Inventory Reduction:
Applying a Pull Ordering System to a Distribution Business

by

Amber J. Chesborough

Bachelor of Science in Materials Science and Engineering, University of Florida, 1999

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

Master of Science in Mechanical Engineering and
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Abstract

This thesis is a description of an internship project at an aerospace parts distribution company. The goal of the project was to reduce inventory by applying a pull ordering system to the distributor's value chain. The thesis provides background on the theory of "push" vs. "pull" systems, and a discussion of how pull systems can reduce inventory while maintaining or improving service level. Typically, pull systems are applied to situations of relatively frequent and constant demand. Using a model developed for the internship company, we demonstrate that a two-bin kanban refill system can be applied to reduce inventory by 50-60%, even given a situation of volatile demand. We describe the pilot project (currently in progress) intended to prove out the kanban system's performance, including the team composition, implementation plan, and perceived barriers to implementation. In conclusion, we reflect on the project's results and present suggestions for future improvement.

Thesis Supervisors

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Biographical Note

The author, Amber Chesborough, is a Leaders for Manufacturing Fellow of the Class of 2004 at MIT. She is a candidate for two graduate degrees at MIT, Master of Business Administration and Master of Science in Mechanical Engineering. Born in Gainesville, Florida, her undergraduate studies were completed at University of Florida and earned a Bachelor of Science degree in Materials Science and Engineering in 1999. Her previous work experience includes three years at Intel Corporation as a Materials Engineer.

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Chapter 1: Introduction and Project Background

Distributors are in the business of managing inventory and information. They exist to perform two functions: serving as a buffer between the variability in supply and demand, and consolidating customer orders from a large supply base. In a competitive environment, distributors must excel at using information to minimize the cost of inventory and logistics. This thesis explores inventory reduction for a distributor in the aerospace industry, which is characterized by long lead times and sporadic, extremely variable demand. The recommended inventory policy described herein is designed to accommodate these special characteristics; however, the approach and analysis can be applied to other types of supply chains.

The material in this thesis is derived from a seven-month internship at Honeywell's Aerospace division in Phoenix, Arizona. In this chapter we will describe the specific problems faced by Honeywell's Hardware Products Group (HPG), a distributor of consumable aerospace parts. First, it is necessary to frame the problem with a brief description of HPG itself and the current business environment, with particular attention to the factors driving inventory reduction. In the second section, we present the problem statement. The chapter concludes with a hypothesis as to the probable causes and possible solution alternatives, which will be pursued in the remainder of the thesis.

1.1 Company Background

Honeywell International Inc. is a diversified technology and manufacturing company with net sales of $23B in 2003. It serves four major markets:

(1) Aerospace products and services
(2) Control technologies for buildings
(3) Automotive products
(4) Specialty chemicals, fibers, plastics and advanced materials

Based in Morris Township, N.J., Honeywell employs approximately 100,000 people in 95 countries. Its shares are traded on the New York Stock Exchange (HON), as well as on the London, Chicago and Pacific Stock Exchanges. It is one of the 30 stocks that make up the Dow Jones Industrial Average and is also a component of the Standard & Poor's 500 Index.

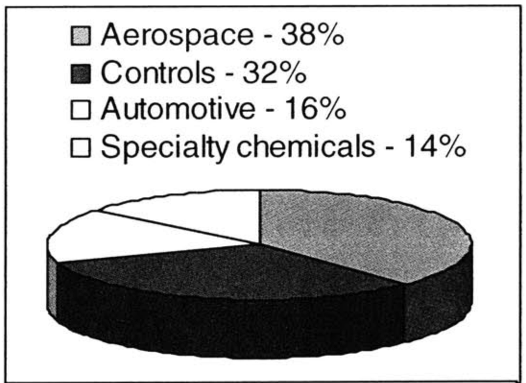

Figure 1. Honeywell Business Segments as Percentage of 2003 Revenue

1.1.1 Relevant Business Groups

The organizations within Honeywell which are relevant to this project are Engines, Systems and Services (ES&S) and the Hardware Products Group (HPG). Figure 2 shows the how these two organizations fit into Honeywell's structure.

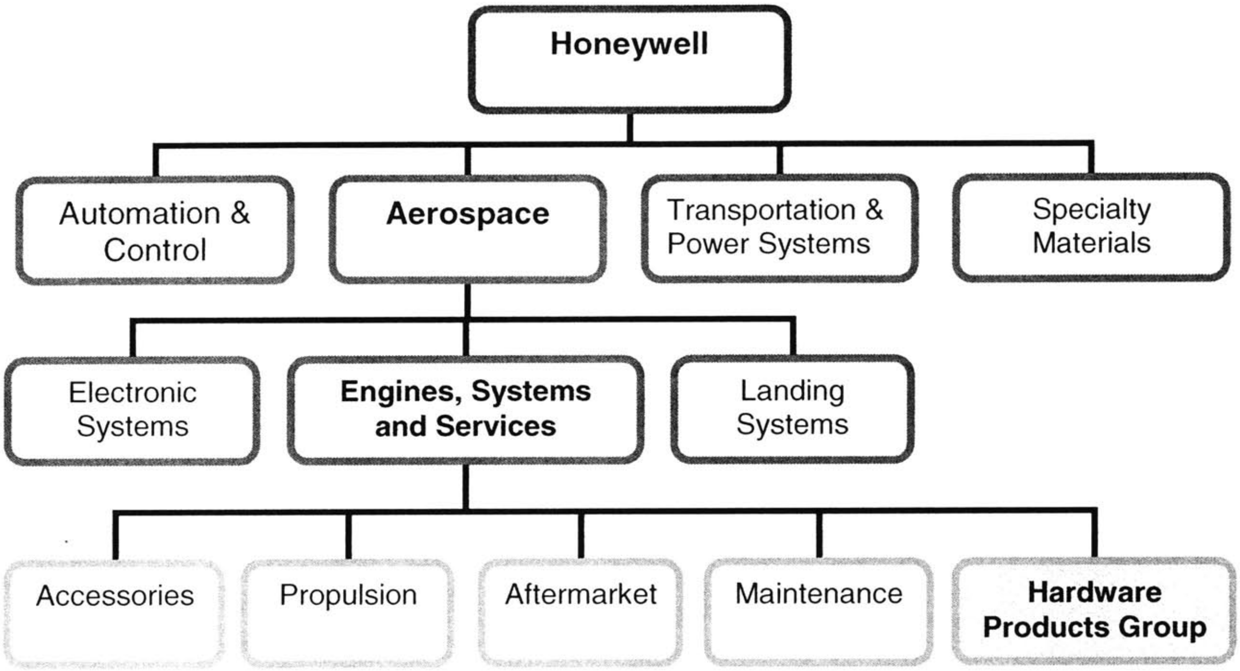

Figure 2. Honeywell Organizational Structure

1.1.1.1 Engines, Systems and Services Business

ES&S (Engines, Systems and Services) is a business unit within Honeywell's Aerospace division (formerly AlliedSignal). It is comprised of all Honeywell's engines and APU (auxiliary power unit) businesses, aircraft systems (environmental control systems, electric power, and engines systems) and accessories businesses. In addition, it contains all of Honeywell's repair and overhaul services (R&O), supply chain services, and parts distribution services. Figure 2 shows a graphical representation of ES&S and its component businesses within Honeywell's organizational structure. ES&S has 51 major operational facilities (see Figure 3 for a partial list) headquartered in Phoenix, AZ. Employing approximately 18,000 people and with $5B in annual sales, ES&S is a leading producer of aircraft components, avionics, and engine systems for business and commercial jets, manned and unmanned military aircraft, and spacecraft[1].

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[1] Honeywell 2003 Annual Report, pp. 20 and 29.

Domestic	International
Arizona	North America
Phoenix	Mexico
Tempe	Canada
Tucson	Europe
Torrance, CA	England
Rocky Mount, NC	France
Greer, SC	Germany
Anniston, AL	Ireland
	Czech Republic
	Asia
	China
	Singapore

Figure 3. Honeywell ES&S Facilities (partial list)

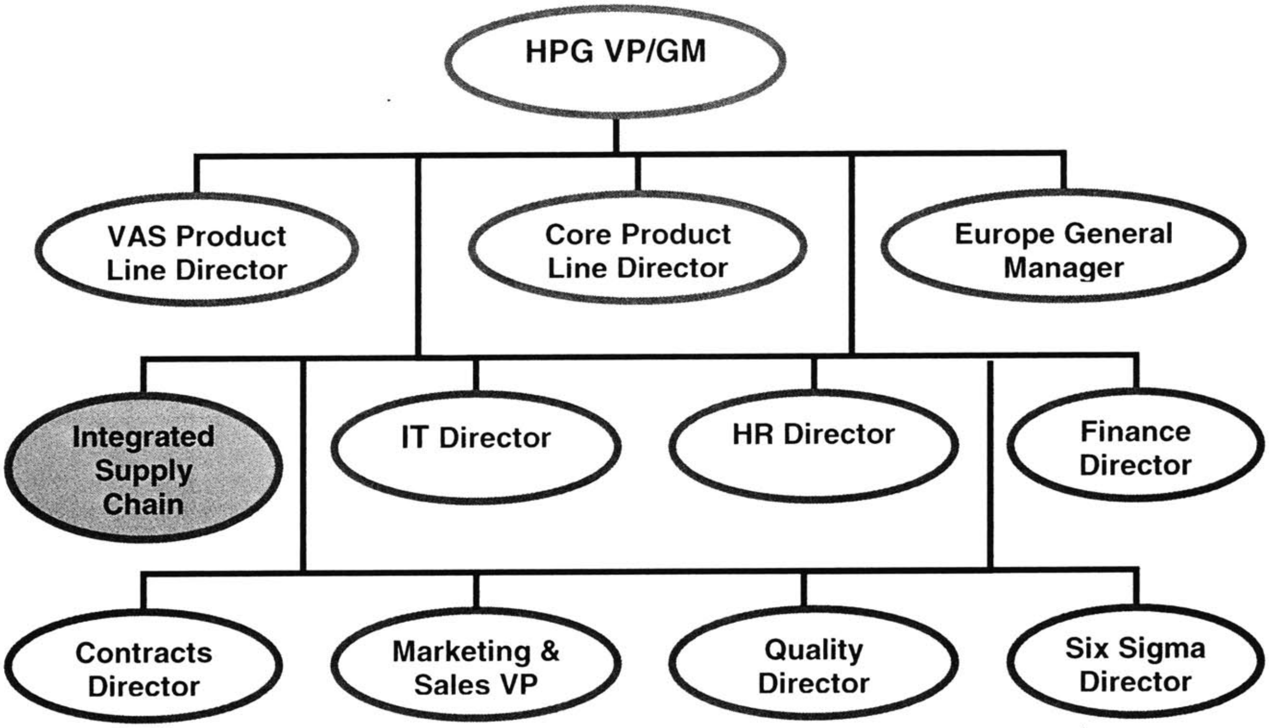

Figure 4. HPG Organizational Structure

1.1.1.2 Hardware Products Group Business

HPG (Hardware Products Group) is a business enterprise within ES&S which provides commodity or "consumables" parts to internal and external aerospace customers. Its four main product lines are Fasteners, Bearings, Electrical Products, and Seals (now entirely outsourced to Kirkhill Aircraft Parts Company, or KAPCO). Although some of the product offerings are proprietary to Honeywell, HPG is purely a distribution service provider. HPG also offers value-added services (VAS) such as direct stocking and kitting. HPG's organizational structure is shown in Figure 4. The integrated supply chain (ISC) or materials management organization, in which this project originated, is depicted in Figure 5 below.

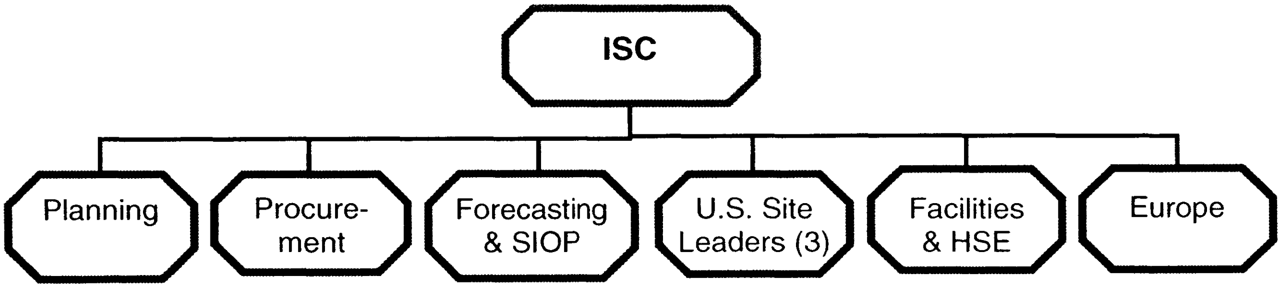

Figure 5. HPG Integrated Supply Chain Organizational Structure

1.1.2 Business Environment

The HPG organization, as a supplier to the aerospace industry, is beginning to feel significant cost pressure from its customers. Historically, the aerospace consumables industry had been fragmented; with the merger of AlliedSignal and Honeywell, a trend of consolidations began. HPG itself was formed around AlliedSignal's "Air Supply" organization, plus several smaller distributors acquired in the late 1990s. HPG's chief competitors, M&M and Wesco, are pure distributors, recent entrants to the aerospace consumables market. This more consolidated industry is also more customer-focused than in the past, offering new services such as just-in-time (JIT) delivery, vendor-managed inventory (VMI), and parts kitting. However, increasing cost competitiveness in the airline industry requires increased focus on controlling the costs of airplane manufacture and maintenance.

Within Honeywell Aerospace, this cost pressure is translated into two key goals: increased productivity (i.e. reducing the cost of raw materials and procurement) and improved cash flow (i.e. reducing investment in working capital). As a key component of working capital, inventory investment receives increased scrutiny. In Honeywell's Six Sigma terminology, inventory is one of the "Critical X's" for operations, meaning that it has a strong influence on operational effectiveness.[2] The relationship between net working capital and inventory is shown in the following equation:

Net Working Capital
= [non-cash current operating assets] – [non-debt current operating liabilities]
≈ [accounts receivable] + **[inventory]** – [accounts payable]

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[2] I am indebted to Scott Selle, Honeywell ES&S Six Sigma Leader, for explaining the focus on working capital in light of industry trends.

The drive for reduced working capital investment, and therefore inventory reduction, is the basis for this project.

1.2 Problem Description

The focus of this project is the reduction of inventory investment within HPG. As compared to its sister enterprises within ES&S, HPG has a disproportionate level of inventory: 425 days of sales, whereas the other ES&S enterprises carry about 100 days of sales. Although it is recognized that distributors typically carry higher inventory than manufacturers or service providers, ES&S management feels that reduction of HPG's inventory is achievable and important, both to ES&S working capital goals and to HPG's operational performance. Therefore, our goal is to identify a new inventory management policy which has the potential to reduce HPG's inventory to 100 days of sales while maintaining on-time delivery performance (also called fill rate or service level) of 95%[3].

1.3 Problem Solving Approach

In approaching this problem, we consider the following factors: the existing distribution system and its infrastructure, the nature of customer demand, and the nature of the materials supply. We then formulate and test various hypotheses using analytical models and management feedback.

1.3.1 Physical Distribution System

The existing HPG distribution system consists of three central "core" warehouses and many smaller customer-focused warehouses, called forward stocking locations (FSLs). A given part is stocked in one core warehouse, the one located most conveniently to the supplier, and in many FSLs. Safety stock is held both at the core warehouse, and at each FSL which has a (nonzero) forecasted demand for the part.

The FSLs are typically dedicated to a single customer, and are often located close to that customer – within a few hours' transit, or even inside the customer's facility. Some FSLs are simply dedicated stocks located within HPG's core warehouses, rather than physically separate facilities; these are referred to as "logical" FSLs. Several of Honeywell's customers have set contractual requirements for minimum stocking levels, which are kept in the dedicated FSLs. There is a very limited amount of transshipment between FSLs, which are independent profit & loss centers run by program managers (PMs).

HPG divides its customers into two categories: VAS and non-VAS (or "core" because they order from the core warehouses). HPG offers two types of delivery service: direct shipment and value-added services (VAS). VAS is similar to just-in-time (JIT) in that it is typically structured as a kanban system, and refills are provided within 24 hours using HPG's parts delivery vans. VAS orders are assigned to the appropriate FSL (or core warehouse if there is no dedicated FSL for the customer). VAS customers are charged a

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[3] HPG defines service level as the percentage of orders shipped by the customer's requested ship date.

premium for this expedited service. Honeywell has its own fleet of delivery vans for VAS orders, but for other orders commercial freight is used. VAS orders represent about 60% of HPG's revenue, but only a small fraction (5-10%) of its customers. HPG led the industry in implementing VAS, and considers it to be a strong point of differentiation and strategic advantage in winning customer contracts.

1.3.2 Customer Demand and Forecasting

Customer orders are characterized as recurring (from repeat customers who share their forecasts with HPG) or non-recurring. HPG's forecasting system uses these two types of demand inputs to generate an annual forecast, which is used for pricing agreements with its suppliers. This annual forecast is equally divided into monthly orders which HPG places with its suppliers. However, as customer demand fluctuates, the internal forecast is updated, and HPG buyers may pull in or push out certain supply orders, and adjust the order quantities to a limited extent.

At the core warehouses, target inventory is calculated based on the part's "value code" category (value codes are defined by a part's historical order frequency and forecasted order volume). For example, fast-moving parts are stocked with the goal of achieving 12 inventory turns per year. The policy for these parts is to hold a safety stock of one-half month of supply and order in quantities of one month of supply (cycle stock) – thus the average level of inventory on hand the core warehouse should be about one month of supply.

For the FSL warehouses, the forecasting system calculates the average monthly consumption (AMC) for each part, which is based on a rolling average of the past six months' demand. In some cases, the AMC is adjusted manually by FSL program managers to account for expected changes in demand for a given part. The AMC quantity is used to calculate stocking levels according to a min/max algorithm. For example, for fast-moving parts the minimum stocking level might be one AMC and the maximum might be three AMC's (effectively three months of supply for a particular part from a specific FSL). When FSL stock falls below the minimum quantity, it automatically reorders the maximum quantity less the on-hand inventory, from the appropriate core warehouse.

Orders are received by phone, fax, internet, or EDI and input to Honeywell's DRP (distribution requirements planning) system, and remain in the system even if cancelled, so that it is possible to examine actual customer demand. Upon inspection, it is apparent that demand is non-normal and sporadic in nature, even for the most commonly ordered parts. Parts which are considered fast-moving may only be ordered once every two or three weeks on average. In this environment, and with very few customers willing to provide detailed forecast data, it is hardly surprising that HPG has relatively low forecast accuracy. As a result, HPG is plagued by excess and obsolete (E&O) inventory – estimated to represent about half of HPG's total system inventory.

1.3.3 Materials Supply and Ordering

HPG works with over one thousand suppliers around the world, ranging from small job shops specializing in only a few parts, to diversified manufacturers producing a broad range of product families. HPG carries over 400,000 unique parts.[4] The average leadtime quoted by HPG's parts suppliers is about 70 days, but for very specialized parts may be as much as 140 days.

HPG currently maintains three types of order systems with suppliers. Most suppliers simply receive purchase orders (PO's) on a monthly basis, via emails which are automatically generated by Honeywell's forecasting and MRP system. Suppliers work directly with an HPG buyer, who has the capability to adjust PO quantities or timing to a limited extent (for changes involving significant dollar amounts, the buyer may need to obtain management approval).

For selected suppliers, HPG uses a system called FPOT, or fixed purchase order time-fence. This is a system for electronically sharing forecasts, enabling suppliers to view HPG's 12-month net forecast horizon for their parts. HPG commits to buy the quantity forecasted for the next 30 days – for example, on January 1 the forecast for February is fixed, and the supplier is expected to deliver the February forecast quantity to HPG's dock by February 1. This "time-fence" system limits HPG's liability to 30 days and reduces the amount of PO paperwork and phone calls.

HPG has recently introduced an SMI (supplier-managed inventory) system with a few key suppliers. This system requires suppliers to own and maintain an inventory of parts at HPG's core warehouse. Restocking is performed according to a min/max system – for example, a minimum quantity equal to safety stock plus one month of supply, and a maximum of safety stock plus three months of supply. The min/max levels are recalculated each quarter, and HPG buyers simply track how many parts are overstocked or more importantly, below minimum or out of stock. Payment is sent to the supplier when the parts are used by HPG – either transferred to an FSL or shipped to a customer.

1.3.4 Solution Hypotheses

After examining the mechanics of the existing ordering system, it seems clear that HPG's difficulties with excess inventory and stockouts are due to a suboptimal inventory management policy – that is, the core warehouses and FSLs are operating independently and there is no global optimization. This is evidenced by the multiple safety stock pools and incompatible order policies at each level of the supply chain. We believe that it is possible to lower inventory costs while maintaining or improving service levels. Since many of HPG's key customers already use pull systems, and since forecasts are not very reliable given the nature of customer demand, we feel that designing a reorder point or other pull system will not only lower inventory but provide a strategic advantage in terms of customer service and reliability of on-time delivery.

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[4] From HPG's public website, <https://www.hpgparts.com/Products/index.jsp>

1.3.5 Recommended Solution

Using an analytical model (described in Chapter 3), we examined several possible pull system configurations. These include make to order, reorder point, min/max, and kanban. The model is designed to estimate the effects of these systems on average inventory, service level, and transaction cost. Our goal was to demonstrate that a pull system could provide acceptable service (95% on-time delivery) with lower inventory levels, compared to a baseline of the current order policy using a perfect forecast. Although we examined the possibility of centralizing all inventory in the core warehouses (eliminating FSLs), this change was determined to be infeasible due to customer contractual requirements.

Based on the numerical results and insights gained from the model, the recommended inventory policy is a kanban ordering system. It is expected to result in 50-60% inventory reduction while maintaining 95% on-time delivery. When fully implemented for HPG's highest-value, fastest-moving parts category, the kanban system is predicted to reduce inventory by about $7M.

1.4 Thesis Organization

In this chapter we have provided an overview of the HPG pull project. The remainder of the thesis is organized as follows:

- Chapter 2 reviews relevant literature on "push" versus "pull" inventory management systems.
- Chapter 3 explains the comparative inventory management model in detail.
- Chapter 4 is a discussion of the model's results and application within HPG.
- Chapter 5 presents conclusions and recommendations for future improvements.

Chapter 2: Inventory Management Systems: "Push" vs. "Pull"

This project centers on the question of converting a "push" inventory management system to a "pull" system. For clarity, this chapter reviews the relevant supply-chain management literature on the definition of these terms, the differences between the two systems, and their recommended applications, as well as some push-pull combinations and variants.

2.1 Definition and Application of "Push"

In a "push" system, inventory is built to stock, and stock levels are based on long-term forecasts.[5] These systems are typically well buffered and react very slowly to changes in demand. If the forecast is too conservative, underproduction can result in inability to serve customers and hence loss of revenue and market share. If the forecast is too generous, inventory piles up and the manufacturer carries a higher risk of obsolescence. Further, the inventory buffer and associated time lag generates the "bullwhip effect" in many supply chains.

Thus variability increases as the number of steps from the customer increases, and the manufacturer must carry enough safety stock to satisfy the high variability at the back end of the supply chain, even if the variability in final consumption is small. The effect can be further amplified by sales promotions and end-of-period incentives. If the manufacturer is unable to level load production, there will also be inefficiencies in production (due to varying batch sizes) and in transportation (partial truckloads during slow periods, need for extra capacity at peak demand).[6]

Push systems are simple to design and manage, in that orders arrive at more or less predictable intervals. These systems are well suited to products with steady and predictable demand, particularly if the products are in the mature stage of a rather long product life cycle. Pushing inventory is also feasible during ramp-up and end-of-life phases, or for seasonal demand, if the trend is predictable. Good forecast data may be based on past experience with similar products or contractual agreements with customers.

2.2 Definition and Application of "Pull"

A pull system is driven by actual customer orders. That is, production is directly linked to (ideally) end user demand. This type of system design reduces the bullwhip effect, so that variability at the manufacturer will be similar (or even less) than the variability in end user demand. One drawback of pull (also called "just in time" or "make to order") is that it requires smaller, more frequent deliveries.[7] Typically, the savings in terms of production efficiency (due to level loading) and reduced inventory investment, can be expected to make up for the costs of inefficient shipments.

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[5] Simchi-Levi et al., Designing and Managing the Supply Chain, p.118.

[6] ibid., p.118.

[7] ibid., p.119.

Strong supply chain relationships are necessary to implement pull. For example, the manufacturer needs to have visibility to consumer demand at the retailer, perhaps though point-of-sale data collection and EDI transfer. Open and honest sharing of data requires a significant level of trust among manufacturer, wholesaler, and retailer. Some investment must be made to allow product traceability (e.g. by UPC barcode and checkout scanners).

Implementation of pull is more difficult where manufacturing and transportation lead times are long, as this creates delay in the system between consumer demand changes and production changes.

2.3 Push-Pull Systems

It is possible, and in many cases advisable, to design a supply chain with elements of both push and pull. In these situations, the back end of the chain is operated by push and the front end is run according to pull. The interface between the two systems is called the push-pull boundary, or the postponement boundary.[8]

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[8] ibid., p.120.

Chapter 3: Comparative Inventory Management Model

In this chapter we review the model used to simulate various inventory management policies. This model is designed specifically for HPG's supply chain, but could be adapted to any two-tier distribution system. The results of the model suggest that the implementation of a two-bin kanban ordering system will improve the performance of HPG's distribution system.

3.1 Model Overview and Purpose

The model was originally created to gain a better understanding of the dynamics of the existing system. Through several rounds of feedback and testing, we broadened the model to report key metrics and to approximate supply chain behavior under different inventory management policies. The model is deterministic, but helps the user gain intuition about the effects of certain policies. Real demand and cost data were gathered to inform the model.

3.1.1 Model Design and Inputs

The model is based entirely in Microsoft Excel. Input data is part-specific unless listed as a fixed value. The required input categories are:

- Real data from HPG's MRP and DRP systems
    - Weekly demand history for the past 18 months, separated into VAS demand and core demand components
    - Current monthly forecast and AMC quantity
- Actual and estimated cost data
    - Unit cost (actual cost to HPG)
    - Transaction cost (fixed: estimated at $50 per transaction)
    - Inventory holding cost (fixed: estimated at 25% of inventory value)
- Quoted logistics parameters
    - Lead time for part supply (manufacturing + transportation + receiving)
    - Transportation time from core to FSL warehouse (fixed: one week)
- Current stocking parameters
    - Minimum and maximum FSL inventory levels (fixed: minimum 2 months, maximum 5 months)
    - Core warehouse targeted months of supply (safety stock and cycle stock)

For simplicity, the model examines a very limited system: one core warehouse and one FSL warehouse. The core warehouse receives orders from core customers, and refill orders from the FSL. The FSL receives all orders from VAS customers. The mechanics of the model are logical expressions which determine where inventory will be located, given the inputs above and acting according to the rules of the inventory policy. The variables include:

- Core and FSL warehouse inventory – beginning and ending on-hand quantity
- Core warehouse orders from supplier – timing and quantity

- FSL refill orders from core warehouse – timing and quantity
- Reverse inventory transfers from FSL to core warehouse (only permitted when the core warehouse is backordered and the FSL inventory exceeds the minimum required quantity)
- Shipments to VAS and core customers – timing and quantity
- Unsatisfied customer demand (backorders)
- Fill rates for core warehouse (includes internal FSL refill orders), FSL warehouse (VAS orders only), and total system (all shipments to external customers)
- Number of transactions (PO's placed to supplier + internal FSL refill orders + inventory reverse transfers)

The model evaluates 7 basic inventory policies for each part:

1. Current "push" system – order to forecast (3 variants listed below)
    a. Real forecast (actual forecast generated by HPG's MRP system)
    b. Historical forecast (from past year's demand data)
    c. Perfect forecast (uses future demand data to give the perfect prediction of annual demand)
2. "On-demand" system – order to customer demand each week
3. Re-order point system – order to 6-week rolling average demand
4. Two-bin kanban reorder system – reorder when inventory falls below kanban qty
5. Feedback system – maintain constant level of days of supply (DOS)
6. SMI min/max system – order (maximum quantity less on-hand inventory) when inventory falls below minimum required quantity
7. FPOT shared forecast system – order next month's demand forecast each month

The first system, the existing "push" system, is modeled with three forecasting assumptions, so that there are 9 model subtypes. Each of these subtypes is modeled both for a two-tier system (one core and one FSL warehouse) and a centralized system (assumes that the core warehouse receives and fills all orders, so the inventory is consolidated in a single location and no regional FSL is used), so that in all there are 18 policy variants. The rules for these policy variants are shown in Figure 6 below.

System	Core Order Trigger	Core Order Size	Core Safety Stock	FSL Order Trigger	FSL Order Size	FSL Safety Stock	FSL Transfer to Core	Delay
Push to System Forecast	First week of every month	1 month forecast	0.5 month forecast	First week of month, only if (inv on-hand) < 2*AMC	5*AMC less EOH inv	4*AMC	if FSL inv > 2*AMC and Core is backordered, transfer any excess over 2*AMC	Quoted LT
Push to Historical Demand		1 month avg hist demand			5*AMC less EOH inv			Quoted LT
Push to Perfect Forecast		1 month avg future demand			5*AMC less EOH inv			Quoted LT
Pull to Customer Demand	Weekly	Last week's total POs	$SS = Z\sigma\sqrt{L}$	Weekly	Last week's total POs	$SS = Z\sigma\sqrt{L}$	same	Quoted LT
Pull to Reorder Point	When (inv on-hand + inv on-order - backorders) < ROP	4*AVG(last 6wks demand), rolling average	ROP = cycle time (wks) * 95th percentile(last 2 quarters), adjusted every quarter	When (inv on-hand + inv on-order) < FSL ROP	2*AVG(last 6wks demand), rolling average	ROP = cycle time (wks) * 95th percentile(last 2 quarters), adjusted every quarter	same	Quoted LT
Pull Quarterly Kanban	When (inv on-hand + inv on-order - backorders) < 1 kanban qty	1 kanban qty	1 kanban = cycle time (wks) * 95th percentile(last 2 quarters), adjusted every quarter	When (inv on-hand + inv on-order) < 1 FSL kanban qty	1 kanban qty	1 kanban = cycle time (wks) * 95th percentile(last 2 quarters), adjusted every quarter	same	2 weeks

KEY:
L or LT = Lead time in weeks, SS = Safety stock in units, σ = Standard deviation of weekly demand, Z = Standard deviation coefficient,
ROP = Re-order point in units, AMC = Average monthly consumption in units, EOH = Ending on-hand inventory in units,
FSL = Forward stocking location, PO = Purchase order, AVG = Average, inv = Inventory in units, FPOT = Fixed purchase order time-fence

Figure 6. Inventory Model Ordering Rules

System	Core Order Trigger	Core Order Size	Core Safety Stock	FSL Order Trigger	FSL Order Size	FSL Safety Stock	FSL Transfer to Core	Delay
Maintain Constant DOS	When on-hand inventory is less than expected demand during leadtime (exp demand per week = average demand from last 21 wks)	Enough inventory to cover expected demand during leadtime	$SS = Z\sigma\sqrt{L}$	When less than 4 weeks of inventory is on hand	4 weeks of inventory	$SS = Z\sigma\sqrt{L}$	same	Quoted LT
Min/Max SMI Pull	When on-hand inventory is less than 5 weeks of average historical demand	10 weeks of average historical demand, less on-hand inventory	5 weeks of average historical demand	When on-hand inventory is less than 1 week of average historical demand	3 weeks of average historical demand, less on-hand inventory	1 week of average historical demand	same	Quoted LT
FPOT Forecast	First week of every month	1 month forecasted demand	0.5 month forecasted demand	First week of month, only if (inv on-hand) < 2*AMC	1*AMC	4*AMC	same	Quoted LT

KEY:
L or LT = Lead time in weeks, SS = Safety stock in units, σ = Standard deviation of weekly demand, Z = Standard deviation coefficient,
ROP = Re-order point in units, AMC = Average monthly consumption in units, EOH = Ending on-hand inventory in units,
FSL = Forward stocking location, PO = Purchase order, AVG = Average, inv = Inventory in units, FPOT = Fixed purchase order time-fence

Figure 7. Inventory Model Ordering Rules (continued)

3.1.2 Model Assumptions

The most significant assumptions made in building the model are described below.

Core-FSL relationship - For simplicity, each part is modeled with only one core warehouse and only one FSL. The core warehouse satisfies orders from all core customers, and the FSL warehouse is responsible for all VAS customer demand. Since minimum and maximum inventory requirements were unavailable for most parts, we assumed a minimum of two months of supply and a maximum of five months of supply in all cases. When the core warehouse cannot satisfy core demand for a given week, it can reverse-transfer inventory from the FSL, but only if the FSL has more than the minimum requirement (two months of supply) on hand.

Order fulfillment - Orders are received the same week that delivery is expected by the customer. This is because the average delay between order receipt and requested delivery is two weeks; but HPG order entry takes about two weeks, so typically there is no advance notice available to the warehouse, and orders must be picked and shipped as soon as they become visible in the system. According to HPG management, customers do not typically cancel orders if the parts are out of stock. Therefore, the model backlogs all unfulfilled orders and fills them (late) when inventory is available; no late charge is assessed by the customer. When inventory becomes available, the model always satisfies existing backorders before allocating inventory to new orders. Because the model only has visibility to the number of parts ordered in the week, not to the number of parts in each customer's order, there is no capability to "fill or kill" orders. In reality, HPG only ships an order if it can be at least 50% fulfilled; the model allows any level of partial order fulfillment without penalty. The on-time delivery metric in the model is defined as the percentage of parts shipped on time to customer request, but the model also measures total parts delivered as a percentage of total customer demand (that is, both on-time and late shipments). Demand inputs are calculated net of customer returns; thus any negative demand quantity results in increased inventory. This is feasible because most returns are due to over-shipment, incorrect shipment, or cancellations; quality issues are rare.

Leadtime delay - All systems assume a fixed one-week transportation delay to resupply FSL orders. The kanban system has a fixed two-week leadtime to resupply the core warehouse; all other systems have a fixed N-week leadtime delay equal to the supplier's quoted leadtime in days. For example, if a supplier quotes 80 working days' leadtime, all systems (except kanban) will generate a 16-week delay between order placement by the core warehouse and the receipt of that order. The kanban system assumes that the supplier will keep one kanban on hand in finished goods, and therefore can immediately ship a kanban refill order which will arrive and be inventoried within two weeks.

System overhead costs - Each order transaction (includes FSL resupply orders from the core warehouse, core warehouse orders from the supply base, and any FSL reverse inventory transfers to the core warehouse) is assumed to cost HPG $50. Inventory holding cost is fixed at 25% of purchase price per annum.

Initial inventory – All "push" systems start with beginning inventory level equal to the safety stock recommended by HPG's current inventory policy. For the FSL, this is equal to one half month of supply (AMC/2). For the core warehouse, this is four months of expected VAS demand, or (MAX-1)*AMC. Pull systems also start out with the recommended safety stock, but this quantity varies for different systems. For the "on-demand" system, safety stock equals Z*sigma*(L^0.5), where Z is the "safety factor" defined as the number of standard deviations required to meet the target service level (for this analysis, target fill rate is fixed at 98% and the Z is always 2.05), sigma is the standard deviation of weekly demand, and L is the leadtime in weeks. For the reorder point system, beginning inventory is equal to the reorder point, defined as safety stock (using the same equation as the on-demand system above) plus demand during the supplier's quoted leadtime. The kanban system starts out with one kanban quantity in stock.

3.1.3 Model Outputs

The inventory model outputs the following metrics for all 18 policy variants for each part:

- Fill rate performance metrics
    - FSL average and worst case fill rates (VAS customers only)
    - Core average and worst case fill rates (Core customers and FSL)
    - Overall customer average and worst case fill rates (all external customers)
- Inventory statistics
    - System max inventory
    - System average inventory
    - Value of average inventory
    - Inventory holding cost
- Transaction statistics
    - Total orders placed
    - Total transaction costs
- Customer service metrics
    - Qty shipped on time to customers
    - On time order fulfillment
    - Qty shipped late to customers
    - Percent of orders shipped late
    - Total qty shipped to customers
    - Total order fulfillment

However, the key metrics used to evaluate the performance of each inventory policy are

1. On-time fill rate
2. Inventory value (average qty on hand * unit cost)
3. Annual overhead cost (transaction cost + inventory holding cost)
4. Annual inventory turns

Inventory value, of course, varies widely depending on the cost of the part and the nature of customer demand. Therefore inventory levels for each candidate inventory policy were compared to the "baseline" of the push model with perfect annual demand information, which represents the ideal conditions for the push system.

3.2 Representative Parts Selection

As mentioned above, the model is deterministic in nature. Due to the non-normality of customer demand, we were unsuccessful in building a stochastic model. However, the immediate customers of this model (HPG integrated supply chain management) were more interested in understanding the effects of new inventory policies on representative parts. The model's graphical outputs are effective in showing system performance (inventory and fill rate) compared to actual demand for a given part.

The model was run for a small number of selected representative parts: gathering and formatting the data for many parts becomes prohibitive. Our intention was to prove that pull systems could feasibly be designed to deal with a wide range of demand patterns, representative of the general mix of HPG parts.

3.3 Results

After applying the model to the selected representative parts, we find that no single model performs best for all types of products. The kanban system has consistently highest service levels, but over-orders for several weeks following a large spike in demand. The reorder point system has slightly lower service levels and much lower inventory than the kanban system, but is even more sensitive to demand changes – for parts with highly volatile demand, the order sizes fluctuate widely. The demand resupply system works best for parts with short leadtimes and/or lower demand volatility.

Figure 8 shows the summary of the model results for three key indicators: on-time fill rate, inventory reduction compared to baseline, and expected annual inventory turns. All of the pull systems work significantly better (lower cost and better service) with fully centralized distribution (in which all customer orders are filled directly from the core warehouse). None of the systems can provide 95% on-time delivery for every part (unless we assume perfect forecasting). On the other hand, all pull systems give at least 95% total order fulfillment if some percentage of late deliveries is allowed.

	ON TIME FILL RATE	INVENTORY REDUCTION	INVENTORY TURNS
Current Push System, Order To Perfect Forecast (BASELINE)	**94%**	**NONE**	**3.2**
Centralized Push System, Order To Perfect Forecast	97%	50%	6.5
Current Push System, Order To System Forecast	91%	NONE	1.3
Centralized Push System, Order To System Forecast	89%	NONE	1.5
Current Push System, Order To Avg Hist Demand	62%	90%	33.3
Centralized Push System, Order To Avg Hist Demand	89%	70%	11.0
Demand Resupply System, Order To Customer Demand	55%	85%	21.0
Centralized Demand Resupply System, Order To Customer Demand	67%	84%	20.4
Reorder Point System, Order To 6-Wk Rolling Avg Hist	62%	83%	19.6
Centralized Reorder Point System, Order To 6-Wk Rolling Avg Hist	57%	95%	60.1
Quarterly Kanban System, Order Kanbans As Needed	80%	57%	7.5
Centralized Quarterly Kanban System, Order Kanbans As Needed	92%	63%	8.7
Feedback Model, Maintain Constant DOS	45%	74%	12.6
Centralized Feedback Model, Maintain Constant DOS	0%	9%	3.5
Min/Max Pull Model (Based On SMI Program)	74%	9%	3.6
Centralized Min/Max Pull Model (Based On SMI Program)	74%	100%	N/A
Current FPOT System, Order To Perfect Forecast	99%	39%	5.3
Centralized FPOT System, Order To Perfect Forecast	100%	45%	5.9

Figure 8. Summary of Results from Comparative Inventory Model

Chapter 4: Application of Model Results

This chapter is a discussion of the impact of the model in terms of stakeholders' responses. We consider the more practical aspects of implementing the changes to the inventory management systems, including the capabilities of the existing system infrastructure, cost of system redesign, conflicting incentives, and physical system design complications not addressed by the model. We propose an implementation plan based on Honeywell's phase-gate framework, the IPDS (Integrated Product Development & Support) process.

4.1 Management Feedback

Managers were generally surprised by the model results, particularly the graphical output showing the dynamics of the current distribution system and inventory policy. A sample graph with the calculated inventory levels, service levels, order timing and order quantities, for a particular demand profile using the rules of the current inventory push system, is shown in Figure 9 below. It is easy to compare the total system inventory (represented by the darker blue "wave" which increases over time) to the actual customer demand (the thick teal line along the bottom of the graph). Much of this inventory clearly serves no purpose, but is required by the current inventory policy.

The chief benefit of the model is that managers immediately gain an understanding of the magnitude of inventory investment and the increasing risk of excess and obsolete inventory. In this example, which is relatively typical, the forecast overestimates demand by about 30%, causing the buildup of system inventory in the push system (see Figure 9). The output is all the more convincing because the input data (demand, unit cost, leadtime) corresponds to real parts, even though the system's response (order quantity and timing) is simulated.

A sample graph of the same demand profile, using the centralized kanban system, is shown in Figure 10 for contrast. The average on-time fill rate for the part in this system is 97.5%. The fill rate drops sharply after an unexpected demand spike, but quickly recovers. Orders to HPG's suppliers (represented by the purple bars) are fewer and vary in quantity over time, as kanbans are recalculated quarterly to adjust to demand trends. The maximum inventory in the system at any given time is two kanbans. As a result of these improvements in system design, for the part in this example (Figs. 9 and 10), the average inventory investment for the kanban system is less than a quarter of the value for the current system model, resulting in a substantial improvement from three inventory turns per year in the push system to 14 per year for the pull system.

The kanban team applied the proposed kanban system to several sets of actual parts, in preparation for launching a pilot implementation program. This data is more realistic than the output from the model, in that it accounts for inventory held at multiple FSL sites, and includes results for approximately 50 real part numbers. Figure 11 shows the general results from a set of candidate pilot program parts. These results indicate that the kanban system will increase inventory turns significantly as compared to other systems.

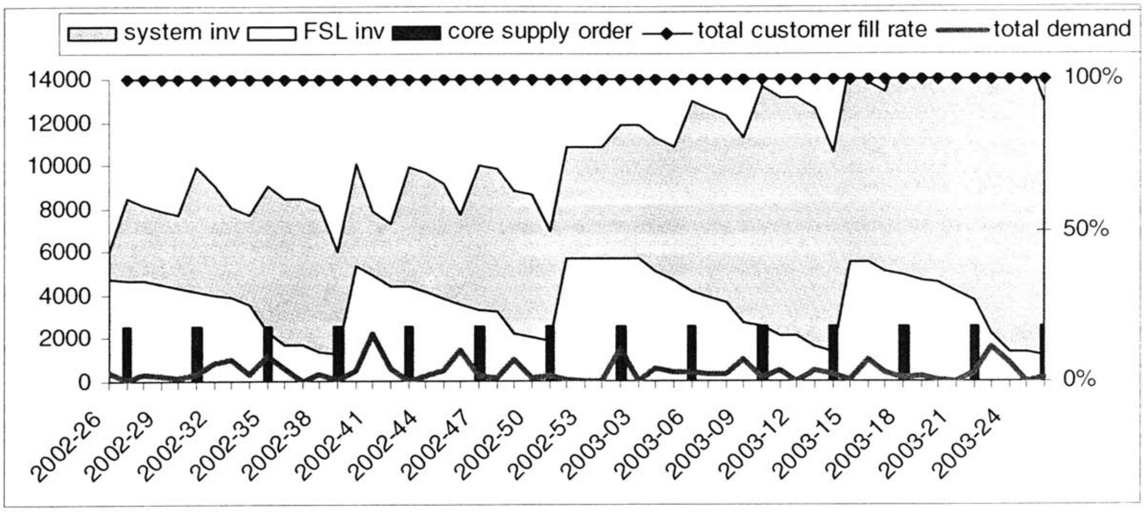


Figure 9. Sample Model Graph for Current "Push" System

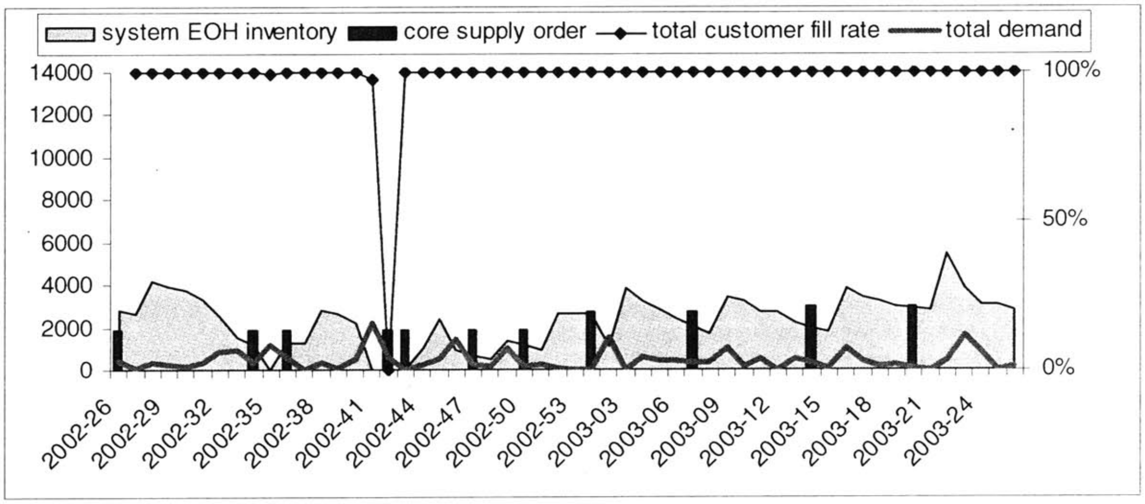


Figure 10. Sample Model Graph for Centralized Kanban System

	Inventory Distribution		**Total Inventory**
	Core	*FSL*	*Annual Turns*
Actual Current On-hand Inventory	65%	38%	2.9 turns
Order Policy Average Recommended Inventory	63%	37%	5.2 turns
SMI Average Recommended Inventory	74%	26%	3.6 turns
Kanban System Expected Average Inventory	55%	45%	10.1 turns

Figure 11. Sample Inventory Comparison for Pilot Parts

4.2 Practical Considerations

Practical considerations of changing the inventory management system include:

- Information Technology. HPG has invested in MRP and DRP systems which plan in monthly intervals. It is not feasible to redesign these systems or switch to more flexible systems within the time frame and budget allowed. For limited volumes (~50 SKUs to be evaluated in the pilot), we addressed this problem by designing a semi-automated database which would recalculate kanban sizes quarterly, and reorder on a weekly basis as needed. Once the ROI is proven and kanbans are or larger volumes (thousands of SKUs), HPG could consider upgrading or replacing its current ordering system for improved efficiency and robustness.

- Outside Testing Requirements. Several of HPG's major customers require part quality to be validated by independent laboratories before accepting shipment. This requirement introduces an additional testing delay, not included in the model. For purposes of small-scale implementation, the team felt it was feasible to avoid working with any items requiring third-party testing. However, it is most likely possible (with increased inventory investment) to design the system to accommodate this delay, for example by holding extra kanbans in queue.

- Customer Expectations. Several of HPG's customers have set contractual requirements for dedicated inventory levels (e.g. HPG must maintain three months of supply on hand in the customer's FSL). Further, all VAS customers have come to expect same-day service, even where this is not necessary for their operations. These expectations make the physical centralization of HPG's inventory infeasible, at least in the short term. Our belief is that once a reliable replenishment is in place for the current decentralized supply chain, customers may be willing to accept centralization and slightly longer lead times, especially if HPG's cost savings can be clearly defined, measured, and shared with loyal customers in the form of discounts.

- Supplier Agreements. HPG managers felt that many suppliers would be willing to try out the kanban refill system. The simplicity of the new system, with reduced phone calls and last-minute rush orders, should appeal to HPG's suppliers. Many of these suppliers already have experience with pull-based ordering systems. However, the new arrangements would require negotiation of a new contract, which could be handled during annual renegotiations.

4.3 Organizational and Cultural Considerations

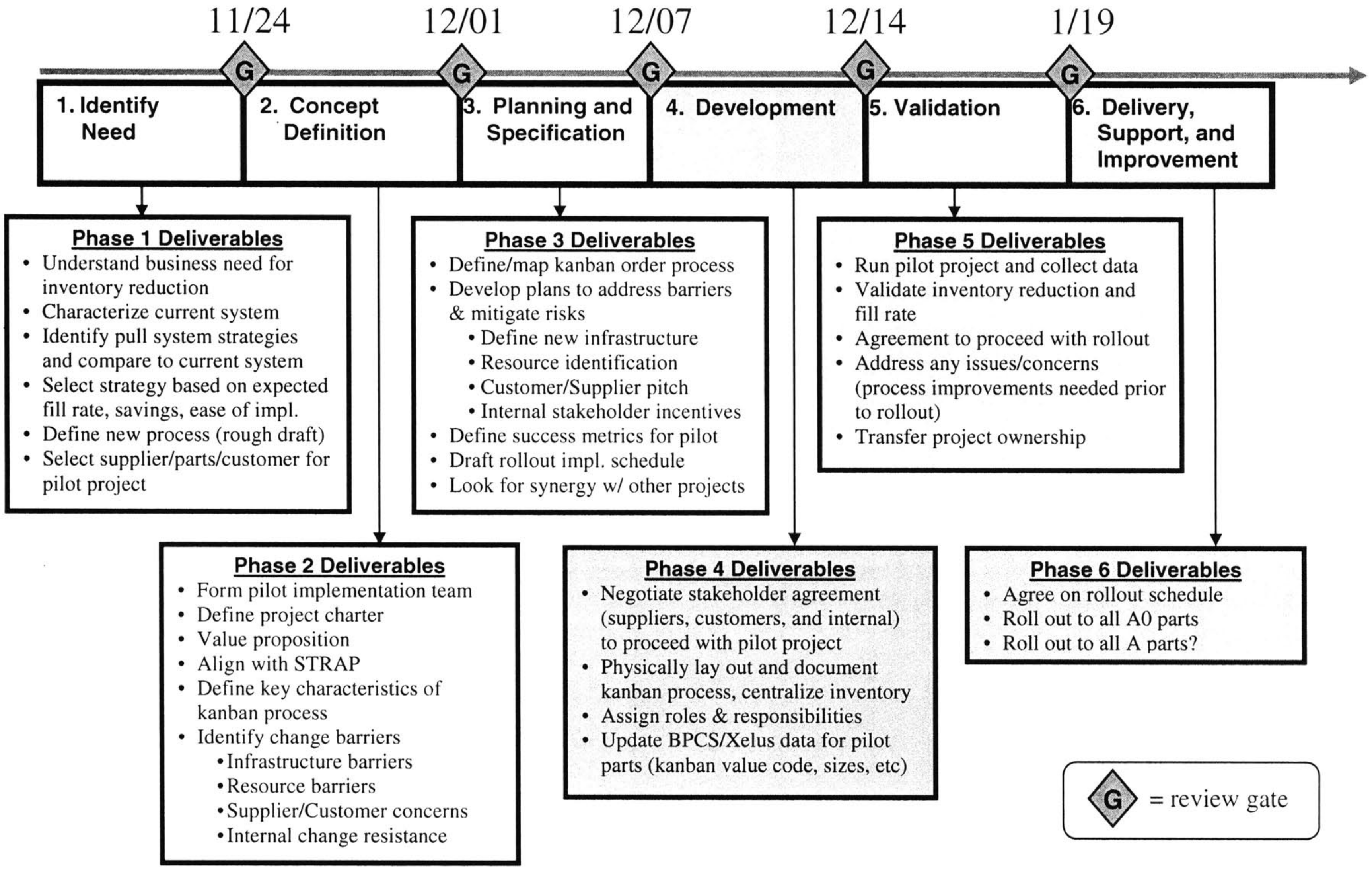
This section describes some of the challenges we encountered in recommending the implementation of a new inventory management system. The first objective was to align internal stakeholders regarding the need for change and the design of the new system. The ES&S inventory reduction goal provided some impetus, but the supply chain staff did not completely agree on the best actions to take. Here the comparative inventory management model was helpful, because internal stakeholders could evaluate various systems' performance, suggest improvements, and observe the results. Most HPG managers and employees were open to the idea of a new system and willing to be convinced by the data.

Our next step was to form a team within HPG which had sufficient knowledge base and external contacts to come up with a good "sales pitch" for the kanban pilot project. This team was chartered to "demonstrate feasibility of the kanban ordering system" (i.e. the new system's capability to reduce inventory while maintaining or improving fill rate, and the possibility of implementing it at low or zero cost). Members included an HPG manager with lean expert and six sigma black belt certifications; a buyer (supplier interface); a VAS account manager (customer interface); and a materials management analyst (IT expert). The diverse perspectives of this "core" team enabled us to devise an informed and feasible implementation plan, taking into consideration the concerns and priorities of external stakeholders. Another advantage of this team was its members' co-location at a single site. As the project expands we expect to add membership from other groups and sites (e.g. warehouse managers, sales & marketing representatives, contract managers, finance experts).

Despite the close physical location of the team members, it was difficult to meet more than twice per month. Every member of the team was already working overtime and could not commit more than an hour or two of their work time to the project each week. Defining the project's ownership was also somewhat challenging, largely because of discontinuities in management. Within ES&S it is typical for managers to spend no more than 12-18 months in a given position; once they move, it takes 2-3 months to backfill the position, so that knowledge transfer is strained. During this backfill gap, someone else in the organization must "wear two hats" and take on the responsibilities of the temporarily empty position; at Honeywell this is viewed as a good opportunity to prove one's capability for a more challenging role. Given this rather uncertain environment, we found it extremely helpful to create a project framework, described in detail in the next section.

4.4 Phase-Gate Implementation Plan

Honeywell uses a planning and implementation framework called IPDS (Integrated Product Development & Support). It consists of six phases, with team review sessions or "gates" between each phase. We found this framework to be extremely useful in managing the project team meetings, creating a shared vision of the process, and defining and prioritizing deliverables. The IPDS plan for the pilot implementation team is shown in Figure 12 below. At the start of each team meeting, we reviewed, updated and agreed upon the status of each deliverable. Meetings were scheduled to coincide with the completion (or near completion) of all deliverables within a phase. The team then proceeded to jointly plan and assign tasks as needed to complete the deliverables in the next phase.



Phase 1 Deliverables
- Understand business need for inventory reduction
- Characterize current system
- Identify pull system strategies and compare to current system
- Select strategy based on expected fill rate, savings, ease of impl.
- Define new process (rough draft)
- Select supplier/parts/customer for pilot project

Phase 2 Deliverables
- Form pilot implementation team
- Define project charter
- Value proposition
- Align with STRAP
- Define key characteristics of kanban process
- Identify change barriers
  - Infrastructure barriers
  - Resource barriers
  - Supplier/Customer concerns
  - Internal change resistance

Phase 3 Deliverables
- Define/map kanban order process
- Develop plans to address barriers & mitigate risks
  - Define new infrastructure
  - Resource identification
  - Customer/Supplier pitch
  - Internal stakeholder incentives
- Define success metrics for pilot
- Draft rollout impl. schedule
- Look for synergy w/ other projects

Phase 4 Deliverables
- Negotiate stakeholder agreement (suppliers, customers, and internal) to proceed with pilot project
- Physically lay out and document kanban process, centralize inventory
- Assign roles & responsibilities
- Update BPCS/Xelus data for pilot parts (kanban value code, sizes, etc)

Phase 5 Deliverables
- Run pilot project and collect data
- Validate inventory reduction and fill rate
- Agreement to proceed with rollout
- Address any issues/concerns (process improvements needed prior to rollout)
- Transfer project ownership

Phase 6 Deliverables
- Agree on rollout schedule
- Roll out to all A0 parts
- Roll out to all A parts?

Figure 12. Kanban Project Implementation Plan

Chapter 5: Conclusions and Recommendations

In conclusion, we feel that the analytical model supports our hypothesis. With the use of some creativity and a non-standard kanban sizing algorithm, it is possible to design a pull system to reduce HPG's inventory investment without damaging customer service levels. This chapter reflects on general learnings from the project, introduces some criticism of our methodology, and concludes with recommendations for the future.

5.1 Reflection and Learnings

Our hypothesis at the outset of this project was that a pull system could be designed to improve inventory management at HPG. In the literature, pull systems are not typically recommended for a system with long lead times and highly variable demand.[9] However, in this case we find that HPG's demand is characterized by intermittent large orders ("spikes") and more frequent smaller orders. Our proposed two-bin kanban system, which essentially is a reorder point system with weekly review and fixed leadtime, is designed to meet a very large order, and will with high probability recover before another large order is received. Thus the system can accommodate even parts with very high volatility (coefficients of variation exceeding 200%).

The kanban system does work best for parts with repetitive demand. That is, the kanban sizing algorithm draws on data from the last six months; if the mix of order sizes during the next six months is wildly dissimilar, the kanban size may be far too large or too small to match customer demand. Therefore some intelligence is needed in selecting appropriate categories of parts for the kanban system, and perhaps in adjusting kanban sizes when a dramatic change in demand is expected (e.g. product ramp-up or phase-out, expected series of repair or overhaul orders, new customer contracts, etc.). Materials management should develop stronger links with customer-focused groups to gather intelligence on market trends. The kanban system, having a more automated character than the existing push-to-forecast system, allows buyers to manage by exception and frees up resources for more proactive activities.

5.2 Long-Term and Strategic Benefits

We believe that implementing a kanban system can be expected to result in some strategic benefits. The kanban system allows HPG to minimize the risks of excess and obsolete inventory, and reduce its reliance on forecasts. Also, as part of HPG's long-term supply chain improvement plan, the pull system will shorten supplier lead times from an average of 14 weeks to two weeks. Using kanbans will further synchronize HPG's distribution supply chain with key customers' pull systems, which may result in a strategic advantage over competitors.

HPG supply-chain management feels that some suppliers will be receptive to the new system and willing to test it with fast-moving parts. The burden of forecasting will rest

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[9] Simchi-Levi et al., p. 119

with the supplier, whereas in the current push system HPG bears all the risk of forecast inaccuracy. The kanban system will incentivize suppliers to develop more flexible, shorter lead time manufacturing processes, so they will be able respond quickly to refill orders without holding excessive quantities of finished goods. In addition, the reliable customer service of the kanban system should over time encourage customers to reduce their kanban sizes, which will result in a more level demand pattern.

5.3 Criticism of the Model and Its Application

The model's main weakness is its highly simplified, deterministic design. This means that, for example, all lead times were assumed to be fixed and exact. In reality, we recognize that leadtimes are variable, and shipments often arrive late. The impact of these probabilities was not taken into account in any of the model variants. However, the inventory systems we modeled are comparable in that the same assumptions are made in all cases. What we cannot determine is the impact of variability, which may differ for each system depending on its sensitivity, for example, to on-time delivery.

Similarly, refill signals (or orders) were assumed to be perfectly accurate and immediately received by the supplier. Ideal inventory accuracy was also assumed, as was a "warm start" with the recommended safety stock quantity immediately available at all locations in each model variant. The "warm start" assumption was intended to create a relatively "steady state" of inventory flow – starting with zero inventory would also be reasonable, but the time required to achieve steady state makes it difficult to interpret the results. Sensitivity of each system to these assumptions was not examined.

Human intervention was not considered; each model system was designed to run as if automated, according to the logical rules for each version. The possibility of human "tweaking" of order sizes or timing, such as the manual pull-ins or cancellations of orders (frequently used in the existing system), is not considered, and indeed should not be needed if the new system is robust. In the same way, the effect of incentives on ordering behavior is not treated in the model. Bonuses, premiums, volume discounts, and minimum order quantities were ignored. Customer demand, of course, is taken from real historical data; but internal orders are assumed to be unaffected by behavioral incentives.

The assumption of two-week material leadtime in the kanban system is based on the reasonably conservative estimates of informed managers, and is considered to be achievable. As mentioned, this leadtime is assumed perfectly fixed in all cases, which is certainly not achievable. The possibility of increased costs due to altered logistics, reduced batch sizes, or other changes required of the supplier, is not included in the total system cost estimate.

Finally, due to time considerations, the model only included two warehouses (one core and one FSL) and examined eight parts that we believe to be representative. The real system, with many more parts and warehouses, is of course more complex. In designing the pilot, we included about 50 fast-moving parts, a single core warehouse, and all of the associated FSL warehouses. The pilot results are expected to validate the assumptions made in the model and give confidence that the new system can be applied to all of HPG's fast-moving parts.

5.4 Recommendations for Implementation

HPG expects to pilot the kanban system during the first half of 2004, working with one or two suppliers and a small selection of fast-moving, high-value parts. Once the pilot project demonstrates reliability and efficiency, and stakeholders at all levels of the value chain are comfortable with the process, it will be further expanded. The pilot will provide more extensive data on cost savings, service levels, inventory turns, and other metrics considered vital to the success of the project.

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Appendix A: List of Acronyms

- AMC – average monthly consumption (measure of demand)
- BOH – beginning on hand (inventory)
- DRP – distribution requirements planning
- DOS – days of supply
- E&O – excess & obsolete (inventory)
- EDI – electronic data interchange
- EOH – ending on hand (inventory)
- ES&S – engines, systems & services (business group within Aerospace)
- FPOT – fixed purchase order time-fence (forecast sharing agreement)
- FSL – forward stocking location (regional warehouse)
- HPG – hardware products group (business enterprise within ES&S)
- HR – human resources
- IPDS – Integrated Product Development & Support (a phase-gate project planning and review framework)
- ISC – integrated supply chain
- IT – information technology
- MRP – material requirements planning
- PO – purchase order
- R&O – repair & overhaul
- ROP – re-order point
- VAS – value-added services (a.k.a. JIT, just in time)
- VMI/SMI – vendor/supplier managed inventory