with their customers, Intel's customers will try to hedge their bets using upside requests. Customers might already have orders booked for one product and then request upsides for another related product. In reality they will sell only one of these products and should be submitting a swap (cancellation of 1 product and an upside of another) instead of an upside request. However, because it is difficult for Intel to discover the real intentions of customers, this is another common way customers game Intel's CPU supply.

The hotlist process is another area of potential research for Intel. Perhaps there are more effective approaches of providing a hotlist-type process that discourage and prevent the gaming that has been discussed above. By reducing this gaming, supply availability may improve for customers and also improve responsiveness. However, this is not in the scope of the current research. This will be discussed further in chapter 8 as one of the other potential approaches to improve customer responsiveness for Intel.

Chapter 3. Intel's Microprocessor Supply Chain and Manufacturing Overview

"Imagine if you had to build 100 million units a year of something that takes hundreds of complex steps to make, requires plants and equipment that cost billions, has a very short life-cycle, and faces ever-increasing customer expectations for more functionality while prices continue to drop… that's Intel."[iv]

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Chapter 3. Intel's Microprocessor Supply Chain and Manufacturing Process Overview

This chapter discusses Intel's microprocessor supply chain and high-level microprocessor manufacturing processes. This overview will provide a valuable foundation for the discussion of metrics and application of inventory models at Intel in subsequent chapters.

Current Supply Chain Organizational Model

At Intel, supply chain functions are decentralized across the company. There does not appear to be any central organization at Intel that defines corporate-wide supply chain strategy and coordinates supply chain activity across organizations. Responsibilities for Intel's supply chain functions are dispersed across multiple organizations including MMBP, Planning, ISNG, EBG, WCST, and SMG.

MMBP

Microprocessor Marketing and Business Planning (MMBP) is the organization which manages the demand forecasting and supply responsibility for Intel's microprocessor and chipset businesses. MMBP is responsible for determining the global demand forecasts for all of Intel's microprocessor products from the marketing and sales perspective. MMBP's demand forecast (internally referred to as Judged Demand) is the demand forecast that is used as the primary input to drive short-term (0-12 month) production planning. From a supply standpoint, MMBP monitors ongoing product supply and customer demand and addresses supply issues when demand exceeds supply. MMBP also takes major responsibility in planning for product transitions from EOL products to new products. In addition to supply and demand, MMBP's responsibilities include product pricing and long-range business planning.

Interestingly enough, MMBP reports to the Desktop Platforms Group (DPG) within Intel's organization, although its demand and supply responsibilities tend to cover products in other divisions beyond DPG, including the Mobile Platforms Group (MPG), which manages the mobile computing (laptop) portion of Intel's business, and the Enterprise Platforms Group (EPG), which manages the enterprise server portion of the business.

Planning

Planning is part of the Manufacturing organization TMG (Technology & Manufacturing Group). PSPs (product supply planners) interface with MMBP and sales personnel to manage last minute requests from geographic sales teams as well as dealing with planners at ATM (Assembly and Test) sites when there are last minute product issues. Planning's main function is to ensure that Intel's Fab and ATM sites are building enough product and holding enough inventory to meet short-term customer demand.

Intel Supply Network Group (ISNG)

ISNG deals primarily with the logistics part of the business and ensures that there is a cost-effective infrastructure for getting products to direct customers and to channel customers on-time and as promised. ISNG is the closest Intel has to a pure "supply chain" group but the group tends to focus mostly on logistics.

E-Business Group (EBG)

EBG is the most synonymous to the IT organization of most companies and its main function is to understand Intel's business at a detailed level and lead projects that will streamline Intel's processes and operations, especially from an IT perspective. Several of EBG's current key initiatives relate to the supply chain: (1) Edge-2-Edge (E2E) – improving the ability for planning and manufacturing to reset their production plans more rapidly to adjust for market changes and customer needs. (2) Edge-2-Customer (E2C) – improving the customer focus and responsiveness of Intel's entire supply chain. The research being discussed in this thesis is very closely connected with both of the E2C and E2E initiatives.

Sales and Marketing Group (SMG)

Sales and Marketing is responsible for all direct interactions with Intel's customers and is the group that manages all customer orders and deals with customer issues. CBAs (customer business analysts) and GBAs (Geo business analysts) play a key part in filtering hotlist requests before they are escalated up to Planning and MMBP. Members of the Geo sales management team provide key input which is used by MMBP to determine Judged Demand.

Worldwide Customer Satisfaction Team (WCST)

WCST's charter is to deliver value to customers through operational and supply chain initiatives that lead to greater customer commitment and revenue while optimizing Intel resources. Its focus has been cost effectively improving the customer experience. WCST is typically engaged in any supply chain initiatives involving customers and provides expertise into customer-facing processes.

IACPU Demand Forecasting Process

As mentioned above, MMBP is the organization responsible for the ultimate demand forecast from marketing and sales (the "Judged Demand") that drives manufacturing and production decisions and plans. When the Judged Demand (JD) forecast is refreshed monthly, updated quarterly forecasts for the next 0-12 months are provided for each microprocessor product at the SKU level.

Every month Intel's largest CPU customers are polled on how many CPU units they plan to purchase in the next 12 months at the product family level. Next the sales teams in each of Intel's four Geos make judgments on the demand forecasts from the customers, adjusting for any double counting of market share wins across customers. Then each Geo submits demand forecasts for their respective geographies to MMBP.

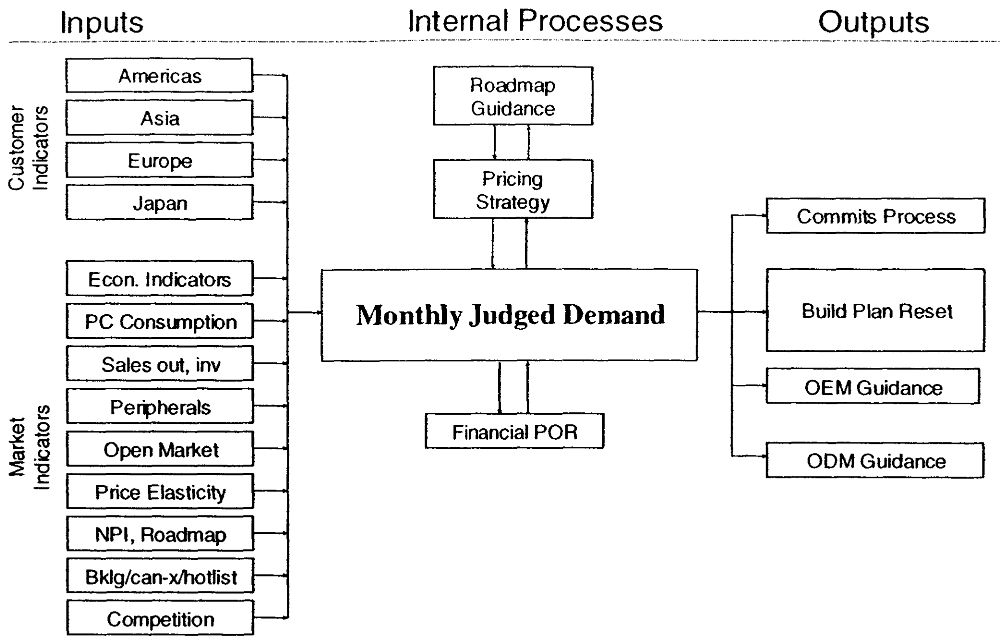

Figure 3-1. Intel CPU's Judged Demand Process

The final Judged Demand is derived by MMBP through detailed analysis using the forecasts from each Geo sales team along with many other relevant inputs including: historical demand data, product and platform roadmaps, pricing strategy, PC BOM costs, customer forecasts, backlog, market segmentation strategies, data on competitors, economic indicators, PC consumption data, industry analyst forecasts, and the human intuition of analysts on the demand forecasting team. (Figure 3-1)

For Intel's short-range CPU forecasts (0-12 months into the future), the demand forecasting team does not currently employ any advanced statistical forecasting techniques that are typically part of traditional inventory theory (e.g. Exponential Smoothing, Winter's Model, etc.) Although MMBP uses a 3rd party demand planning software solution to store and manage demand data, the software's statistical forecasting functionality is not used as input in determining Judged Demand for the CPU business. For long-range CPU forecasting (1-5 years into the future), MMBP leverages information from Intel Corporate Market Research which does employ sophisticated statistical and econometric models, growth models, and country-by-country surveys on PC penetration, affordability and desirability.

Forecasting demand for CPUs is extremely challenging given the dynamics of the PC industry, short CPU product life cycles, sensitivity of the market to CPU price changes, and many other factors. Despite these challenges, MMBP had an average forecast error of only < 2% in 2003 in its quarter-level monthly forecasts for all CPUs. At the product family level, forecast error was ~5-10% in 2003. However, there does appear to be significantly much more error and variability when Judged Demand is being determined for products at more disaggregated levels like the sku level. This forecast error and forecast error variability directly impacts how much safety stock inventory Intel needs to hold to provide specific levels of service to customers, as discussed in a later chapter. It might be valuable for MMBP to re-explore the possibility of using advanced statistical forecasting techniques as another key input into determining Judged Demand (and not as a replacement for the Judged Demand process), especially at product levels below the product family level.

Build Plan Reset Process

Once planning receives the Judged Demand from MMBP, planning then takes this input to define a production build plan for Fab and ATM. One of the challenges in the build plan process (among many challenges) has been converting Judged Demand, which is reported in quarterly time periods, into monthly and weekly build plan numbers for Fab and ATM. Intel CPU demand is typically not linear throughout the quarter. Intel had been using the heuristic of 30%-30%-40% to split Judged Demand into the 3 months of a quarter since demand historically appears to be backloaded in every quarter. In late 2003 Judged Demand at the monthly granularity level was implemented to replace the need for the 30%-30%-40% heuristic with the goal of providing more accurate monthly forecasts. Once the monthly forecast is established, a weekly build plan is defined, assumably by dividing the monthly forecast by 4.

Build plans historically had been reset about once a month but in late 2003 a mid-month build plan adjustment process was also been implemented to enable Intel's CPU supply chain to be more responsive to customer changes. This mid-month build plan update is not a complete build plan reset yet because of the complexity involved in a full build plan reset but is moving towards that.

The inventory models in this thesis assume that build plan reset and the lag time to get a new request for die into the system and into the build plan still take about 4 weeks. As the inventory models will show later, shortening this lag time or build plan reset time can decrease WIP inventory requirements directly as well as reduce safety stock requirements.

Microprocessor Manufacturing Process

From a general supply chain standpoint there are two major stages in the manufacturing process of microprocessors (simplifying significantly since each one of these are extremely complicated processes and involves hundreds of detailed steps):

(1) Semiconductor Fabrication (Fab)
(2) Assembly/Test (ATM)

The Fab stage is the process of converting raw silicon wafers to finished die.

The ATM stage is the process of assembling and packaging the die into its final microprocessor finished product in either tray or box media.

Safety stock inventory is held at two main areas:

(1) Die safety stock (ADI – Assembly Die Inventory) is held at each ATM site and new die units are shipped from Fab sites worldwide.
(2) Finished goods (FG) safety stock is held at components warehouses (CW) close to the ATM sites and new FG units are provided by the ATM sites.

Figure 3-2 illustrates Intel's microprocessor manufacturing process.

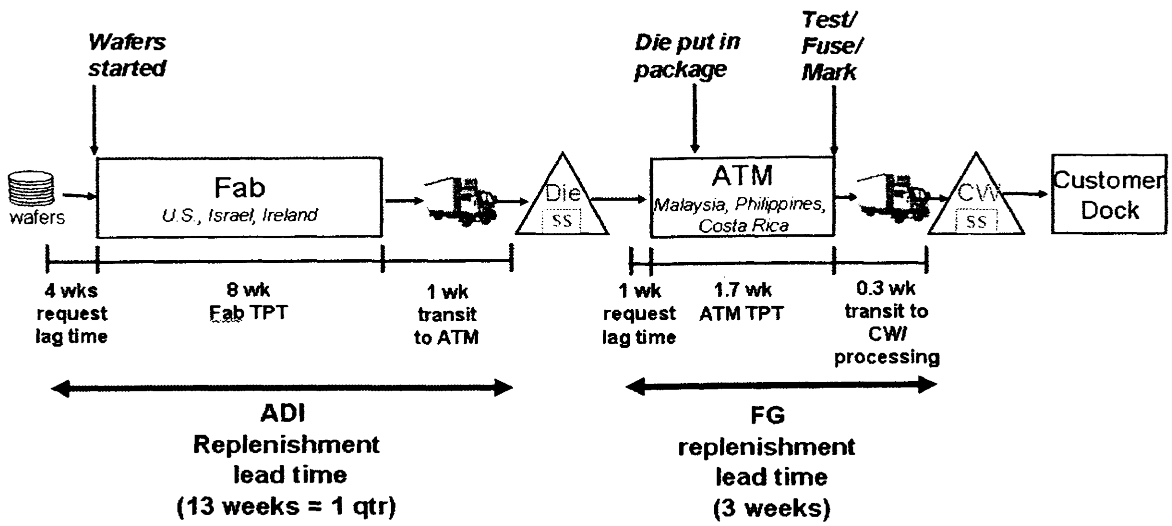

Figure 3-2. Manufacturing process and lead times for microprocessor products in tray format.

For the sake of simplicity, inventory which is held at distribution hubs and at supplier sites through channel JMI (joint managed inventory) is assumed to be a relatively small amount and ignored.

Intel's Fab sites are in Oregon, Arizona, New Mexico, Massachusetts, California, Colorado, Israel, and Ireland. Intel's ATM sites are in Malaysia, Philippines, Costa Rica, and China.

ADI Replenishment Time

From a lead time standpoint, the Fab process itself takes about 8 weeks. It takes about 1 week for die manufactured from the Fab process to be shipped to an ATM site. With the current build plan reset process discussed previously, it takes about 4 weeks to get a request for additional die into the Fab build plan. Thus, in general, the die replenishment time is about 13 weeks (1 calendar quarter). Recently a partial mid-month build plan update process has been piloted to allow new requests for die to get into the build plan on a 2-week cycle instead of a 4-week cycle. However, the inventory models discussed in this thesis will continue to assume a 4 week request lag time.

FG Replenishment Time

It takes about 1.7 weeks to take die, assemble, and package it into a finished microprocessor product state. Then it takes about 0.3 weeks to take the product from the ATM site and move it into the components warehouse where the product is processed and made available for shipment. With the current ATM process, it takes about 1 week to get a request for additional units from ATM (assuming that there is die available). Thus, the replenishment lead time for finished goods is 3 weeks for tray format (which is illustrated in Figure 3-2). For finished goods which need to be packaged in boxes (box media) for channel distribution, 2 additional weeks are required. Thus for box format, the replenishment time is 5 weeks. However, since the bulk of Intel's sales are in tray format sold to the global PC manufacturers, the research in this thesis will focus on the 3 week replenishment time for tray finished good products.

Chapter 4. Implementing Corporate Customer-Focused Supply Chain Metrics

"You can't get any better if you don't know where you are"[v]

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Chapter 4. Implementing Corporate Customer-Focused Supply Chain Metrics

One of the prerequisites for improving customer responsiveness is ensuring that proper corporate-wide supply chain metrics are in place to measure and provide visibility to those aspects of the supply chain that impact customer service the most. This chapter will examine how Intel measures customer service today from a supply chain perspective, provide a gap analysis for Intel's current approach, and provide recommendations for implementing a comprehensive set of customer-focused supply chain metrics.

Measuring Customer Service Today

After interviews with 15+ people from Intel's MMBP, supply chain, and planning groups, it appears that Intel today does not regularly measure and monitor a comprehensive set of customer-focused metrics.

Intel's CPU business appears to track customer service in three ways:

1) Delivery fulfillment performance using RGID/EGID
2) Hotlist Request Fulfillment using % Hotlists Supported
3) CCP Product Request Fulfillment using % CCP units supported

Measuring Delivery Fulfillment Performance using RGID/EGID

The main metrics that Intel's CPU supply chain related groups appear to monitor regularly are ones that relate only to internal delivery performance: % RGID late and % EGID late.

"<u>% RGID (Requested Goods Issue Date) late</u>" measures the % of total shipments where finished goods have left the warehouse later than the estimated date needed to give the transportation provider enough time to meet the customer's requested delivery date.

"% EGID (Earliest Goods Issue Date) late" measures the % of total shipments where finished goods have left the warehouse later than the earliest possible date (e.g. the best possible delivery date) that Intel could have achieved based on current conditions.

Figure 4-1 is a sample of the weekly % RGID late and % EGID late report.

Intel tracks these RGID/EGID-related indicators weekly and publishes them to a large email distribution list that includes staff as well as executives within MMBP and Planning. Since performance bonuses for planning and supply chain executives are tied to this metric, executives are held accountable and incentivized to monitor how well Intel's CPU supply chain has performed to these metrics.

June ACT Delivery Performance (WW25)

* **Direct VOC RGID meets the <10% goal. Currently at 6.7% (1.5% degradation from WW23).**
* **Direct VOC EGID meets the <5% goal. Currently at 1.8% (0.4% degradation from WW23).**

	RGID (% late)			[redacted]	EGID (% late)		
	Jun ACT	May ACT	Apr ACT		Jun ACT	May ACT	Apr ACT
Internal	0.0%	11.5%	11.3%		28.6%	12.6%	13.1%
Direct VOC	3.0%	4.6%	6.2%		1.8%	2.0%	3.1%
Product1	7.4%	4.3%	6.3%		4.2%	1.8%	3.8%
Product2	0.0%	9.4%	12.5%		0.0%	0.0%	2.1%
Product3	0.0%	9.4%	12.6%		0.0%	2.2%	4.3%
Product Group1	**6.7%**	**4.7%**	**7.0%**		**3.7%**	**1.8%**	**3.8%**
Product4	0.0%	15.6%	11.5%		0.0%	0.0%	1.7%
Product5	0.0%	8.3%	18.8%		0.0%	2.9%	3.7%
Product6	0.0%	3.4%	6.2%		0.0%	2.8%	2.2%
Product7	0.0%	33.3%	16.7%		0.0%	0.0%	20.0%
Product8	0.0%	4.9%	7.3%		0.0%	3.1%	2.8%
Product9	0.0%	6.3%	7.5%		0.0%	2.9%	2.6%
Product Group2	**0.0%**	**5.1%**	**7.5%**		**0.0%**	**3.0%**	**2.7%**
Product10	0.0%	4.0%	3.4%		0.0%	1%	4%
Product11	0.0%	4.0%	3.2%		0.0%	1.4%	1.2%
Product12	0.0%	2.3%	6.0%		0.0%	1.6%	4.0%
Product Group3	**0.0%**	**3.7%**	**3.7%**		**0.0%**	**1.3%**	**2.2%**

Figure 4-1. Sample of Intel's weekly % RGID and EGID late report.

It is difficult to review historical data trends since this data is stored on weekly spreadsheets in a shared network directory and would require manual retrieval of information from all these spreadsheets.

Measuring Hotlist Request Fulfillment using % Hotlists Supported

The only other main metric that Intel appears to track regularly is % hotlist requests supported. The Intel Planning and MMBP groups review this metric every week to gain visibility on what % of total units requested by customers through hotlists that arrive during the week are supported. Hotlist support is important since often these hotlists are critical last-minute product requests from customers who have realized that their product needs have changed in the near-term 0-13 week horizon. Since hotlist requests are customer requests for product and how well Intel supports these hotlist requests impacts how flexible and responsive Intel is as a supplier, hotlist support measurement is a valuable area to measure.

Intel tracks % hotlists supported at an aggregate level for all CPUs as well as by product family level through summaries in Excel which are sent to a distribution list each week. % hotlist supported today includes both % of total units supported as requested (meeting requested quantity and timing) AND % of total units supported with alternate linearity (meeting requested quantity but not in the timing that the customer originally requested).

Today this metric is not tied to any specific performance bonuses but viewed as useful data to drive future decisions. It is difficult to observe historical data trends since this data is stored on weekly spreadsheets in a shared network directory and would require manual retrieval of information from all these spreadsheets.

Measuring CCP Product Request Fulfillment using % CCP units supported

One other customer-focused metric that is measured today by Intel's MMBP group and reviewed after the end of every quarter is % CCP units supported. This metric captures the % of total units requested by customers during the regular CCP process that Intel is able to fulfill. Since customer product requests for CPUs either come as CCP requests or hotlist requests, this metric is also important to measure.

Today this metric is not tied to any specific performance bonuses but viewed as useful data point to drive future decisions.

Analysis of Current Metrics Today

Based on the supply chain metrics that Intel has in place today as described above, Intel's current metrics relating to customer service appear incomplete and internally-focused.

First, the primary delivery performance metrics being used today (% RGID late, % EGID late) focuses on internal performance. These metrics answer how well Intel is performing in getting goods out the door in time to be delivered by logistics providers to customers, but they do not provide any visibility into whether the customer actually received their goods by their requested and promised dates. Intel might be able to meet its RGID date for an order and get the goods out of the warehouse to give logistics adequate lead time, but if logistics is late in its delivery, customers still regard Intel as being late despite Intel meeting its internal RGID date. Thus, a low % RGID late or % EGID late performance does not necessary lead to a high level of service to customers. To provide a true picture of customer service, Intel needs to capture data on when customers actually receive their goods and whether the quantity is what was requested.

Second, the metrics above do not provide a complete picture of customer service. There is no visibility into how promptly Intel is able to respond to customer requests and there is no complete picture of how well Intel is meeting customer requests. For example, suppose Intel addresses the gaps in how it measures delivery performance and executes well on accurate delivery performance metrics. Even if this may be the case, this does not automatically imply that Intel is providing superior customer service. Does Intel take 5 minutes or 5 days to give an answer to a customer when a customer submits a request for product? What percentage of units requested by customers is Intel able to meet in the timeframe and quantities that customers want? A 95% delivery performance level when

Intel isn't able to support over 50% of the units demanded by customers is still not very good customer service.

Recognizing that improving customer service is a key priority for the company, Intel executives formed a cross-functional corporate initiative called Edge-2-Customer (E2C) that focused on improving all aspects of customer responsiveness at Intel. A subgroup of that initiative, the E2C metrics team, was chartered to identify a comprehensive set of customer-focused metrics to provide a more complete picture of customer service for Intel's microprocessor supply chain. The author of this thesis was an active participant in the E2C metrics team and the rest of the chapter describes many of the concepts and frameworks that were introduced by the author and implemented as a part of the E2C team.

Gap Analysis and Proposal for New Customer-focused Supply Chain Metrics

In identifying new proposed customer-focused supply chain metrics and filtering out which ones would be most relevant, three frameworks were heavily drawn upon:

1) Customer Responsiveness Framework (as discussed in chapter 1) – This framework was extremely helpful in dissecting a typical customer order interaction into its important customer responsiveness dimensions of Promptness, Availability, and Execution
2) SCOR Supply Chain Metrics Framework - The SCOR (Supply Chain Operations Reference) Model was developed by a supply chain consortium called the Supply Chain Council. It has been invaluable in providing specific "industry standard" supply chain baseline metrics that supposedly have been adopted by 800+ companies across the globe.
3) AMR Supply Chain "Metrics Pyramid" Framework - A metrics framework created by AMR Research was leveraged significantly to help prioritize and organize the numerous metrics that were brainstormed as potential measures of customer service in Intel's CPU supply chain.

Customer Responsiveness Framework

Using the Customer Responsiveness Framework that was developed for Intel and discussed in chapter 1, the following aspects of the three customer responsiveness dimensions were identified as potential candidates to be measured:

Dimension of Customer Responsiveness	**What is Important to Measure?**	**Potential Way(s) to Measure**
Promptness	How quickly are we typically able to respond back to the customer's request with an answer?	Total cycle time from a customer submitting a request to receiving a specific answer back.
Availability (of Product)	How often were we able to meet the customers' needs in quantity and timing?	% of time periods/total units/total line items supported as requested
Execution	How often do we meet our delivery promises to the customer?	% of time periods/total units/total line items/other that met promised delivery date

SCOR Metrics Framework

The SCOR Metrics Framework provided a comprehensive set of supply chain metrics that encompass all areas within a company. These metrics were organized into 3 main areas: (1) Customer facing, (2) Internal facing, and (3) Shareholder facing. Along with this framework came working definitions, benchmarking sources, and suggested Level 2 and Level 3 metrics drill downs.

The customer facing metrics in the SCOR model were most directly related to the research discussed in this thesis. Theses customer-focused metrics provided a key "industry standard" baseline which the E2C metrics team referenced often in defining Intel's new customer-focused supply chain metrics. The SCOR customer-focused metrics are shown in Figure 4.2. The entire set of SCOR supply chain metrics can be found in Appendix A.

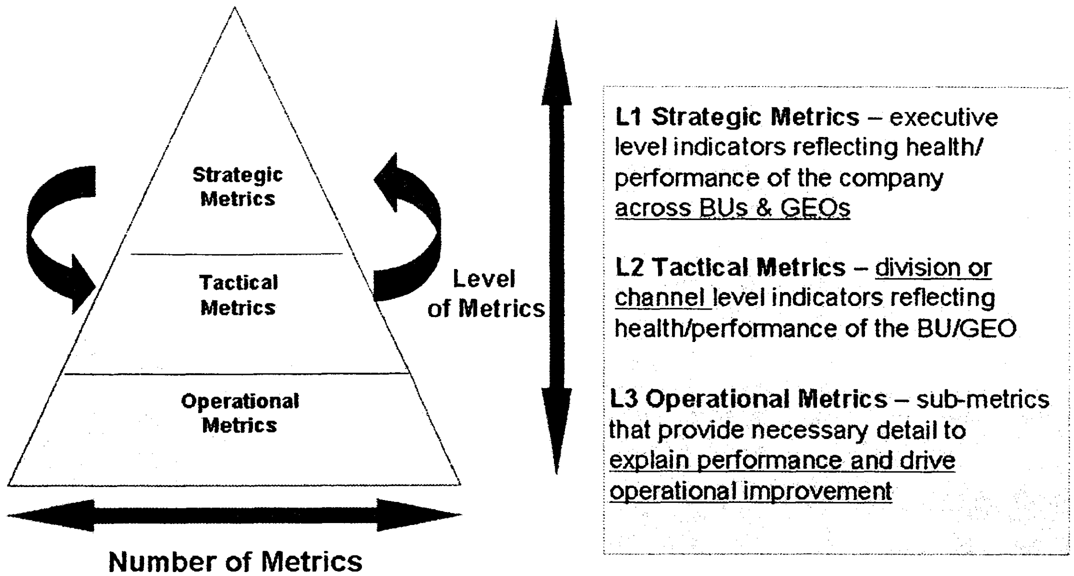
	Performance Attribute or Category	Level 1 Performance Metrics	Working Definition	Benchmark Sources	Main Level 2 Components
CUSTOMER FACING	**Supply Chain Delivery Reliability** The performance of the supply chain in delivering: the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation.	Delivery Performance *(see SCOR Glossary for definitions of all metrics)*	Delivery Performance measures the percentage of orders delivered "on time and in full" to customer request date and/or to customer commit date.	PMG On time and in full delivery to customer request and customer commit.	Supplier on time and in full delivery, Manufacturing schedule attainment, Warehouse on time and in full shipment, and Transportation provider on time delivery.
		Fill Rates	Fill Rates measures the percentage of ship from stock orders shipped within 24 hours of order receipt. Many companies use Line Item Fill Rate as an alternative metric measured by the percentage of lines filled within "committed to" hours of order receipt.	No Source Identified Most companies have their own internal gauge as to their competitive rank for line item fill rate.	Forecast Accuracy has been assigned level 2 relationship to fill rate or Inventory Days of Supply.
		Perfect Order Fulfillment	Perfect Order Fulfillment measures the percentage of orders delivered "on time and in full" to customers request date AND flawless match of purchase order, invoice, and receipt.	No Source Identified This metric is important but difficult to get good statistical benchmark comparisons.	In addition to Delivery Performance components, Supplier Match % and Customer Match %.
	Supply Chain Responsiveness The velocity at which a supply chain provides products to the customer.	Order Fulfillment Lead Time	Order Fulfillment Lead Time measures the number of days from order receipt in customer service to the delivery receipt of at the customer's dock.	PMG Order Receipt to Order Entry, Order Entry to Order Shipment, Order Shipment to Order Receipt, and overall Order Fulfillment Lead Time.	For Stock Items Order Receipt to Order Entry, Order Entry to Order Shipment, Order Shipment to Order Receipt. For To Order Items Order Receipt to Order Entry, Order Entry to Complete Manufacturing to Order Shipment, Order Shipment to Order Receipt. Backorder Duration Another frequently used level 2 decomposition is that of Back Order Duration.
	Supply Chain Flexibility The agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage.	Supply Chain Response Time	Supply Chain Response Time measures the number of days it takes a supply chain to respond to (plan, source, make, and deliver orders) an unplanned significant increase or decrease in demand without cost penalty.	No Source Identified This metric is important but difficult to get good statistical benchmark comparisons.	Source Leadtime (often contractual), Order Fulfillment Lead Time for To Order items.
		Production Flexibility	Production Flexibility measures the number of days to achieve an unplanned 20% increase or decrease in orders without cost penalty.	PMG Upside Production Flexibility.	Days to Increase or Decrease Production Labor, Material, and/or Capacity.

Figure 4-2. Customer-focused Metrics from SCOR Metrics Framework

AMR Supply Chain "Metrics Pyramid" Framework

As the E2C metrics team started to brainstorm different metrics relating to customer service, the list of potential metrics grew quickly. One framework that was adopted to help prioritize and organize the list of potential metrics was based on AMR's Supply Chain Performance Measurement Framework.

In this framework (the "Metrics Pyramid"), metrics were prioritized according to whether they offered strategic, tactical, or operation information.



Source: Based on AMR Research supply chain performance measurement framework

Figure 4-3. Metrics Pyramid Framework

Strategic metrics ("Level 1") - a very small number of metrics providing key information for executives at a highly aggregated business level. For instance, strategic metrics could be five metrics that a company's executive team members review to get a quick view of the entire company's performance and health during a certain time period.

Tactical metrics ("Level 2") - a larger number of metrics providing key information at a business division, channel, or geographic level. The intention is to provide more detailed information behind the strategic metrics so one can "drill down" on the strategic metrics. For instance, an executive may see that the strategic metric "delivery performance" was 69% for the entire company. Then the executive can drill down into the "tactical" level 2 metric to find out that Europe's delivery performance was 50% and pulling down the rest of the geographies which have a delivery performance of around 90%. The management of these geographic regions might just focus on the Tactical Level 2 metric for their own region.

Operational metrics ("Level 3") - an even larger number of metrics providing key information in one of two ways: (1) this information could be a further drill-down of specific tactical metrics (e.g. which countries in Europe contributed most to the poor delivery performance) or (2) this information could be from other metrics which are considered too detailed to be included as a strategic or tactical metric or which pertain to only specific business divisions, channels, geographies, etc. Typically it is this level of metrics that provides actionable data that can drive improvements in the business.

Operational metrics ("Level n") - metrics that provide deeper detail into Level 3 operational metrics. (These are not shown in the metrics pyramid.) The level of metrics can go as deep as a company would like as long as these metrics are providing useful detail into the metrics at the next level higher and as long as the number of metrics are manageable and sustainable.

New Customer-Focused Supply Chain Metrics for Intel

Key Elements of Customer Responsiveness	Intel Today	Proposed Metric	Measurement Approach	Challenges
Promptness	Not measured today formally	Booking cycle time (hours)	Total cycle time from a customer submitting a request to receiving a specific answer back	- Difficult to collect data from a variety of mediums (IT systems, spreadsheets, emails, phone calls) used to collect and respond to order requests from customers
Availability (of Product)	- Partially measured today using hotlist support % and CCP support % but these are not metrics used outside of MMBP	Fill Rate (synonymous with "service level" that will be discussed in chapter 5)	% of total units supported as requested in quantity and timing (Level 2 metric would provide additional data on % total units supported with alternate linearity)	- Difficult to collect date from a variety of data sources - Original customer requested date and quantity are not stored in any system
Execution	- Partially measured using % RGID late and % EGID late - No visibility to actual date customer	Delivery Performance to Requested Date	% of line items where actual delivery date <= requested delivery date and where actual delivered qty = requested qty	- Original requested date not stored in some systems - Actual delivery date just started being captured - Difficult to

	receives product			collect data on whether actual delivered qty = promised qty
		Delivery Performance to Scheduled Date (Level 2)	% of line items where actual delivery date <= scheduled delivery date and where actual delivered qty = schedule qty	- Actual delivery date just started being captured - Difficult to collect data on whether actual delivered qty = promised qty

Implementation of Customer-focused Metrics at Intel

In January 2004 the E2C team began the roll out of the new proposed metrics to the entire Intel organization. The team created an internal website called the "Supply Network Dashboard" on the corporate intranet that is accessible to anyone in the organization who has security clearance to access Intel's intranet. The purpose of the Supply Network Dashboard was to provide easily accessible and regularly updated customer-focused metrics information in a highly visual and intuitive format.

When a person first comes to the Supply Network Dashboard, the initial view is the Strategic Metrics ("Level 1 Metrics"). The metrics are categorized according to the key performance attributes to be measured. The name of the metric is visible along with the current time period's value, the trend (up, down, or same) compared to last time period, the corporate goal for this metric, the frequency that the metric is updated, a link to a graph that can show a visual of the metric or trends, a link to raw data where available, and a detailed Word document with full detail on the metric and how it is measured.

All data in the screenshots below are fictitious and made up by the author.

C:\intel1\metrics\sn dashboard for presentation\main1.htm - Microsoft Internet Explorer

File Edit View Favorites Tools Help | Back | Search | Favorites | Media

Address C:\intel1\metrics\sn dashboard for presentation\main1.htm

Supply Network Dashboard (Fictitious data)

1/29/2004

Performance Attribute	Level 1 Metric	Current value	Trend	Goal	Frequency	Graph	Data	Definition
Reliability	Delivery Performance to Request Date	92%	↑	90%	Weekly			
	Fill Rate: Initial Response Alignment to Request	90%	↑	92.5%	Quarterly			
Responsiveness	Booking Cycle Time (hours)	9	↓	4	Quarterly			
Cost	Supply Network Cost as a % of Revenue	3%	↑	1.5%	Quarterly			
Asset Management Efficiency	Inventory Turns	20	↓	25	Quarterly			

A person can then click on the name of any one of these metrics to see the tactical metric detail ("Level 2"). Below is an illustration of the Level 2 for Delivery Performance to Request Date metric.

C:\intel1\metrics\sn dashboard for presentation\page1a.htm - Microsoft Internet Explorer

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1/29/2004

(Fictitious data)

Performance Attribute	Level 2 Metric	Current value	Trend	Goal	Graph	Data
	Delivery Performance to Request Date	**92%**	↑	**90%**		
Geo	AM	89%	↑	90%		
	AP	83%	↑	90%		
	EU	75%	↑	90%		
	JP	95%	⇔	90%		
Channel	OEMs	93%	⇔	90%		
	LOEMs	90%	↓	90%		
	Disti	87%	↓	90%		
Supergroup	IAG	93%	⇔	N/A		
	ICG	90%	⇔	N/A		
	WCCG	85%	⇔	N/A		

The Level 2 screen gives more specific detail on Delivery Performance to Request Date by Geography ("Geo"), Customer Channel ("Channel"), and Business Division ("Supergroup").

As of late April 2004, the customer-focused metrics defined by the E2C team in the

Supply Network Dashboard were awaiting ratification to become the new operational metrics for Intel's Supply Network Group (ISNG).

Best Practices for Implementing Corporate-Wide Supply Chain Metrics

For supply chain metrics to be adopted successfully across an organization, there are several key takeaways from the Intel case study that can be shared as best practices:

<u>Do not proceed without high-level executive support</u>

There must be at least one high-level executive champion (preferably at the management team level) who cares about these corporate-wide metrics, regularly reviews these metrics, and enforces accountability when performance is not satisfactory. This high-level executive champion has the organizational power to drive alignment across divisions and organizations so that everyone is focused on the same metrics and are aligned in achieving the same goals. Without this high-level executive champion, the corporate-wide metrics effort will not have the credibility and management enforcement to make this a long-lived success.

<u>Establish a cross-functional team</u>

Because these metrics are far-reaching across different organizations and divisions (especially at Intel), there must be a cross-functional team that has representation from all the major constituents. Without this participation, there is likely to be resistance or refusal to accept the new metrics from organizations or divisions which feel left out of the decision-making process

<u>Leverage a detailed template for clearly defining and communicating metrics</u>

One of the challenges with metrics is that they are often communicated as a set of numbers without much supporting information that clarifies exact definition, underlying assumptions, method for calculation, and related issues. Without this information, the credibility of metrics are often challenged and questioned. A metrics definition template adopted by the Intel E2C team that successfully captured and communicated this information included:

1. Metric name
2. Definition of metric
3. Unit of measure
4. Specific formula/rules to determining this metric
5. How often measured
6. How often updated and published
7. Data source
8. Issues/Gaps in current metric
9. Granularity (what level of product/organization is this measuring)
10. Communication medium
11. Ties with performance bonuses
12. Owners: business, data, and technical
13. Sample display format/charts
14. Extent of historical data to be included

A metrics definition document was filled out for each metric and linked as a Word document next to each metric on the Intel Supply Network Dashboard.

Bring all major stakeholders together to define metrics goals

Along with every metric, there should be a reasonable goal associated with it to incentivize performance improvement. It is crucial to identify and bring all stakeholders together to set goals for corporate-wide metrics, especially if the metric affects multiple organizations and goals. Sometimes there will be conflicting interests that need to be worked out across stakeholders to come up with a metrics goal that is most reasonable for all parties involved. For instance, at Intel, fill rate is one metric that will require significant discussion across multiple groups. Sales and WCST (the group that represents the voice of the customer) might demand a high fill rate goal to increase sales and customer satisfaction. However, this will mean higher levels of inventory. On the other hand, manufacturing and supply chain groups might push for a lower fill rate goal to minimize inventory and inventory costs. Discussions of tradeoffs will need to happen for all these groups to come up with a mutual and reasonable goal for the fill rate metric.

Tie metrics goals to performance bonuses where possible

Metrics and metrics goals by themselves may not be enough to incentivize employees to improve company performance over time. Often employees may ignore metrics if they do not impact them personally. One of the most effective ways to increase employee focus on metrics is to tie achievement of metrics goals to performance bonuses. However, companies must make sure that metrics goals and performance bonus incentives across divisions are aligned with overall company objectives and not optimizing locally.

Employ a highly visual and interactive communication medium

For metrics to be widely adopted, it must be easy for users to understand and navigate through the information being presented. Once the Intel E2C metrics team developed a Supply Network Dashboard on an intranet site using a visual HTML format with links that allowed for further information drilldown, users and management appeared to embrace the concepts and information much more quickly than showing metrics and data via Excel or Powerpoint (as was done originally).

Make metrics data accessible anytime from anywhere

Often the extra effort to find metrics data and access metrics data are so cumbersome that users are discouraged from looking for such data. For metrics to be widely adopted and leveraged, metrics must be easily accessible to those who wish to reference such data. Implementing a metrics dashboard on an intranet site like Intel did allows for data to be easily accessible and viewable anytime from anywhere. This makes it much easier than combing through hundreds of Excel spreadsheets or Powerpoint slides. If security is an issue, a username and password can be used to safeguard access to the intranet site.

Chapter 5. Analysis of Intel's Current Strategy for Determining Inventory Targets

"When all else fails, use a heuristic"[vi]

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Chapter 5. Analysis of Intel's Current Strategy for Determining Inventory Targets

A key to being responsive to customers from a supply chain perspective is availability of product, one of the key dimensions of the Customer Responsiveness Framework. Availability of product refers to having the right amount of inventory of the right products at the right time to meet the often variable demand of customers. This chapter will examine how Intel sets inventory targets today and how its current approach affects the level of service it provides to customers today.

Intel's Current Strategy for Determining CPU Inventory Targets

Instead of using traditional inventory theory to determine optimal inventory levels, Intel uses a basic heuristic that drives its target inventory levels for CPUs. In general, Intel uses the heuristic of 5 weeks of inventory (WOI) total in transit and in safety stock, of which 2 weeks is die inventory (ADI) and 3 weeks is finished goods (FG) inventory.

For certain products for which Intel wants to provide higher levels of service to customers (such as certain mobile and server products), Intel has defined the heuristic of 7 WOI total in transit and safety stock (4 WOI in ADI, 3 WOI in FG).

Discussions and interviews with numerous Intel personnel from different groups working on supply chain related initiatives (MMBP, planning, EBG, etc.) confirm that many Intel employees acknowledge this heuristic as what has been used to determine target CPU inventory levels. However, no one interviewed was able to provide a detailed explanation for how the current heuristic of 5 WOI inventory was derived. The best explanation provided was "this is how we have done it for a long time and it's worked pretty well."

The 5 WOI heuristic is implemented by taking the latest demand forecast available (assumed to be Judged Demand) and setting target inventory levels equivalent to 5 weeks of the latest demand forecast. It is unclear how often the inventory targets are recalculated and updated.

Intel's Current Heuristic for CPU Inventory Targets
= 5 WOI = 5 * latest demand forecast (converted to weekly terms)

It is important to note that the 5 WOI does NOT equate to 5 WOI safety stock inventory. As shown in the illustration below, the 5 WOI (2 WOI ADI and 3 WOI FG) include inventory in transit.

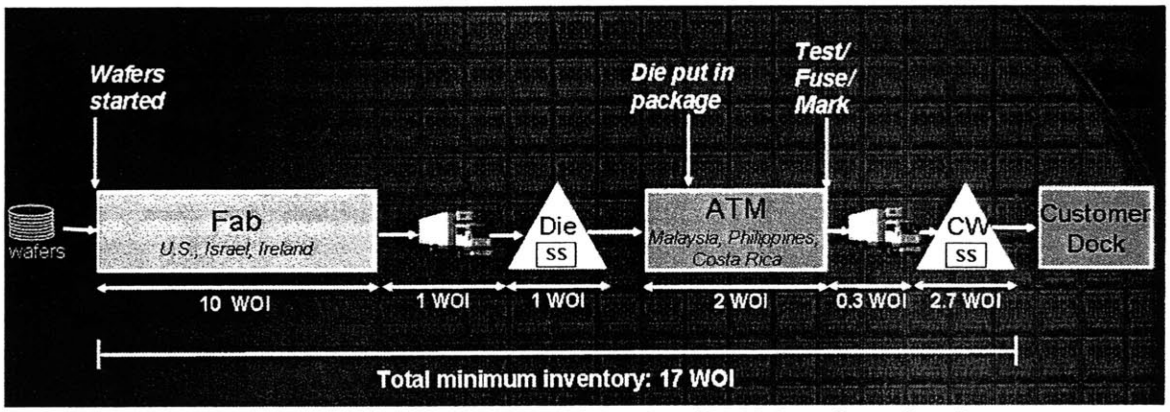

Figure 5-1. Inventory Breakdown of Intel's CPU Manufacturing Process

True safety stock is that inventory that is physically located at the final inventory destination and ready to be used. In-transit inventory that is being transported from Fabs to the ATM sites do not count as safety stock nor does the in-transit inventory that is being transported from ATM sites to component warehouses (CW). Since it takes about 1 week to transport inventory from Fabs to ATM and about 0.3 weeks to transport FG from ATM to CW, Intel's heuristic translated for safety stock only is 1 WOI for ADI SS and 2.7 WOI FG SS = 3.7 WOI total safety stock. An assumption was made that Intel has continuous production and delivery from its Fabs to ATMs and from its ATMs to CWs so cycle stock is negligible.

Advantages and Disadvantages

Advantages

There are numerous advantages with Intel's approach of using a heuristic to determine target inventory levels for CPUs:

The heuristic provides a straightforward rule of thumb that is easy to understand and communicate globally.

With the number of CPU SKUs in the hundreds, products being launched and going EOL regularly, multiple organizations involved in the planning of new production runs, numerous fab and ATM sites manufacturing product across the globe, and product demand often changing, Intel's CPU business is extremely complex. A simple heuristic makes it easy to communicate the inventory strategy, reduces complexity, and minimizes the possibility of making major mistakes.

The heuristic shields employees from a highly complex manufacturing process that is extremely difficult to model quantitatively.

Intel's manufacturing process involves so much more complexity than the level of complexity typically covered by academic inventory models. For example, there is demand and supply variability in the Fab and ATM processes, lead times are variable, die is fungible between different product families, bin splits across different CPU speeds are not always controllable, and there many other complexities in the CPU manufacturing process. Traditional inventory models are too simplistic and significant work and resources would be needed to come up with a quantitative inventory model that accurately reflects Intel's real-world scenario. If a simple heuristic can work relatively well and can eliminate dealing with all the variables and complexity, a heuristic approach would be preferred.

The heuristic is adaptable to the changing customer demand.

Because the heuristic incorporates weeks of inventory as a variable, the heuristic is not static and can adapt as customer demand increases or decreases. This gives the heuristic the ability to automatically adapt to new trends in customer demand.

The heuristic was developed based on experience and has been time-tested.

Another advantage of the heuristic is that it seems to have worked "pretty well" over time without significant crises arising out of the approach. Apparently enough slack has been built into the heuristic that it has been able to address many of the complexities in the CPU manufacturing process to date.

Disadvantages

Although there are many strong advantages for the use of Intel's heuristic to determine target inventory levels for CPUs, closer examination of the heuristic brings forth some significant disadvantages, some of which can lead to suboptimal business decisions and inability to plan to specific service level targets.

<u>The current heuristic does not take into account the correct factors to determine safety stock, which can lead to misleading safety stock inventory recommendations.</u>
The philosophy behind safety stock is to hold extra inventory to address fluctuations in demand or supply. From an academic standpoint, safety stock levels are determined quantitatively by a company's desired service level to customers, the level of variability in demand and supply, and the lead time needed to replenish inventory. (Detailed discussion of traditional inventory models can be found in chapter 6.) Intel's heuristic is not based on any of these factors. It is purely based on average demand, which can lead to levels of safety stock not correlated at all to any of the relevant factors.

<u>The current heuristic may overcompensate when demand increases or decreases and lead to too much or too little safety stock.</u>
A positive feature of the current heuristic is that it is adaptive when demand increases or decreases. However, a downside is that the heuristic may overcompensate when demand does change. Since the heuristic is used today to determine safety stock, the heuristic increases/decrease safety stock at a rate equal to the rate of change in demand. When demand increases period over period, this does not necessarily mean that demand variability also increases at the same rate if at all (and safety stock requirements increase). Similarly demand decreasing over time does not necessarily mean demand

variability decreases (and safety stock requirements decrease) at the same rate if at all. Average demand can change independently from demand variability.

> Example #1:
> Suppose forecasted demand for finished CPU units (FG) is 1M per week for a given product in Q3 2004. According to the heuristic, you will need 2.7 x 1M = 2.7M WOI safety stock for FG. Assume that this is the correct level of safety stock in this situation.
>
> Now suppose forecasted demand for finished CPU units for this product increased to 1.5M per week in Q4 2004 but demand variability in absolute units remained about the same. The heuristic would recommend 2.7x1.5M = 4.05M WOI safety stock for FG. (For the purposes of this example, demand variability remains the same. When demand increases, one would expect demand variability to increase, but not as much proportionally as the increase in demand.)
>
> If the heuristic were followed, an unnecessary additional 4.05M-2.7M=1.35M FG safety stock units would have been held in inventory.
>
> If a unit of FG cost $50/unit (fictitious cost), this would lead to 1.35M*$50 = $67.5M more in unnecessary inventory.
>
> Example #2:
> Suppose forecasted demand for finished CPU units (FG) is 1M per week for another product in Q3 2004. According to the heuristic, you will need 2.7 x 1M = 2.7M WOI safety stock for FG. Assume that this is the correct level of safety stock in this situation.
>
> Now suppose forecasted demand for finished CPU units for this product decreased to 0.75M per week in Q4 2004 but demand variability in absolute units remained about the same. The heuristic would recommend 2.7x0.75M = 2.03M WOI safety stock for FG. (For the purposes of this example, demand variability remains the same. When demand decreases, one would expect demand variability to decrease, but not as much proportionally as the decrease in demand.)
>
> If the heuristic were followed, there would have been 2.7M-2.03M=0.67M FG safety stock units too few held in inventory and customer service levels might unintentionally decrease because of it.
>
> If the cost of a lost sale is $10/unit (fictitious cost), this would lead to 1.35M*$20 = $27M in cost of lost sales.

<u>The current heuristic is biased towards higher safety stock levels for products with higher average demand.</u>

With the current heuristic, products with higher demand forecasted will have higher safety stock levels. In reality, a product with lower average demand and high demand variability may need just as much safety stock as a product with higher average demand but lower demand variability. In addition, stable products with high demand volumes may require fewer units of safety stock than ramping products with lower average demand.

The current heuristic does not enable Intel to plan to specific customer service levels

Using the current heuristic, Intel cannot directly set its inventory targets to meet specific levels of service to its customers (as traditional inventory models allow). Instead, customer service levels are potentially variable outcomes of the system as determined by the heuristic and current variability in demand and supply and current lead times. Because demand levels might change over time as well as demand variability and supply variability, customers may experience inconsistent customer service levels from product availability over time. This can definitely affect customer perceptions of responsiveness of Intel's supply chain. With this heuristic, Intel does not drive customer service level. Inventory strategy drives customer service level and Intel can only react to it.

Impact of Intel's Heuristic Approach to Customer Responsiveness

Although Intel's heuristic approach to determining CPU inventory levels has significant merits for its simplicity in driving decisions for such a complex manufacturing process and business, the heuristic approach may not be optimizing CPU safety stock levels for high levels of product availability (and resulting customer responsiveness). The heuristic approach also may lead to inconsistent levels of product availability and service level over time. Finally, the current approach does not enable Intel to plan to specific customer service levels explicitly.

The application of traditional inventory theory to determine inventory targets is explored in the next chapter as an alternative to using this heuristic approach that may allow Intel to improve responsiveness to its customers.

Chapter 6. Applying Traditional Inventory Models to Determine Inventory Targets

"Can there be method to this madness?"

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Chapter 6. Applying Traditional Inventory Models to Determine Inventory Targets

This chapter examines improving customer responsiveness by continuing to focus on the "availability" aspect of the Customer Responsiveness Framework. This involves applying quantitative inventory models and the concept of "service level" to determine optimal safety stock inventory levels which should better align Intel's inventory targets with desired levels of customer service and product availability. Then the effectiveness of this approach will then be compared with the heuristic approach as described in the previous chapter.

Traditional Base Stock Inventory Model

One of the cornerstones of inventory theory is the base stock inventory model (as shown below). This model is relevant for Intel's CPU manufacturing process (in contrast to the continuous review model) since CPU inventory is reviewed periodically at regular intervals and the appropriate quantity is ordered after each review.

BASE STOCK INVENTORY MODEL
Total inventory units
= WIP inventory + safety stock inventory
= mean demand * LT + z * std deviation of demand* sqrt (LT)

Input variable	Description	Example (fictitious data)
Mean demand	The average demand (in units) of a product for a specific time period	Average demand of 30M units of CPUs per week
Std deviation of demand	The std deviation of the demand for a lead time interval of 1 (i.e. how much does the demand vary from the mean over one lead time period)	Std deviation of 6M units of CPUs per week
Replenishment lead time (LT)	The replenishment time from the time a request for product is submitted and the time the product is received and available. It is not just the time	Replenishment lead time of 20 weeks

	to manufacture or assemble a product.	
Z	The multiplying factor which is determined by the desired service level	95% desired service level = Z-factor of 1.64. (Can be derived using a normal distribution table or using the normsinv(.95) function in Excel.). Here service level is approximated to be the probability of being able to fulfill a request for one unit of product during a LT cycle.

(In the base stock model discussed in this thesis, review period and cycle stock are not included since continuous production is assumed for Intel's CPU manufacturing process.)

First, inventory models looking at only demand variability will be examined. Supply variability will be discussed in an enhanced inventory model later in this chapter.

The base stock inventory model is typically used in two ways:

1. To determine how much inventory should be held given a mean demand, standard deviation of demand, a replenishment lead time, and a target service level.
2. To determine what service level is being provided to customers given the current inventory targets, mean demand, standard deviation of demand, and a replenishment lead time.

Types of Inventory

It is important to distinguish between the different types of inventory in a given manufacturing system.

Inventory Type	Description	Applied to Intel CPU business
WIP (Work-in-Progress)	Inventory which is waiting in the system for processing or is being processed.	The in-progress inventory inside the Fab and ATM processes. It includes the ADI inventory in transit from the Fabs to ATM sites as well as the FG inventory in transit from ATM sites to component warehouses.
Safety Stock	Inventory used to buffer against fluctuations in demand or supply during the replenishment lead	Intel has two CPU safety stock stages: ADI safety stock at each ATM site and FG safety stock

	time.	at each CW site.
Cycle Stock	Inventory that is used to cover demand during the review period. It is consumed during the review period and replenished at the end of the review period. On average, the amount of cycle stock is ½ the amount of units during the review period. This is more relevant for batch production.	Because production of CPUs is assumed to be continuous, review period and cycle stock does not apply in the inventory models discussed in this research.

Application of the Base Stock Inventory Model

Before the base stock inventory model can be applied to determine Intel's optimal inventory levels, several important questions must be answered first:

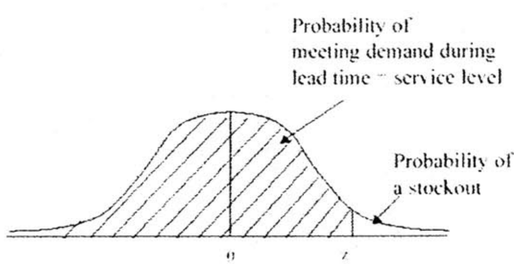
1. How should "service level" be defined for Intel's CPU business?
2. What demand signal is best to use?
3. What variability signal is best to use?
4. How should replenishment lead time be defined?

Defining "service level" for Intel's CPU business

One of the first challenges in applying traditional inventory models to Intel's CPU business is coming up with a specific and clear definition for "service level" since this term can be used to refer to many different aspects in customer service. Chapter 1 had discussed the various dimensions of customer service.

The dimension of "service level" that is most relevant to inventory modeling is availability of product (e.g. Did we have exactly what the customer wanted when the customer wanted it?). How much product that is available in safety stock inventory directly impacts a company's ability to fulfill customer demand (i.e. the service level).

From an academic standpoint, the level of safety stock will affect a company's probability of meeting demand during the replenishment lead time. Figure 6-1 illustrates this.



$R = DL + z\sigma_L$

where

D = average demand

L = lead time

σ_L = standard deviation of demand over lead time

z = number of standard deviations for desired service level

$z\sigma_L = SS$

Figure 6-1. Academic definition of "service level"

Applying Service Level Definition to Intel's CPU Business

The next step is to relate the ideas of product availability and service level to Intel's CPU business. At Intel, customers place requests for product through the CCP or hotlist process and these requests are supported (turning into purchase orders) or not supported (sale is potentially lost). Each product request has a quantity (e.g. the number of units) and desired timing (e.g. the desired delivery date).

Based on this reasoning, the definition for service level determined to be most appropriate for Intel's current CPU business is:

Service level = % of demand requested by customers with requested date and requested quantity satisfied

This definition of service level is what many companies equate to "fill rate" (e.g. percent of demand that is filled). Fill rate is a concept that is often more familiar and specific to supply chain and logistics professionals. We will use "fill rate" and "service level" interchangeably from this point forward. "Fill rate" is also one of the customer-focused supply chain metrics that have been implemented as a top level metric on Intel's Supply Network Dashboard described in chapter 4.

It is important to note that in industries such as retail that sell directly to end consumers, "fill rate" is defined as the amount of orders fulfilled from inventory within 24 hours. (Examples may be Dell or Amazon.com.) This creates some potential confusion since Intel's CPUs customers typically submit requests for product weeks (or months) in advance and do not expect 24 hour fulfillment from inventory (a last-minute hotlist may be the exception). However, the spirit behind "fill rate" applies in both Intel's case and the retail case is same: (a) there is some quantity of products demanded and (b) there is some timing expectation for product. In the case of retail, the time expectation is 24 hours and in Intel's case, the time expectation is weeks into the future. Thus, the concept of fill rate still applies in Intel's case.

Once this base definition has been determined, the next step is to translate this service level definition into concrete and measurable terms that relate and fit best with Intel's CPU business. After research of literature, Internet and informal interviews with supply chain professionals at other companies, service level typically is measured in the following ways:

Methods to Measuring Service Level	**Places importance on**	**Advantages**	**Disadvantages**
1. by total % of units fulfilled*	as many units of demand as possible are fulfilled	- incentivizes employees to give priority to largest orders (and largest customers)	- may bias towards fulfilling large customers first and putting smaller customers second - potential for fulfilling few very large volume orders and ignoring many small volume orders
2. by total % of order line items fulfilled*	as many order line items as possible are fulfilled	- theoretically gives all line items (no matter what size of customer) equal weight - treats every line item and every customer as important - data may be more easily accessible since many companies track delivery by order line item	- missing an order line item of 100K units is no worse than missing an order line item of 10 units - may incentive employees to fulfill smallest/easier orders first and put large orders/customers second
3. By total % of time periods where 100% of demand was fulfilled*	as many time periods as possible have 100% fulfillment	- encourages 100% demand fulfillment every time period	- if 100% demand fulfillment is missed within a time period, employees not incentivized to care whether it is 95% or 50% fulfillment

*"fulfilled" here refers to fulfilling both quantity requested and date requested

Each of these methods to measure service level has its merits and potential flaws. A company should select the one method which will provide the richest information that can drive action and can impact the bottom line the most. For Intel, market share and volume are extremely significant so method 1 "by total % of units fulfilled" would be the most appropriate. To Intel, missing 100 units or 100K units is a huge difference, which is why method 2 "by total % of order line items fulfilled" would not be ideal. For another company where customer service is the main differentiator and it matters that every order, whether large or small, is fulfilled with the same importance, method 2 may be more appropriate. Method 3 is most appropriate in companies where tracking the total % of all time periods in which there was 100% demand fulfillment is more important than tracking units or order line items.

Thus, for Intel's CPU business:

Service level = % of <u>all units</u> requested by customers with requested date and requested quantity satisfied

Determining the best mean demand signal to use

Another key input variable for the quantitative inventory models is mean demand. This variable directly determines how much WIP and cycle stock inventory there will be in the system. Mean demand does not impact the level of safety stock since safety stock is affected only by service level, standard deviation of demand, and replenishment lead time.

In the Intel CPU domain, there are a number of possible demand signals that can be used as the mean demand for the inventory models:

Demand Signal	Description	Demand Time Period	Frequency of Updates	Pro	Con	Risk
Judged Demand	The official demand forecast signal from marketing incorporating regional sales forecasts, past trends, and economic analysis.	Units demanded per quarter (recent initiative to attempt units demanded per month)	Monthly (also mid-month minor update)	- Most "accurate" demand signal for a quarterly timeframe	- Not based on any actual booked or billed units	- Good demand signal on a quarterly basis but harder to predict JD for each month with a high level of accuracy
Backlog	Number units confirmed by customers and expected to bill	Units demanded per week	Weekly	- This is the quantity customers have "booked" and signaled that they want. - Even if not all backlog will turn into billings, backlog is still what the customer has demanded and this quantity needs to be supported	- Backlog usually most accurate within several weeks of delivery - Actual customer demand may be much greater than actual units booked in backlog due to supply issues. - Customers may be gaming and be "booking" more backlog than they actually intend to purchase	- Is not an accurate demand signal > 13 weeks from delivery date
Actuals (also known as Billings)	Actual units ordered	Units demanded per week, month, quarter, or yearly	Weekly	- Actual quantities that customers billed	- Actual customer demand may be much greater than	- May underestimate actual demand

					actual units purchased due to supply issues.	
Hotlist Demand	Last minute units requested through hotlist requests.	Units demanded per week, month, quarter, or yearly	Weekly	- Actual quantities that customers demanded through hotlists	- Hotlist demand is only a small subset of total actual demand - Hotlist volume may be higher than actual due to customer gaming.	- Hotlists are subject to significant gaming by customers (since no cancellation penalty) - Hotlist demand volume highly dependent on supply availability, supply confidence, and economic outlook

In Intel's CPU current inventory system design, there are 2 safety stock inventory stages that would need to be modeled. Each of these 2 inventory stage needs to identify the best average demand signal that would lead to the most accurate inventory recommendations.

Choosing the most relevant demand signal for die (ADI) inventory

Since the replenishment time for die is about 13 weeks, a quarterly demand signal would be most appropriate. Judged Demand appears to be the demand signal that best fits this description. One could take weekly backlog or billing demand and multiply it by 13 weeks and get an estimate of quarterly demand, but since backlog and billings are not linear throughout a quarter, there would be some question of which week in a quarter to use as the base weekly backlog or billing demand. Thus, Judged Demand appears to be the most clear and relevant demand signal.

Choosing the most relevant demand signal for FG inventory

The replenishment time for FG is about 3 weeks so a weekly demand signal would be most appropriate. Taking Judged Demand and dividing by 13 weeks may not generate the most accurate weekly demand signal since weekly demand is not linear over a quarter.

The demand signal that appears to have the least forecast error for estimating FG demand within 13 weeks of delivery is backlog. Backlog is the number of units that customers have booked via orders for a given week into the 0-13 week future horizon.

Determining the best variability signal to use

One of the other key inputs into the traditional inventory models is standard deviation of demand, sometimes referred to as "variability of demand." The standard deviation of demand reflects how much demand is expected to fluctuate around the average demand during the replenishment lead time. Standard deviation is one of the main factors that directly determine what safety stock requirements will be.

At first look, the standard deviation of demand may seem straightforward by calculating the standard deviation of historic mean demand data (such as from Judged Demand). However, in Intel CPU's business, this is much more complicated. Intel CPUs experience short product life cycles (1-2 years on average and less than 1 year for some products) and because of this, product demand over time is typically not constant because of rapid product ramp ups and ramp downs. Calculating standard deviation of mean demand when there are these short lifecycles would most likely lead to misleading results since variability will be skewed much higher from the ramp up and ramp down effects. Consequently inventory models would recommend much higher safety stock requirements than actually necessary for a given service level.

In Intel's case, the best proxy for standard deviation of mean demand appears to be standard deviation of forecast error, which is discussed in Levesques (2004), based on a related supply chain research project conducted at Intel.

Std deviation of mean demand ~
Std deviation of forecast error = Std deviation of (forecasted demand – actuals)

Assuming demand forecast error is relatively stable and demand forecast processes have not changed significantly (both of which appear to be true at the all CPU and product family levels), the concept is that how much the demand forecast error varies over time is a close reflection of the natural variability of customer mean demand. Of course, the proxy is not perfect since demand forecast error could change due to a new forecasting process or new personnel taking over the job, but using this proxy will produce less misleading results than using the standard deviation of mean demand. More about this concept can be found in Levesques' research.

The next consideration is how many data points constitute a valid standard deviation of forecast error. With a short product lifecycle, many historical data points may be hard to come by. It is suggested that for products with very few data points (suggested < 5) that the recommendations from the inventory models be scrutinized closely and sensitivity analysis be performed to identify potential ranges of error.

One final important point is that the standard deviation of forecast error should be updated regularly once new data is available to ensure that the models are incorporating the latest data. Business processes or IT automation should be put in place to put up alerts in case there is a significant change from existing values.

Determining replenishment lead time

"Lead time" is often an abused term that can refer to many different aspects of a supply chain. There are manufacturing lead times, delivery lead times, and replenishment lead times to name a few.

For traditional inventory models, the lead time that is needed as a key input is the replenishment lead time. The replenishment lead time is how much time is needed to submit a request for a new unit of product, receive it, and have it available and ready to be shipped to a customer. (The definition of replenishment lead time in this model includes the lead time for any time lag getting a request for product into the system.)

Manufacturing lead time (or manufacturing throughput time (TPT)) is not sufficient. For example, consider an ATM site that needs to hold die inventory. Manufacturing lead time is 9 weeks and the time lag to get a new request into the system is 4 weeks (for a total of 13 week replenishment time). If the ATM site only stocks 9 weeks of inventory because it only considered manufacturing lead time, then it would be short of inventory for the remaining 4 weeks until supply is replenished. The ATM site needs to stock enough inventory for the full replenishment time (as well as additional safety stock to buffer against demand and supply variability during these extra weeks).

Lead time impacts WIP inventory directly as well as safety stock inventory to a lesser extent. The longer the lead time, the more inventory there is in progress in the system. The longer the lead time there is, the higher the safety stock requirements by a factor of square root of the lead time according to the base stock formula.

Limitations of the Base Stock Inventory Model

Although the base stock inventory model is one of the most valuable cornerstones of inventory theory, there are a number of critical limitations that need to be understood:

Assumption: Demand is relatively constant

As discussed previously, Intel's CPU product lifecycle is very short and demand typically is not constant due to NPI and EOL effects. If a mean demand is taken from a NPI period, then the inventory model may overstate recommended inventory levels. Furthermore, because of the short life cycles, it is challenging to come up with a pure standard deviation of mean demand. It is important to take inventory level recommendations for ramping products or products going EOL with caution.

Assumption: Demand falls in a normal distribution

The assumption for this thesis and research is that demand for Intel's CPU products fall in a normal data distribution over time. In reality, this may not be completely true since customer demand is often influenced by Intel in terms of marketing promotions, pricing strategies, competitor offerings, etc.

Assumption: Lead time is constant

In Intel's manufacturing process, there are hundreds of steps to convert a raw silicon wafer into finished die. There is natural variability in lead time in Fab (as well as in ATM) so this is not captured in the base stock model.

Assumption: There are no capacity constraints

Intel's business and flexibility to manufacture CPUs is highly dependent on Fab and ATM capacity. New Fab capacity is extremely expensive and takes significant time to build. The base stock inventory model does not incorporate any consideration for capacity limitations.

Assumption: There is no supply variability

The base stock model also assumes no supply variability. In Intel's case, there is significant supply and yield variability from Intel's complex Fab manufacturing processes, introduction of new semiconductor manufacturing techniques, and new products at the highest speeds.

Assumption: Single node inventory model

The base stock model only covers a single node inventory model. Even in the most simplified state, Intel's CPU manufacturing process is a dual node inventory model with die inventory held at ATM sites and FG inventory held at the components warehouse.

Assumption: Demand from one time period to the next period is independent.

The base stock model assumes that demand across time periods are independent. This may not always hold true at Intel. For instance, if Intel is not able to meet some portion of a customer's CPU demand for one period, this demand may roll over to the next time period.

Extending the Base Stock Model to Include Two Stages and Supply Variability

As noted above, there are many limitations of the base stock model that restrict its effectiveness in modeling Intel's real manufacturing process. An ideal model would be able to incorporate multiple inventory stages and address all the limitations above. Research of operations management and inventory management textbooks did not uncover any such multi-stage models that addressed the above issues.

However, in Levesques' LFM research at Intel, a two-stage inventory model was developed by enhancing an existing model originally developed by Mark Graban (1999) for the Eastman Kodak company. Levesques' model incorporates two stages (Fab and ATM), allows for separate service levels for each stage, allows for supply variability, allows for variable lead times, and provides inventory recommendations for ADI and FG simultaneously.

The base stock model and a further enhanced version of Levesques' two-node inventory model were used to generate the inventory findings and analysis discussed below. One important limitation mentioned above but still not addressed by either inventory model is the assumption that there is unlimited capacity.

One final significant assumption made with the two stage inventory analysis is that all product families have the same supply variability and yields. In actuality, this is not true since some newer products tend to have much higher supply variability and lower yields. This assumption was made since supply variability and yield data were only available for one of Intel's CPU product families. In addition, because this product family is one of Intel's most stable and high-volume CPU product families, its supply variability is most likely lower than that of other product families. As a result, recommended total safety stock requirements across all products probably will be lower than what is needed in actuality.

Approach: Applying Inventory Models to Intel's CPU Business

Modeling Approach

Analysis of Intel's CPU inventory system using traditional inventory models was applied in 5 steps to enable incremental learning and observations:

1) Single stage model - combining Fab and ATM as one stage
2) Single stage model – standalone Fab stage (ADI inventory only)
3) Single stage model – standalone ATM stage (FG inventory only)
4) Two stage model - Fab and ATM stages (no supply variability)
5) Two stage model - Fab and ATM stages with supply variability

<u>Step 1: Analyze single stage model combining Fab and ATM</u>

The purpose of looking at Intel's system as a single stage model first was to choose the simplest scenario and get some ballpark results on what is the minimal level of inventory that should be held in the entire system as well as how much safety stock might be needed if the system were this simple. The Excel-based single stage model used for Steps 1-3 can be found in Appendix B.

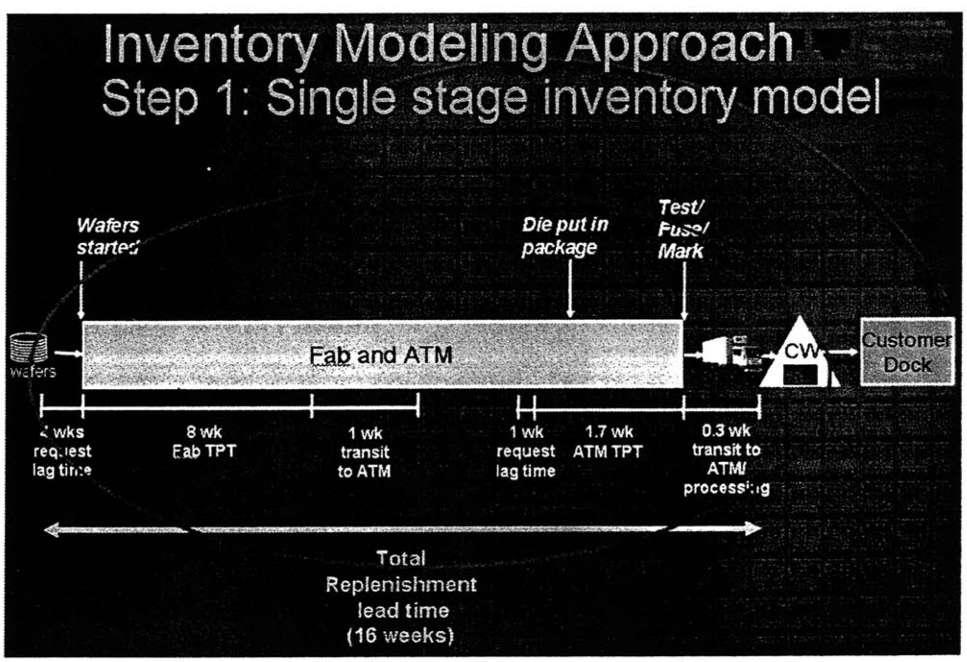


Figure 6-2. Single stage inventory model for Intel.

Step 2: Analyze standalone Fab stage (ADI inventory only)

The next step was to start breaking down the overall CPU manufacturing process into its two main parts: Fab and ATM. (ATM will be discussed in step 3). The purpose of doing this was to start heading towards a two-stage inventory system but to analyze what the die inventory requirements of just the Fab process alone would be in a single stage model.

This model assumes that raw silicon wafers (critical raw material for making die) are 100% available when needed. This assumption is not a bad one to make since raw wafers are relatively inexpensive and not hard to procure. This also assumes that the substrates needed in processing die are also available when needed.

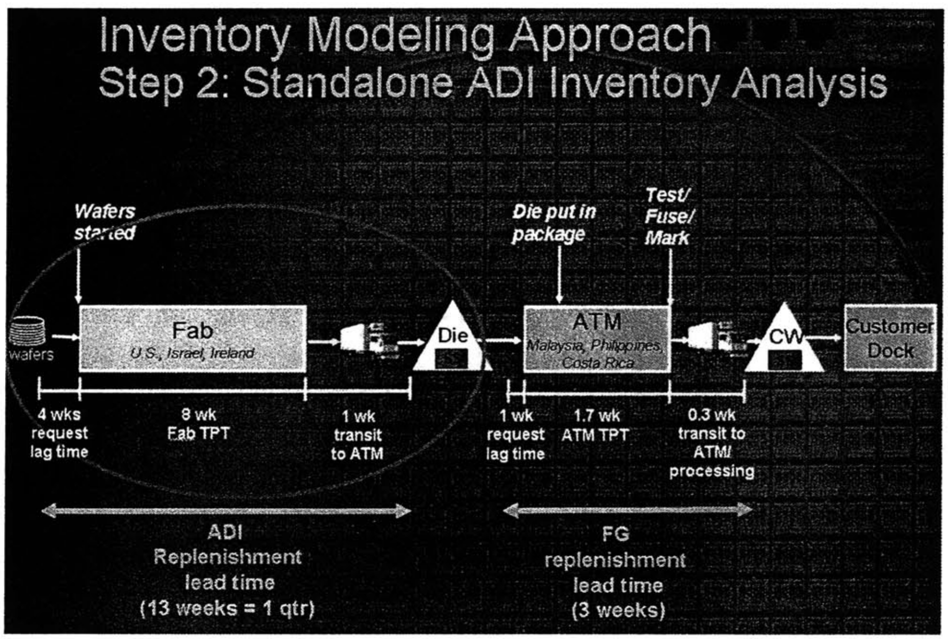


Figure 6-3. Standalone ADI Inventory Model for Intel.

It is important to note that the step 2 model does not reflect that ADI target inventory levels are impacted by the ATM part of the process. If the yields from the ATM process are less than 100%, then ATM requires additional die units to cover for the yield loss.

$$\text{ADI target levels} = (1/\text{ATM yield }\%)*\#\text{ FG units needed}$$

The yield consideration will be incorporated in the inventory models in steps 4 and 5.

Step 3: Analyze standalone ATM stage (FG inventory only)

The third step was to look at the ATM process as a standalone single stage process. The purpose is to analyze what the FG inventory requirements of just the ATM process alone would be.

This model assumes that the correct die to make the desired finished products in ATM is 100% available when needed. This is not always true in reality so the results most likely will underestimate the actual inventory needed. The two-stage model in steps 4 and 5 will incorporate this issue and include a die service level reflecting how well Fab meets ATM's die needs.

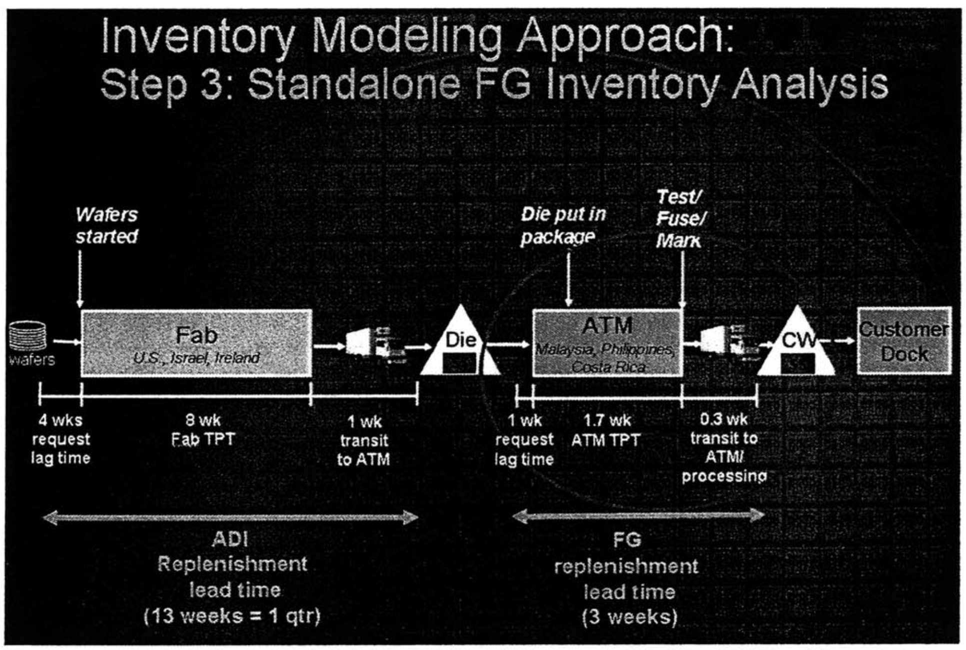


Figure 6-4. Standalone FG Inventory Model for Intel.

Step 4: Two stage model without supply variability included

The next step was to model the system with two stages (Fab and ATM) and have one model that provides optimal inventory recommendations for ADI and FG simultaneously. As mentioned previously, the two stage model used in this analysis (see Appendix C) was developed by Levesques, who enhanced an inventory model developed by Graban. Levesques' model was extended with additional functionality to allow users to calculate overall service level given safety stock WOI at the ADI and FG stages (see Appendix D).

In addition, users can input different service levels for the ADI and FG stages and calculate the overall service level.

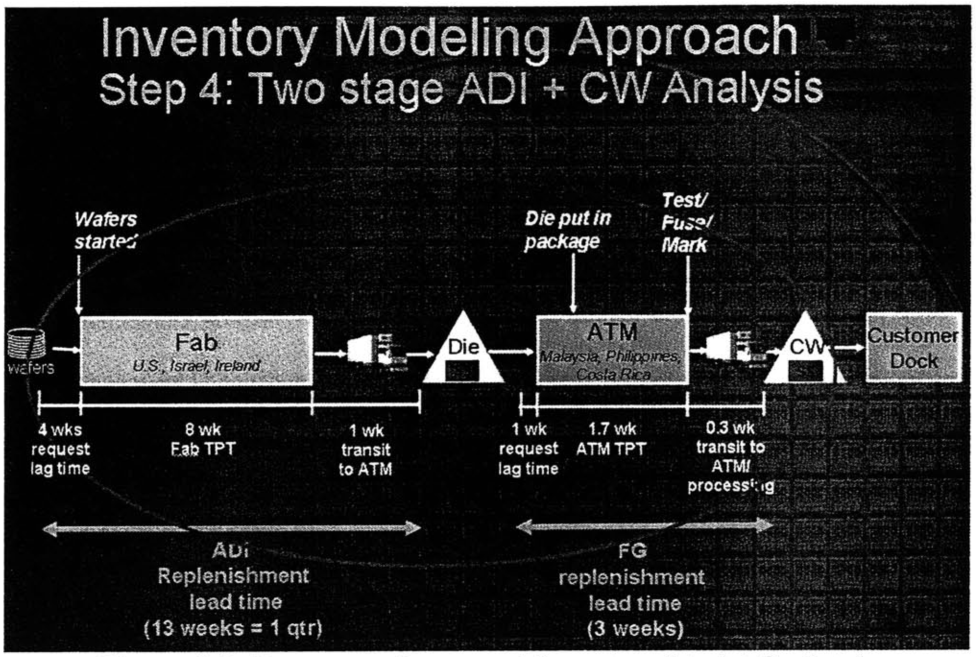


Figure 6-5. Two-stage Integrated Inventory Model for Intel.

This model incorporates the dependencies between both Fab and ATM stages and defines overall service level of the system to be the product of the individual service levels of the ADI inventory and FG inventories. It is important to note that taking the product of the individual service levels may underestimate the overall service level of the system. This will be addressed later in this chapter.

In addition, no supply variability was assumed in this step. (Supply variability will be incorporated in step 5 of the modeling approach.)

<u>Step 5: Two stage model with supply variability included</u>

The final step was to model the system with two stages and incorporate supply variability to analyze how supply variability affects the overall inventory levels of ADI and FG.

Product Granularity Considerations

One significant consideration in applying traditional inventory models is what level of product granularity to perform the analysis. Depending on the level of product chosen for analysis, this could lead to vastly different safety stock recommendations. Modeling Intel's CPU products at a highly aggregated level could lead to pooling of demand variability across products and overall reduction in demand variability. This would lead to lower safety stock requirements than actually needed.

At Intel, CPU products are organized in this hierarchy (as it appears in Intel's demand planning system):

All CPU Products
- Vertical (Desktop, Mobile, Server)
  - Value Segment (Perf vs. Value)
    - Brand (P3, P4, P4HT, etc.)
      - Family (Banias, Northwood, etc.)
        - Cache (512K, etc.)
          - Speed
            - Package
              - Front Side Bus
                - SKU

Occasionally "Level 4" is used to describe a product level even lower than the SKU level that includes product steppings (different manufacturing versions of the same SKU).

To compare the effects of variability pooling and to identify any significant differences in inventory recommendations by product level, the 5-step inventory analysis was conducted for Intel's CPU business at these product granularities:

- All CPU Products
- Desktop vs. Mobile vs. Server
- Performance vs. Value
- Product Family (Banias, Gallatin, Madison, Northwood, Prestonia, Tualatin, and Willamette)

- Desktop Performance vs. Desktop Value vs. Mobile Performance vs. Mobile Value vs. Server
- Box vs. Tray

Data Used: Applying Inventory Models to Intel's CPU Business

Die inventory analysis:

Input Data	Data Source	Time Window of Data
Mean Demand	Judged Demand (final JD from Q3 2003)	Q3 2003
Std Dev of Demand	Std Dev of JD Forecast Error (Historical Judged Demand 3 months out – Actual billings)	Q1 2002 – Q3 2003 (as much data that was available)
Lead Time	Model steps 1-3 used lead times learned anecdotally from employee interviews. Model steps 4-5 used lead time data provided by Levesques.	Q3 2003
Z (Service Level) Factor	Generating inventory vs. service level curve for 75%-99.9% in increments of 5%	N/A

FG inventory analysis:

Input Data	Data Source	Time Window of Data Used
Mean Demand	Judged Demand from Q3 2003 (divided by 13 to get average weekly demand) (final JD from Q3 2003)	Q3 2003
Std Dev of Demand	Std Dev of Backlog Forecast Error (Backlog 3 weeks out – Actuals)	2003 WW15 – 2003 WW39
Lead Time	Model steps 1-3 used lead times learned anecdotally from employee interviews. Model steps 4-5 used lead time data provided by Levesques.	Q3 2003
Z (Service Level) Factor	Generating inventory vs. service level curve for 75%-99.9% in increments of 5%	N/A

Analysis: Applying Inventory Models to Intel's CPU Business

Key Observations from Applying the 5-Step Inventory Analysis

Some significant insights were drawn just from looking at a single product level (all Intel CPUs aggregated together) and applying the 5-step inventory analysis. Below is a table summarizing how total system inventory and safety stock are impacted by how Intel's manufacturing system is modeled and by what data source is used to calculate demand variability. An arbitrary service level of 90% was used for the inventory analysis.

Model Scenario: (All IACPU aggregated, 90% svc level target) (All inventory data in WOI)	Demand Data Source	ADI Demand Variability Data Source	FG Demand Variability Data Source	Replen Lead Time (wks)	Total Inv	Total WIP	Total SS	Total ADI SS	Total FG SS
One-stage model for whole system	JD	JD	JD	16	18.1	16.0	2.1		
Die standalone	JD	JD	N/A	13				1.6	
FG standalone with no supply variability #1	JD	N/A	JD	3					0.9
FG standalone with no supply variability #2	JD	N/A	B&B	3					0.3
FG standalone with no supply variability #3	B&B	N/A	B&B	3					0.3
Two-Stage Model with no supply variability #1	JD	JD	JD	16	18.9	16.0	2.9	2.0	1.0
Two-Stage Model with no supply variability #2	JD	B&B	B&B	16	17.3	16.0	1.3	0.9	0.4
Two-Stage Model with no supply variability #3	JD	JD	B&B	16	18.4	16.0	2.4	2.0	0.4
Two-Stage Model with supply variability #1* -	JD	JD	JD	15.8	21.0	15.8	5.3	2.5	2.8
Two-Stage Model with supply variability #2*	JD	B&B	B&B	15.8	20.2	15.8	4.4	1.8	2.6
Two-Stage Model with supply variability #3*	JD	JD	B&B	15.8	20.9	15.8	5.1	2.5	2.6

*Assumes all families and skus have same yields and supply variability

Figure 6-6. Results from inventory models applied to all CPU products aggregated

In applying the various models, different data sources were used to calculate demand variability – some used "JD" variability of Judged Demand forecast error (JD minus actuals) to be a proxy for demand variability for both ADI demand and FG demand, some used "B&B" variability of backlog forecast error (backlog minus actual billings) to be a proxy for demand variability for both ADI demand and FG demand, and some used a combination of both. Using a combination of both seems be the most realistic model of Intel's CPU operations since JD 13 weeks out is the main data input that drives how much ADI is put into the build plan and backlog is the main data input that drives how much FG is built.

From this table we can make some interesting observations:

WIP inventory constitutes the bulk of total inventory in the system

The long overall replenishment lead times drive most of the total inventory in the system. Replenishment lead time is generally 16 weeks from raw wafers through finished goods, so there is about 16 WOI WIP in the system (assuming negligible cycle stock). Total safety stock, in worst case, only amounts to an additional 5.3 WOI. Thus, if reducing inventory is a priority, finding ways to reduce manufacturing lead times and/or lag time to get a new request into the system would make the most significant impact on overall inventory.

Converting from a one-stage model to two-stage increases SS requirements

The single stage model for the whole system provides one of the lowest total inventory and total safety stock levels. The reason for this is that the Fab and ATM processes are viewed as one continuous step with no die buffer in between and much of the variability in demand for die and demand for FG are pooled together. This leads to lower safety stock levels than two-stage models. This would be an expected result according to traditional inventory theory.

As ADI and FG are decoupled from a one-stage model into a two-stage model, each stage introduces its own demand variability into the system and requires safety stock at ADI and FG. The overall safety stock needed in a two-stage model typically is greater than that needed for a one-stage model even if all inventory model inputs are the same.

Without supply variability, ADI SS > FG SS as suspected

ADI replenishment time is 13 weeks whereas FG replenishment time is 3 weeks. Mathematically safety stock is determined by:

z * std deviation of demand* sqrt (replenishment LT)

If we assume z and std deviation of demand are the same for ADI and FG, automatically ADI SS (sqrt(13)) should be greater than FG SS (sqrt(3)) by sqrt(13)/sqrt(3) = 2.08 times. The 3 two-stage scenarios with no supply variability confirmed this: ADI SS is greater than FG SS in each case.

Supply variability significantly increases the total SS requirements

In the two-stage models without supply variability, total SS requirements ranged from 1.3-2.9 WOI. Once supply variability is introduced into the picture, total SS requirements jump to 4.4-5.3 WOI. Most dramatically, it appears that FG SS increases due to ATM supply variability: from 0.4-1.0 WOI to 2.6-2.8 WOI.

The source of variability data (JD vs. backlog) makes a big difference in total SS requirements

In general forecast error variability based on B&B (backlog) is less than forecast error variability based on JD since backlog (typically tracked < 13 weeks out) is closer in time to the date product is needed and tends be a better predictor of actual billings. Scenarios where B&B is used for both ADI and FG demand variability are the typically the "best" case scenarios resulting in the lowest safety stock requirements across the two-stage models. Scenarios where JD is used for both ADI and FG variability are typically the "worst" case scenarios with the highest safety stock requirements across the two-stage models. The scenario where JD is used to compute ADI variability and B&B is used to compute FG variability is in between these extreme scenarios and reflects Intel's business most closely.

Comparison of Inventory Model Results with Intel's Current Inventory Strategy

As previously discussed in chapter 5, Intel's inventory strategy today is based primarily on a heuristic of 5 WOI combined in transit and in safety stock. Broken down into the two inventory stages, the heuristic is 2 WOI in ADI and 3 WOI in FG inventory. Translated into safety stock terms, Intel's heuristic is 1 WOI ADI SS and 2.7 WOI FG SS.

FG Safety Stock Levels > ADI Safety Stock Levels demystified

Early in the research the question arose as to why there is significantly more FG safety stock (SS) than ADI SS in Intel's inventory heuristic since replenishment lead time for ADI is 4 times as long as FG replenishment lead time. It was hypothesized that more ADI

SS should be held than FG SS and ADI SS should be increased and FG SS should be decreased. This hypothesis was also supported by the fact that cost to hold an additional unit of die is considerably lower than the cost to hold an additional unit of FG. (The actual costs cannot be disclosed due to confidentiality reasons.) However, as was discovered from the inventory models, more FG SS is needed than ADI SS because of the supply variability in the ATM process. This explains why Intel's heuristic of 1 WOI for ADI SS and 2.7 WOI for FG SS has 2.7x higher FG SS requirements than ADI requirements.

Intel's heuristic today leads to approximately 83.7% service level today according to the two-stage inventory model with supply variability

Reverse engineering Intel's current heuristic for 1 WOI for ADI SS and 2.7 WOI for FG SS into the two-stage model with supply variability equates to a 74.3% ADI service level and a 95.4% FG service level. Taking the product of these two service levels results in a 70.9% overall service level. However, it is important to note that 70.9% is the minimum overall service level possible. When ADI is short in supply, FG is not always short at exactly the same time. FG may have enough buffer to cover for the ADI shortage for some percentage of cases. Assuming that FG has enough safety stock to cover for ADI shortages 50% of the time, the estimated "effective service level" is 74.3%*95.4% + 0.5(100%-74.3%) = 83.7%.

Product Level	ADI SS WOI	FG SS WOI	ADI Svc Level	FG Svc Level	Overall Service Level (min)*	Est. Effective Service Level
All IACPU	1	2.7	74.3%	95.4%	70.9%	83.7%

Overall Service Level (min) vs. Est. Effective Service Level
Overall minimum service level = 74.3%*95.4% = 70.9%
Estimated effective service level = 74.3%*95.4% + 0.5(100%-74.3%) = 83.7%.

If Intel wished to reach a 90% estimated effective service level, it would require 2.26 WOI ADI SS and 2.37 WOI FG SS (assuming equal ADI and FG service levels at 93% each). Compared to these numbers, Intel's heuristic underestimates ADI SS by 1.26 WOI and overestimates FG SS by 0.33 WOI for 90% service level. Intel could also reach 90%

estimated effective service level through combinations of different ADI and FG service levels as shown below. Intel might choose to reach 90% estimated effective service level by striving for ADI fill rates higher than FG fill rates and vice versa.

ADI Fill Rate	FG Fill Rate	Min Service Level	Est Effective Service Level	ADI SS WOI	FG SS WOI	Total SS WOI
97.0%	91.2%	88.5%	90.0%	2.88	2.17	5.05
96.0%	91.7%	88.0%	90.0%	2.68	2.22	4.90
95.0%	92.1%	87.5%	90.0%	2.51	2.26	4.77
94.0%	92.6%	87.0%	90.0%	2.38	2.32	4.70
93.0%	93.0%	86.5%	90.0%	2.26	2.37	4.63
89.2%	94.9%	84.6%	90.0%	1.89	2.62	4.51
87.0%	96.0%	83.5%	90.0%	1.72	2.81	4.53
85.0%	97.0%	82.5%	90.0%	1.58	3.01	4.59
83.4%	98.0%	81.7%	90.0%	1.48	3.29	4.77
81.7%	99.0%	80.9%	90.0%	1.38	3.73	5.11
80.2%	99.9%	80.1%	90.0%	1.3	4.95	6.25

Figure 6-7. ADI fill rate and FG fill rate combinations to achieve 90% estimated effective service level (These numbers were generated from the Custom Safety Stock Calculator # 3 in the spreadsheet model shown in Appendix D.)

In all the combinations above to achieve 90% estimated effective service level, Intel's heuristic of 1 WOI ADI SS underestimates the amount of ADI safety stock recommended by the inventory model.

An important point in the table above is not to focus on which combination of ADI fill rate and FG fill rate that will result in the lowest Total SS WOI. The cost to manufacture and hold one unit of ADI SS is much lower than the cost for one unit of FG. Thus, even if a certain combination may lead to the lowest SS WOI overall, it may not necessarily be the lowest cost option from an inventory cost standpoint.

One final caveat is that these numbers must be viewed with some scrutiny since the two-stage inventory model is still a simplified approximation of Intel's inventory system and does not take in account all the complexity in the real system. In addition, the above numbers were based on models of all CPU products aggregated so there might be significant pooling of variability and likely underestimation of safety stock needs. Furthermore supply variability data was only available for one product family (the most stable one) and applied to all CPU products. This would also tend to skew safety stock recommendations lower than needed. However, the models and the results do provide some ballpark estimate of where Intel might be today in regards to service levels for its CPU business.

Other Key Observations

In conducting the 5-step inventory analysis at the various product granularity levels, the results confirmed that as one moves down the product hierarchy into additional product granularity, demand variability does increase (due to increasing demand forecast error as we try to generate forecasts at a more detailed product level). Figure 6-7 illustrates this.

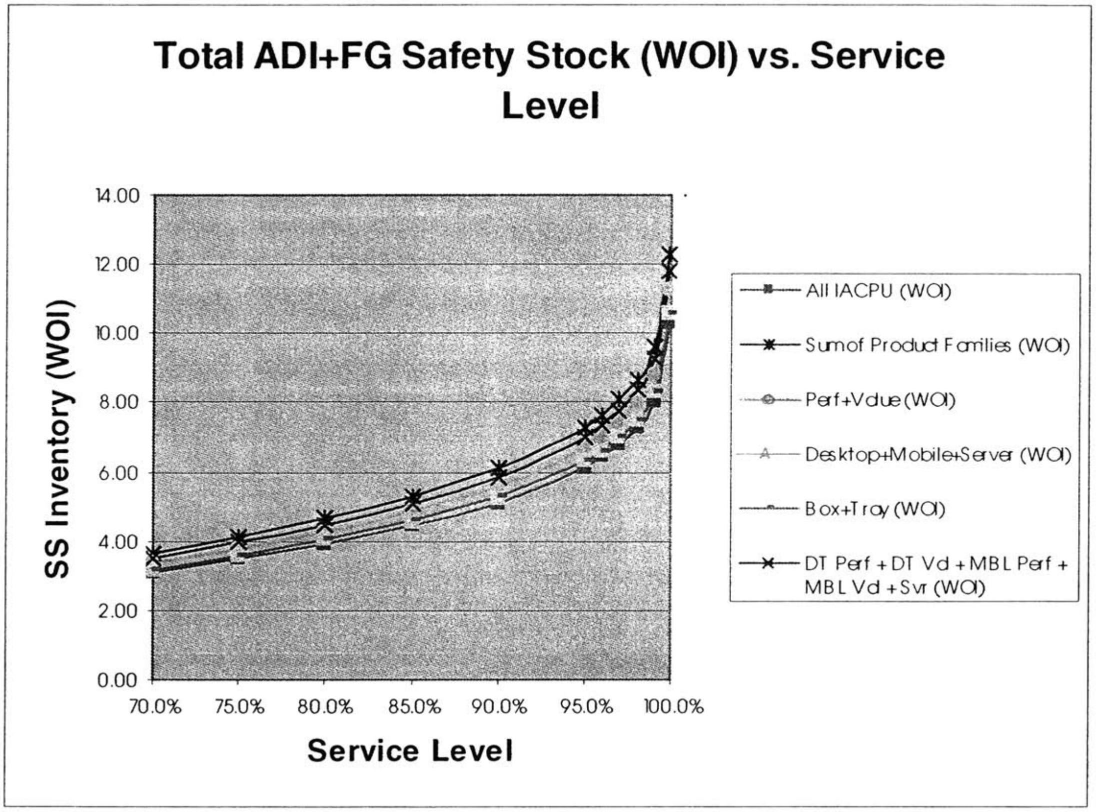


Figure 6-7. Comparison of Inventory vs. Safety Stock curves by product level

The lowest curve on the graph (which represents the lowest inventory requirements) is the curve for All IACPU, which aggregates all products as similar products and pools a lot of the demand variability so overall variability is lower than actual. As one starts segmenting Intel's CPU products and calculating the recommended safety stock levels, the curves move upward. Not surprising, the curve for all product families is the highest curve since there are very different product families with varying levels of demand variation.

Conclusions/Key Learnings: Applying Inventory Models to Intel's CPU Business

Application of inventory models with an iterative approach can lead to valuable insights.
Following the 5-step inventory model approach is not required. One could have just jumped straight to the two-stage model with supply variability. However, starting with simpler models and adding more variables and complexity at each step led to key insights which may not have been gained otherwise.

What input data is used can significantly affect inventory recommendations.
As discussed, inventory recommendations from the models can very considerably depending on whether demand variability was calculated from Judged Demand (JD) or from backlog (B&B), This variability data highly affects overall safety stocks. If a product is new and there are few historical data points, variability may appear higher than it actually is and safety stock levels may be overinflated. The converse also holds true. Variability might be lower than it actually is due to few data points and can lead to underplanning of safety stock.

The level at which products are analyzed affects inventory recommendations.
The product granularity at which inventory modeling is conducted also affects inventory recommendations significantly. In general, the higher the product level applied to the inventory models for Intel's CPU business, the more pooling of variability and the lower the safety stock requirements. In addition, the higher the product level analyzed, typically the lower the demand forecast error and variability. This also leads to lower safety stock requirements.

Chapter 7. Applying Service Levels by Product Segment to Optimize Inventory Mix

"One size does not fit all – think segmentation"[vii]

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Chapter 7. Applying Service Levels by Product Segment to Optimize Inventory Mix

This chapter continues the theme of increasing customer responsiveness of the supply chain by improving availability of product through the use of quantitative inventory models. By extending the application of these models one step further, a company like Intel not only can optimize inventory levels but can also optimize its inventory mix to better provide the right inventory of the right products at the right time.

One extension of the application of quantitative inventory models and service levels to drive inventory targets is to set different service levels for different products or segments. The previous chapter looked at applying inventory models and setting all products to have the same service level for customers. In every company, including Intel, there might be some products which require higher levels of service to meet customer needs (such as newly launched CPUs in high demand). Or there may also products that are more profitable or strategic to the company and which may merit a higher level of service than others. Using one service level for all products could lead to having a lower than desired service level for some products and higher than necessary service level for other products. This translates into less safety stock than desired for some products and more safety stock than needed for other products. Figure 7-1 illustrates this concept. Product A has lower than desired service level while Products B, C, and D have a higher service level than necessary. Because of the one-size-fits-all service level approach, Product A will have fewer safety stock units than desired while Product B has slightly more safety stock than necessary and Products C and D have much more safety stock than actually desired.

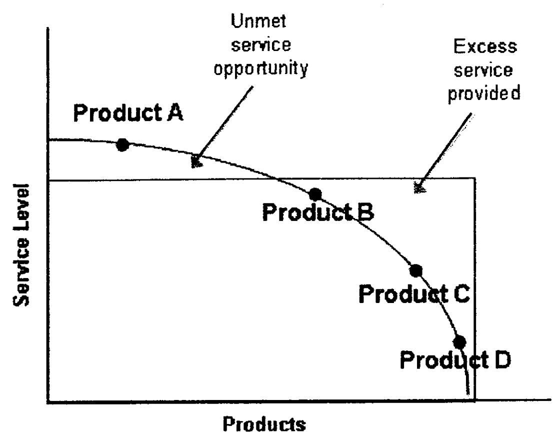

Figure 7-1. Single service level for all products – scenario 1

Another common scenario is setting an extremely high service level for all products with the service level matching the highest service level needed for any of the products (Figure 7-2). The service level is optimal for Product A but much higher service levels than needed are provided for Products B, C, and D.

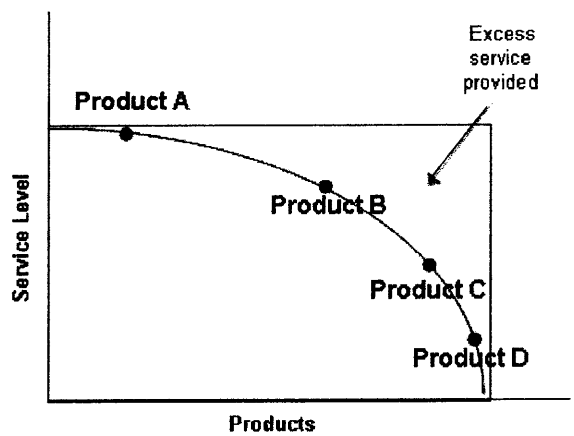

Figure 7-2. Single service level for all products – scenario 2

A seemingly more optimal approach is to set different service levels for different product groups. Individual products with similar service level goals are grouped together and share a common service level. This approach reduces the amount of excess service provided and products can have safety stock levels much better aligned with the desired levels of service for those products.

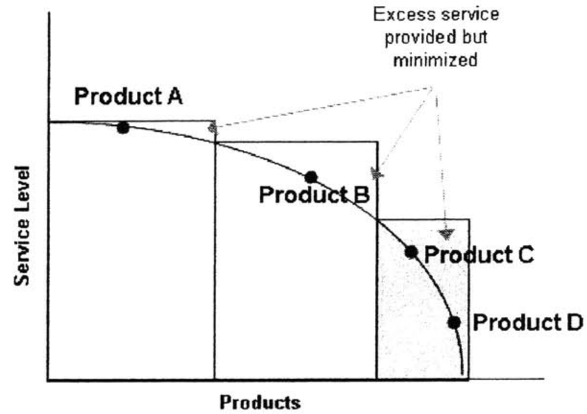

Figure 7-3. Different service levels for different groups of products

Setting service levels by product or customer segments is a relatively straightforward extension once a base inventory model has been established, as it already has been for Intel's CPU business (chapter 6).

Setting service levels by product or customer segment

By leveraging traditional inventory models, not only can Intel take control of specifying a service level across all products but Intel can also set different service levels by product segment or customer segment. This will allow Intel to align its safety stock inventory for different products more closely with desired business goals such as profitability, market segment share, and strategic advantage.

There are numerous ways which Intel's CPU products can be segmented by product or customer segments:

Possible Segments	Intel-specific Example
Product Vertical	Desktop vs. Mobile vs. Server
Product Value Segment	Performance vs. Value
Product Lifecycle	Ramping vs. Stable vs. EOL
Customer	Top 10 Customers vs. Non-top 10 Customers by Revenue
Customer Channel	OEM vs. Distribution
Product Media	Box vs. Tray
Geographic Segment	ASMO vs. APAC vs. EMEA vs. IJKK

Product Cost	Products with high production costs (manufacturing costs or materials/inventory cost) vs. products with low costs
Product Demand/Sales Volume	Products with high demand vs. products with low demand
Reliability of Demand Signal	Demand signal with high confidence of accuracy vs. low confidence of accuracy (chipset may have reliability since customers are further down the supply chain away from the customer)
Cost of Lost Sales	Products with a high cost of a lost sale (e.g. strong competition) vs. products with a low cost of a lost sale

These segments can also be combined to provide a further level of granularity in setting service levels.

Criteria for choosing a segmentation approach for service levels

With so many ways to segment Intel's CPU products, the next question to answer is which approach is best for Intel's CPU products to be segmented so different service levels can be assigned to each segment.

The following criteria were defined to select the best product segmentation approach:

1. Product segments should be easy and intuitive to understand.
2. Product segments should be aligned with how the business is run and how decisions are typically made around the business.
3. Only the product segments with the most impact to the business (profitability, market segment share, etc.) should be selected.
4. The granularity of product segments must be manageable and maintainable from a manufacturing and inventory standpoint.

Recommended Service Level Segmentation Approach for Intel

Based on this criteria, the product segmentation approach that appeared to fit the best for Intel's CPU business was a three-way breakdown of:

[Product Vertical] plus [Product Value Segment] plus [Product Lifecycle]

Product Vertical is the term representing Intel's three main CPU product vertical segments: desktop, mobile, and server.

Product Value Segment is the term representing an additional way how Intel segments its CPU products by performance ("perf") (higher-end CPUs) or value (lower-end CPUs).

Product Lifecycle is the term representing what product lifecycle stage a product is in: ramping, stable, or EOL (end-of-life).

The set of all possible categories that resulted are:

Prod Vertical	Prod Value Segment	Product Lifecycle
Desktop	Perf	Ramping
	Perf	Stable
	Perf	EOL
	Value	Ramping
	Value	Stable
	Value	EOL
Mobile	Perf	Ramping
	Perf	Stable
	Perf	EOL
	Value	Ramping
	Value	Stable
	Value	EOL
Server	N/A	Ramping
	N/A	Stable
	N/A	EOL

This particular segmentation approach was recommended for several reasons:

- This approach is closely aligned with how Intel's CPU business is run today and is quite intuitive. Demand forecasting and pricing is closely based on a CPU product's vertical and market segment, such as desktop performance vs. desktop value.
- Product vertical and product value segment typically affect product profitability as well as market share so both have high impact.
- Product lifecycle is a key driver as to how much inventory needs to be held.
- Three levels of granularity (leading to 15 different combinations which would each need a separate service level target) seemed manageable and reasonable to

maintain over time. Adding a more levels of granularity would make the approach more unmanageable since Intel personnel would need to specify target service levels for many more product segments each time period.

Other segmentation approaches considered:

- [Product Vertical] plus [Product Value Segment] – This is a simpler version of the segmentation approach recommended above and would require less effort to maintain. However, it leaves out a vital piece of information (product lifecycle) that Intel often uses to drive important inventory decisions. Thus, it was considered inferior to the recommended approach.

Prod Vertical	Prod Value Segment
Desktop	Perf
	Value
Mobile	Perf
	Value
Server	N/A

- One other variation that reflects Intel's CPU business well but could not be explored within the limited timeframe of this research project was one that separated the Mobile vertical into two separate verticals (Mobile – Mobility, Mobile – Portability) and also distinguished servers as having product value segments "MP" (multi-processor) and "DP" (dual-processor). This resulted in 24 unique combinations, which would require much more effort to maintain and update without IT automation. It is recommended that this approach be explored in the future by Intel.

Prod Vertical	Prod Value Segment	Product Lifecycle
Desktop	Perf	Ramping
	Perf	Stable
	Perf	EOL
	Value	Ramping
	Value	Stable
	Value	EOL
Mobile-Mobility	Perf	Ramping
	Perf	Stable
	Perf	EOL
	Value	Ramping
	Value	Stable
	Value	EOL
Mobile-Portability	Perf	Ramping
	Perf	Stable
	Perf	EOL
	Value	Ramping
	Value	Stable
	Value	EOL
Server	MP	Ramping
	MP	Stable
	MP	EOL
	DP	Ramping
	DP	Stable
	DP	EOL

Applying service level by product segment at Intel

The following process was followed to implement service levels by product segment:

(1) Desired service levels were defined for each unique product segment.
Members of Intel's MMBP group were interviewed in November 2003 to provide their recommendations on the desired service levels of the various product segments defined. It was helpful to establish a level of abstraction to avoid arguments about specific numeric service level values. The MMBP personnel were asked to recommend one of the following abstract service levels for each segment: Very Low, Low, Medium, High, or Very High.

Prod Vertical	Prod Value Segment	Product Lifecycle	Service Level Goal
Desktop	Perf	Ramping	Very High
	Perf	Stable	High
	Perf	EOL	Low
	Value	Ramping	High
	Value	Stable	Medium
	Value	EOL	Low
Mobile	Perf	Ramping	Very High
	Perf	Stable	High
	Perf	EOL	Low
	Value	Ramping	High
	Value	Stable	Medium
	Value	EOL	Very Low
Server	N/A	Ramping	Very High
	N/A	Stable	High
	N/A	EOL	Low

(2) Next a service level translation table was defined to translate the abstract service levels into numeric values. The table below represent sample values.

Sample Numeric Goals:	
Very high	95%
High	90%
Medium	85%
Low	80%
Very Low	70%

This provided a baseline numeric service level for each of the product segments. In actual application, service levels for individual product segments may have to be tweaked to reflect tradeoffs in service level vs. inventory levels and inventory cost for each segment.

(3) Then existing unique product groups were mapped into the product segment categories and matched with their corresponding baseline service levels.

Intel Product	Vertical (Desktop, Mobile, Server)	Perf vs. Value	Current Product Life Cycle Stage (2003Q3)	Target Service Level	Numeric Service Level
Intel Product Group 1	Mobile	Perf	Ramping	Very High	95%
Intel Product Group 2	Server		Stable	High	90%
Intel Product Group 3	Server		Stable	High	90%
Intel Product Group 4	Desktop	Perf	Stable	High	90%
Intel Product Group 5	Desktop	Perf	Stable	High	90%
Intel Product Group 6	Desktop	Value	Stable	Medium	85%
Intel Product Group 7	Mobile	Value	Stable	Medium	85%
Intel Product Group 8	Mobile	Perf	Ramping	Very High	95%
Intel Product Group 9	Mobile	Perf	Stable	High	90%
Intel Product Group 10	Server		Stable	High	90%
Intel Product Group 11	Desktop	Value	Stable	Medium	85%
Intel Product Group 12	Mobile	Perf	EOL	Low	80%
Intel Product Group 13	Mobile	Value	EOL	Very Low	70%
Intel Product Group 14	Server		EOL	Low	80%
Intel Product Group 15	Desktop	Value	EOL	Low	80%
Intel Product Group 16	Desktop	Perf	EOL	Low	80%

(4) A quantitative inventory model was run for each one of the 16 product groups using the target service level as a key input as well as demand data from Q3 2003. Recommended target inventory levels for each product grouping were documented.

Comparison of Overall Inventory: One Service Level for All Products vs. Service Levels by Product Segment

After applying inventory models to each of the 16 product segments, total overall safety stock requirements were calculated by summing safety stock inventory needs for each product group. An overall service level was calculated to be 88.5% by taking a weighted average of each product group's service level and percent contribution to overall CPU demand volume.

Then these results were compared against the total safety stock requirements from setting a service level of 88.5% for all CPU products. The total overall inventory (in units) remained about the same. The Service Level by Product Segment approach resulted in a slight increase in units (+1%), but this appeared to be insignificant compared to total number of CPU units. Some segments increased in safety stock from this approach and some decreased in safety stock from this approach, reflecting the profitability or strategic importance of the various product segments.

Key Takeaway

Using this new approach of setting different service levels by product segment, Intel can maintain about the same level of total inventory and maintain overall total service level, but optimize inventory mix by aligning it better with Intel's desired business strategy. There will be more inventory units (and increased service level) for the products which are important to Intel's profitability and strategy and less units of products which have lower profitability and more risk of becoming obsolete.

Other Considerations

Impact on inventory levels

Using this approach of service levels by segment, inventory levels may end up being lower than the inventory level from having one service level for all products. However, overall inventory units could also increase compared to total inventory units from having one service level for all products. If maintaining the same level of inventory as the original inventory level is crucial, then individual service levels for the various segments can be adjusted so that the overall inventory level is about the same as before.

Impact on overall ASP of inventory

This approach will likely increase the overall average selling price (ASP) of Intel's CPU inventory since Intel will hold more safety stock inventory of products which make Intel high profits (like server CPUs) and less of the CPU units that only make marginal profits like EOL desktop CPUs.

Impact on inventory valuation

From a financial standpoint, this approach has the risk of increasing valuation of inventory, which may be a concern to the CFO and Intel's financial group. There may be fewer physical units of inventory but they may be of higher value so this might increase inventory valuation.

Impact on inventory holding cost

If Intel uses this approach and holds more quantities of high value units (which cost more to manufacture), this could also have an increase annual inventory holding cost. This may also be a concern to the CFO.

Impact on customer service

This strategy could have a negative impact on perceived customer service. For customers who buy a range of CPU products, Intel will appear to provide higher service levels for some products and lower service level for other products. This inconsistency may not build strong confidence in Intel from a customer standpoint. However this inventory approach will help Intel achieve its strategic goals better. It is a tradeoff that Intel will have to consider.

Implementation Pre-Requisites for Implementing Quantitative Inventory Approaches

Overall it appears that using quantitative inventory models to drive inventory targets as well as specifying different service levels by product segment can significantly increase product availability and improve the customer responsiveness of Intel's supply chain.

However, before this approach can be implemented successfully, Intel would need to put a number of key things in place first:

Analysis of the financial impact of the new inventory approach

A cost-benefit analysis was not able to be completed within the timeframe of the thesis research project. The benefits of using a quantitative approach to drive inventory targets and mix need to be quantified: Will additional revenue be generated due to better product availability or better product mix? How much does Intel benefit in the short and long term from increased customer responsiveness? What is the cost of a lost sale? What is the cost of a deferred sale? Is there a long-term cost for not building customer loyalty? Will there be a labor savings? Although many of the benefits are difficult to quantify or are intangible, it is important to try to define some assumptions that others may be able to accept and quantify the benefits based on those assumptions. Then the benefits can be weighed against the costs associated with this new approach: cost of additional inventory (if necessary), cost of new IT systems, cost of training, cost of resources to implement this project, etc.

Improvement of IT systems supporting historical demand and supply data

The traditional inventory models are only as good as the data which is inputted into them. Much of the historical data needed as key input into the traditional inventory models are stored on spreadsheets or not stored anywhere at all, with the exception of MMBP's Microstrategy data warehouse which has historical JD and actual demand data. Historical demand variability data is manually intensive to calculate and requires regular updating as new data is available. Supply variability data is extremely difficult to access in a consistent format from various fabs (since many of them use different systems) for all product families. For the recommended inventory approach to be a maintainable long-term solution, the relevant data and calculations must be automated in some IT system. MMBP's Microstrategy data warehouse would be ideal for storing historical demand variability data and would need to be made available for a wider audience.

Business Process Impact Analysis

An analysis would need to be done ahead of implementation to understand which processes and people would be impacted by moving forward with the recommended inventory approach. Future "to-be" process flows would need to be defined to ensure that all major process gaps have been addressed for each of the organizations and people affected.

Incentive Analysis

An analysis of the key stakeholders and the metrics on which they are measured to achieve their bonuses is also critical. Some IMBOs and metrics may have to be temporarily waived or readjusted to address potential effects of the implementation of the inventory approach. Otherwise these stakeholders may not be supportive of the initiative. For instance, employees on the financial side of the business may face the risk of inventory value increasing and jeopardizing their performance metrics and bonuses. This would invoke resistance from implementing the new inventory approaches although they would be beneficial for the company. However, if the group's performance incentives are altered and aligned with the new inventory approach, then there would be no issue.

Potential Implementation Challenges

Implementing the quantitative inventory model approaches discussed in this chapter and in the last chapter are likely to encounter these challenges:

Company Inertia

Although increasing the customer responsiveness of Intel's CPU supply chain is critical to Intel's long-term competitiveness, there is no current major crisis or problem that puts this as a top priority in management mindshare. With the amount of effort and potential disruption to the company, the initiative can easily be placed in the backburner by management unless top Intel management makes this a key corporate initiative.

Getting agreement on target service level goals between sales/marketing and supply chain/manufacturing.

Typically sales and marketing will push for the highest service levels to maximize revenues and minimize potential loss of sales. Supply chain and manufacturing, the groups which have visibility into the cost of producing and holding products, will typically push for lower service levels to minimize inventory. The final agreement on service level will most likely come from discussing the tradeoff between inventory cost and cost of lost sales between the two sides.

Getting agreement on target service level goals for different products within marketing

Even within marketing, disagreement may be encountered in setting different service level goals for different products. It may be a challenge to explain to one product group why their product will be given a lower service level than another product, especially if product stakeholders have financial incentives to maximize sales of their respective products.

Data/IT issues may delay this project for years

Currently there is no IT automation that would allow Intel to easily manage, track and change service levels by product segment regularly and to keep variability data and calculations updated. The process to collect data and build inventory models for different product segments is very manually intensive today without much IT automation and support. And there are no automated interfaces to take the inventory model recommendations to feed into the Intel CPU build plan process. Furthermore, as we increase the product granularity of our analysis, it becomes increasingly difficult to manage and maintain without automation.

Intel may not have the available capacity to provide higher service levels

Even if we set higher service level targets for different product segments, Intel may not have available Fab and ATM capacity to provide higher service levels with the current level of demand. If Intel is forced to build new Fabs just to support this new inventory approach, the costs of the new Fabs would definitely outweigh any savings or additional revenue generated by our recommended inventory approach.

Chapter 8. Other Approaches for Improving Customer Responsiveness

"Opportunity dances with those who are ready on the dance floor"[viii]

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Chapter 8. Other Approaches for Improving Customer Responsiveness

This chapter provides an overview of other potential supply chain approaches that might improve the customer responsiveness of Intel's supply chain. Due to the limited timeframe of the internship, there was not enough time to research these approaches in detail. However, these approaches may lead to important future initiatives to improve the customer responsiveness of Intel's supply chain.

Approach #1: Find New Ways to Reduce Overall Replenishment Lead Times

Today at Intel, overall CPU replenishment lead time from raw silicon wafer to finished good is 16 weeks. This leads to a significant amount of WIP inventory in the system and hinders Intel's flexibility to be responsive to changes in the business environment, especially in the fast-moving world of high-tech electronics. If Intel can identify new ways to shorten this replenishment time significantly, WIP inventory can be reduced (and safety stock inventory to a lesser extent) and Intel can be more flexible in responding to customer needs and changes to the business environment. In addition, reduction in replenishment lead times will allow Intel and Intel's customers to forecast closer to the actual date products are needed. This may lead to lower demand forecast error and variability, which translate into lower safety stock requirements.

Intel's Fab TPT time for converting a raw silicon wafer into die is 9 weeks. In addition to that, there is a lag time of about 4 weeks to get a new request for die into the build plan. The total replenishment lead time for converting wafers to die is 13 weeks, which makes up 77% of the total replenishment time for die->finished CPU unit.

Based on this analysis, one recommendation is to look for ways to significantly shorten total ADI replenishment time in the Fab process. The lowest "hanging fruit" is shortening the lag time for getting a new die request into the Fab build plan through streamlined processes and use of IT automation to speed information flow. Today much of the process to get a new die request in the system is manual and most of the information resides on individual Excel spreadsheets. The E2E initiative is closely looking into this area and has piloted a process to shorten the lag time to 2 weeks through a mid-month build plan reset process.

Another obvious recommendation which can reap huge benefit is to explore ways to significantly shorten Fab TPT time which makes up 70% of the total replenishment time in the Fab part of the manufacturing process. Because of the complexity involved in the Fab process, this undertaking would require significant effort and resources but the benefit is substantial from an inventory and competitive standpoint.

Similar approaches can also be applied to shorten overall FG replenishment time (3 weeks) in the ATM process. ATM TPT time for converting die into CPUs is 2.7 weeks. In addition to that, there is a lag time of about 0.3 weeks to get a new request for a CPU into the ATM plan. If FG replenishment time can be shortened enough, if high service levels of die from Intel's Fabs can be maintained, and if there is enough ATM free capacity, Intel could even consider a build-to-order model or at least start moving towards a hybrid push-pull manufacturing system.

Approach #2: Enable a Postponement Strategy Using Single-Mark

To distinguish CPU products which are sold through distribution and which have a warranty longer than those products sold directly to computer OEMs, Intel currently imprints a unique mark on all those units designated for the distribution channel during the ATM process. Although this approach helps Intel distinguish which units Intel is obligated to provide extended warranty, this approach artificially segregates one safety stock pool of the exact same product into two distinct pools of products which can no longer be leveraged interchangeably. In situations where one of the pools of product is short on supply, this inventory design restricts Intel's flexibility to pull inventory from the other pool and prevents Intel from being more responsive to customer needs.

Another side effect of this approach is that Intel now has to carry extra safety stock on the same product since it can no longer have one general pool to cover unexpected product demand in both the direct OEM and distribution channel. Furthermore, if forecast error is significant (especially since forecasting demand from the channel is more difficult than forecasting demand from OEMs), Intel might find itself in a situation where it has excess CPU products that cannot be sold in the distribution channel while some OEM customers are short of supply of the exact same product.

There has been internal discussion of a "single mark" strategy where the same product would not be marked differently depending whether it is intended for OEM sales or distribution sales. Instead, there will be a "single mark" on all products and the warranty tracking would be done through IT systems instead of physically on the product itself. This postponement approach would allow Intel to have more inventory flexibility and be more responsive to meet customer product needs.

Approach #3: Re-engineer customer order processes for the CPU business

Because of Intel's CCP and hotlist processes, every product request from a customer must be reviewed by at least one person at Intel and often escalated up and down a review chain that may include the customer sales rep, the Geo sales manager, a product planner, and a member of MMBP's supply team. Such human intervention is needed for every CPU product regardless of whether supply is available or not. Not only does this require costly human resources to process each request, it also prevents Intel from responding to customers quickly.

Intel should look into different possible ways of re-engineering its customer order processes for its CPU business. Might Intel be able to adopt a more typical available-to-promise process for some products instead of an allocation-like process? Could a workable hybrid between CCP and ATP exist?

In addition, Intel could look into using IT to enable new ways of processing customer product requests and orders. This might include enhancing external websites through which customers can submit order requests and get self-serve tracking, introducing automated workflow routing systems with smart rules that can automatically respond to a customer's request if supply is available, and enhancing IT systems like OCOT or building a new IT system that can enabled a seamless, paperless, and rapid flow between the customer and all the internal Intel groups that need to review each product request. Today the overall process is automated in some parts, very manual in other parts, and lacks real-time visibility across the customer through all the internal Intel groups involved.

Re-engineering the customer order process can potentially speed up the promptness of Intel's responses to customers as well as improve customer demand visibility. Both of these would lead to increasing customer responsiveness.

Approach #4: Communicate service levels for different product request windows

Another way to improve customer responsiveness is to provide more information to customers up front and set their expectations accordingly. Today when Intel's CPU customers want to change how much they originally ordered through the CCP process and want to request additional units for the next 0-13 weeks, they must go through the hotlist process. When customers submit hotlist requests today, the requests could be for product to be delivered immediately or anytime over the next 13 weeks. Customers have no idea whether or not a hotlist will be supported until they hear back from Intel.

To improve customer responsiveness, Intel could communicate some notion of service level to its customers. For instance, Intel could let customers know that they should expect a 90% service level for hotlist requests with a delivery lead time 3 weeks or greater and a 25% service level for hotlist requests with a delivery lead time < 3 weeks. Communicating this information sets service expectations and may influence customers to change their behavior and submit hotlist requests with more lead time. This may result in fewer expedite requests in ATM and increase overall product availability.

Further research needs done to determine the specific expectations and service level that would be optimal to communicate to customers.

Approach #5: Introduce new programs that incentivize more honest behavior from customers

Today Intel's CPU customers have tremendous flexibility in their order terms and conditions. In general it appears that most customers can cancel their orders anytime within 1-2 weeks of their orders with no penalty and in some cases, especially with Intel's largest customers, customers can cancel with no penalty anytime even up to the point when orders are already in transit. Such terms are very generous from a customer service standpoint and Intel sales personnel will most likely argue that this is needed to be competitive. However, these terms and conditions have led to customer behavior that actually hurts overall responsiveness to the entire customer base.

Because customers have generous cancellation terms, they often book orders on amounts more than they usually need and then cancel at the last minute without penalty. Customers leverage this to protect themselves against forecast error or unexpected last minute demand at Intel's expense. Customers also leverage these generous terms to cover themselves when a product is going EOL, which is very common and often with CPUs of specific speeds and steps. In situations where a product is going EOL, customers tend to double book to hedge their bets – they book orders on the new product but they also book just as many on the old product in case the EOL transition to new product does not materialize as quickly as planned. Customers hold both products as long as possible until orders materialize and then cancel at the latest moment possible. This is also true of hotlist grants where customers order and "load up" on product early in a quarter, request push-outs through the quarter and then cancel their orders at the last minute possible.

This hurts Intel in several major ways:

(1) The fictitious demand resulting from gaming the system artificially increases demand for products. With Intel's limited (and expensive) Fab capacity, this could be causing Intel to manufacture more units than necessary and to use up valuable Fab capacity unnecessarily. This could also be delaying the manufacturing of units which are needed by customers.

(2) This fictitious demand also increases inventory in the system. Because of the customer cancellations at the last minute, Intel will tend to have more inventory than needed in the system. WIP inventory is also inflated.

(3) Overall customer responsiveness may be hurt by this customer behavior. Inventory which customers have booked but don't intend to bill is reserved for these customers while other customers who have real demand may not be able to get any supply at all.

There are two types of possible solutions to this problem: (1) reactive and (2) proactive.

Reactive solutions accept this customer behavior as a given and as unmodifiable. One approach would be to try to beat customers at their own game and try to predict the excess artificial demand (the "bubble") from customer gaming based on historical information. Then based on Intel's estimate of the size of the "bubble," Intel may decide to take a risk and overcommit an amount of CPUs to customers who have real demand. However, this is a risky approach and the "bubble" is hard to predict since there are so many variables that influence the ordering behavior of Intel's customers. This may be viewed more as a "band-aid" solution than a solution that attacks the root cause of the problem.

Proactive solutions view this customer behavior as the result of current customer incentives. Proactive solutions would focus on initiating new programs and terms and conditions that will discourage Intel's customers from gaming the system. Some ideas for proactive solutions are:

1) Enhancing ordering and cancellation processes and IT systems to allow Intel to have visibility on the worst offenders who cancel orders the most. Today Intel's internal systems do not appear sophisticated enough to aggregate and summarize order cancellation information down to the customer level. With this information, Intel will have more leverage and evidence to come down upon those customers who are gaming the system the most.
2) Redefining new customer terms and conditions which are still attractive and very competitive but do not allow customers to cancel orders without penalty the last minute. This one is difficult because Intel has already allowed the privilege of canceling last minute without penalty to customers. Revoking the privilege or imposing stricter terms without offering something in return probably will enrage customers. Ideally if Intel can get customers to agree to some type of cancellation penalty and have this penalty enforced, this will change customer behavior. However, Intel will need to offer something to customers in return.
3) A relatively new area of supply chain thinking around options contracts may also be a possible proactive solution. The premise is that Intel may be able to offer options (similar to options in the finance world) to customers who want to purchase a guaranteed right to buy CPUs at a certain price and certain date. The options would be priced differently based on lead time of request as well as quantity to be purchased. This work would leverage some of the leading edge supply chain thinking done by Schmidt (2003) and supply chain software companies like Vivecon. Based on some initial analysis, this approach may not be feasible due to Intel's frequent dynamics in product pricing and customer discounts. Setting options prices for products which are often changing in price will require additional management and maintenance. In addition, this could lead to a new opportunity for gaming by Intel's customers. Because Intel CPUs are in high demand globally and can be traded like commodities, implementing options may bring about new secondary options markets that can lead to unintended pricing consequences. However, it is a very intriguing area for further research.

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Chapter 9. Implementing Change at Intel

"To move an elephant, you start by finding its most ticklish spots…
but make sure you get out of its way so it doesn't fall on top of you."

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Chapter 9. Implementing Change at Intel

This chapter examines the larger organizational factors that will impact the overall chances of success for both the metrics and inventory modeling approaches at Intel. Implementing these approaches successfully goes way beyond tracking metrics, implementing several frameworks, and plugging numbers into quantitative inventory models. Implementing lasting change at huge corporation like Intel with 80,000 employees requires looking beyond a project's details and understanding the project's alignment with Intel overall from a strategic, political, and cultural point of view.

Organizational Analysis of the Customer-focused Supply Metrics Initiative

In July 2003 the E2C metrics team started with strong momentum and backing from a larger E2C corporate-wide initiative to improve and streamline customer-focused processes across the company. The E2C initiative had decent executive level visibility with regular reviews with high-level executives, which gave the E2C metrics team reasonable executive mindshare. However, the entire E2C initiative encountered a major setback in late 2003 when the initiative was indefinitely shelved due to apparent budgetary constraints.

The E2C metrics initiative continued to live on, championed by a key member of the WCST (Worldwide Customer Satisfaction Team). In January 2004 the team released a pilot Supply Network Dashboard for which the team has worked to get buy-in and support from multiple Intel organizations.

In analyzing the critical success factors for the future of this initiative, it is valuable to examine the alignment of this project from strategic, political, and cultural perspectives.

Strategic Alignment

From a strategic alignment standpoint, there had been some potential concern about lack of executive support in improving customer service but this seems to have been alleviated. The indefinite postponement of the E2C initiative in late 2003 appeared to be a signal from Intel management that improving customer service was not a critical short-term company imperative worth budgeting. However, the recent reorganization of many of the groups involved with E2C into a new initiative, Tactical Demand Fulfillment, appears reassuring. Backed by high-level executives in Intel's Technology Manufacturing Group (TMG) and Sales and Marketing Group (SMG), this initiative has been chartered to investigate ways to respond more quickly and positively to customer demand. The metrics project is still being driven under WCST and does not have the same level of cross-functional backing and management visibility as it did through the E2C effort, but it seems to have made significant progress. The customer-focused metrics proposed by the metrics team are awaiting ratification as ISNG's new operational metrics.

Political Alignment

From a political standpoint, WCST is an excellent organization to sponsor this project since the project fits well within its charter to deliver value to customers through operational and supply chain initiatives. However, it is not clear whether WCST has the organizational influence and clout to achieve company-wide support and buy-in for the customer-focused supply chain metrics. One of the critical keys to getting organizations to adopt and track metrics is to tie performance bonuses to metrics. Because WCST may not have the organization power to do this and to enforce accountability of such metrics, WCST faces a huge challenge ahead. Furthermore, without executive level support, middle management is likely to resist implementation of these metrics since it will force them to do more work and use up valuable resources to track these metrics regularly without clear payback for them.

Cultural Alignment

Intel has a very execution-focused and data-driven culture. Indicators and metrics are commonly tracked in every organization in Intel. However, there is an overwhelming amount of data everywhere and employees tend to focus only on those indicators and data that tie directly to their work performance and performance bonuses. Without the proposed customer-focused supply chain metrics tied to individual or group performance incentives and in absence of a culture that places high emphasis on customer service, the metrics initiative also has some significant cultural hurdles to overcome.

Critical Success Factors

Given the strategic, political, and cultural issues identified above, the following critical success factors have been identified for the future success of the metrics initiative:

1. Find and engage a high-level executive champion.

The main priority for this team in moving forward is to find and engage a high-level executive champion who has the ear of other company executives and who has the organizational clout to establish accountability (see #2). Without this executive champion, the project faces significant risks of not succeeding in the long-term.

2. Have the high-level champion establish regular accountability for the metrics.

New metrics will just be ignored or considered a "nice-to-know" unless management is held accountable to these metrics regularly. Just assigning accountability and never following up are not enough.

3. Involve other key stakeholders who would benefit most from the metrics.

One way of building momentum and support for the metrics initiative is to involve other influential stakeholders from other organizations who can benefit positively from the information from the new metrics. Once these stakeholders show their support for these metrics, some momentum may be created to influence other parts of the organization to come on board.

4. Work towards linking metrics performance to performance bonuses.

In additional to establishing regular accountability, tying metrics to group or individual performance bonuses is one way to quickly align an organization around a set of metrics and keep employees focused on them. Otherwise, these metrics will be ignored or just considered "nice to know."

Organizational Analysis of the Inventory Modeling/Service Level Initiative

The research conducted around using inventory models and service levels to determine target inventory levels and inventory mix is closely linked to the E2E initiative, which is attempting to streamline all of Intel's planning and inventory processes to enable a more responsive and flexible organization.

The E2E project has been ongoing for several years and has significant support and visibility from high-level company executives. The research work described in this thesis as well as the research done by Levesques have provided key insights into Intel's inventory system and have influenced future related research as a part of the E2E initiative. Intel is currently exploring the use of inventory optimization tools such as Optiant to automate much of the inventory analysis done in this thesis and in Levesques' thesis and extend the analysis much further in more complex models.

Strategic Alignment

The E2E supply chain initiative is well aligned with executive management's desire to create a more streamlined and efficient organization. Because of the size and impact of this initiative, there has been significant management support and visibility. The E2E team is composed of Intel employees from a variety of organizations so this has aided cross-functional buy-in. One concern is that it is not clear whether company executives truly appreciate and recognize the potential of leveraging the supply chain to drive new sources of competitive advantage for Intel. There seems to be a perception that supply chain is a merely necessary function to get products to customers as compared to design and manufacturing, which are viewed as the company's esteemed areas of competitive advantage. This general attitude toward supply chain could derail valuable initiatives like E2E in the future.

Political Alignment

The E2E initiative is driven by the E-Business Group (EBG) which is equivalent to the IT organization of other companies. EBG's charter is to leverage IT to develop solutions that add value to Intel's business. EBG's members are dispersed throughout many business functions of Intel while maintaining a dotted line relationship to EBG. EBG is reasonably well aligned politically to influence different parts of Intel and make significant business impact through the E2E endeavors. However, EBG does face challenges from the structure of Intel's organization. Intel's supply chain functions are decentralized across a variety of organizations. There are often concurrent supply chain initiatives that overlap, and there is no central supply chain group that sets supply chain strategy and coordinates across projects. As a result, EBG must deal with this fragmented supply chain environment to engage all the relevant parties and get their buy-in.

Cultural Alignment

Intel has an engineering-oriented culture. Along with this culture comes some natural skepticism and cynicism. The E2E initiative through various incarnations has been going on for several years now and was unsuccessful in some previous initiatives. Consequently there is some skepticism and cynicism among employees who have been at Intel since the beginning of E2E and who view the E2E initiative as a never-ending project of questionable value. This skepticism may affect the momentum and rollout of any new initiatives of the E2E team. The E2E team will need to win the skeptics over by showing tangible results and improvement.

Critical Success Factors

Given the strategic, political, and cultural issues identified above, the following critical success factors have been identified for the future success of the metrics initiative:

<u>1. Focus on incremental short-term wins to gain the confidence of the organization</u>

To dispel any skepticism or cynicism among management or employees towards the value or effectiveness of the E2E initiative, it is important for the team to focus on incremental short-term wins to show the rest of Intel that the E2E project can result in significant value to Intel.

2. Keep executive champions closely engaged

One of the strengths of the initiative is the current high-level executive support and visibility for the E2E program. It is important to keep the E2E project highly visible and to continue to engage current and new executive champions on a regular basis. Without this support (especially as executives turn over or move within the company), the E2E initiative is not likely to succeed.

3. Continue to foster cross-functional involvement and support

Because Intel is such a large organization and has decentralized supply chain functions, the E2E team must continue to foster strong ties with key stakeholders from various parts of the organization and involve them early in the process. This will be hugely beneficial in getting cross-functional buy-in and may speed implementation of new initiatives.

4. Provide frequent communication and updates to the rest of the organization

One strategy for keeping employees engaged and interested in the E2E project is to continue to provide frequent communication and updates about programs and results. This is crucial for the overall change management process so there are no surprises across the organization. This raises project awareness and often invokes useful feedback and ideas from employees not on the project team.

Chapter 10. Conclusions and Recommendations

"Only the paranoid survive."[ix]

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Chapter 10. Conclusions and Recommendations

For companies looking to improve customer service and customer responsiveness, often a wealth of untapped opportunities lies within their supply chains. A company's supply chain not only affects how promptly a company can respond back to customer requests but it also affects how well a company can meet customer needs through product availability. And the execution piece of the supply chain is what proves a company's responsiveness to the customer by delivering to the company's promises.

In helping Intel's CPU business unlock new ways to improve the customer responsiveness of its supply chain, this thesis examined two key approaches in depth:
(1) implementation of customer-focused supply chain metrics
(2) application of traditional inventory theory to drive optimal inventory targets and inventory mix aligned with customer needs and company business strategy

These two approaches are fundamental to improving customer responsiveness. A company cannot improve the customer responsiveness of its supply chain if it is not capturing the right metrics and does not know how responsive its supply chain is in the first place. A company's safety stock levels are crucial in determining how responsive it can be to the product needs of customers and what service levels it can provide to customers. Furthermore, segmenting products to allow for different service levels and safety stock levels by product segment enables a company to better align its inventory mix with customer needs as well as with company strategy. Using inventory models to determine inventory targets is much more complicated and requires more support infrastructure than using a simple heuristic. However, the potential benefit can be significant from higher inventory turns, increased sales, increased customer loyalty, improved utilization of fixed assets, and increased control over customer service levels.

With the customer-focused supply chain metrics effort, Intel has made important progress towards being able to provide world-class customer service. These new metrics will drive additional focus and visibility on many crucial but often overlooked aspects of Intel's supply chain which significantly impact customer responsiveness. Once there is greater understanding and realization of how Intel is performing in these areas, this may uncover other opportunities to improve customer responsiveness further. The metrics team needs to continue evangelizing the importance of these metrics throughout the company and continue to gain support and buy-in. Executive level backing is also critical to ensure that various organizations across Intel are held accountable to these metrics in the future.

For a company to be responsive to customers, its supply chain design and processes must also be aligned to support the desired levels of customer responsiveness. One significant opportunity area for Intel to improve customer responsiveness through its supply chain processes is in how it determines safety stock inventory levels. The application of quantitative inventory models to set safety stock levels (as discussed in this thesis along with the work done by Levesques) has tremendous potential to enable Intel to have much more control over the levels of service it can provide to its CPU customers compared to its heuristic approach today. In addition, these models can help Intel align its overall CPU safety stock inventory mix much better with customer demand and company strategy. Although the quantitative inventory models discussed in this paper and in Levesques research rely on many assumptions and limited data, they provided key insights into how Intel's safety stock inventory needs at ADI and FG are potentially affected by CPU demand and supply variability, lead time, and desired level of customer service. These models lay a rich foundation for further research at Intel and may lead to changes in Intel's strategy for setting ADI and FG safety stock levels. Currently the E2E team is exploring inventory optimization software solutions that would automate the types of inventory models developed in this research and in Levesques' research. Furthermore, these software solutions would be able to support much more complex and dynamic models that reflect Intel's actual inventory system more closely. One important prerequisite for the successful application of such models is accessibility of clean and robust data. The recommendations from these models are only as good as the data that is inputted into them. For the research discussed in this paper, it was a very time-intensive and manual process to pull together the required data. If these quantitative inventory modeling approaches are to be rolled out at Intel in the future, more automated means of pulling together the latest available data would be needed for long-term manageability of these approaches.

Identifying supply chain metrics, defining frameworks, building spreadsheet models and finding the right data to plug into these models are not trivial but is the easy part. The much more difficult part is taking these approaches, which clearly can add tremendous value for Intel, and successfully implementing them across an 80,000-employee global organization that has a huge organizational structure but no centralized organization coordinating supply chain strategy. This is where many of the strategic, political, and cultural considerations discussed in chapter 9 come into play. Half the battle is coming up with these new approaches to increase customer responsiveness; the other more difficult half is getting many organizations within Intel to adopt them and use them successfully.

Other compelling areas for further research were also identified for Intel to potentially improve customer responsiveness, as described in chapter 8. Some of these are internally focused and lead to increased internal flexibility that may lead to improvements in customer responsiveness. Examples of these are reducing product replenishment lead times, single-mark postponement strategy, and re-engineering customer order processes. Other ideas involve working with customers to proactively manage their expectations better and to discourage gaming of supply. Research into any one of these given areas could lead to significant improvement in customer responsiveness of Intel's supply chain.

In the first quotes mentioned in this thesis, supply chain is becoming "one of the business battlegrounds for the foreseeable future." For companies like Dell, Wal-Mart, and Amazon.com, the mentality of using supply chain as a competitive weapon has propelled them to the top of their industry segments. As the supply chain is increasingly being viewed by companies as a potentially rich source for strategic advantage, Intel management should review how it leverages its supply chain holistically today and how it may want to leverage supply chain differently in the future to extract competitive advantage from it. Intel may want to consider establishing a central supply chain organization in the future that sets a cohesive supply chain strategy for the company. A

VP of Supply Chain position (as many other high-tech companies have) might be created and would report into one of Intel's executives, such as the COO. This would give supply chain initiatives high executive visibility and mindshare. In addition, this would allow Intel to coordinate the many fragmented supply chain initiatives underway today and manage its entire supply chain as one well-oiled system. The new organization would also enable more rapid rollout of cross-functional supply chain initiatives. Accountability for top level supply chain performance and metrics would roll up to the VP of Supply Chain instead of being shared across organizations; this may reduce the tendency to put the blame for poor supply chain performance on other organizations. These are just some ideas how Intel might coordinate and leverage its supply chain into more of a competitive weapon.

Many of the supply chain approaches and learnings discussed in this thesis are applicable to other companies, not just to Intel. The application of customer-focused supply chain metrics can bring benefit to any organization which currently does not track how well it serves its customers. Even for companies that have supply chain metrics established, the metrics frameworks and metrics rollout approaches (such as the metrics dashboard) can be leveraged to improve the effectiveness of existing company metrics. The approach, findings, and insights of applying quantitative inventory models to Intel's CPU business can also be leveraged by other companies who wish to implement quantitative inventory models. Many of the issues around what data to use, service level definition, product granularity, and model limitations are common across companies. Segmenting service levels by product segment is an inventory strategy that companies using quantitative models can utilize to drive better alignment of inventory mix, customer service goals, and business strategy.

In the famous words of Intel chairman Andy Grove "only the paranoid survive." With Intel as the world's top semiconductor company, every competitor is constantly looking for opportunities to steal Intel's customers away. Intel should be very paranoid about losing its customers, one of the company's most important assets. However, given Intel's increasing focus toward developing world-class customer service and efforts to improve the customer responsiveness of its supply chain, this should lead to higher customer satisfaction and stronger customer loyalty in the long-run. And hopefully Andy Grove will be able to sleep a little better at night… for now.

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Appendix A. SCOR Metrics Framework

	Performance Attribute or Category	Level 1 Performance Metrics	Working Definition
CUSTOMER FACING	**Supply Chain Delivery Reliability** The performance of the supply chain in delivering: the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation.	Delivery Performance *(see SCOR Glossary for definitions of all metrics)*	Delivery Performance measures the percentage of orders delivered "on time and in full" to customer request date and/or to customer commit date.
		Fill Rates	Fill Rates measures the percentage of ship from stock orders shipped within 24 hours of order receipt. Many companies use Line Item Fill Rate as an alternative metric measured by the percentage of lines filled within "committed to" hours of order receipt.
		Perfect Order Fulfillment	Perfect Order Fulfillment measures the percentage of orders delivered "on time and in full" to customers request date AND flawless match of purchase order, invoice, and receipt.
	Supply Chain Responsiveness The velocity at which a supply chain provides products to the customer.	Order Fulfillment Lead Time	Order Fulfillment Lead Time measures the number of days from order receipt in customer service to the delivery receipt of at the customer's dock.
	Supply Chain Flexibility The agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage.	Supply Chain Response Time	Supply Chain Response Time measures the number of days it takes a supply chain to respond to (plan, source, make, and deliver orders) an unplanned significant increase or decrease in demand without cost penalty.
		Production Flexibility	Production Flexibility measures the number of days to achieve an unplanned 20% increase or decrease in orders without cost penalty.
INTERNAL FACING	**Supply Chain Cost** The costs associated with operating the supply chain.	Cost of Goods	Cost of Goods measures the direct cost of material and labor to produce a product or service.
		Total Supply Chain Management Cost	Total Supply Chain Management Cost measures the direct and indirect costs to plan, source and deliver products and services. Make costs are often captured in COGS while Return costs are calculated in Warranty/Returns Processing Costs.
		Value Added Productivity	Value Added Productivity is calculated by subtracting direct material cost from the revenue and dividing the result by the number of employees. This is similar to sales per employee.
		Warranty/Returns Processing Cost	Warranty/Returns Processing Cost measures the direct and indirect costs associated with returns including defective, planned maintenance, and excess inventory. This includes the entire reverse logistics process.
	Supply Chain Asset Management Efficiency The effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.	Cash-to-Cash Cycle Time	Cash-to-Cash Cycle Time Cash-to-Cash Cycle Time measures the number of days that cash is tied up as working capital.
		Inventory Days of Supply	Inventory Days of Supply measures the number of days that cash is tied up as inventory.
		Asset Turns	Asset Turns is calculated by dividing revenue by total assets including both working capital and fixed assets.

	Performance Attribute or Category	Level 1 Performance Metrics	Working Definition
SHAREHOLDER FACING	**Profitability** Income after cost.	Gross Margin	Gross Margin is calculated by subtracting Cost of Goods from Revenue and is most often expressed as a % of the remaining dollars to sales.
		Operating Income	Operating Income (or Margin) is calculated by subtracting Cost of Goods AND Sales, General and Administration (SG&A) from Revenue and is most often expressed as a % of the remaining dollars to sales.
		Net Operating Income	Net Operating Income (or Margin) is calculated by subtracting Cost of Goods AND Sales, General and Administration (SG&A) AND Taxes from Revenue and is most often expressed as a % of the remaining dollars to sales.
		Economic Profit	Operating Income (or Margin) is calculated by subtracting Cost of Goods AND Sales, General and Administration (SG&A) AND Taxes AND Cost of Capital from Revenue and is most often expressed as a % of the remaining dollars to sales.
	Effectiveness of Return	Return on Assets	Return on Assets is calculated by dividing Net Operating Income by Total Net Assets
		Return on Sales	Return on Sales is calculated by dividing Net Operating Income by Total Revenue.
		Return on Investment	Return on Investment (or invested capital) is calculated by dividing Net Operating Income by Total Invested Capital
	Share	Earnings Per Share	Earning Per Share is the adjusted income available to Common divided by the diluted weighted average shares outstanding.
		EPS Percent Change TTM	This is the percent change in the trailing twelve month (TTM) EPS as compared to the same TTM period one year ago.
		Stock Price Percent Change TTM	This is the percent change in the trailing twelve month (TTM) Stock Price as compared to the same TTM period one year ago.

Summary of SCOR Supply Chain Metrics (Bolstorff, 2002)

Appendix B. Single-stage Inventory Model

Single-stage Inventory Model for Product Family A (Q3 2003 Data)

Sample data

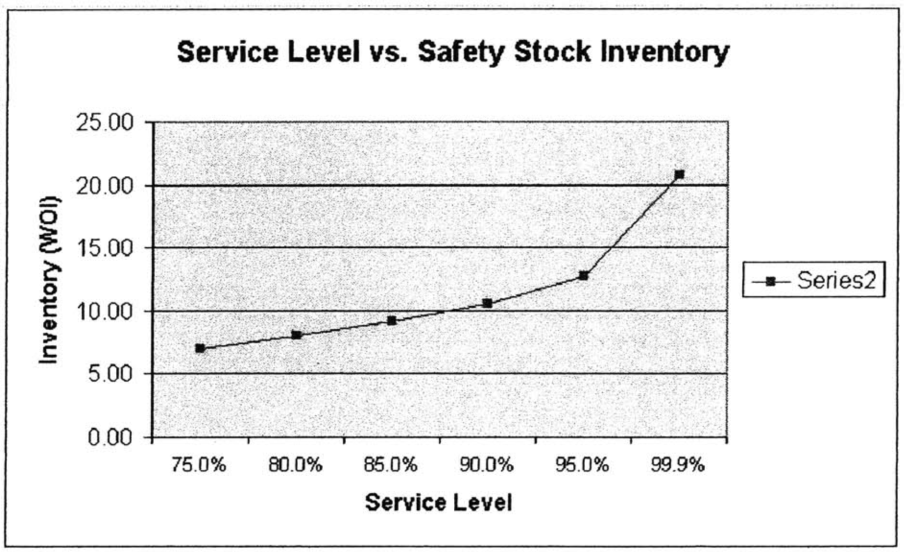
Lead time	1.23	quarter	for replenishment (includes mfring TPT time + review period)
Mean	4,761,498	units/quarter	
Std Dev	1,961,149	units/quarter	
Avg demand per lead time	5,856,643		

Expected inventory level = WIP inventory + safety stock inventory

Expected inventory level = Replenishment lead time*mean demand + z*stddev(demand)*sqrt(replenishment lead timel)

Fill rate	z value	exp inventory level	safety stock for lead time	quarters of inventory	weeks of inventory	weeks of safety stock
75.0%	0.6745	7,323,693	1,467,051	1.54	20.00	7.00
80.0%	0.842	7,688,009	1,831,366	1.61	20.99	7.99
85.0%	1.037	8,112,138	2,255,495	1.70	22.15	9.15
90.0%	1.28	8,640,667	2,784,025	1.81	23.59	10.59
95.0%	1.645	9,434,550	3,577,907	1.98	25.76	12.76
99.9%	3	12,381,701	6,525,058	2.60	33.80	20.80

z=number of std deviations of protection that the safety stock will cover



(All data shown here is fictitious to protect confidentiality.)

Appendix C. Levesques' Two Stage Inventory Model with Supply Variability

Base Stock Inventory Model

(fictitious data)

→ Fab → Adi → ATM → CW

	Fab	Adi	ATM	CW	Total Inv
Inv (Units)	3,256,352	4,067,423	761,299	899,397	8,984,470
Inv (WOI)	8.3	10.4	1.9	2.3	22.9
SS (WOI)		6.3		1.3	7.6

Red	Actual Data
Grey	Est Data
Grey	#s Calc'ed
Color	Results

ATM

Supply Data (Weekly)				Adj	Inventory Data (Weekly)				Demand Data (Weekly)				Adj
TPT (Weeks)	Average	μ_{LT}^{Atm}	1.94	/	Pipeline Stock (WIP)		761,299		Demand (Units/Wk)	Average	μ_d^{Atm}	392,422	/
	Std. Dev.	σ_{LT}^{Atm}	0.92	/					To Service Customer Orders	Std. Dev	σ_d^{Atm}	94,318	/
					Cycle Stock (FGI)		392,422						
Yield (DPU)	Average	μ_s^{Atm}	0.993	/	**Safety Stock (FGI)**		**506,975**		Review Period (Wks)	Average	r^{Atm}	1.00	/
	Std. Dev.	σ_s^{Atm}	0.054	/	Good FG in CW		899,397						
									Desired Service Level (Pct)	Minimum	CSL^{Atm}	90.00%	
	Avg(1/Yld)	$\mu_{1/s}^{Atm}$	1.008	/	Avg cost/unit	$	140.00	/	Calc Z Factor		z^{Atm}	1.28	
	StDev(1/Yld)	$\sigma_{1/s}^{Atm}$	0.049	/	Total $ in Inventory	$	125,915,631						
	Needed for upstream demand variability												

Fab

Supply Data (Weekly)				Adj	Inventory Data (Weekly)				Demand Data (Weekly)				Adj
TPT (Weeks)	Average	μ_{LT}^{Fab}	8.24	/	Pipeline Stock (WIP)		3,256,352		Demand (Units/Wk)	Average	μ_d^{Fab}	395,183	
	Std. Dev.	σ_{LT}^{Fab}	0.84	/					To Service ATM Yield Variability	Std. Dev	σ_d^{Fab1}	546,435	
					Cycle Stock (die)		1,580,753		ADI demand variability only	Std. Dev	σ_d^{Fab2}	543,925	/
Yield (DPW)	Average	μ_s^{Fab}	145.23	/	**Safety Stock (die)**		**2,486,669**		Review Period (Wks)	Average	r^{Fab}	4.00	/
	Std. Dev.	σ_s^{Fab}	42.32	/	Die in ADI		4,067,423						
									Desired Service Level (Pct)	Minimum	CSL^{Fab}	90.00%	
					Avg cost/unit	$	119.50	/	Calc Z Factor		z^{Fab}	1.28	
					Total $ in Inventory	$	486,056,992		Assume: Keep service level from Fab equal to ATM				

Total Safety Stock	**2,993,645**	**"Estimated" Overall Service Level**	**81.00%**
Total Work In Process	**4,017,650**	Actual will be slightly higher. More accurate for high service levels.	**86.00%**
Total Cycle Stock	**1,973,175**		

(All data shown here is fictitious to protect confidentiality.)

Appendix D. Levesques' Two Stage Inventory Model Extended by Chow

Levesques' two stage inventory model was extended with functionality to determine individual service level vs. inventory curves for each stage. Functionality was also added to allow determination of service level given inventory level inputs. (All data shown here is fictitious to protect confidentiality.)

FG Safety Stock Inventory versus Service Level

	Fill rate	z value	inventory level	Non-WIP FG in CW	Safety stock	Weeks of inventory	Weeks of safety stock	Mfr Cost of SS units ($K)	Cost per yr ($K)
	75.0%	0.6745	1,420,545	659,247	266,825	3.62	0.68	$37,355	$9,339
	80.0%	0.8416	1,486,662	725,363	332,941	3.79	0.85	$46,612	$11,653
	85.0%	1.0364	1,563,728	802,430	410,008	3.98	1.04	$57,401	$14,350
	90.0%	1.2816	1,660,696	899,397	506,975	4.23	1.29	$70,977	$17,744
	95.0%	1.6449	1,804,416	1,043,118	650,696	4.60	1.66	$91,097	$22,774
	99.9%	3.0903	2,376,209	1,614,910	1,222,488	6.06	3.12	$171,148	$42,787
	Custom FG Safety Stock Calculator:								
Enter FG Fill Rate:	86.0%	1.0803	1,581,090	819,791	427,369	4.33	1.09	$59,832	$14,958
Enter FG SS WOI:	99.9%	3.0903	2,376,209	1,614,910	1,222,488	6.06	3.00	$171,148	$42,787

ADI Safety Stock Inventory versus Service Level

	Fill rate	z value	Exp inventory	Non-WIP Die in ADI	Safety stock	Weeks of inventory	Weeks of safety stock	Mfr Cost of SS units ($K)	Inv Holding Cost per yr
	75.0%	0.6745	6,145,856	2,889,504	1,308,751	15.68	3.34	$156,396	$39,099
	80.0%	0.8416	6,470,151	3,213,799	1,633,046	16.49	4.16	$195,149	$48,787
	85.0%	1.0364	6,848,157	3,591,805	2,011,052	17.45	5.12	$240,321	$60,080
	90.0%	1.2816	7,323,774	4,067,423	2,486,669	18.66	6.34	$297,157	$74,289
	95.0%	1.6449	8,028,709	4,772,357	3,191,604	20.46	8.13	$381,397	$95,349
	99.9%	3.0903	10,833,301	7,576,949	5,996,196	27.61	15.28	$716,545	$179,136
	Custom ADI Safety Stock Calculator:								
Enter ADI Fill Rate:	87.0%	1.1264	7,022,707	3,766,355	2,185,602	17.90	5.57	$261,179	$65,295
Enter ADI SS WOI:	63.9%	0.4043	5,621,571	2,365,219	784,466	14.33	2.00	$93,744	$23,436

Total Safety Stock Inventory versus Overall Service Level

(assumes ADI and FG service levels are equal; fill rate = SL_adi * SL_fg)

	Overall Fill rate	ADI and FG svc levels	Exp inventory	Non-WIP Die in ADI	Safety stock	Weeks of inventory	Weeks of safety stock	Mfr Cost of SS units ($K)	Inv Holding Cost per yr
	70.0%	83.67%	8,281,982	4,264,332	2,291,156	21.10	5.84	$261,747	$70,437
	75.0%	86.60%	8,578,589	4,560,939	2,587,763	21.86	6.59	$318,222	$79,555
	80.0%	89.44%	8,911,752	4,894,101	2,920,926	22.71	7.44	$359,191	$89,798
	85.0%	92.20%	9,304,005	5,286,354	3,313,179	23.71	8.44	$407,427	$101,857
	90.0%	94.87%	9,803,611	5,785,961	3,812,786	24.98	9.72	$468,865	$117,216
	95.0%	97.47%	10,556,462	6,538,811	4,565,636	26.90	11.63	$561,444	$140,361
	96.0%	97.98%	10,778,478	6,760,828	4,787,652	27.47	12.20	$588,746	$147,186
	97.0%	98.49%	11,053,028	7,035,378	5,062,203	28.17	12.90	$622,508	$155,627
	98.0%	98.99%	11,420,645	7,402,995	5,429,819	29.10	13.84	$667,714	$166,929
	99.0%	99.50%	12,005,818	7,988,168	6,014,993	30.59	15.33	$739,674	$184,918
	99.9%	99.95%	13,677,253	9,659,603	7,686,428	34.85	19.59	$945,213	$236,303
	Custom Total Safety Stock Calculator #1 (assumes ADI and FG service levels are equal):								
Enter Overall Fill Rate:	88.0%	92.74%	9,392,957	5,375,306	3,402,131	23.94	8.67	$418,365	$104,591
Enter Overall SS WOI:	63.9%	79.94%	7,951,601	3,933,950	1,960,775	20.26	5.00	$241,120	$60,280

Custom Total Safety Stock Calculator #2 (does NOT assume ADI and FG service levels are equal):

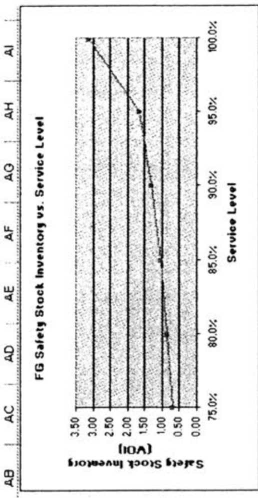
Enter SS WOIs:	ADI SS WOI	1.00
	FG SS WOI	2.70

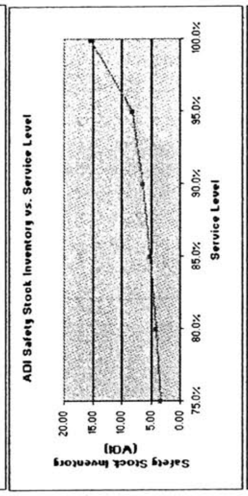
Results:	Fill rate	z value	inventory level	Non-WIP Die in ADI	Safety stock	Weeks of inventory	Weeks of safety stock	Mfr Cost of SS units ($K)	Cost per yr ($K)
ADI Results	58.0%	0.2019	5,228,851	1,972,499	391,746	13.32	1.00	$46,814	$11,703
FG Results	99.6%	2.6521	2,202,867	1,441,569	1,049,147	5.61	2.70	$146,681	$36,720
Overall Totals			7,431,718	3,414,068	1,440,892	18.94	3.67	$193,694	$48,424
Service Level (min)	57.8%								
Service Level (est)	78.8%								

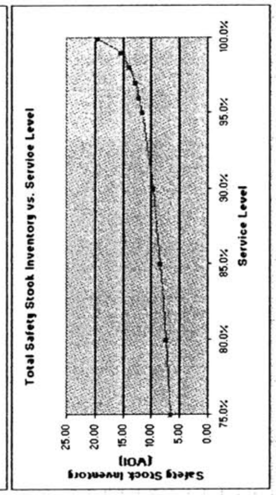
Custom Total Safety Stock Calculator #3 (does NOT assume ADI and FG service levels are equal):

Enter Fill Rates:	ADI Fill Rate	90.5%
	FG Fill Rate	90.0%

Results:	Fill rate	z value	inventory level	Non-WIP Die in ADI	Safety stock	Weeks of inventory	Weeks of safety stock	Mfr Cost of SS units ($K)	Cost per yr ($K)
ADI Results	90.5%	1.3106	7,380,098	4,123,746	2,542,993	18.81	6.48	$303,886	$75,972
FG Results	90.0%	1.2816	1,660,696	899,397	506,975	4.23	1.29	$70,977	$17,744
Overall Totals			9,040,794	5,023,144	3,049,968	23.04	7.77	$374,864	$93,716
Service Level (min)	81.5%								
Service Level (est)	86.2%								







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