The Study of Inventory Management of Raw Materials for a Pharmaceutical Company

by

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B.Eng, Mechanical Engineering

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ABSTRACT

TCG is a multinational pharmaceutical company. As part of its drive to adopt lean manufacturing methodology in the plant and to stay competitive in the industry, TCG plans to effectively maximize its capital assets and reduce the warehouse space from 3500 to 1500 pallet spaces. This thesis focuses on the raw materials procurement and ordering methods in TCG. We study the accuracy of the demand forecasts for the finished products. And we investigate methods to improve procurement and inventory control.

We use a 2-factor classification method to rank the 38 types of raw materials in the warehouse in terms of their importance based on their past procurement costs and the amount of warehouse space they occupied. We propose a just-in-time approach for the 9 most important items by having timely orders that match closely to the production schedule. A continuous review model is used for the next 11 items of less importance and a periodic review model is used for the remaining 18 items, which are of the least importance. We discuss and justify the assumptions used in our analysis. We provide a few further recommendations on how to improve inventory control based on observations of the current practices. The overall result shows that it might be possible to reduce the amount of space occupied by raw materials from the current average of 1076 pallets by 72%.

Thesis Supervisor: Stephen C. Graves

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Chapter 1: Introduction

1.1 Introduction

1.1.1 The Company's Background

TCG Phamaceuticals is a large pharmaceutical company that develops and manufactures a wide range of drugs for its patients. TCG was incorporated in the year 1999 and produced its first batch of products in early 2001.

1.1.2 Manufacturing Facilities

The plant has 3 separate manufacturing facilities, each located in different buildings. The Active Pharmaceutical Ingredient (API) facility produces both Product B and Product A, the active ingredients that are needed to produce certain pills. In the Pharmaceutical Facility 1 (PF1), Product C is produced using about 60% of the Product A manufactured in the API facility. A new product, code name Product D will be produced in its Pharmaceutical Facility 2 (PF2) starting December 2007.

1.1.3 Warehouse Space

The sole warehouse in the plant serves the 3 manufacturing facilities. It currently has a total of 3500 pallet spaces. TCG has been setting aside 2000 pallet spaces to keep raw materials, intermediate products and finished products from the 2 current active manufacturing facilities. The other 1500 pallets spaces are planned to be reserved to support the manufacturing of the upcoming product, Product D.

Current Warehouse	Pallet Spaces
API	1000
PF1	1000
TOTAL	**2000**
PF2 (Product D) Requirements	**Pallet Spaces**
Raw materials, packaging components	0
Active Ingredient	300
Finished Products	1200
TOTAL	**1500**

Table 1-1: Current Space Allocation in the Warehouse

TCG's Global Supply Chain & Logistics team obtained the figures in Table 1-1 for Product D based on a study conducted in early 2005. TCG used the simulation software, Arena to simulate a dynamic model for the material flow across the Product D formulation process. The focus of the analysis was to evaluate the storage space required to handle the raw materials, intermediate products and finished products for Product D.

The study concluded that at least 1480 total pallet spaces are recommended to support its operations. This includes 300 pallet spaces for incoming active ingredient, 1120 pallet spaces for bulk tablets in storage drums and at least 60 pallet spaces for materials waiting for quality testing results. In addition, they recommended at least 300 pallet spaces for the active ingredient at the Contract Manufacturer to act as strategic inventory. This amount is equivalent to about 15 days of additional inventory and may be called for during ramp-up production stage. They also assumed that lean manufacturing methods will be adopted in the Product D production and therefore they should not need any more pallet spaces to store the raw materials and packaging components than they have reserved for the other facilities.

1.1.4 Products of TCG

Product B and Product A are the products of TCG while Product C is jointly produced by TCG and one of its partner companies. The partner company supplies some of the raw materials to TCG to produce the finished products of Product C. The Joint Venture (JV) is a company that bridges communication between the 2 companies. Every month, JV will forecast the monthly demand for Product C for the next 2 years. Similarly, TCG receives the monthly forecast for Product A and Product B from its own Global Chemical Planning (GCP) group.

TCG produces Product A and Product B for sister plants that require them as raw materials for other TCG products. TCG has 6 other main customers for Product C and they are sister plants that package Product C into pills that can be sold to end users, the patients. The planners in TCG make use of the latest demand forecast for each product from GCP and JV to plan the production schedules for the coming months and make sure customers receive the right amount of products on time.

1.1.5 Planning and Scheduling Infrastructure

The forecast demand data is uploaded into an information system known as Data3 that can be accessed by all employees in TCG. Besides showing the current inventory level for each material in the plant, the system also has planning and scheduling capabilities which include Master Production Schedule (MPS) and Material Requirements Planning (MRP).

Based on the MPS and MRP from the system, the planners will order about 3 months' worth of raw materials and keep about one month's worth of finished products. There are possibilities that equipment may break down, materials may not pass the stringent quality test required by pharmaceutical plants or customers may increase their demand for the products before shipment. Therefore, TCG keeps high levels of safety stocks to assure that production in the plant will not be starved and that customer demands can be satisfied without delay.

1.2 Motivation

Based on TCG's long range operating plan, demands for the products they are producing will increase steadily. They believe that if they continue their current way of operation, an addition of 1500 pallet spaces for the API facility and PF1, and another 4100 pallet spaces for the PF2 at the start of year 2009 are needed. With the projected 8600 to 9100 pallet spaces needed in the next 2 years, the current warehouse space is definitely not able to support the whole plant's operation. TCG did not explain how they derived this conclusion.

However, the management wants to adopt lean manufacturing methodology in the plant and has plans to capitalize the use of land for the profit-making activity of making finished goods. Therefore, instead of adding more warehouse space, TCG has decided to downsize the warehouse from its current size of 3500 pallet spaces to only 1500 pallet spaces.

1.3 Objectives

The purpose of the project with TCG is to determine a phased and cost effective way to reduce the warehouse space to 1500 pallet spaces. In order to meet the increasing customer demands and only make use of 1500 pallet spaces in the warehouse, any wastages of space must be reduced inside the warehouse. TCG should only order the amount of raw materials they need for the near future and keep the amount of finished products they want to ship out soon. The intermediate products inventories that are kept in the warehouse should also be reduced.

TCG would also like to explore the benefits of air versus sea shipments for the finished products. Currently, all finished products are shipped by air freights, but sea shipment may be more cost effective. On the other hand, although finished products are now shipped only after quality tests are passed, the possibility of shipping finished products while waiting for the quality test results to be concluded can be explored.

Given that the reduction in warehouse space is rather drastic, the use of 3rd party warehouse facilities to store part of the inventories may be considered. However, having a new warehouse is not an option to the management.

1.4 Project Scope

The project is split into 3 separate areas and is tackled by 3 graduate students from Massachusetts Institute of Technology working as interns in TCG from the period of May 2007 to August 2007.

The first area of the project deals with raw material inventories and ordering methods. The second area covers the intermediate product inventories and campaigning activities when one of the production lines switch from one product to another. The last area covers the handling of finished product inventories and shipment.

This thesis focuses on the raw material inventories and ordering methods in TCG. I studied and analyzed the current ordering method for raw materials and the past inventory level for each raw material. I also investigated methods to improve procurement and inventory control. The results were compared with the current situation and recommendations were proposed.

1.5 Organization of the Thesis

In the first chapter, I give a general description of the company that our project is based on and highlight the purpose of this project. In the Chapter 2, I describe in detail the 3 manufacturing facilities and their products, and show the current inventory levels in the API facility and PF1. The inventory management system in TCG is then described together with its problems. I studied a better way of managing raw material inventories in Chapter 3 and compare the results with the current situation. Lastly, in Chapter 4, I conclude by listing all the recommendations we have derived from our study and give further recommendations on how TCG can improve its inventory management system for raw materials.

Chapter 2: Current Situation

2.1 Manufacturing Facilities

2.1.1 Active Pharmaceutical Ingredient (API) Facility

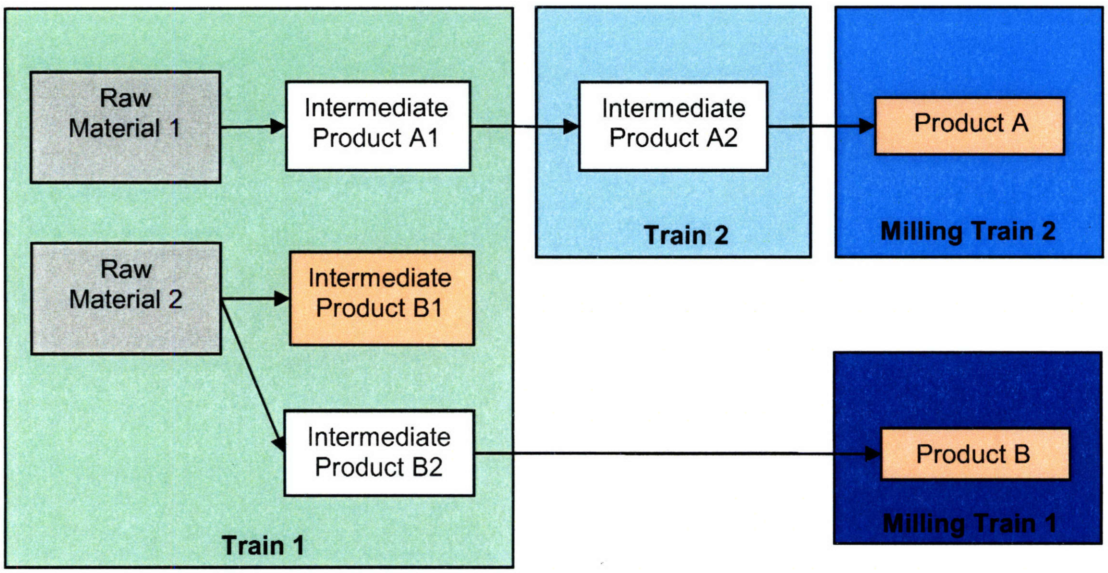


Figure 2-1: Product Flow Chart in the API Facility

The API facility produces 3 finished products, namely Product A, Intermediate Product B1 and Product B. In the pharmaceutical industry, production lines are referred to as Trains. Within the API facility, TCG has two production lines called Train 1 and Train 2. As seen from Figure 2-1 above, there is also a Milling Train, which separates into Train 1 (Milling) and Train 2 (Milling).

2.1.1.1 Train 1

Train 1 produces the intermediate products, Intermediate Product A1 from Raw Material 1 and Intermediate Product B2 from Raw Material 2 respectively. The finished product Intermediate Product B1 is also produced in Train 1 from Raw Material 2.

Intermediate Product B1 is chemically equivalent to Intermediate Product B2, but it is referenced by a different name and part number to distinguish between its final usage and its packaging methods. Intermediate Product B2 is milled to produce the finished product Product B. The process steps for producing Intermediate Product A1and Intermediate Product B1 are shown below.

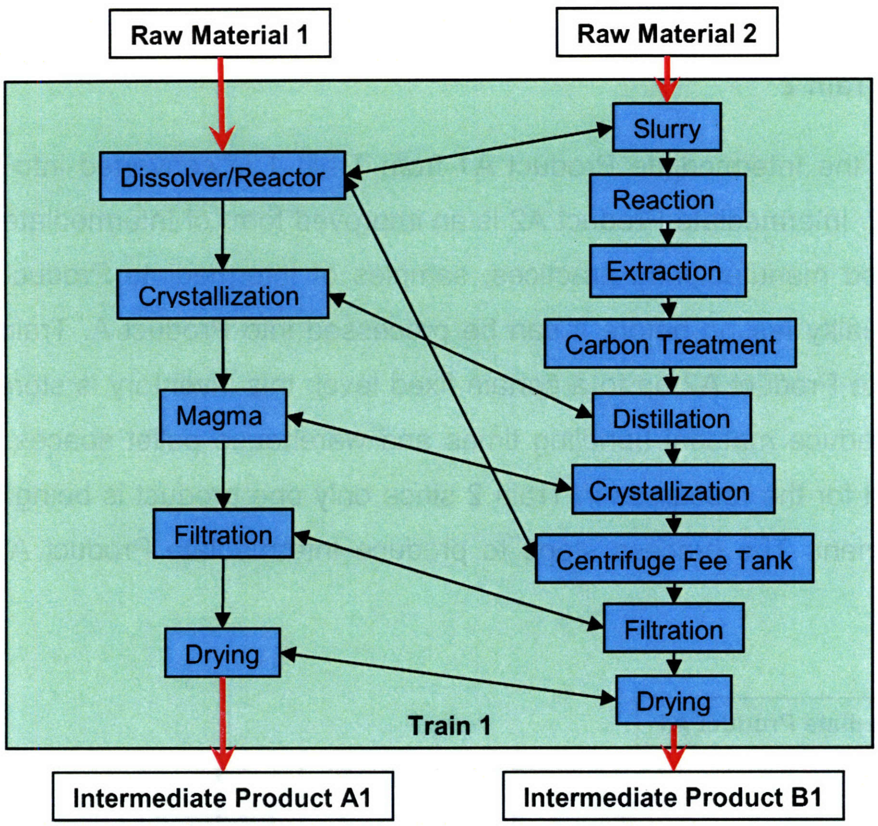


Figure 2-2: Process Steps to Produce Intermediate Product A1and Intermediate Product B1 in Train 1

Due to the heavy cross utilization of equipment, production of Intermediate Product A1 and Intermediate Product B1 are mutually exclusive. That is, Train 1 alternates between producing a campaign of Intermediate Product A1 and producing a campaign of Intermediate Product B1. In the pharmaceutical industry, a campaign is the term used to describe the period of production when a Train is producing one particular product. Production planning of the above products has to take into the account the fact that switching between Intermediate Product A1 and Intermediate Product B1 requires 2 weeks of downtime for cleaning. After production, samples of both products are sent for quality testing as part of the good manufacturing practices in TCG. Quality testing for Intermediate Product A1 takes about 7 days and 14 days and is required for Intermediate Product B1. During this period, both products are stored in the warehouse.

2.1.1.2 Train 2

In Train 2, the Intermediate Product A1 from Train 1 is converted into Intermediate Product A2. Intermediate Product A2 is an improved form of Intermediate Product A1. Due to good manufacturing practices, samples of Intermediate Product A2 need to undergo quality testing before it can be processed into Product A. Train 2 produces Intermediate Product A2 up to a certain fixed level; this inventory is stored in the API facility to reduce material handling times and warehouse pallet spaces. There is no competition for the resources in Train 2 since only one product is being produced on this equipment. The process steps to produce Intermediate Product A2 are shown below.

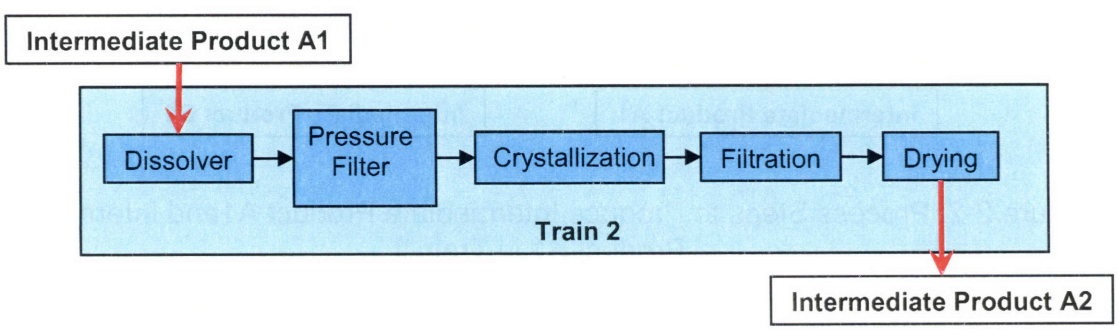


Figure 2-3: Process Steps to Produce Intermediate Product A2 in Train 2

2.1.1.3 Milling Train

The back end process in the API facility is the Milling Train. This train is separated into 2 sections, one for Product A and the other for Product B; thus the 2 products can be processed separately without conflict. Both products undergo similar processes of charging, milling and blending. The process steps in the Milling Train are shown below.

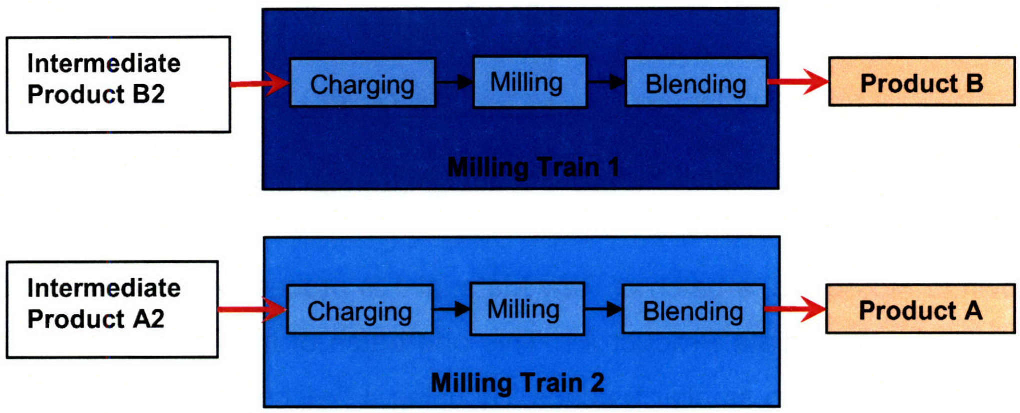


Figure 2-4: The process steps in Milling Train 1 (top) and Milling Train 2 (bottom)

The coordination of the production schedule for Intermediate Product A1 with the production schedule for Intermediate Product A2 has to be carefully managed such that the downstream processes are not starved.

2.1.1.4 Batch Size

A single batch of Product A requires 3 batches of Intermediate Product A2. A single batch of Intermediate Product A2 in turn requires half a batch of Intermediate Product A1. Thus, one and a half batches of Intermediate Product A1 are required for each batch of Product A.

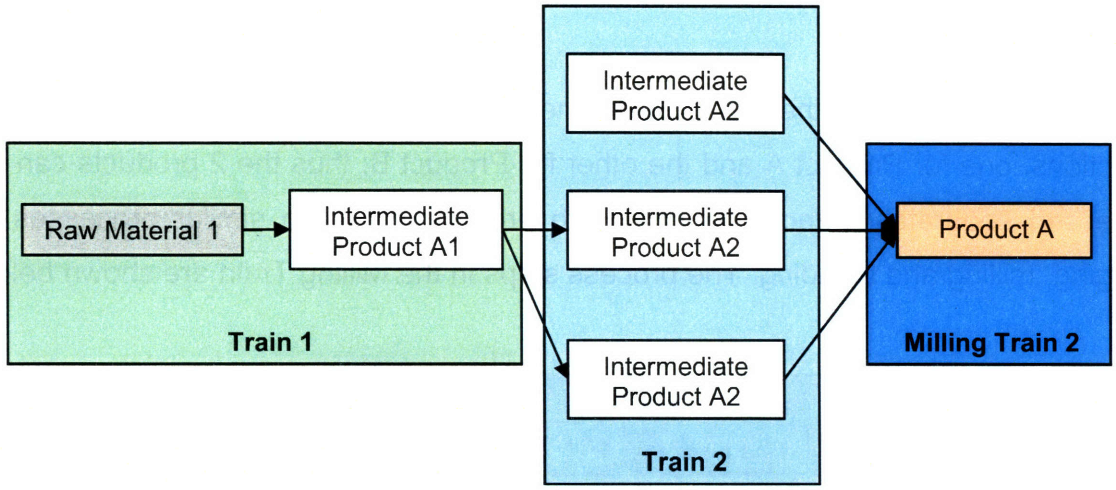


Figure 2-5: Batch Flow of Product A through the API Facility

As shown in Figure 2-5, a batch of Raw Material 1 is processed in Train 1 to produce one batch of Intermediate Product A1. This one batch of Intermediate Product A1 is later separated into two smaller batches. By using 3 batches of Intermediate Product A2, one batch of Product A is produced from Milling Train 2.

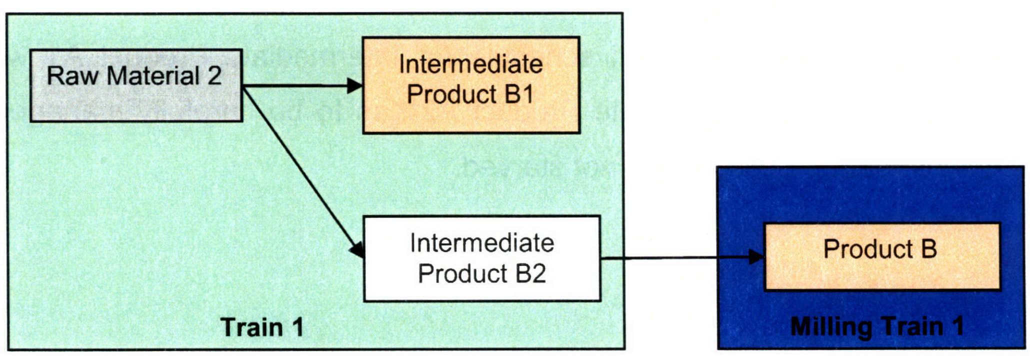


Figure 2-6: Batch Flow of Intermediate Product B1 and Product B through the API Facility

A single batch of Intermediate Product B1 requires only one batch of Raw Material 2. As shown in Figure 2-6, a batch of Raw Material 2 is processed in Train 1 to produce one batch of Intermediate Product B1 or one batch of Intermediate Product B2. One batch of Intermediate Product B2 can produce a batch of Product B in Milling Train 1.

Table 2-1 below shows the production capacity for each product when only one product is produced at one time.

Product	Production Capacity (batches per week)
Intermediate Product B1	10
Product B	5+
Intermediate Product A1	6
Intermediate Product A2	9
Product A	3.5

Table 2-1: Production Capacity for Each Product in the API Facility

2.1.1.5 Processing Times

The breakdown of the time to convert one batch of Product A from Raw Material 1 is shown in Table 2-2. On average, TCG takes 30 days to convert Raw Material 1 to Product A when there are no quality deviations. Almost half of the time is taken for the quality testing after each process step. An additional 19 days or less is needed if there is a deviation.

Step Number	Process Description	Time Taken
1	Convert Raw Material 1 to Intermediate Product A1	4.7 days
2	Quality testing	2.6 days
3	Convert Intermediate Product A1 to Intermediate Product A2	2.1 days
4	Quality testing	2.6 days
5	Convert Intermediate Product A2 to Product A	3.6 days
6	Quality testing	9.2 days
7	Packaging for shipment	5 days
	TOTAL	**30 days**

Table 2-2: Time Taken for Each Process Step to Produce One Batch of Product A from Raw Material 1

The breakdown of the time to convert one batch of Intermediate Product B1 from Raw Material 2 is shown in Table 2-3. Converting Raw Material 2 to Intermediate Product B1 takes an average of 30 days if there are no quality deviations. An additional 75 days or less is needed if there is a deviation.

Step Number	Process Description	Time Taken
1	Convert Raw Material 2 to Intermediate Product B1	4.7 days
2	Quality testing	19.3 days
3	Packaging for shipment	5 days
	TOTAL	**30 days**

Table 2-3: Time Taken for Each Process Step to Produce One Batch of Intermediate Product B1 from Raw Material 2

2.1.1.6 Past Demand

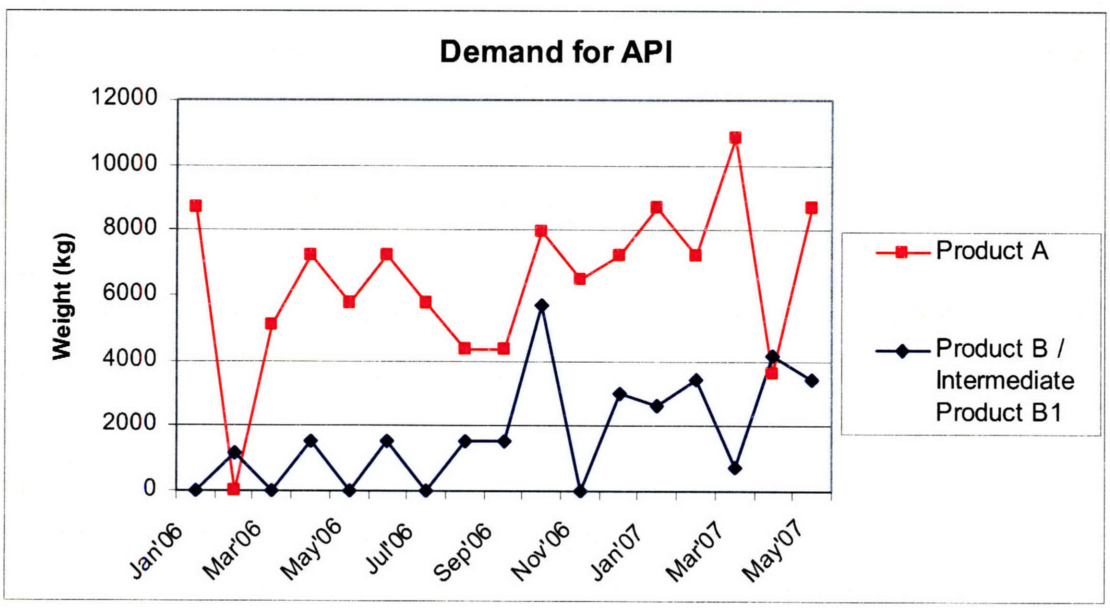


Figure 2-7: Past Aggregated Demand for API

About 40% of Product A is shipped to external customers while the rest is kept in the warehouse to be used in PF1 or the Pharmaceutical Facility 2 (PF2) to produce

Product C and Product D. The past aggregated demand for the APIs is plotted in Figure 2-7. The demand figures used in the graph for Product A include both external customer demand and internal PF1 demand.

2.1.2 Pharmaceutical Facility 1 (PF1)

The production of Product C in PF1 is a serial process where the main raw materials are Product A and Raw Material 3. There is no intermediate product in this process.

Finished products from PF1 consist of Product C in the form of Tablet W, Tablet X, Tablet Y and Tablet Z with Tablet W being the weakest and Tablet Z the strongest in terms of strength. The difference in the 4 strengths of tablet lies in the amount of the active ingredient Product A that each tablet contains. The tablets are produced in 2 batch sizes, large and small.

2.1.2.1 Batch Size

PF1 can currently produce a maximum of 25 batches of Product C in each week or 21 batches of Product C in each week. These numbers include the amount of downtime, and the changeover time between products of different strengths.

2.1.2.2 Processing Times

The cycle time for each batch to be processed is measured to be around 7 to 8 days with some variability. Additional days are needed if any quality deviation is found in a batch.

2.1.2.3 Past Demand

The past aggregated demand for Product C is plotted in Figure 2-8 below.

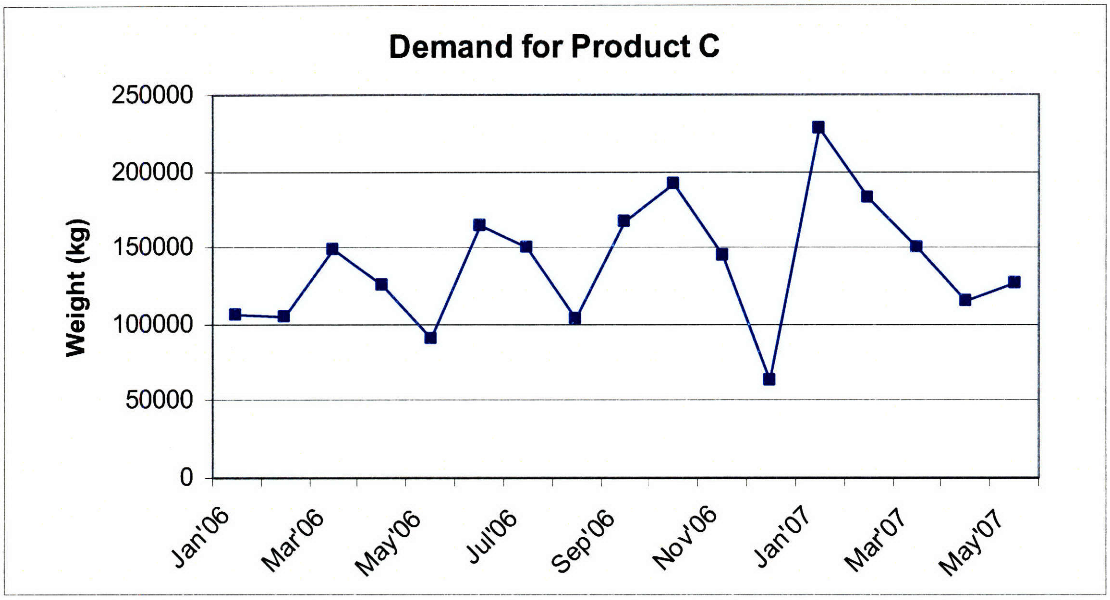


Figure 2-8: Past Aggregated Demand for PF1

2.1.3 Pharmaceutical Facility 2 (PF2)

This new facility will produce a new series of products, code named Product D. There are 2 types of this product: Product D1 and Product D2. The production of both products will begin only after year 2007. Only Product D2 uses Product A from the API facility as one of its main ingredients.

The production capacity in PF2 is known to be 19 batches of Product D1 per week. However, the Bill of Materials (BOM) and packaging methods are not known to us at the time when this report is written.

2.1.4 Product Classification

Besides classifying Product C based on the tablet's strength, all finished products are classified in terms of the markets they serve. Basically, the market each product serves is dictated by the source of the active ingredient approved for that market. The active ingredients of concern are Raw Material 1 and Raw Material 2. They are produced in 4 locations: P1, P2, P3 and P4. This means that each customer will order a finished good specified by the source of Raw Material 1 or Raw Material 2 contained in the product. In order to differentiate the products, the location names are added to their names as affixes to indicate the source of the active ingredient:

For example, in the API facility, "Tablet W (P2)" will indicate that this Product C is produced using the active ingredient from P2. In PF1, Product A will be indicated as "Product A (P3)" if produced using Raw Material 1 from P1 and "Product A (P2)" if produced using Raw Material 1 from P2. The affix will also be added to the name of the active ingredients to differentiate its origin.

The specific market where each finished product with a different supplier of the raw material serves is not a concern in this project. This is because the customers of TCG are its sister plants and they will only order a certain proportions of the different types of finished products. However, since Dec '06, TCG has received no demand for Product A (P3) or Product C that uses Raw Material 1 (P3) as the active ingredient. On the other hand, Product A (P4) and Intermediate Product B1 (P4) have recently found a new market to serve and there will be a spike in their demands starting from Aug '07 due to this new customer demands.

2.1.5 Good Manufacturing Practices

Good manufacturing practices (GMP) in the pharmaceutical industry involve the quality testing of all batches of raw materials, intermediate products and finished products to ensure that the end products are safe to be consumed by patients. When an order of raw material arrives in the warehouse, a part of the material will be extracted from each batch to be sampled. Similarly, intermediate products will be sampled for testing before moving to the next step in the manufacturing process, while finished products are tested before shipment. The materials being tested will sit in the warehouse while waiting for the results.

In cases where a test reveals a deviation in the quality of a material, the material will undergo further testing to confirm the results. TCG imposes a maximum number of days a material can sit in the warehouse while waiting for the results. For example, Product A is allowed to sit in the warehouse for a maximum of 20 days for further testing before being disposed of. On the other hand, Intermediate Product B1 is given as much as 75 days.

2.2 Customer Service Level

The manufacturing network of TCG consists of many manufacturing facilities and packaging plants distributed worldwide. TCG is in the middle of this global supply chain where finished products from one facility are transferred to another facility until they are ready to be packaged and sold to the end customers, the patients.

In order not to starve the production in the downstream part of the supply chain, TCG always try to meet the customer demands. It is very important not to let production stop because patients need a constant supply of the pills and failure to do so may lead to undesirable outcomes that involve human lives. Therefore, TCG keeps a certain level of safety stocks for most of the raw materials and finished products.

Customers (i.e., the sister plants) have to send their order for any finished products 3 months in advance so that the manufacturing facilities can have enough time to meet the orders. The maximum cycle time for producing Product A from the raw material of Raw Material 1 is 50 days and it takes a maximum of 105 days to convert Raw Material 2 to Intermediate Product B1, while Product C takes about a month to be produced from its raw materials. Therefore, the 3 months of lead time is practical for TCG to plan the production schedule.

Customer orders will be updated in the monthly forecast data given by GCP and JV. Although the customers are allowed to change their order quantities within the 3 months lead time, the planners estimate that the customer orders are pretty fixed with less than 10% of the orders increasing their quantities; these changes are small.

2.3 Current Inventory Level

We compile the start-of-the-month inventory level for each raw material, for each intermediate product and for each finished product from June ‘06 to May ‘07. Only materials kept in the warehouse are included in the data, while solvents are ignored since they are kept in a separate facility. We convert the inventory level into the amount of pallet spaces the material occupies. Materials are contained in different types of drums, boxes or Flexible Intermediate Bulk Containers (FIBCs). A pallet may hold up to 24 drums or several boxes, depending on the size of the container. However, it can hold only one FIBC.

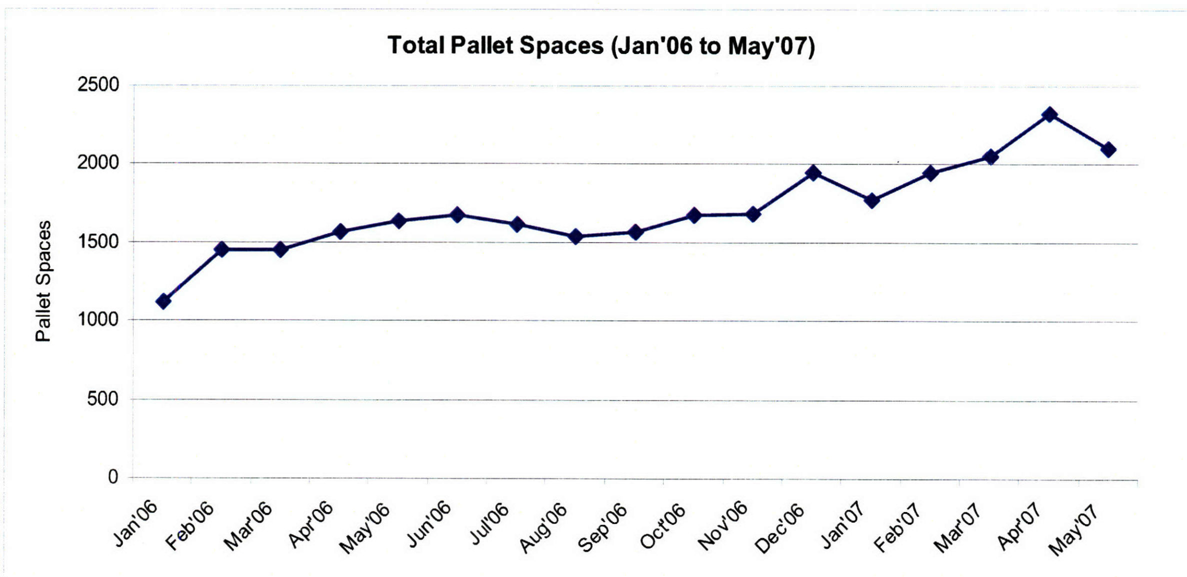


Figure 2-9: Monthly Total Pallet Spaces Occupied in the Warehouse

The plot of the total start-of-the-month inventory level for all materials from Jan ’06 to May ’07 in Figure 2-9 shows that the pallet spaces being occupied in the warehouse is increasing steadily. This increase is caused by the increase in demand for API and Product C in the same period. We also note that the inventory level went beyond the

2000 pallet spaces reserved for both the API facility and PF1. Therefore, with the coming launch of production in PF2, coupled with no improvement made to the inventory management methods, inventory space will soon increase beyond the maximum capacity of 3500 pallet spaces in the warehouse.

Next, we classify the materials into finished products (FG), intermediate products (WIP), raw materials only (RM) and packaging materials (PK) and plot the monthly distribution of these 4 types of inventories for the same period. From Figure 2-10, we observe that on average, RM makes up slightly more than 40% of the pallet spaces used each month. WIP occupies a little more space than packaging material, but FG uses the least space.

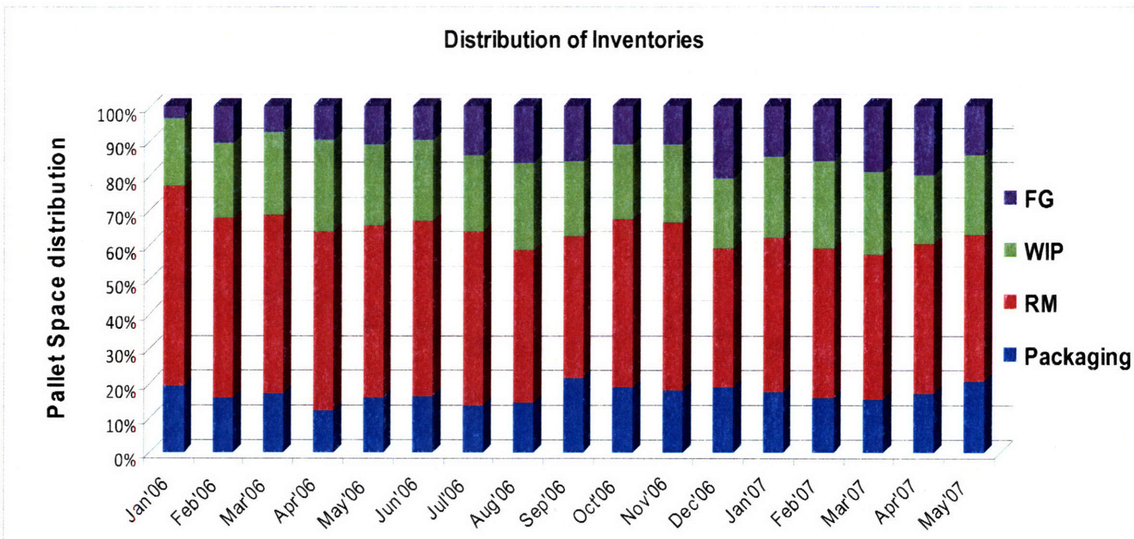


Figure 2-10: Monthly Distribution of Inventories

There are a total of 52 materials that are kept in the warehouse. We rank all these materials in terms of their average and maximum inventory levels for the same period from Jan '06 to May '07. Table 2-4 shows the top 10 inventories with the most average pallet space occupied.

Material	Type	Average Pallet Space Occupied	Rank	Max. Pallet Space Occupied	Rank
Raw Material 3	RM	**305**	1	**463**	1
Raw Material 2 (P2)	RM	**205**	2	**350**	2
Product A MF (P2)	INT/FG	**164**	3	**269**	3
Raw Material 5	PK	**108**	4	**180**	4
Product C - Tablet Y (P2)	FG	**81**	5	**131**	7
Raw Material 4	RM	**71**	6	**110**	9
Raw Material 11	PK	**60**	7	**124**	8
Product A (P3)	INT/FG	**58**	8	**180**	5
Intermediate Product A1 (P2)	INT	**56**	9	**159**	6
Raw Material 7	RM	**50**	10	**78**	16

Table 2-4: Top 10 Materials that Occupy the Highest Average Pallet Spaces

The data shows that on average, the inventory of Raw Material 3 holds the highest amount of pallet spaces in the warehouse, followed by Raw Material 2 (P2) and then the Product A (P2). However, the fact that Raw Material 3 is top ranked is not surprising since the Bill of Materials (BOM) for Product C shows that 58 – 67% of a tablet's weight is made up of Raw Material 3.

Table 2-4 also shows that most of the top 10 materials in terms of average pallet space occupied are also the top 10 in terms of the maximum pallet space each occupied for the one year period. The total average pallet space occupied by the top ten materials makes up 88% of the overall average pallet space used up by all materials. Therefore, we put more focus on these 10 materials in this project.

2.4 Current Inventory Ordering Methods

Each month, the planners in TCG will order raw materials based on the MPS and MRP schedule produced by the Data3 system. The planners will constantly adjust the schedules from the MRP to avoid the 2 weeks' changeover time between production of Intermediate Product A1 and Product B as much as possible. The planners also adjust the schedules to fit the production capacity. They will include a certain amount of safety stock for each raw material in the schedules to ensure a stock out does not happen.

The lead time to receive the raw materials after the release of a purchasing order depends on the supplier's lead time and the time to sample the raw materials for quality checks. Both lead times are variable for most raw materials. Therefore, the planners will include safety lead times to ensure the raw materials arrive in time for the next production.

Their actions of keeping both safety stocks and safety lead times have ensured zero stock out for raw materials in the past 2 year but have also resulted in high inventory level for the raw materials. Due to the limitation of the Data3 system, orders of materials that are common to both facilities are not aggregated. The planner for one facility will order these materials for his facility alone without considering the demand for the same materials in the other facility.

2.5 Problems with MRP

The basic idea of a MRP system is that once the final due date for a product is known, and the time required for each production step is known, then intermediate due dates and material requirement times can be determined. It uses a product's BOM and component lead times to decide when production should begin. For the replenishment of raw materials, the MRP system will plan to place an order a lead time before the material is needed, so that the materials will arrive just in time for the planned production. By treating demand outside the system as independent demand and demands for components and raw materials as dependent demands, a MRP system allows buyers to synchronize with producers for the first time in manufacturing history.

However, despite the hype MRP enjoyed when the American Production and Inventory Control (APICS) launched the MRP Crusade in 1972 to promote this system, MRP did not live up to its expectation of reducing inventory level. This is due to the fact that MRP is deterministic but in reality, demand and lead times are not fixed. Therefore, the system needs safety stocks and safety lead times to buffer against these uncertainties.

Furthermore, MRP typically treats capacity as infinite, which frequently results in infeasible schedules. Therefore, constant manual intervention is required to compensate for these poor schedules.

We see 4 main challenges with using the MRP system in TCG:

1. They need to add safety stocks and safety lead times to the system to prevent stock out. This has resulted in high inventory level for raw materials.
2. The planners readjust the MRP schedule when the forecast is revised or when production capacity changes due to equipment breakdown or manpower shortages. The planners are also in-charge of procuring raw materials and making sure they receive the orders. Therefore, their constant adjustment of the schedule has resulted in them not concentrating on whether the orders arrive in time. In order to be sure they have the raw materials before production, they have the tendency to add more safety stock and safety lead time to the orders.
3. The Data3 MRP system does not aggregate the demand for common materials that the facilities use. Therefore, each common material is ordered separately for each facility resulting in a higher inventory level than if the demands were aggregated.
4. The Data3 system only shows the current inventory on hand but does not show how much pallet spaces are taken up by the inventories at any time. Therefore, the planners do not know how much space is left in the warehouse when planning for the next order. TCG has never plotted the historic inventory level to determine if the level has surpassed the 2000 pallet spaces reserved for the 2 active production facilities because it is a tedious process of compiling data on receipt, shipment, stock movement, stock correction (due to mistake in calculation) and stock return. Our

experience in trying to compile the data has taught us that it may take at least a month to plot the actual inventory level trend for the past 2 years. Therefore, we use the monthly financial data that shows an estimate of the inventory on-hand for all our analysis.

2.6 Forecast Accuracy

The MPS and MRP from Data3 are based on the forecast of customer demand from GCP and JV. Raw materials are also ordered based on the forecast data. Making these production and inventory decisions as if the projected data is accurate will result in either stock out situations if the true demand is higher than projected or high inventory levels if the true demand is over-projected. Therefore, we do the following study on the accuracy of the forecast data to determine how confident we are that the production and inventory decisions we make using the data can meet the actual demands.

The monthly forecasted demands for each product for the next 2 years are updated by GCP and JV every month, close to the end of each month. Therefore, the true demand for a certain month can only be obtained from the data sent out in the following month.

To calculate the forecast accuracy, we let $f_t(t+i)$ be the forecast made at time t for the customer demand for finished products in period $t+i$, where $i = 1, 2, \ldots 24$ months. The actual demand observed in period t is denoted by $f_t(t)$, the forecast made in period t for the demand in period t. There is no information beyond the forecast horizon of 2 years.

Every month, an updated new set of forecasts $f_t(t+i)$ will be generated and we define the updates of the forecasts from month to month by the forecast revision, $\Delta f_t(t+i)$:

$$\Delta f_t(t+i) = f_t(t+i) - f_{t-1}(t+i) \qquad \text{Equation 2-1}$$

We then measured the *i-th* period forecast error as the difference between the actual demand in period *t* and the forecast of this demand made *i* periods earlier:

$$f_t(t) - f_{t-i}(t) = \Delta f_t(t) + \Delta f_{t-1}(t) + \ldots + \Delta f_{t-i+1}(t), \qquad \text{Equation 2-2}$$

where $\Delta f_t(t) = f_t(t) - f_{t-1}(t)$.

To assess how each forecast revision improves the forecast, we calculate the variance of the *i*-th period forecast error by using:

$$\begin{aligned} Var[f_t(t) - f_{t-i}(t)] &= Var(\Delta f_t(t)) + Var(\Delta f_{t-1}(t)) + \ldots + Var(\Delta f_{t-i+1}(t)) \\ &= \sigma_0^2 + \sigma_1^2 + \ldots + \sigma_{i-1}^2 \end{aligned} \qquad \text{Equation 2-3}$$

where we assume that the forecast revisions are independent over time; thus we can add the variances.

2.6.1 API

The projected forecasts for the demands of API products, Product A and Intermediate Product B1 and Product B Milled in the months of Jan '07, Feb '07 and Mar '07 are tabulated against the month when the forecasts are made. The graphs below show how the forecasts change from more than a year ago to the delivery months of Jan '07, Feb '07 and Mar '07.

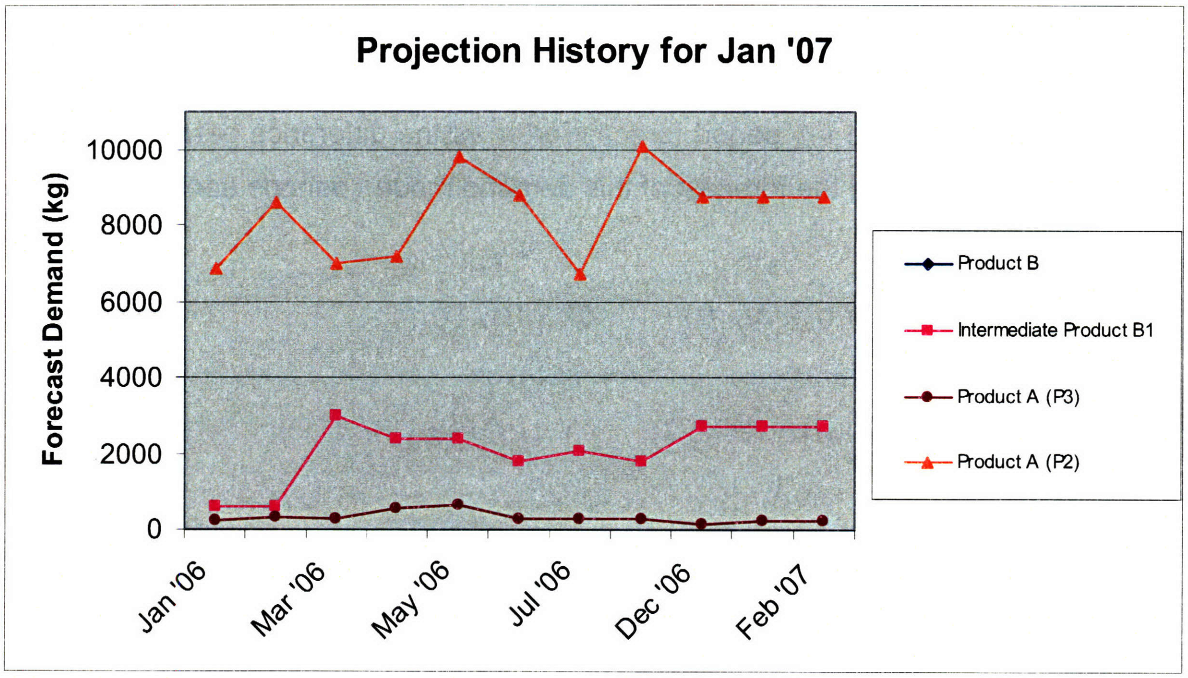


Figure 2-11: Projection of API Forecast Demand for Jan ‘07

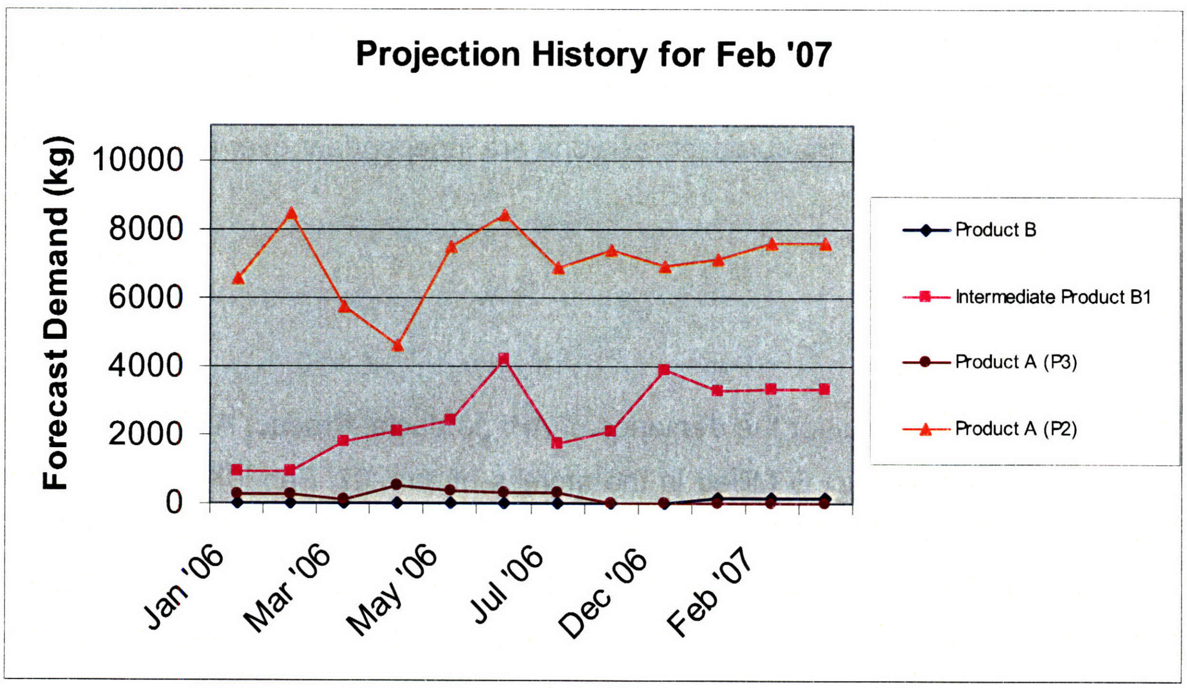


Figure 2-12: Projection of API Forecast Demand for Feb ‘07

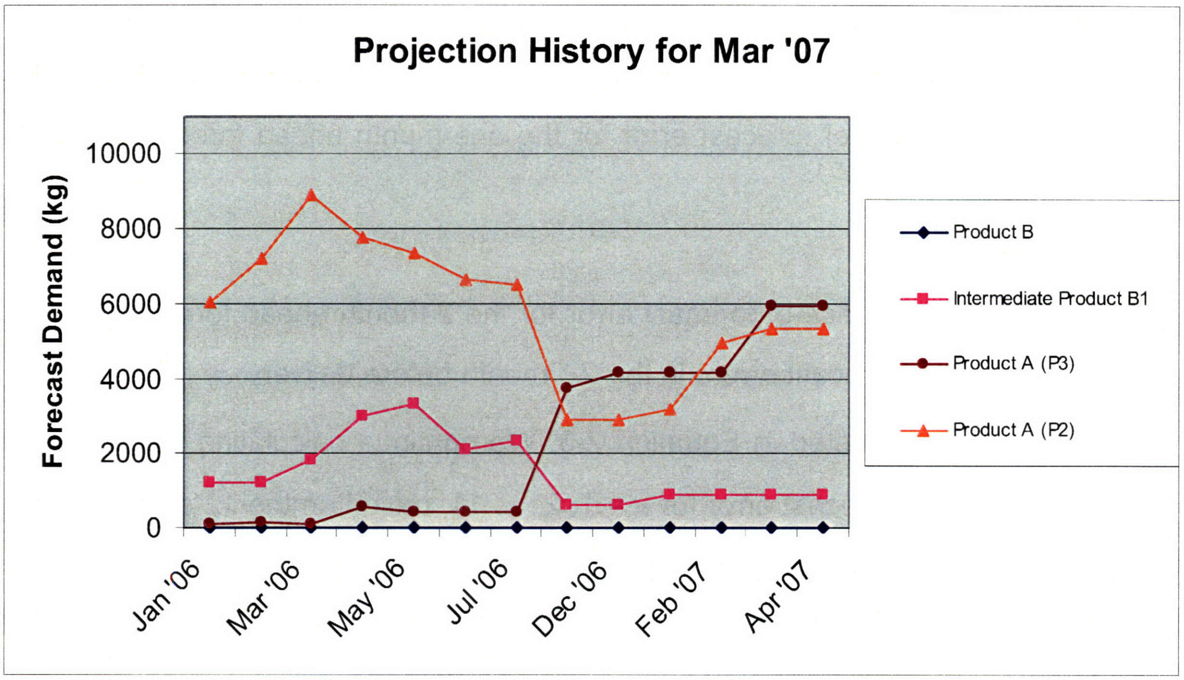


Figure 2-13: Projection of API Forecast Demand for Mar '07

Although customer lead time for API is 3 months and an order normally arrives 3 months before shipment, we observe that each month, some products experienced a large change in demand 1 to 3 months prior to shipment. This is because sometimes customers ask for a shorter lead time or increase their order quantities within the lead time. TCG has the right to reject these orders, but because the customers are sister plants, they will cater to them if the stock is available or if they have the capacity to produce in time.

The largest forecast error comes from the projection of Product B in the month of Feb '07 where no demand was projected till a demand of 146 kg showed up in Jan '07, 2 months prior to shipment. This resulted in the true demand to be 457% higher than the average forecast demand.

For each of the 3 delivery months of Jan '07, Feb '07 and Mar '07, we calculate $\Delta f_t(t)$, the forecast error for period i=0, which is the difference between the forecast one month before shipment and the actual demand for each of the products for each of the

3 delivery months (Jan '07, Feb '07 and Mar '07). We then calculate σ_0^2, the variance of the 12 forecast error values we got from all 4 products in the 3 delivery months studied. The variance of forecast error for the one-month ahead forecast is equal to σ_0^2.

We calculate the variance of forecast error for the 2-month ahead forecast by adding the variance of the forecast errors in the 2nd month before delivery σ_1^2, to the previous value of σ_0^2, as suggested in Equation 2-3. We continue calculating the variance of the n-month ahead forecast error for n = 1, 2, ... 11, based on the 12 observations for each period. We plot in Figure 2-14 the variances of these forecast error for all the periods. This is valid under the assumption that the forecast revisions are independent over time.

The projection trend of the graph shows that the variance of error decreases progressively as the time the forecast is made is closer to the shipment date. The forecast accuracy only improves significantly 5 months before shipment.

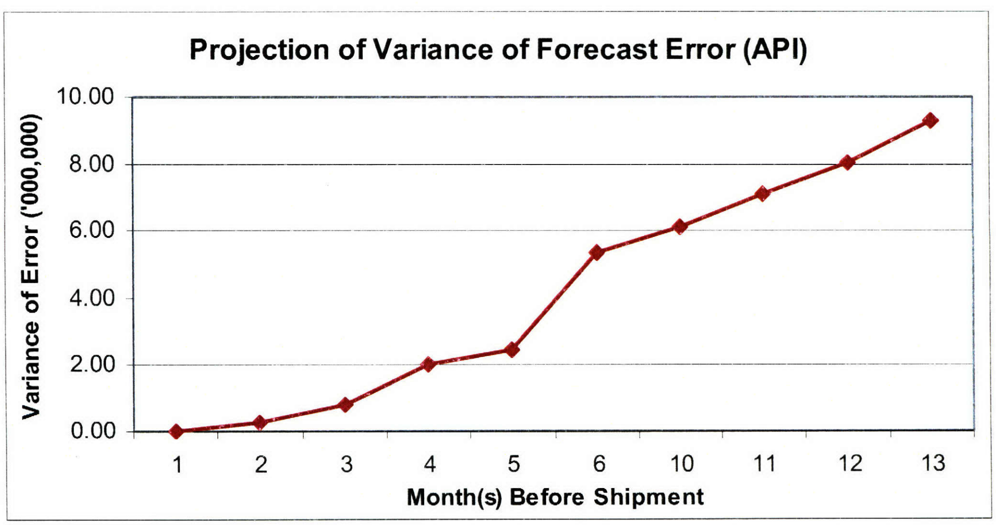


Figure 2-14: Projection of Variance of Forecast Error for API

2.6.2 PF1

The projected forecasts for the demands of all 12 types of Product C in the months of Feb '07, Mar '07 and Apr '07 are tabulated against the month when the forecasts are made. The graphs below show how the forecasts for each product change from more than a year ago to the delivery months of Feb '07, Mar '07 and Apr '07. The products Tablet W (P1) and Tablet Z (P1) are not included in the graphs because there is no demand for them in the 3 delivery months.

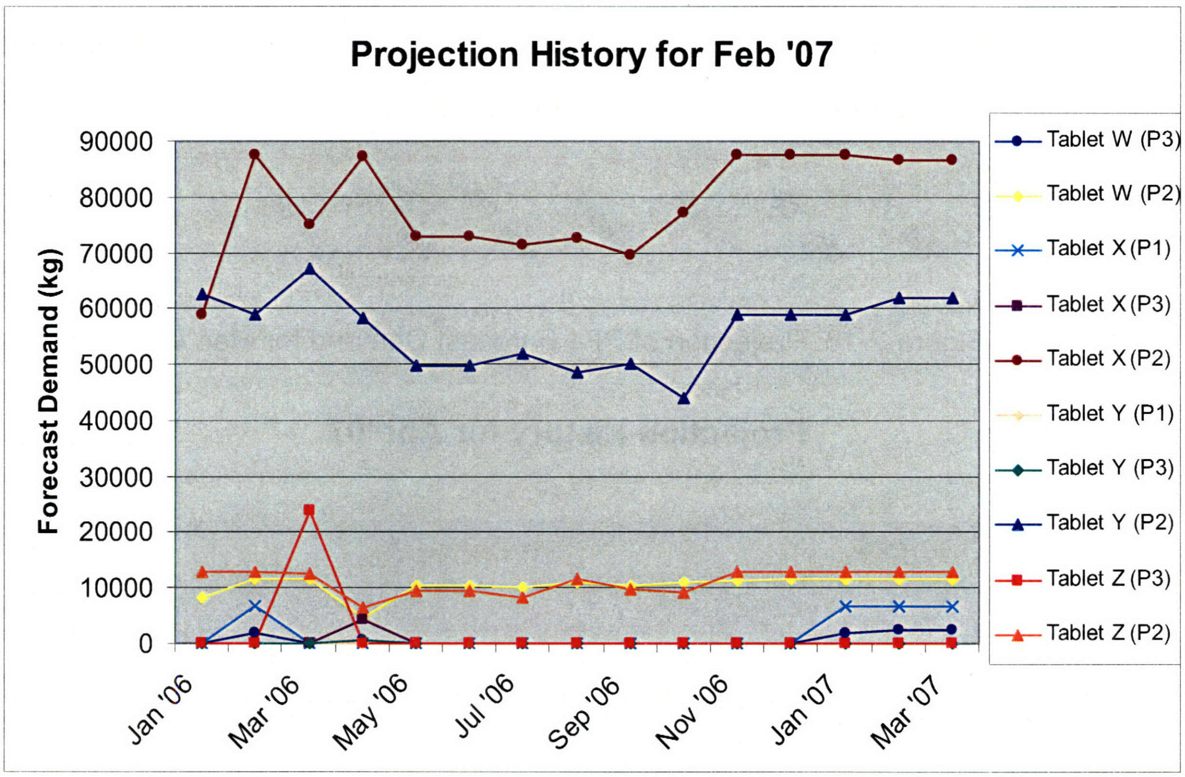


Figure 2-15: Projection of PF1 Forecast Demand for Feb '07

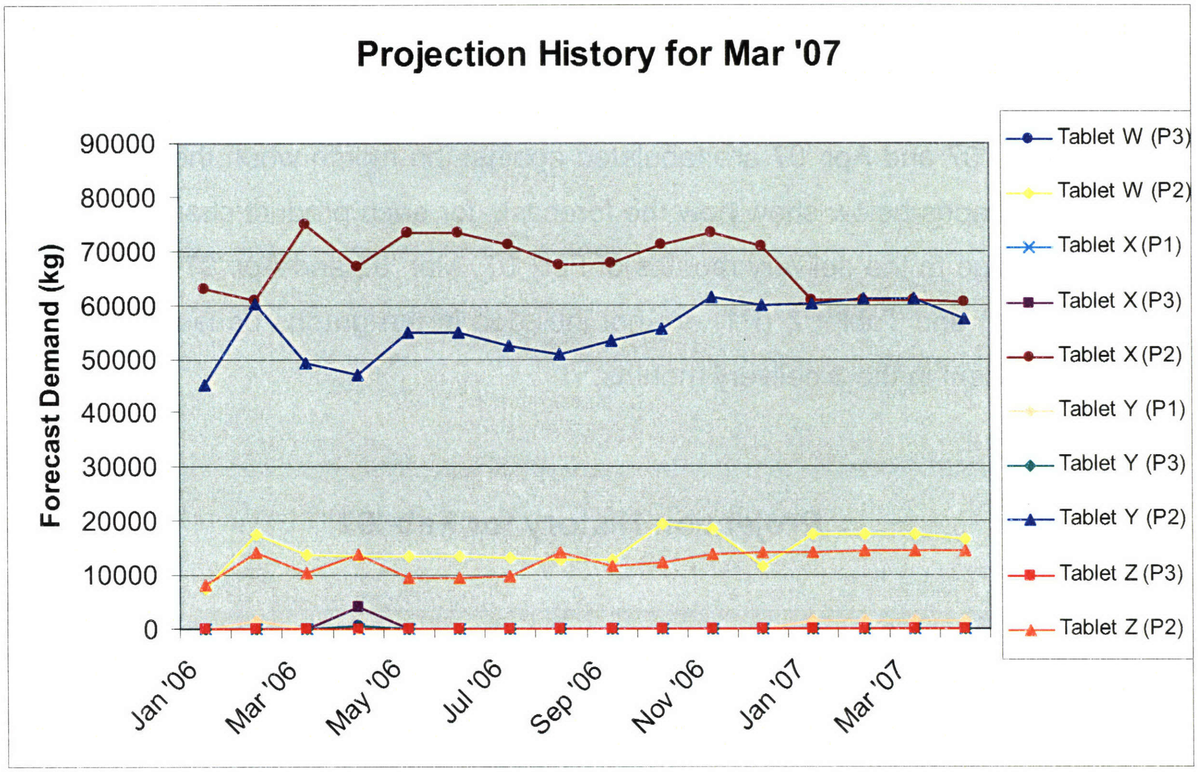


Figure 2-16: Projection of PF1 Forecast Demand for Mar '07

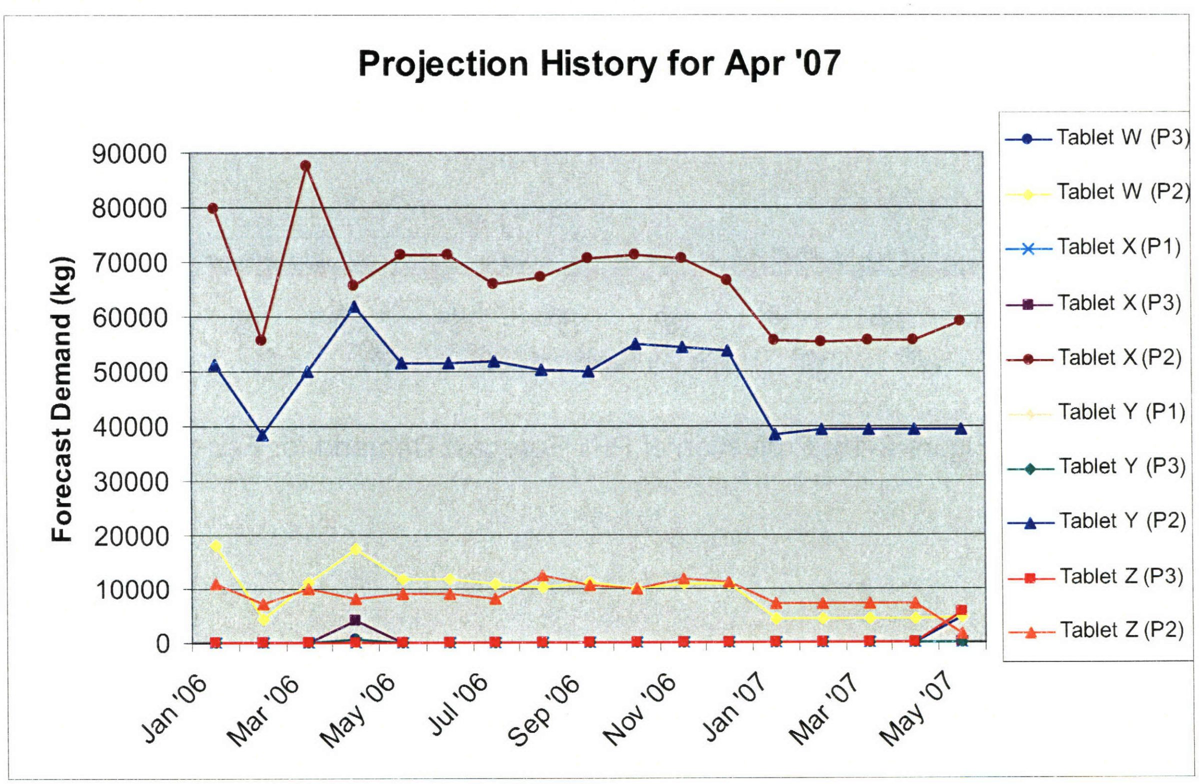


Figure 2-17: Projection of PF1 Forecast Demand for Apr '07

The graphs show that product Tablet X (P2) (brown line) has the highest projected forecast demands in all 3 shipment months, followed by product Tablet Y (P2) (blue line). Tablet W (P2) (yellow line) and Tablet Z (P2) (orange line) have almost similar projected demands but are lower than that of Tablet Y (P2). The rest of the products experienced the least projected demands.

The graphs also show rather flat trends which indicate that the forecast for Product C is quite accurate. While TCG keeps a certain level of safety stock for API, they adopt a produce-to-demand policy for Product C. In the case where a customer increases his order of Product C within the 3-month lead time, TCG may give the customer a portion of another customer's demand for the same product. This is provided that the quantity is not too large and the customer who has given up the portion of the finished product is compensated with a similar product of the same strength.

Customers also prefer to receive another Product C type of the same strength but with raw material from a different supplier rather than receive another Product C of different strength but with the same supplier's raw material. Therefore, an alternative way of characterizing the forecast error for the demand of Product C may be to aggregate the forecast demands for all products of equal strength. There are 4 groups of Product C of different strengths: Tablet W, Tablet X, Tablet Y and Tablet Z. The graphs in Figures 2-18 to 20 plot the forecast histories of the aggregated demands for Product C of the same strength, for the months of Feb '07, Mar '07 and Apr '07.

The graphs show that products belonging to Tablet X (maroon line) have the highest aggregated projected demands in all the 3 shipment months, followed by products belonging to Tablet Y (yellow line). Products belonging to Tablet W (blue line) and Tablet Z (orange line) have almost similar projected demands.

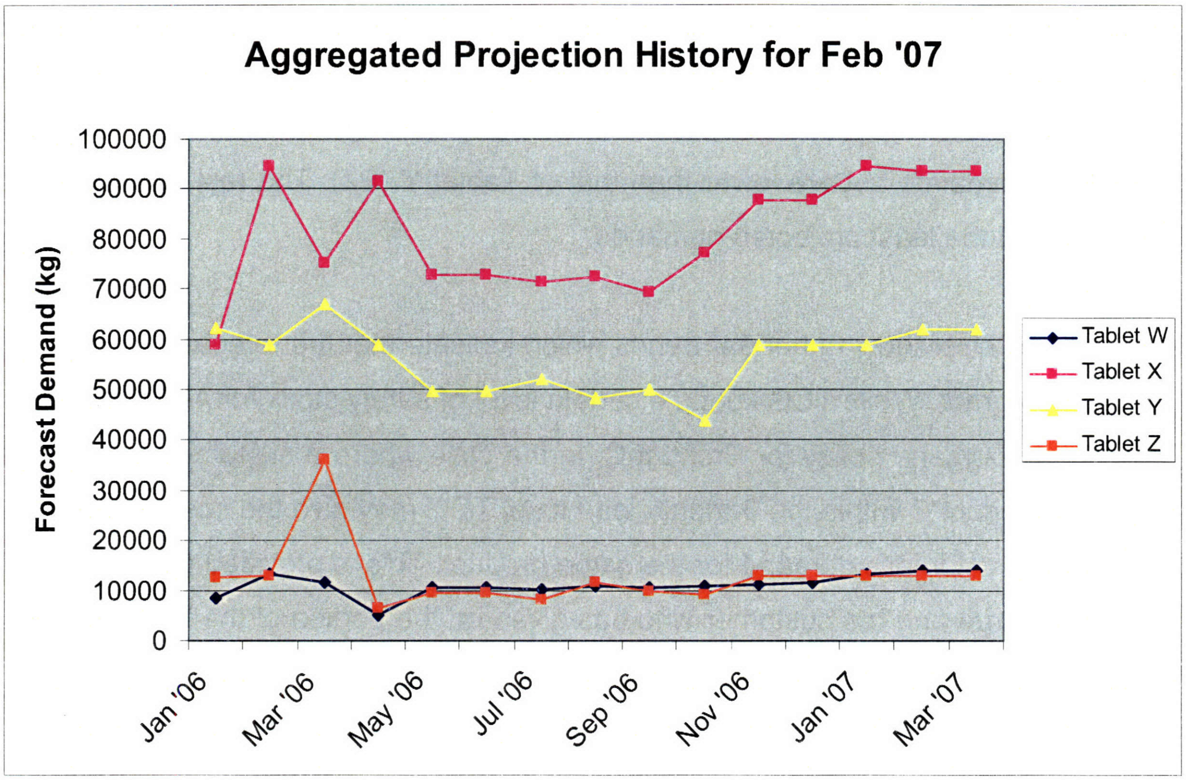


Figure 2-18: Projection of Aggregated PF1 Forecast Demand for Feb ‘07

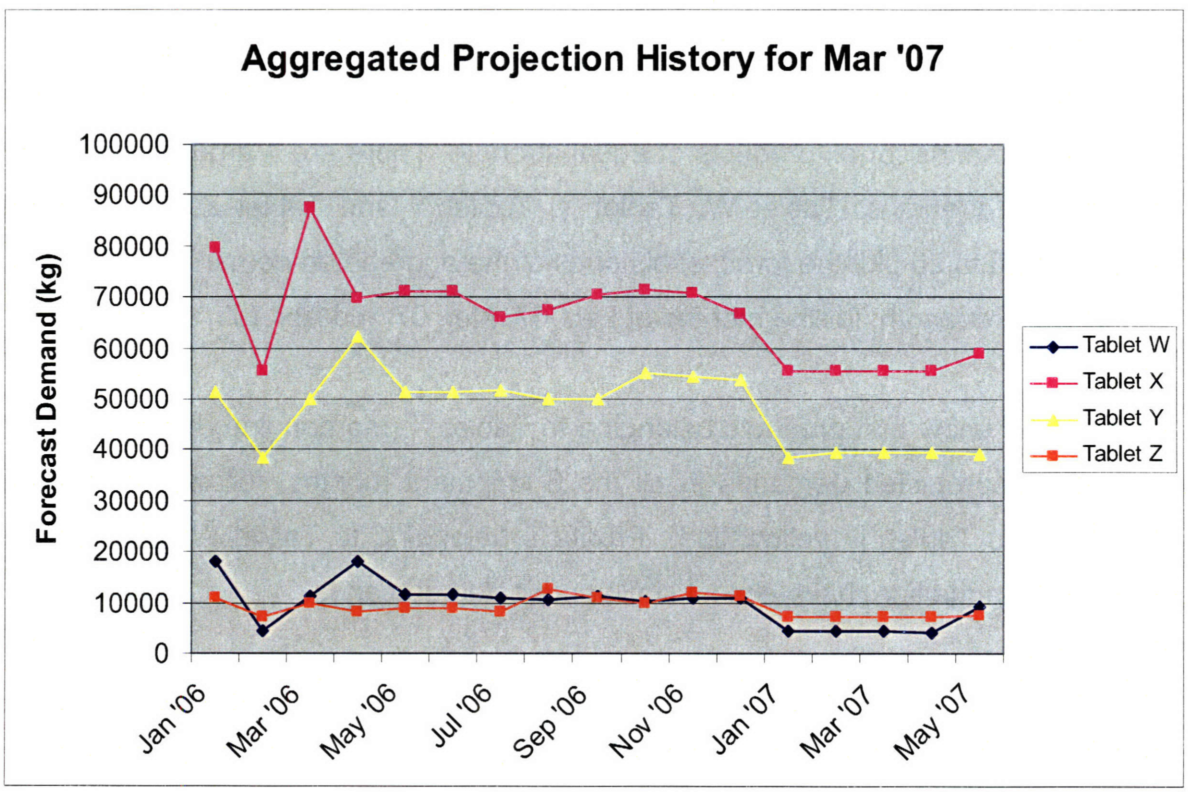


Figure 2-19: Projection of Aggregated PF1 Forecast Demand for Mar ‘07

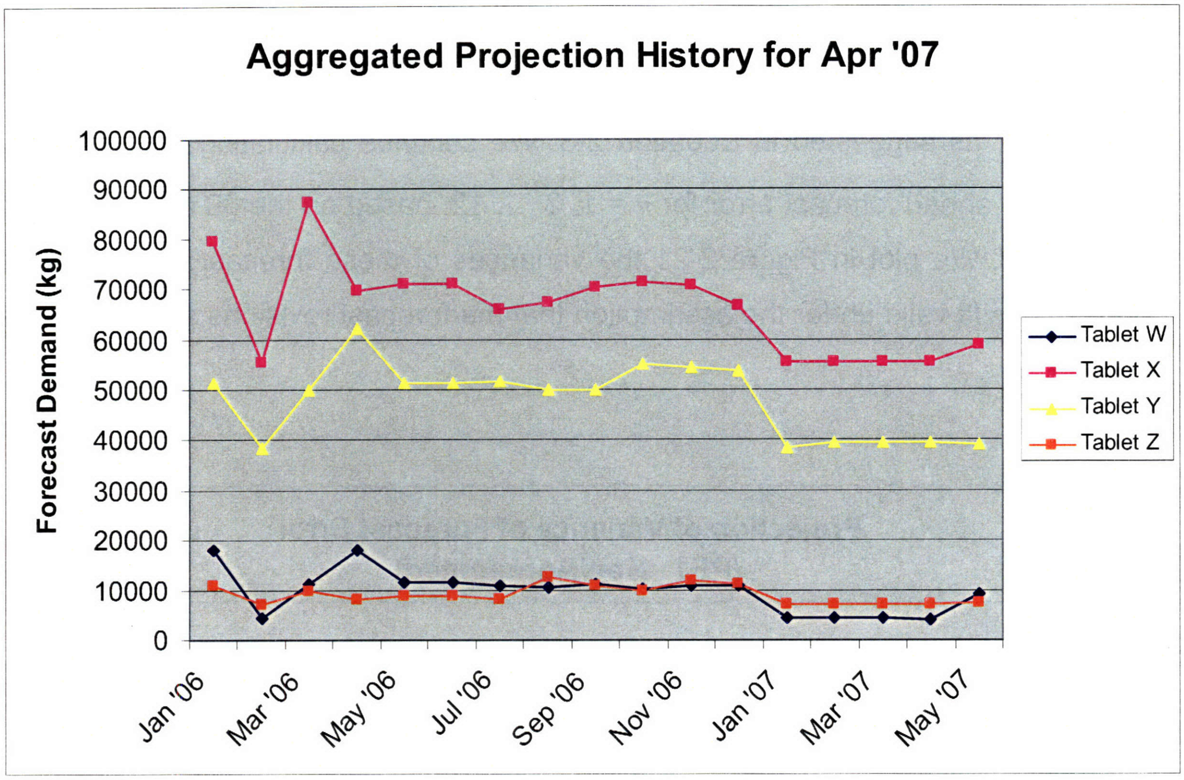


Figure 2-20: Projection of Aggregated PF1 Forecast Demand for Mar '07

We observe that the forecast accuracy does not seem to have improved from the previously non-aggregated case. Therefore, we need to compare the results from the calculated values of the forecast errors for both non-aggregated and aggregated demands to find out if there is really no improvement.

To find the forecast errors for the non-aggregated demands, we first calculate $\Delta f_t(t)$, the forecast error for period *i*=0, which is the difference between the forecast one month before shipment and the actual demand for each of the products for each of the 3 delivery months (Feb '07, Mar '07 and Apr '07). We then calculate σ_0^2, the variance of the 30 forecast error values that we obtained from the 10 products in the 3 delivery months studied. The variance of forecast error for the one-month ahead forecast is equal to σ_0^2.

We calculate the variance of forecast error for the 2-month ahead forecast by adding the variance of the forecast errors in the 2nd month before delivery σ_1^2, to the previous value of σ_0^2, as suggested in Equation 2-3. We continue calculating the variance of the n-month ahead forecast error for n = 1, 2, ... 12, based on the 30 observations for each period. We plot in Figure 2-21 the variances of these forecast error for all the periods. This is valid under the assumption that the forecast revisions are independent over time.

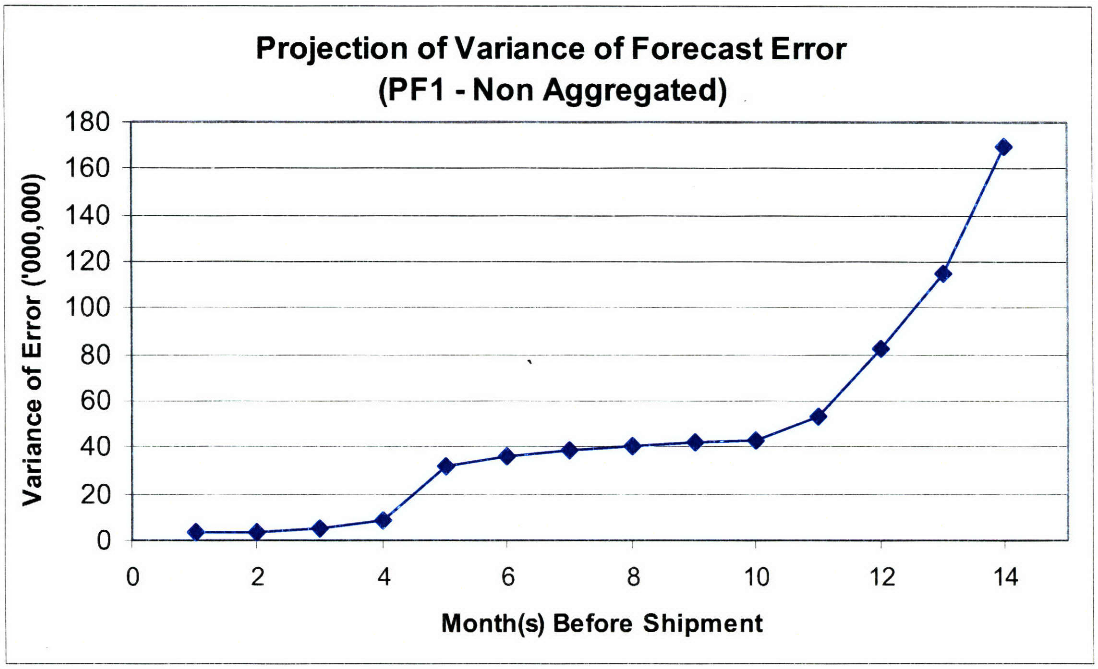


Figure 2-21: Projection of Variance of Forecast Error for PF1 (Non-Aggregated Forecast)

The projection of variance of the forecast error for the non-aggregated forecast demands in Figure 2-21 shows that variance changes very little 12 months before shipment and there is a significant drop in variance in the 5-month period before shipment.

Next, we find the forecast errors for the aggregated demands by first aggregating the monthly forecast data for the products classified as Tablet W, Tablet X, Tablet Y or

Tablet Z. We then use the 12 forecast error values that we obtained from the 4 aggregated products in the 3 delivery months studied to calculate the variance of each of the n-month ahead forecast error for n = 1, 2, ... 12. We plot in Figure 2-22 the variances of these forecast error for all the periods.

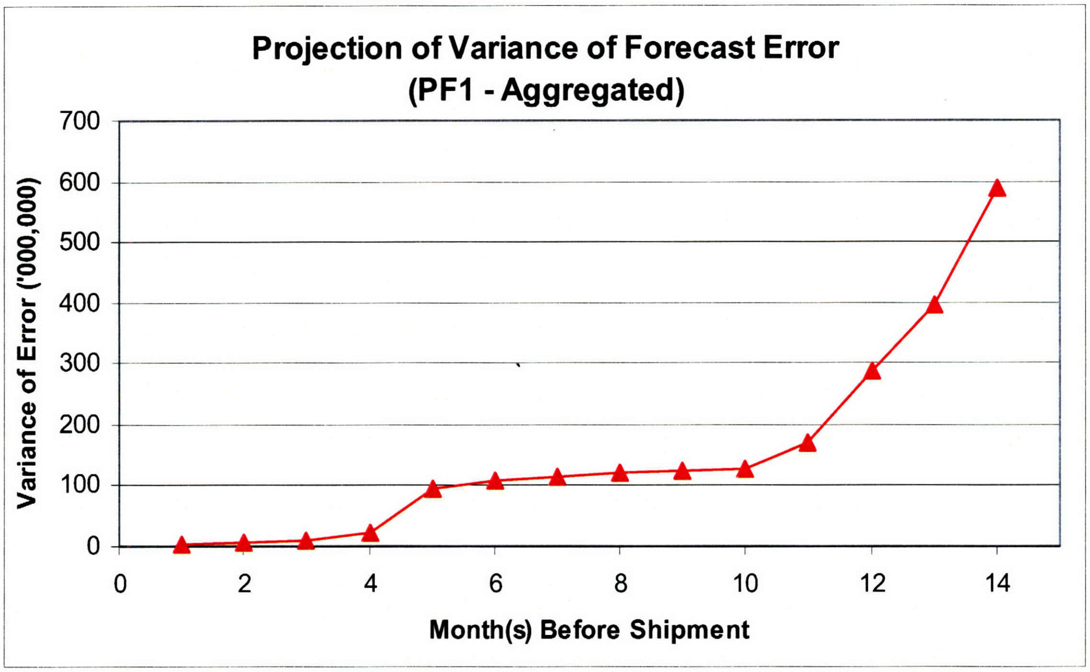


Figure 2-22: Projection of Variance of Forecast Error for PF1 (Aggregated Forecast)

The projection of variance of the forecast error for the aggregated forecast demands in Figure 2-22 shows that variance changes very little 12 months before shipment and there is a significant drop in variance in the 5-month period before shipment. This observation is similar to what we observed in Figure 2-21 for the non-aggregated forecast demands.

To make a fair comparison between the forecast errors for the non-aggregated forecast and aggregated forecast, we compare their coefficients of variation (CV) for each n-month ahead of forecast in Figure 2-23. The coefficient of variation is calculated as:

$$CV = \frac{SD_{\text{forecast error}}}{\bar{x}} = \frac{\sqrt{Var[f_t(t) - f_{t-i}(t)]}}{\bar{x}} = \frac{\sqrt{\sigma_0^2 + \sigma_1^2 + \ldots + \sigma_{i-1}^2}}{\bar{x}} \qquad \text{Equation 2-4}$$

where $\bar{x}$ is the average of the forecasts in the n^{th} month.

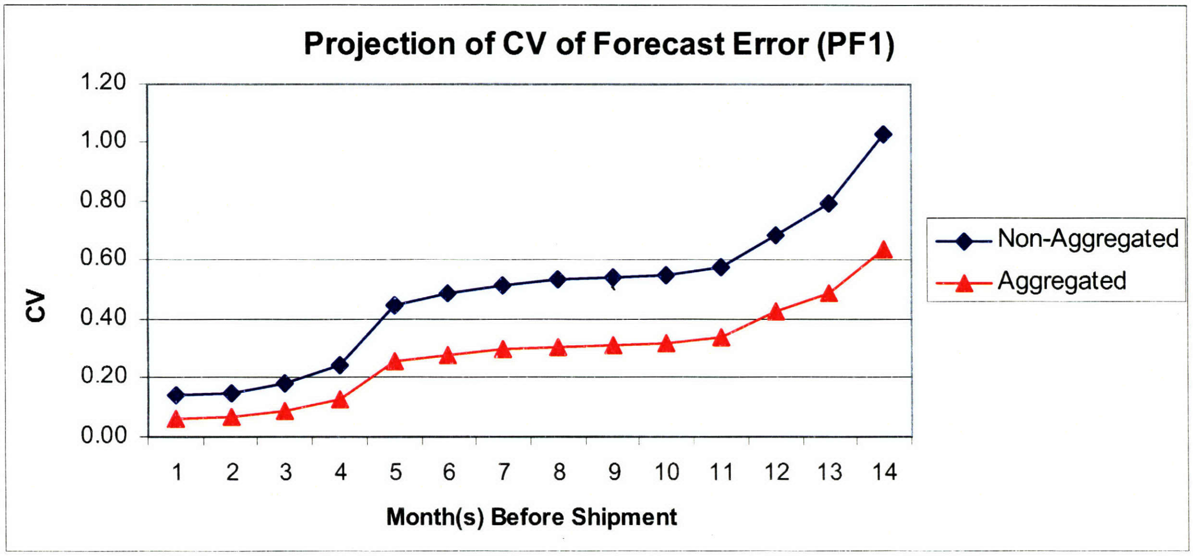


Figure 2-23: Comparison of the Projection of Variances of Forecast Error for PF1 (Non-Aggregated and Aggregated Forecasts)

The graph shows that for every period, the CV of the forecast error is lower when the forecasts are aggregated. Therefore, by aggregating the forecasts, we reduce the variance of the forecast error; this is a form of risk pooling. That is, on average there is some cancellation of the variability of the demand of individual products; if one product has a forecast that is too high, then there might be another product with a forecast that is too low, and hence the errors will cancel each other. We expect this to happen as long as the product demands are not positively correlated with each other. Therefore, we should get a more accurate result if we use the aggregated data for all analysis.

2.6.3 Comparison of Results Between API and PF1

To make a fair comparison between the forecast errors for APIs and PF1, we compare their coefficients of variation for each n-month ahead of forecast. We calculate the CV of the forecast error for APIs for each period using Equation 2-4 and plot the values alongside the same plots for the aggregated and non-aggregated forecast for PF1 in Figure 2-24.

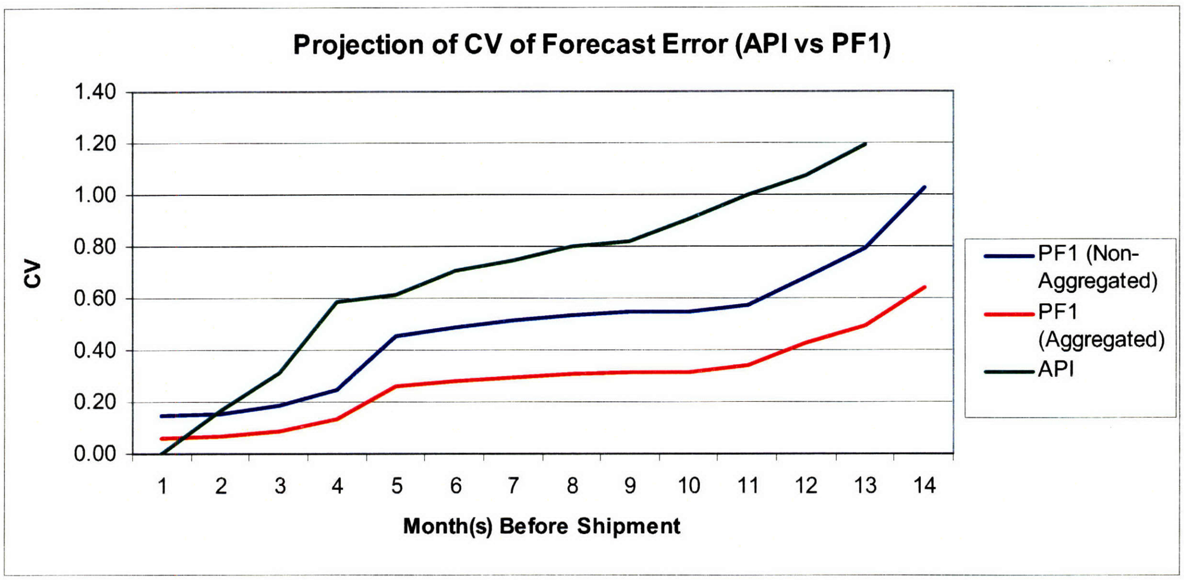


Figure 2-24: Comparison of Coefficients of Variance of Forecast Error Between APIs and PF1

Figure 2-24 shows that the forecast data for APIs from GCP is less accurate than the data for PF1 products from JV. All graphs show significant improvements in forecast errors in the 4 to 5-month period before shipment. This is probably because some purchase orders are received before the 3 months' lead time and they are updated into the demand forecast data. Therefore, it implies that demand forecast within the 5-month period is highly accurate.

Overall, all graphs show small changes in the CV from the 1-month to the 12-month period, with the CV values kept below one. This suggests that the forecast within the 12-month period is fairly accurate. Beyond the 12-month period, the CV increases sharply beyond the value of one, indicating the forecast error is quite large. Therefore, we should be comfortable in using the forecast data for the demand in the next 12 months for all our analysis

Chapter 3: Scientific Inventory Management for Raw Materials

3.1 Approach

We mentioned previously the 4 main challenges that TCG faces when using the Data3 MRP system. A blanket approach of using MRP on all raw materials may not be a good policy because different raw materials need different degrees of attention. In order to bring down the inventory level, we need to examine methods of changing their MRP system or the application of scientific inventory ordering method for each raw material.

We first study the characteristics of each raw material and classify them in terms of their importance. Important items are those that TCG should spend the most money and effort on keeping their inventory levels as low as possible. The less important items should therefore require less attention. We would then recommend the right inventory management approach for each raw material based on its importance.

There are a total of 38 raw materials, including packaging materials in the 2 active manufacturing facilities. 3 common materials, Raw Material 12, Raw Material 13 and Raw Material 30 are used in both API facility and PF1, but are ordered separately in the 2 facilities even though they can be shared. The breakdown of the materials is shown below:

	API Facility	**PF1**	**Common**
No. of Raw Materials Only	8	8	1
No. of Packaging Materials	10	9	2

Table 3-1: Breakdown of Raw Materials in the API Facility and PF1

3.2 ABC Analysis

3.2.1 Factors for Consideration

We decide that the following 2 factors determine the importance of a raw material:

1. The cost TCG spent on procuring this item in the past 2 years.
2. The average amount of pallet spaces the item takes up in the warehouse.

The items are classified into the following categories:

	Procurement Cost	Average Pallet Space Occupied
A	Medium to High	Medium to High
B	Medium	Medium
C	Low	Low

Table 3-2: ABC Classification of the Raw Materials

3.2.2 Procurement Cost

We calculate the total cost spent in terms of millions of Singapore dollars on procuring each of the 38 raw materials from May '05 to May '07 and plot the figures in Figure 3-1. Table 3-3 tabulates the results.

From the graph, we notice that most of the expenditures were spent on a small number of items, which is the trend mentioned by Pareto's 80-20 rule. These items are considered important because the large amount of money spent on procuring them justify the need for more attention to be paid on ordering them to reduce investment cost and wastages.

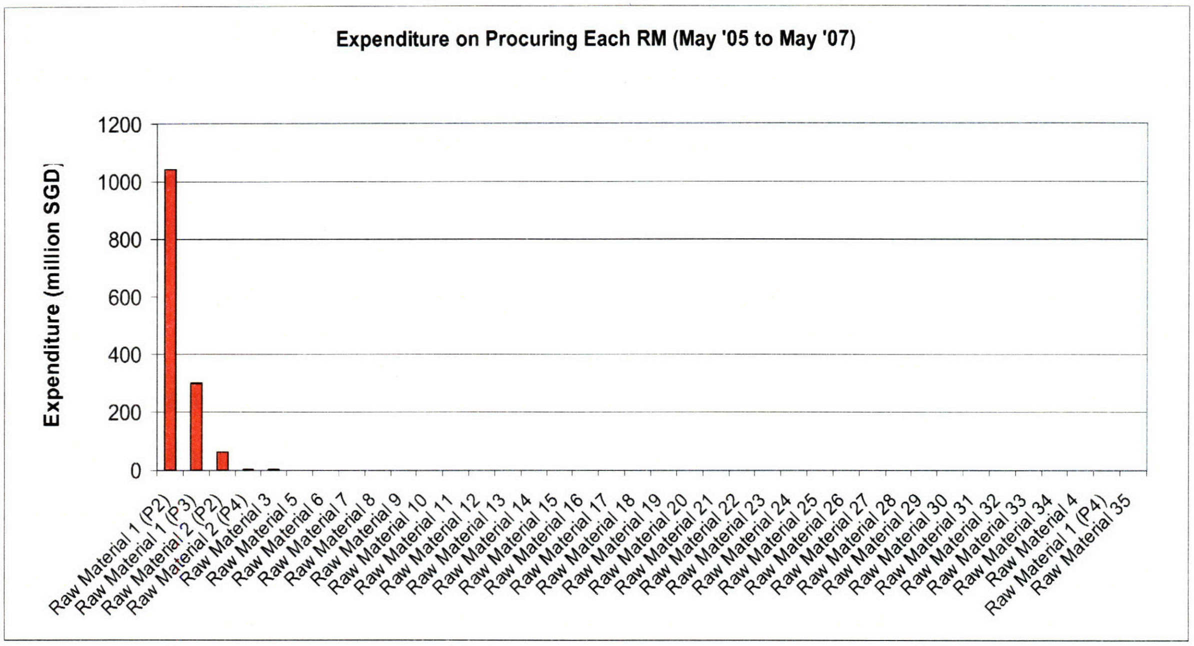


Figure 3-1: Tabulation of Expenditure on Procurement for each Raw Material

Items	% of total	Items	% of total
Raw Material 1 (P2)	73.55	Raw Material 19	0.00
Raw Material 1 (P3)	21.11	Raw Material 20	0.00
Raw Material 2 (P2)	4.45	Raw Material 21	0.00
Raw Material 2 (P4)	0.25	Raw Material 22	0.00
Raw Material 3	0.18	Raw Material 23	0.00
Raw Material 5	0.09	Raw Material 24	0.00
Raw Material 6	0.08	Raw Material 25	0.00
Raw Material 7	0.07	Raw Material 26	0.00
Raw Material 8	0.05	Raw Material 27	0.00
Raw Material 9	0.04	Raw Material 28	0.00
Raw Material 10	0.04	Raw Material 29	0.00
Raw Material 11	0.02	Raw Material 30	0.00
Raw Material 12	0.01	Raw Material 31 *	0.00
Raw Material 13	0.01	Raw Material 32 *	0.00
Raw Material 14	0.01	Raw Material 33 *	0.00
Raw Material 15	0.01	Raw Material 34 *	0.00
Raw Material 16	0.01	Raw Material 4	0.00
Raw Material 17	0.00	Raw Material 1 (P4) *	0.00
Raw Material 18	0.00	Raw Material 35 *	0.00
(Total expenditure = $1,414,407,354)		**TOTAL**	**100.00**

API PF1 Common

Table 3-3: Percentage of Total Expenditure Spent on Procuring each Raw Material

At the top of the table, we observe that although TCG receives no demand for products using Raw Material 1 (P3) since Dec '06, this active ingredient has incurred 21% of the total expenditure. At the bottom half of the table, the 6 items marked by an asterisk have no receipt record for the 2-year period because they were not ordered during that period since they had enough stocks to meet the production demand for at least 2 years.

The cost of procuring Raw Material 4 is zero because this raw material is owned by the partner company as part of their joint venture with TCG to make Product C. Although Raw Material 4 is shipped from the partner's nearby plant, TCG still keeps a significant amount of this raw material in its warehouse as we shall see later.

In the case of Raw Material 1 (P4), there was no demand for any finished product using this particular active ingredient for that period. Therefore, no amount of this raw material is ordered and the inventory level is zero.

3.2.3 Average Pallet Space

We collect the data for the total quantity of each raw material at the end of each month from Jan '06 to May '07. We then convert the quantities converted into pallet spaces and plot the average pallet spaces occupied by each of the items in that period in Figure 3-2. Table3-4 tabulates the results.

We observe that a few items occupy most of the pallet spaces taken up by raw materials and if the inventory level of these few items can be reduced, the overall effect will be great. Therefore, these are also considered to be important items.

The item that takes up the most warehouse space is Raw Material 3 because it has a very high content in the ingredients for making Product C.

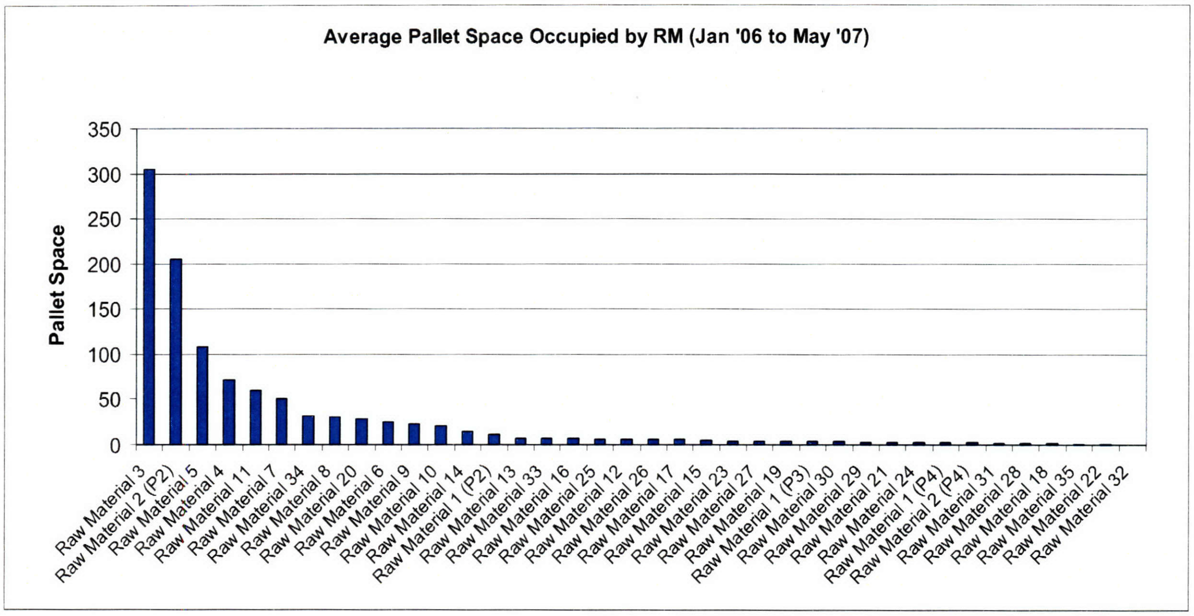


Figure 3-2: Tabulation of Expenditure on Procurement for each Raw Material

Items	% of total	Items	% of total
Raw Material 3	**28.23**	Raw Material 26	**0.56**
Raw Material 2 (P2)	**18.99**	Raw Material 17	**0.55**
Raw Material 5	**10.01**	Raw Material 15	**0.48**
Raw Material 4	**6.59**	Raw Material 23	**0.41**
Rawe Material 11	**5.53**	Raw Material 27	**0.41**
Raw Material 7	**4.65**	Raw Material 19	**0.40**
Raw Material 34	**2.88**	Raw Material 1 (P3)	**0.37**
Raw Material 8	**2.78**	Raw Material 30	**0.36**
Raw Material 20	**2.58**	Raw Material 29	**0.34**
Raw Material 6	**2.30**	Raw Material 21	**0.33**
Raw Material 9	**2.15**	Raw Material 24	**0.30**
Raw Material 10	**1.93**	Raw Material 1 (P4)	**0.27**
Raw Material 14	**1.34**	Raw Material 2 (P4)	**0.25**
Raw Material 1 (P2)	**1.10**	Raw Material 31	**0.22**
Raw Material 13	**0.64**	Raw Material 28	**0.21**
Raw Material 33	**0.64**	Raw Material 18	**0.15**
Raw Material 16	**0.64**	Raw Material 35	**0.13**
Raw Material 25	**0.57**	Raw Material 22	**0.13**
Raw Material 12	**0.57**	Raw Material 32	**0.00**
(Total average pallet spaces = 1076)		**TOTAL**	**100.00**

API PF1 Common

Table 3-4: Percentage of Total Average Space Held by each Raw Material

The bottom half of the table is occupied by mostly packaging materials which have small footprints. We also see little demand in Raw Material 1 (P4) and Raw Material 2 (P4) where the demand for products using these active ingredients had been small. On the other hand, although there had been no demand for products using Raw Material 1 (P3) since Dec '06 and TCG sees no foreseeable demand for it within the next 2 years, it occupied 0.37% of the total average occupancy of 1080 pallet spaces. Though this equates to only 4 pallet spaces, given the fact that TCG wants to drastically reduce warehouse size to only 1500 pallet spaces, such wastage of space should not be tolerated.

3.2.4 2-Factor Classification

Based on the 2 factors for determining the importance of each item, we formulate the following 2-factor classification method for the 38 items:

$$f(\text{importance}) = f(\%\ \text{procurement cost}) + f(\%\ \text{inventory level}) \qquad \text{Equation 3-1}$$

We add the percentage of the total procurement cost each item incurred to the percentage of total average inventory space it takes up. We then rank the items according to this sum. The purpose of using this 2-factor classification is to give items with high rankings in either procurement cost or inventory space (but not in both) average rankings that match closer to their importance. For example, Raw Material 4 is supplied by the partner company to TCG under their joint venture and the zero cost in procuring it may make it seem unimportant. However, looking at its 4^{th} rank in terms of inventory level, we cannot easily brush it off as a B or C-item. The results from this 2-factor classification are shown below:

Rank	Items	f (importance)	Previous Rankings: % Procurement Cost	Previous Rankings: % Inventory Level
1	Raw Material 1 (P2)	74.65	1	14
2	Raw Material 3	28.41	5	1
3	Raw Material 2 (P2)	23.44	3	2
4	Raw Material 1 (P3)	21.48	2	26
5	Raw Material 5	10.10	6	3
6	Raw Material 4	6.59	36	4
7	Raw Material 11	5.55	12	5
8	Raw Material 7	4.72	8	6
9	Raw Material 34	2.88	35	7
10	Raw Material 8	2.83	9	8
11	Raw Material 20	2.58	21	9
12	Raw Material 6	2.38	7	10
13	Raw Material 9	2.19	10	11
14	Raw Material 10	1.97	11	12
15	Raw Material 14	1.35	15	13
16	Raw Material 13	0.66	14	15
17	Raw Material 16	0.65	17	17
18	Raw Material 33	0.64	34	16
19	Raw Material 12	0.58	13	19
20	Raw Material 25	0.57	26	18
21	Raw Material 26	0.56	27	20
22	Raw Material 17	0.55	18	21
23	Raw Material 2 (P4)	0.50	4	32
24	Raw Material 15	0.49	16	22
25	Raw Material 23	0.41	24	23
26	Raw Material 27	0.41	28	24
27	Raw Material 19	0.40	20	25
28	Raw Material 30	0.36	31	27
29	Raw Material 29	0.34	30	28
30	Raw Material 21	0.33	22	29
31	Raw Material 24	0.30	25	30
32	Raw Material 1 (P4)	0.27	34	31
33	Raw Material 31	0.22	32	33
34	Raw Material 28	0.21	29	34
35	Raw Material 18	0.16	19	35
36	Raw Material 22	0.13	23	37
37	Raw Material 35	0.13	38	36
38	Raw Material 32	0.00	33	38

API PF1 Common

Table 3-5: Rankings Based on 2-Factor Classification Approach

We note that Raw Material 2 (P4) and Raw Material 1 (P4) are both given a lower than average rankings of 23 and 32 respectively. As mentioned previously, there is projected spike in demands for Product A (P4) and Intermediate Product B1 (P4) starting from Aug '07, and since Raw Material 1 (P4) and Raw Material 2 (P4) are their main ingredients, the low rankings of the 2 raw materials may have underestimated their potential values. Therefore, we will first leave out Raw Material 1 (P4) and Raw Material 2 (P4) from the classification and then consider them later.

Based on the rankings from the 2-factor classification for the other 36 items (excluding Raw Material 1 (P4) and Raw Material 2 (P4)), we define:

> **A-items**: The top 7 items, equivalent to 20% of the 36 items,
> **B-items**: The next 11 items, equivalent to 30% of the items, and
> **C-items**: The last 18 items, equivalent to 50% of the items.

And we give special attentions to the following items:

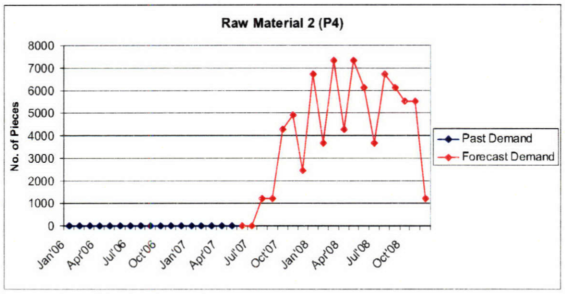
> **S-items**: Raw Material 1 (P4) and Raw Material 2 (P4)

3.2.5 Special Considerations for S-Items

		Inventory Level (pallet spaces)		
Ranking	**Items**	**Average**	**Max**	**SD**
23	Raw Material 2 (P4)	3	29	8
32	Raw Material 1 (P4)	3	25	8

Table 3-6: List of S-Items

These 2 items account for 0.25% of the total expenditure and occupy only 0.52% of the total average pallet space in the warehouse. We first observe their past and projected forecast demands that are derived from the demand data from GCP and the BOM for each finished product. We calculate the quantity of each item needed to produce the amount of finished products required every month and plot their demands for each month in Figure 3-3.



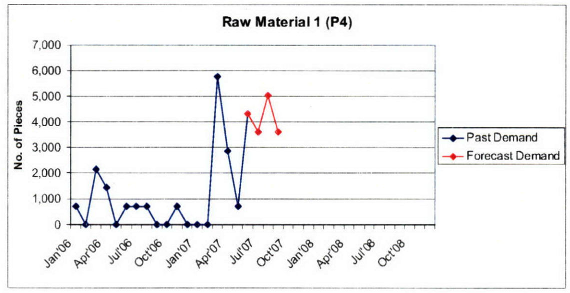


Figure 3-3: Demand Chart for Each S-Item

The graph on the right shows that there is no demand for Raw Material 2 (P4) until Aug '07. The graph on the left shows that the average monthly demand for Raw Material 1 (P4) increased from 513 kg before Mar '07 to 3694 kg between Mar '07 and Sep '07. The forecast data for Raw Material 1 (P4) is only up to Sep '07 and we do not know how the demand after Sep '07 will behave. Hence, we do a rough analysis of Raw Material 1 (P4) by assuming that its demand from Jun '07 to Jun '08 will have the same mean and standard deviation as the demand during Mar '07 and Sep '07.

We compare the means and standard deviations of the demands for these 2 items with the other raw materials of the same type for the period from Jun '07 to Jun '08 in Table 3-7:

	Mean of Demand	SD of Demand
Raw Material 1 (P2)	6692	2419
Raw Material 1 (P3)	870	1753
Raw Material 1 (P4)	3694	1629
Raw Material 2 (P2)	1868	2045
Raw Material 2 (P4)	4123	2464

Table 3-7: Comparisons of the Mean and Standard Deviations of Demands for Raw Material 1 and Raw Material 2

The results show that the average demand for Raw Material 1 (P4) is about half of the average demand for the top ranked item Raw Material 1 (P2), but higher than Raw Material 1 (P3), another A-item. On the other hand, the average demand for Raw Material 2 (P4) is twice the average demand for Raw Material 2 (P2), also an A-item. Since demands for both Raw Material 1 (P4) and Raw Material 2 (P4) are comparable to the high demands for the A-items, we recommend that they should also be treated as A-items.

3.3 Inventory Management

3.3.1 For A-items

		Inventory Level (pallet spaces)		
Ranking	**Items**	**Average**	**Max**	**SD**
1	Raw Material 1 (P2)	12	30	8
2	Raw Material 3	305	463	115
3	Raw Material 2 (P2)	205	350	128
4	Raw Material 1 (P3)	4	15	5
5	Raw Material 5	108	180	36
6	Raw Material 4	71	110	19
7	Raw Material 11	60	124	29
8	Raw Material 7	50	78	13
23	Raw Material 2 (P4)	3	29	8
32	Raw Material 1 (P4)	3	25	8

Table 3-8: List of A-Items

The above A-items account for 99.7% of the total expenditure and 71% of the total average pallet space in the warehouse. The high cost and high inventory level of this small group of item warrants the use of sophisticated and time-consuming methods to match their arrival to their demand in the production schedule. A just-in-time (JIT) approach will benefit these items by having deliveries in small quantities that match closely to the requirement of the production schedule. The inventory level will be kept to a very low level if the items are only allowed to sit in the warehouse for a short period of time.

In a JIT approach, supplies of the items will only arrive at the factory just before they are needed for production, and hence the name. TCG has never used the JIT approach in inventory management although they are adopting a lean manufacturing methodology for the whole plant. However, with the need to reduce warehouse space, they should consider the JIT approach. We recommend the following steps to this approach:

1. Provide suppliers with the visibility of demand,
2. Order small quantities at a high frequency,
3. Reduce the order lead time, and
4. Keep a small amount of safety stock to protect against variability over the lead time.

3.3.1.4 Provide Suppliers with the Visibility of Demand

TCG should share its production schedule with suppliers whenever it is updated. This will give the suppliers high visibility to the demand and any revision in the schedule will alert them to changes in the demand immediately, thereby giving them more time to react. The close relationship with the suppliers may even render purchase orders useless because purchase orders are based on the demand from the production schedule that both parties receive. A JIT contract that stipulates that orders are based on the demand from the production schedule should be enough to replace the purchasing orders.

3.3.1.5 Order Small Quantities at a High Frequency

For every order, TCG has to order a quantity that is a multiple of the order lot size. The order must also meet the minimum order quantity requirement if there is any. The minimum order quantities and lot size stipulated by the suppliers for the raw materials are shown in Table 3-9. The table also shows the average number of orders and the average amount ordered for each item in the past 2 years.

Items	Average order per year	Units	Average Amount Ordered	Minimum Order Quantity	Order Lot Size
Raw Material 1 (P2)	9	Kg	8072	718.3	718.3
Raw Material 3	12	Kg	31006	5000	600
Raw Material 2 (P2)	4	Kg	11561	0	50
Raw Material 1 (P3)	3.5	Kg	5959	0	35
Raw Material 5	9	Pieces	1552	480	480
Raw Material 4	9.5	Kg	1637	0	11
Raw Material 11	5	Pieces	597	272	272
Raw Material 2 (P4)	2	Kg	1286	0	50
Raw Material 1 (P4)	0	Kg	0	718.3	718.3

Table 3-9: Current Ordering Information on A-Items

In order to keep a low inventory of these items, TCG should order small quantities at high frequencies. Therefore, we recommend that for each item, TCG should try to order every week a quantity that can satisfy the demand for one week of production. However, for Raw Material 5 and Raw Material 11 which have minimum order quantities that exceed the demand for one week of production, TCG should order the minimum quantity and let the stock be depleted before receiving new stocks.

For example, Raw Material 3 has an average demand of 9234 kg per week and the minimum order quantity is 5000 kg. Therefore, TCG should order 9800 kg of it based on the order lot size requirement. This order may serve the production needs for one week and another amount will be ordered for the following week's requirement. On the other hand, Raw Material 11 has an average demand of 15.8 pieces per week and its minimum order quantity of 272 pieces can fulfill 17 weeks of production demand. Therefore, TCG should order the minimum order quantity of 272 pieces of Raw Material 11 and let the stock be depleted in about 17 weeks before receiving a new stock.

For the purpose of estimating the average cycle stock for each item to study the benefit from the JIT approach, we estimate the time between orders and then estimate the order quantity, Q based on the above argument. We note that the order quantity for each item has to be slightly higher than the demand and hence some surplus will be left when the demand is fulfilled. In certain weeks, the amount of surplus accumulated will be large enough to require a smaller amount of stock to be ordered. Therefore, the order quantity will be higher in some weeks and lower in other weeks. We adopt a conservative approach in our analysis and show the higher order quantity for each item in Table 3-10.

Items	Units	Demand per week	Estimated Order Period (weeks)	Estimated Q (per order)
Raw Material 1 (P2)	Kg	1673	1	2155
Raw Material 3	Kg	9234	1	9800
Raw Material 2 (P2)	Kg	467	1	500
Raw Material 1 (P3)	Kg	218	1	245
Raw Material 5	Pieces	347	1	480
Raw Material 4	Kg	453	1	462
Raw Material 11	Pieces	15.8	17	272
Raw Material 2 (P4)	Kg	1031	1	1050
Raw Material 1 (P4)	Kg	924 (estimated)	1	1437

Table 3-10: Current Demand Rate and Recommended Number of Weeks of Production each Order Should Serve

The average cycle stock will be calculated to be half of the expected order quantity. Using the parameters from Table 3-10, we can obtain an estimation of the average cycle stock by:

$$I_{\text{cycle}} = \frac{Q}{2}$$

Equation 3-2

This equation will overstate the cycle stock due to our conservative approach of using the higher ordering quantity. The actual cycle stock is therefore likely to be less than calculated.

3.3.1.6 Reduce Order Lead Time

Order lead time for each item is the time taken between ordering and receiving plus the cycle time taken for quality testing when the order arrives. All supplies are subject to quality testing and have to be deemed good enough before they can be released to the manufacturing facilities. Testing takes 7 to 14 days depending on the item being tested and also the manpower capacity of the quality control department. At certain times, the quality control department has an increased work load due to quality deviation issues in raw materials, intermediate products or finished products and therefore will take a longer time to conduct the tests. Table 3-11 below shows the average order lead times obtained from the Data3 MRP system for the items.

Items	Lead time (days) - inclusive of inspection	Inspection Cycle Time (days)
Raw Material 1 (P2)	84	7
Raw Material 3	90	7
Raw Material 2 (P2)	84	7
Raw Material 1 (P3)	42	7
Raw Material 5	75	15
Raw Material 4	21	7
Raw Material 11	84	7
Raw Material 2 (P4)	84	7
Raw Material 1 (P4)	42	7

Table 3-11: Current Order Lead Times and Inspection Cycle Times for A-Items

The variability in testing cycle time can lead to uncertainty in the lead time from ordering to receiving by the manufacturing facilities. Therefore, we recommend that TCG do without the quality testing when the orders arrive because the supplies should have already passed the quality tests at the supplier's end before being shipped out. This is allowed in the pharmaceutical industry as long as the intermediate products and finished products pass the quality tests and are deemed safe to be consumed. By doing so, the manufacturing facilities will be able to receive the supplies and use them immediately when they arrive at the warehouse.

However, the success of implementing this approach depends very much on the reliability of the suppliers. They have to deliver the right amount of the items on time and the items must meet the stringent quality required in the pharmaceutical industry under the Good Manufacturing Practices. This is because by not testing the quality of the supplies, TCG will be taking the risk of using raw materials of poor quality for production, thereby destroying the whole batches of products and delaying delivery of finished products. Therefore, there is a need to adopt a vendor certification program (VCP) to ensure the suppliers are up-to-standard.

VCP involves the periodic audit of the supplier procedures and efforts to help vendors improve their systems. Before our engagement in this project, TCG has been keen on exploring the possibility of adopting VCP so that raw materials do not need to go through a quality testing process that may take up to 2 weeks in cycle time. TCG has been hit by a shortage of manpower in the industry and hence forgoing inspections for some items will free up some work for the quality control department. Cycle time for the inspection of other items, including finished products can be subsequently reduced.

3.3.1.7 Keep a Small Amount of Safety Stock

TCG does not feel comfortable with the fact that the JIT approach does not allow any safety stock of the A-items to be kept in the warehouse. This is because during the initial stage when TCG and the suppliers are building a closer relationship between themselves, some suppliers may still be delaying shipments or the quality of the supplies may not be up to mark. Therefore, we recommend that they keep enough safety stock to protect against variability over the supplier lead time. This supplier lead time is the time taken for the stock to arrive from the supplier after the purchasing order is issued and does not include any quality test cycle time since we have recommended to do without it to reduce the overall lead time.

We do not have the data to calculate the supplier lead time variability for each item, but we are told that most of the raw materials like Raw Material 1 (P2) and Raw

Material 3 are shipped by sea and it is typical for the order to arrive 2 weeks beyond the lead time. Therefore, we assume that a delivery lead time can vary by 20% of its time. This is a fair assumption since the supplier lead times for Raw Material 1 (P2) and Raw Material 3 are 77 days and 83 days respectively, and a 20% variation means they can arrive late by 15 days and 17 days respectively, which are more than 2 weeks.

To find the amount of safety stock they should keep for each item, we calculate the demand rate per day by dividing the average monthly forecasted demands from Jun '07 to Jun '08 by 30 days. We assume the demand is random and stationary over time. We then multiply the demand rate by 20% of the supplier lead time to obtain the safety stock level for each item. The recommended safety stock level is compared with the current safety stock level kept by the MRP system in Table 3-12.

Items	Supplier Lead time (days)	Demand per day	Units	Current Safety Stock	Recommended Safety Stock
Raw Material 1 (P2)	77	223	Kg	0	3435
Raw Material 3	83	1231	Kg	94000	20438
Raw Material 2 (P2)	77	62	Kg	0	959
Raw Material 1 (P3)	35	29	Kg	0	203
Raw Material 5	60	46	Pieces	3400	555
Raw Material 4	14	60	Kg	2100	169
Raw Material 11	77	2	Pieces	903	32
Raw Material 2 (P4)	27	137	Kg	0	742
Raw Material 1 (P4)	35	123 (estimated)	Kg	0	862

Table 3-12: Current and Recommended Safety Stock for Each A-Item

We notice that with the exception of the Raw Material 1 and Raw Material 2 (all with no safety stocks), our recommended safety stock levels are lower than the current safety stock levels. We are unclear how TCG derives the safety stock levels.

3.3.1.8 Feasibility of Approach

We recommend TCG to shorten the lead time by not testing the raw materials when they arrive. However, even without the quality testing, the lead times are still 14 days to 83 days long. This makes our recommendation of a weekly order of raw materials inappropriate because demands may increase during the long lead time. Since a large portion of these lead times are the time needed for the suppliers to prepare the orders and only a small portion is the time spent on transporting the materials, we assume that once demands are visible to the suppliers, they will require a shorter lead time of less than 2 weeks.

On the other hand, the JIT approach can only be implemented with the support of suppliers. Our recommendation of ordering most of the raw materials once per week as compared to the current average frequency of about once in 2 months may not be welcomed by the suppliers who will have to ship orders more frequently than usual. Furthermore, suppliers may not want to participate in the VCP and put themselves up for audit by TCG.

However, the suppliers should understand that the approach will give them visibility of demands and therefore they should not need to stock up on inventories to buffer against the variability of demand. Moreover, JIT contracts are normally long term and the suppliers can be guaranteed orders in the future.

The suppliers of Raw Material 1 and Raw Material 2 are TCG's sister plants, and therefore it should be easy to convince these group of suppliers to support the JIT approach with TCG for the benefit of both parties. Furthermore, we note that Raw Material 4 is received from the partner company facility a stone's throw away from TCG and since communication between the 2 companies has already been established with the help of JV, implementing JIT on this item should be the easiest among the 9 items.

3.3.2 For B-items

		Inventory Level (pallet spaces)		
Ranking	**Items**	**Average**	**Max**	**SD**
8	Raw Material 7	50	78	13
9	Raw Material 34	31	33	2
10	Raw Material 8	30	50	10
11	Raw Material 20	28	96	26
12	Raw Material 6	25	40	10
13	Raw Material 9	23	38	6
14	Raw Material 10	21	35	8
15	Raw Material 14	14	21	5
16	Raw Material 13	7	10	2
17	Raw Material 16	7	11	2
18	Raw Material 33	7	20	7

Table 3-13: List of B-Items

The above B-items account for 0.31% of the total expenditure and 22.5% of the total average pallet space in the warehouse. In contrast to A-items, B-items are either less expensive or have lower inventory levels. Therefore, it will not be economical to give them the same sort of attention as given to A-items. However, because B-items occupy a rather significant proportion of the warehouse space, a continuous review inventory policy is appropriate to ensure the inventory is kept within a certain limit but with no stock out.

In a continuous review model, the inventory level is reviewed every day and an order is placed for an item when the total inventory on hand and on order reaches a reorder point, R. For every reorder, we order an amount equal to the order quantity Q. The basic assumptions for the continuous review policy are:

1. The demand is random and is stationary over time; that is, there is no trend or cyclicality and we will also assume for convenience that demand follows a normal distribution,
2. Because TCG cannot determine a fixed order cost, we give a constraint to the number of replenishment orders per year,

3. Order lead times are known; for convenience, we assume they are fixed, and
4. Unfilled demand is backordered.

The expected inventory level for the continuous review model is:

$$I_{continuous} = \frac{Q}{2} + z\sigma\sqrt{L} = \text{cycle stock} + \text{safety stock} \qquad \text{Equation 3-3}$$

and the reorder point is:

$$R = L\mu + z\sigma\sqrt{L} \qquad \text{Equation 3-4}$$

where Q = replenishment quantity (in units)

z = safety factor associated with service level

L = replenishment lead time from supplier to production (in months)

μ = average demand (per month)

σ = standard deviation of the demand (in units)

3.3.2.1 Assumption #1: The demand is random and normally distributed

We begin by testing the first assumption that demand follows a normal distribution. The past and future forecast demands are collected for each of the 11 items from the demand data from GCP and JV, and the BOM for each finished product. We calculate the quantity of each item needed to produce the amount of finished products required in every month and plot the following graphs.

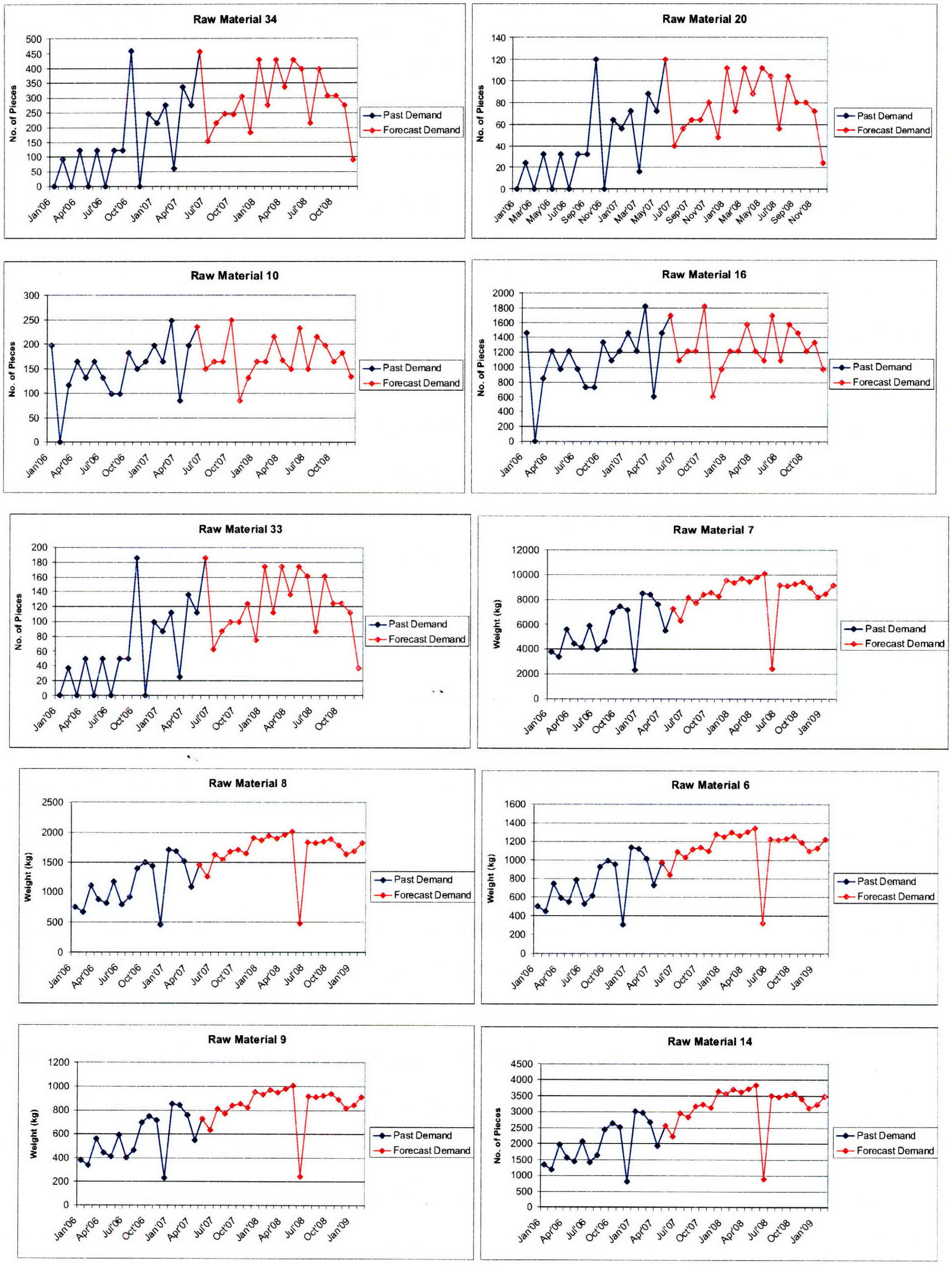


Figure 3-4: Demand Chart for Each B-Item (continue next page)

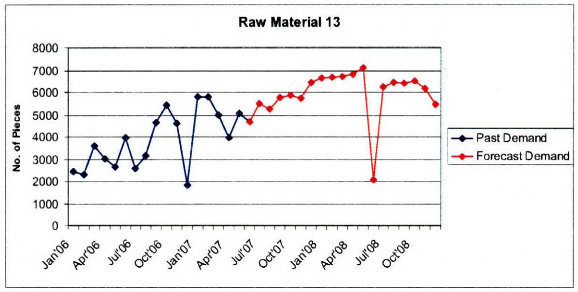


Figure 3-4: Demand Chart for Each B-Item

We observe that the forecast demand graphs follow 2 trends. The first trend is seen in Raw Material 34, Raw Material 20, Raw Material 10, Raw Material 16 and Raw Material 33 from the API facility. The other trend is found in Raw Material 7, Raw Material 8, Raw Material 6, Raw Material 9, Raw Material 14 and Raw Material 13 mostly belonging to PF1.

When we look at the whole period from Jan '06 to Dec '08 for both sets of graphs, we observe the demand to be rising gradually. However, the forecast demand from June '07 to Dec '08 is random and well behaved. For the purpose of setting the safety factor to achieve a certain service level, we assume that the demand for each item follows a normal distribution.

3.3.2.2 Assumption #2: There is a constraint to the number of replenishment orders per year

For every order, TCG has to order a quantity that is a multiple of the order lot size. The order must also meet the minimum order quantity requirement if there is any. The minimum order quantities and lot size stipulated by the suppliers for the raw materials are shown in the table below. The table also shows the average number of orders and the average amount ordered for each item in the past 2 years.

Items	Average order per year	Units	Average Amount Ordered	Minimum Order Quantity	Order Lot Size
Raw Material 7	8.5	Kg	9732	8000	500
Raw Material 34	0	Kg	0	2937.6	12.24
Raw Material 8	4.5	Kg	3000	2000	50
Raw Material 20	2	Pieces	205	100	100
Raw Material 6	6.5	Kg	1371	0	1000
Raw Material 9	8	Kg	1154	680	34
Raw Material 10	5.5	Pieces	300	300	300
Raw Material 14	7	Pieces	4032	0	50
Raw Material 13	7.5	Pieces	7391	1000	100
Raw Material 16	4.5	Kg	2720	544	2722
Raw Material 33	0	Kg	0	0	0

Table 3-14: Current Ordering Information on B-Items

To find Q, we can use the economic order quantity model to find Q^*, the optimal ordering quantity that will result in the minimum total (inventory holding and ordering) cost per year. However the model is based on a fixed order cost. TCG does not record a fixed order cost for each order of any raw material. They also do not pay fixed transportation cost for the order as the unit cost of each raw material is already inclusive of the transportation cost. Therefore, instead of using the economic order quantity model, we add a constraint on the number of replenishment orders per year to compute the order quantity, Q by the formula:

$$Q = \frac{D}{F} \qquad \text{Equation 3-5}$$

where D = expected demand per year and

F = order frequency per year.

We obtain the D value for each raw material from the forecasted demands from Jun '07 to Jun '08. Here, we assume the demand rate to be fixed and deterministic. Therefore, we need to set a value for F to calculate Q. Figure 3-5 shows that as we increase the order frequency, the inventory level decreases to almost zero. It is therefore not possible to find the optimal order frequency.

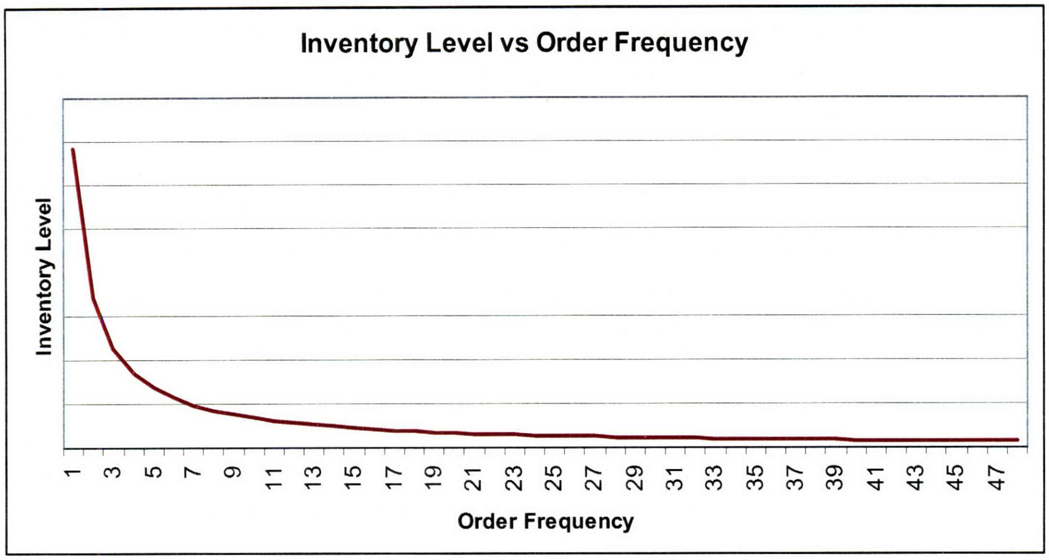


Figure 3-5: Graphs Depicting How Inventory Level Changes with Order Frequency

However, since the cycle stock is equals to half of Q, we propose a solution that requires more frequent orders of small quantities in order to reduce the inventory while keeping the same level of safety stock. We try to choose the F value for each item so that the calculated Q is equal to or slightly less than the minimum order quantity. If Q is less than the minimum order quantity, we will let the minimum order quantity be Q and keep a small amount of surplus. We also limit the order frequency to be less than 12 times a year. The results are shown below.

Items	Units	D (per year)	SD of demand (per year)	F (per year)	Q (per order)
Raw Material 7	Kg	102324	19716	12	9000
Raw Material 34	Kg	3589	1250	1	3598.56
Raw Material 8	Kg	20441	3936	11	2000
Raw Material 20	Pieces	939	327	10	100
Raw Material 6	Kg	13627	2624	7	2000
Raw Material 9	Kg	10221	1968	12	884
Raw Material 10	Pieces	2096	495	7	300
Raw Material 14	Pieces	38685	7788	7	5550
Raw Material 13	Pieces	71012	13387	12	6000
Raw Material 16	Kg	15347	3616	12	3266.00
Raw Material 33	Kg	1456	507	6	242.66

Table 3-15: Current Demand Rate and Recommended F and Q Values for B-Items

3.3.2.3 Assumption #3: Order lead times are fixed and known

Order lead time for each item is the time taken between ordering and receiving plus the cycle time taken for quality testing when the order arrives. The consideration of the cycle time for quality testing is practical because items will only be released for production if they pass the inspection which may take up to 2 weeks. Table 3-16 shows the order lead times obtained from the Data3 MRP system for the items. We assume these lead times to be deterministic and fixed.

Items	Lead time (days) - inclusive of inspection	Inspection Cycle Time (days)
Raw Material 7	60	7
Raw Material 34	49	7
Raw Material 8	42	7
Raw Material 20	21	7
Raw Material 6	21	7
Raw Material 9	21	7
Raw Material 10	84	7
Raw Material 14	21	7
Raw Material 13	60	7
Raw Material 16	98	7
Raw Material 33	16	14

Table 3-16: Current Order Lead Times and Inspection Cycle Times for B-Items

3.3.2.4 Assumption #4: Unfilled demand is backordered

We assume there is no lost sale if TCG is unable to fulfill an order on time. However, TCG has the obligation to maintain a high customer service level by making sure that production does not stop and patients will not be starved of the drugs they need. Therefore, the MRP system is told to keep a certain level of safety stock for each item as shown in the table below. In the table, we also list the average inventory of each item that we obtain from its monthly inventory levels from Jan '06 to May '07.

Items	Units	Average Inventory	Safety Stock	$\frac{\text{safety stock}}{\text{avg. inventory}} \times 100\%$
Raw Material 7	Kg	24860	21000	84
Raw Material 34	Kg	4494	498	11
Raw Material 8	Kg	5901	4200	71
Raw Material 20	Pieces	220	131	60
Raw Material 6	Kg	3653	2800	77
Raw Material 9	Kg	3109	2100	68
Raw Material 10	Pieces	809	390	48
Raw Material 14	Pieces	5553	3400	61
Raw Material 13	Pieces	15879	17000	-
Raw Material 16	Kg	3878	2288	59
Raw Material 33	Kg	214	0	0

Table 3-17: Calculated Safety Stock Percentages for B-Items

We notice that with the exception of Raw Material 13 (the average inventory is lower than safety stock) and Raw Material 33 (no safety stock), the inventory level of most items consists of a high proportion of safety stock. However, we are not sure how TCG derives the safety stock levels.

In our continuous review model, we propose a z value of 3, which gives a 0.999 probability of stock out on each order occasion, under the assumption that the lead-time demand is normally distributed. We calculate that during the 2-year period from May '05 to May '07, there were a total of 296 deliveries of raw materials. Therefore, a z value of 3 will equate to 0.3 stock out, which is equivalent to almost zero stock out per year. This service level should be high enough to satisfy its customers.

3.3.3 For C-items

		Inventory Level (pallet spaces)		
Ranking	**Items**	**Average**	**Max**	**SD**
19	Raw Material 12	6	8	2
20	Raw Material 25	6	8	2
21	Raw Material 26	6	7	0
22	Raw Material 17	6	10	2
24	Raw Material 15	5	8	2
25	Raw Material 23	4	8	2
26	Raw Material 27	4	8	2
27	Raw Material 19	4	7	2
28	Raw Material 30	4	5	0
29	Raw Material 29	4	6	1
30	Raw Material 21	4	6	2
31	Raw Material 24	2	3	1
33	Raw Material 31	2	3	0
34	Raw Material 28	2	4	1
35	Raw Material 18	2	3	1
36	Raw Material 22	1	3	1
37	Raw Material 35	1	2	1
38	Raw Material 32	0	0	0

Table 3-18: List of C-Items

The above 18 C-items account for 0.04% of the total expenditure and occupy only 6.12% of the total average pallet space in the warehouse. Therefore, TCG should not put too much attention on these items, but concentrate on the more important A and B-items. Hence, we recommend a periodic review inventory model that reviews the inventory level less frequently than with a continuous model.

In a periodic review model, the inventory level of an item is reviewed at a periodic basis where an amount equal to the demand since the last replenishment epoch will be ordered. The basic assumptions for the periodic review policy are:

1. The demand is random and is stationary over time; that is, there is no trend or cyclicality and we will also assume for convenience that demand follows a normal distribution,
2. A replenishment order will be placed on a regular cycle and we denote r as the review period,

3. Replenishment lead times are known; for convenience, we assume they are fixed, and
4. Unfilled demand is backordered.

The expected inventory level for the period review model is:

$$I_{periodic} = \frac{r\mu}{2} + z\sigma\sqrt{r+L} = \text{cycle stock} + \text{safety stock} \qquad \text{Equation 3-6}$$

where r = length of the review period (in months)

μ = average demand (per month)

σ = standard deviation of the demand (in units)

z = safety factor associated with service level

L = replenishment lead time from supplier to production (in months)

3.3.3.1 Assumption #1: The demand is random and normally distributed

The past and future forecast demands are derived for each of the 18 items from the demand data from GCP and JV, and the BOM for each finished product. We calculate the quantity of each item needed to produce the amount of finished products required in every month and plot the following graphs.

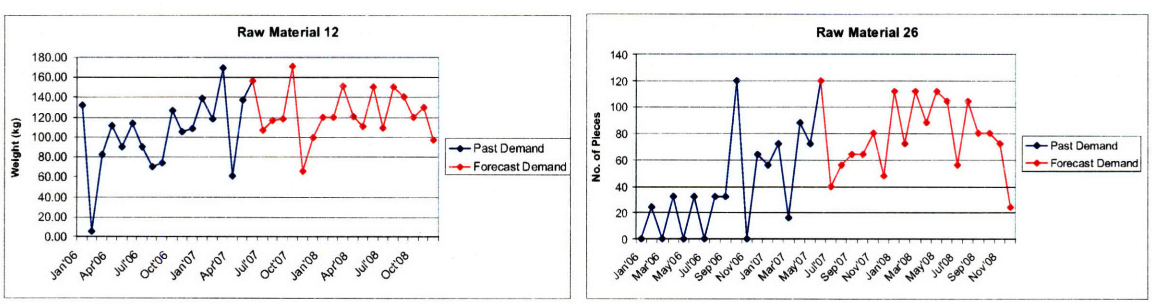


Figure 3-6: Demand Chart for Each C-Item (continue next page)

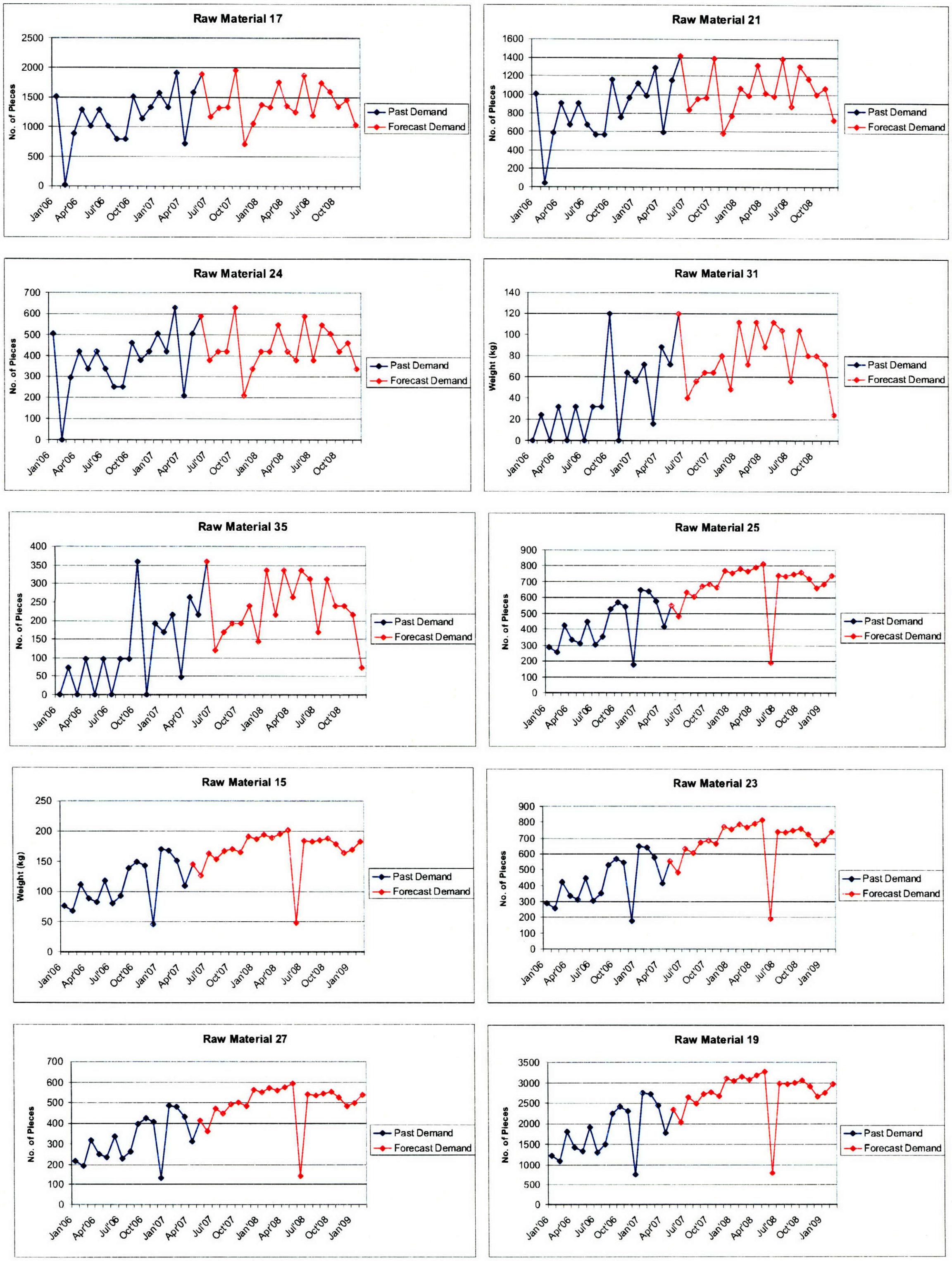


Figure 3-6: Demand Chart for Each C-Item (continue next page)

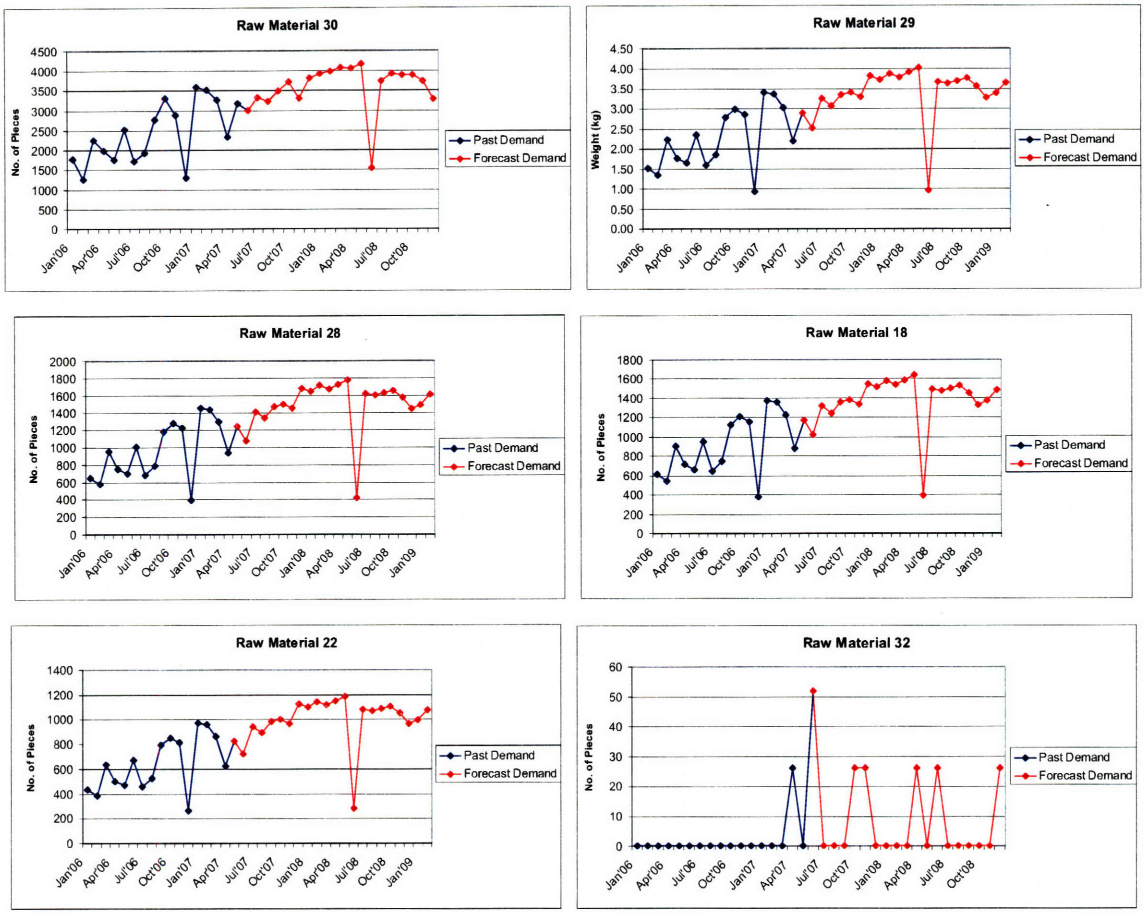


Figure 3-6: Demand Chart for Each C-Item

We observe that most of the forecast demand graphs follow 2 trends. The first trend is seen in Raw Material 12, Raw Material 26, Raw Material 17, Raw Material 21, Raw Material 24, Raw Material 31 and Raw Material 35 mostly from the API facility. The other trend is seen in Raw Material 25, Raw Material 15, Raw Material 23, Raw Material 27, Raw Material 19, Raw Material 30, Raw Material 29, Raw Material 28, Raw Material 18 and Raw Material 22 mostly belonging to PF1. The graph for Raw Material 32 has a trend of its own.

We notice a gradual rise in demand in most of the graphs when we look at the whole period from Jan '06 to Dec '08. However, the forecast demand from June '07 to Dec '08 is random and well behaved, thus providing some support for the assumption of a normally distribution for most of the items.

3.3.3.2 Assumption #2: A replenishment order will be placed on a regular cycle

The minimum order quantities and lot size stipulated by the suppliers for the raw materials are shown in Table 3-19 below. The table also shows the average number of orders and the average amount ordered for each item in the past 2 years.

Items	Average order per year	Units	Average Amount Ordered	Minimum Order Quantity	Order Lot Size
Raw Material 12	8.5	Kg	146	181.44	181.44
Raw Material 25	1	Pieces	4000	0	3750
Raw Material 26	0.5	Pieces	500	0	50
Raw Material 17	1.5	Pieces	193333	500	500
Raw Material 15	2	Kg	828	260	12
Raw Material 23	2	Pieces	6015	6000	200
Raw Material 27	2	Pieces	3754	2000	2000
Raw Material 19	5	Pieces	5775	2000	125
Raw Material 30	1.5	Pieces	41667	25000	25000
Raw Material 29	2	Kg	34	0	5
Raw Material 21	4.5	Pieces	2490	500	500
Raw Material 24	5	Pieces	3300	500	500
Raw Material 31	0	Pieces	0	0	1000
Raw Material 28	3.5	Pieces	5389	8450	650
Raw Material 18	5	Pieces	3300	0	500
Raw Material 22	2.5	Pieces	4620	3000	3000
Raw Material 35	0.5	Pieces	2000	0	1000
Raw Material 32	0	Pieces	0	0	150

Table 3-19: Current Ordering Information on C-Items and Recommended r Values

In this model, the planners should review the inventory level of each item at a fixed review period, r and replenish the stock by the amount of inventory used since the last review. We determined r of each item by observing the minimum order quantity and the monthly demand rate, λ. The constraint is that the demand during the review period should be more than the minimum order quantity.

$$r \cdot \lambda > \text{minimum order quantity} \quad \text{Equation 3-7}$$

where λ is obtained from the average monthly forecasted demands from Jun '07 to Jun '08.

In order to minimize the efforts spent by the planners in keeping track of the inventory level of these 18 items, we group them into 2 groups: one with a lower r and another with higher r, while keeping to the constraint in Equation 3-7.

The results in Table 3-20 show that 9 items require monthly review while the other 9 items require a review every 9 months.

Items	Units	Demand Rate (per month)	r (month)
Raw Material 12	Kg	123.69	9
Raw Material 25	Pieces	684.81	9
Raw Material 26	Pieces	78.32	1
Raw Material 17	Pieces	1404.63	1
Raw Material 15	Kg	170.34	9
Raw Material 23	Pieces	684.81	9
Raw Material 27	Pieces	501.05	9
Raw Material 19	Pieces	2772.29	1
Raw Material 30	Pieces	3584.84	9
Raw Material 29	Kg	3.41	1
Raw Material 21	Pieces	1040.84	1
Raw Material 24	Pieces	442.11	9
Raw Material 31	Pieces	78.32	1
Raw Material 28	Pieces	1503.14	9
Raw Material 18	Pieces	1386.14	1
Raw Material 22	Pieces	1002.10	9
Raw Material 35	Pieces	234.95	1
Raw Material 32	Pieces	9.58	1

Table 3-20: Recommended r Values for C-Items

3.3.3.3 Assumption #3: Replenishment lead times are fixed and known

Similar to B-items, the order lead time for each item is the time taken between ordering and receiving plus the cycle time taken for quality testing when the order arrives. Table 3-21 below shows the order lead times obtained from the Data3 MRP system for the items. We assume these lead times to be deterministic and fixed.

Items	Lead time (inclusive of inspection)	Inspection Cycle Time
Raw Material 12	21	7
Raw Material 25	74	14
Raw Material 26	21	7
Raw Material 17	49	7
Raw Material 15	60	7
Raw Material 23	74	15
Raw Material 27	74	14
Raw Material 19	35	7
Raw Material 30	63	7
Raw Material 29	21	7
Raw Material 21	63	7
Raw Material 24	70	7
Raw Material 31	21	7
Raw Material 28	74	14
Raw Material 18	21	7
Raw Material 22	74	14
Raw Material 35	21	7
Raw Material 32	21	7

Table 3-21: Current Order Lead Times and Inspection Cycle Times for C-Items

3.3.3.4 Assumption #4: Unfilled demand is backordered

We calculate the average inventory of each item from its monthly inventory levels from Jan '06 to May '07. We understand that the MRP system is told to keep a certain level of safety stock for each item as shown in Table 3-22.

We notice that with the exception of Raw Material 32 (the average inventory is lower than safety stock), the inventory level of most items consists of some proportion of safety stock ranging from 1% to 89%.

Items	Units	Average Inventory	Safety Stock	$\frac{\text{safety stock}}{\text{avg. inventory}} \times 100\%$
Raw Material 12	Kg	462	33.6	7
Raw Material 25	Pieces	105010	1600	15
Raw Material 26	Pieces	2753	131	5
Raw Material 17	Pieces	9333	2840	30
Raw Material 15	Kg	1024	420	41
Raw Material 23	Pieces	8412	6000	71
Raw Material 27	Pieces	4511	4000	89
Raw Material 19	Pieces	9235	6800	74
Raw Material 30	Pieces	138486	1046	1
Raw Material 29	Kg	62.1	8.4	14
Raw Material 21	Pieces	4280	2049	48
Raw Material 24	Pieces	4206	903	21
Raw Material 31	Pieces	3727	131	4
Raw Material 28	Pieces	12111	3000	25
Raw Material 18	Pieces	4664	3400	73
Raw Material 22	Pieces	4640	3600	78
Raw Material 35	Pieces	1501	392	26
Raw Material 32	Pieces	0	26	-

Table 3-22: Calculated Safety Stock Percentages for C-Items

Similar to our continuous review model, we propose a z value of 3, which gives a 0.999 probability of stock out for the periodic review model, under the assumption that demand over the lead time plus review period is normally distributed.

3.4 Results

3.4.1 Average Inventory Level of A-items

We obtain the recommended safety stock level for each A-item from the result in Table 3-12. We also calculate the average cycle stock using Equation 3-2 with the Q parameter from Table 3-10. The average inventory level based on the JIT approach is the sum of cycle stock and the safety stock. The table below compares the result of implementing the JIT approach on the A-items (Now) with the current situation (then).

		Safety Stock			Average Inventory		
Items	**Units**	**Then**	**Now**	**%Δ**	**Then**	**Now**	**%Δ**
Raw Material 1 (P2)	Kg	0	3435	-	5351	4513	**-16**
Raw Material 3	Kg	94000	20438	**-78**	152094	25338	**-83**
Raw Material 2 (P2)	Kg	0	959	-	18390	1209	**-93**
Raw Material 1	Kg	0	203	-	1674	326	**-81**
Raw Material 5	Pieces	3400	555	**-84**	2586	795	**-69**
Raw Material 4	Kg	2100	169	**-92**	3169	400	**-87**
Raw Material 11	Pieces	903	32	**-96**	593	168	**-72**
Raw Material 2 (P4)	Kg	0	742	-	241	1267	**426**
Raw Material 1 (P4)	Kg	0	862	-	241	1581	**556**

Table 3-23: Expected Safety Stocks and Average Inventories Before and After Implementing JIT Approach on A-Items

The results show that all the items will have lower safety stocks and average inventories by applying the continuous review model. The average inventories for all other A-items will be reduced by at least 16% with our recommendation with the exception for Raw Material 2 (P4) and Raw Material 1 (P4) where their demands are expected to surge from Aug '07.

The table below shows the same comparison as in Table 3-23 but with the figures converted into number of pallet spaces.

	Safety Stock			Average Inventory		
Items	**Then**	**Now**	**%Δ**	**Then**	**Now**	**%Δ**
Raw Material 1 (P2)	0	8	**-**	12	10	**-17**
Raw Material 3	188	41	**-78**	305	51	**-83**
Raw Material 2 (P2)	0	11	**-**	205	14	**-93**
Raw Material 1	0	1	**-**	4	1	**-75**
Raw Material 5	142	24	**-83**	108	34	**-69**
Raw Material 4	47	4	**-91**	71	9	**-87**
Raw Material 11	91	4	**-96**	60	17	**-72**
Raw Material 2 (P4)	0	9	**-**	3	15	**400**
Raw Material 1 (P4)	0	2	**-**	1	4	**300**
TOTAL	468	104	**-78**	769	155	**-80**

Table 3-24: Expected Safety Stocks and Average Inventories Before and After Implementing JIT Approach on A-Items in Terms of Pallet Spaces

Most of the items will experience at least a 65% reduction in pallet spaces occupied with the JIT approach. Overall, the A-items will occupy 155 pallet spaces with the approach; this is a 80% reduction from the current average pallet spaces of 769 they are currently taking up.

3.4.2 Average Inventory Level of B-items

Table 3-25 below shows the re-order point R, for each of the B-items that we compute using Equation 3-4. We use the average and standard deviations of the forecasted demands from Jun '07 to Jun '08 in our calculations, together with the lead times from Table 3-16 and with z=3.

We calculate the average cycle stock and safety stock for each B-item from the continuous review model using Equation 3-3, and the average and standard deviation of the forecasted demand from Jun '07 to Jun '08. The other parameters are the lead times parameter from Table 3-16 and z=3. Table 3-26 compares the result of implementing the continuous inventory review model to the B-items (Now) with the current situation (Then).

Items	Units	Reorder Point, R
Raw Material 7	Kg	24026
Raw Material 34	Kg	888
Raw Material 8	Kg	3549
Raw Material 20	Pieces	123
Raw Material 6	Kg	1344
Raw Material 9	Kg	1008
Raw Material 10	Pieces	696
Raw Material 14	Pieces	3886
Raw Material 13	Pieces	9264
Raw Material 16	Kg	5812
Raw Material 33	Kg	157

Table 3-25: Calculated Reorder Points for B-Items

		Safety Stock			Average Inventory		
Items	**Units**	**Then**	**Now**	**%Δ**	**Then**	**Now**	**%Δ**
Raw Material 7	Kg	21000	6972	**-67**	24860	11472	**-54**
Raw Material 34	Kg	498	399	**-20**	4474	219	**-95**
Raw Material 8	Kg	4200	1164	**-72**	6123	2164	**-65**
Raw Material 20	Pieces	131	68	**-48**	220	118	**-46**
Raw Material 6	Kg	2800	549	**-80**	3653	1549	**-58**
Raw Material 9	Kg	2100	412	**-80**	3109	854	**-73**
Raw Material 10	Pieces	390	207	**-47**	809	357	**-56**
Raw Material 14	Pieces	3400	1629	**-52**	5553	4404	**-21**
Raw Material 13	Pieces	17000	4733	**-72**	15879	7733	**-51**
Raw Material 16	Kg	2288	1634	**-29**	3878	3267	**-16**
Raw Material 33	Kg	0	93	**-**	214	214	**0**

Table 3-26: Expected Safety Stocks and Average Inventories Before and After Implementing Continuous Review Model on B-Items

The results show that all the items will have lower safety stocks and average inventories by applying the continuous review model. An exception is Raw Material 33 which incidentally has the same average inventory level before and after our recommendation.

The table below shows the same comparison as in Table 3-26 but with the figures converted into number of pallet spaces.

	Safety Stock			Average Inventory		
Items	**Then**	**Now**	**%Δ**	**Then**	**Now**	**%Δ**
Raw Material 7	42	14	**-67**	50	23	**-54**
Raw Material 34	4	3	**-25**	31	2	**-94**
Raw Material 8	21	6	**-71**	31	11	**-65**
Raw Material 20	17	9	**-47**	28	15	**-46**
Raw Material 6	19	4	**-79**	25	11	**-56**
Raw Material 9	16	4	**-75**	23	7	**-70**
Raw Material 10	10	6	**-40**	21	9	**-57**
Raw Material 14	9	5	**-44**	14	12	**-14**
Raw Material 13	7	2	**-71**	7	4	**-43**
Raw Material 16	4	3	**-25**	7	6	**-14**
Raw Material 33	0	3	**-**	7	7	**0**
TOTAL	149	59	**-60**	244	107	**-56**

Table 3-27: Expected Safety Stocks and Average Inventories Before and After Implementing Continuous Review Model on B-Items in Terms of Pallet Spaces

Overall, the B-items will occupy 107 pallet spaces; this is a 56% reduction from the current average pallet spaces of 244 they are currently taking up.

3.4.3 Average Inventory Level of C-items

We calculate the average cycle stock and safety stock for each C-item from the periodic review model using Equation 3-6, and the average and standard deviation of the forecasted demand from Jun '07 to Jun '08. The r value for each item is calculated previously in Table 3-20. The lead time parameter is obtained from Table 3-21 and we use z=3. The table below compares the result of implementing the periodic inventory review model to the C-items (Now) with the current situation (Then).

Items	Units	Safety Stock Then	Safety Stock Now	Safety Stock %Δ	Average Inventory Then	Average Inventory Now	Average Inventory %Δ
Raw Material 12	Kg	34	234	**597**	462	277	**-40**
Raw Material 25	Pieces	1600	1385	**-13**	10510	4467	**-57**
Raw Material 26	Pieces	131	107	**-19**	2753	146	**-95**
Raw Material 17	Pieces	2840	1587	**-44**	9333	2289	**-75**
Raw Material 15	Kg	420	326	**-22**	1024	1093	**7**
Raw Material 23	Pieces	6000	1385	**-77**	8412	4467	**-47**
Raw Material 27	Pieces	4000	749	**-81**	4511	1752	**-61**
Raw Material 19	Pieces	6800	2365	**-65**	9235	3751	**-59**
Raw Material 30	Pieces	1046	5974	**471**	138486	9738	**-93**
Raw Material 29	Kg	8.4	2.6	**-69**	62.1	4.3	**-93**
Raw Material 21	Pieces	2049	1259	**-39**	4280	1780	**-58**
Raw Material 24	Pieces	903	571	**-37**	4206	792	**-81**
Raw Material 31	Pieces	131	107	**-18**	3727	146	**-96**
Raw Material 28	Pieces	3000	2994	**0**	12111	9758	**-19**
Raw Material 18	Pieces	3400	2502	**-26**	4664	8740	**87**
Raw Material 22	Pieces	3600	1996	**-45**	4640	6505	**40**
Raw Material 35	Pieces	392	320	**-18**	1501	437	**-71**
Raw Material 32	Pieces	26	81	**210**	0	85	**-**

Table 3-28: Expected Safety Stocks and Average Inventories Before and After Implementing Periodic Review Model on C-Items

2 out of the 3 common items between the API facility and PF1, Raw Material 12 and Raw Material 30 will have higher safety stocks based on our recommendation after we aggregate their demands in the 2 facilities. However, their average inventory level will be reduced. The average inventory levels of Raw Material 15, Raw Material 18, Raw Material 22 and Raw Material 32 will increase, but the effect on the pallet spaces they will occupy will not be significant since they have small footprints.

The table below shows the same comparison as in Table 3-28 but with the figures converted into number of pallet spaces.

	Safety Stock			Average Inventory		
Items	**Then**	**Now**	**%Δ**	**Then**	**Now**	**%Δ**
Raw Material 12	1	3	**200**	6	4	**-33**
Raw Material 25	1	1	**0**	6	3	**-50**
Raw Material 26	1	1	**0**	6	1	**-83**
Raw Material 17	2	1	**-50**	6	2	**-67**
Raw Material 15	2	2	**0**	5	6	**20**
Raw Material 23	3	1	**-67**	5	3	**-40**
Raw Material 27	2	1	**-50**	2	1	**-50**
Raw Material 19	3	1	**-67**	4	2	**-50**
Raw Material 30	1	1	**0**	3	1	**-67**
Raw Material 29	1	1	**0**	4	1	**-75**
Raw Material 21	2	1	**-50**	4	2	**-50**
Raw Material 24	1	1	**0**	3	1	**-67**
Raw Material 31	1	1	**0**	2	1	**-50**
Raw Material 28	1	1	**0**	2	2	**0**
Raw Material 18	1	1	**0**	2	3	**50**
Raw Material 22	1	1	**0**	2	2	**0**
Raw Material 35	1	1	**0**	1	1	**0**
Raw Material 32	1	1	**0**	0	1	**-**
TOTAL	26	21	**-19**	63	37	**-41**

Table 3-29: Expected Safety Stocks and Average Inventories Before and After Implementing Periodic Review Model on C-Items in Terms of Pallet Spaces

Most items will take up less than 3 pallet spaces by applying the periodic review model, with Raw Material 15 occupying the most space of 6 pallet spaces. The pallet spaces taken up by Raw Material 15, Raw Material 18 and Raw Material 32 will increase with our recommendation, but the increase is only one pallet space for each. Overall, the C-items will occupy 37 pallet spaces; this is a 41% reduction from the current average pallet spaces of 63 they are taking up.

3.4.4 Overall Results

We compile all of the previous results from adopting our recommendations (Now) with the current situation (then) in the table below.

Items	Safety Stock			Average Inventory		
	Then	Now	%Δ	Then	Now	%Δ
A	299	104	**-65**	769	155	**-80**
B	149	59	**-60**	244	107	**-56**
C	26	21	**-19**	63	37	**-41**
TOTAL	474	184	**-61**	1076	299	**-72**

Table 3-30: Expected Safety Stocks and Average Inventories Before and After Implementing Our Recommendations in Terms of Pallet Spaces

The combined result from the A, B and C-items shows that the raw materials will take up 299 pallet spaces based on our recommendations. This is a 72% reduction from the average of 1076 pallet spaces all raw materials are currently occupying in the warehouse.

If TCG were to use 3rd party warehouse facilities to store some of the materials, the materials they will most likely choose to place in that warehouse will be of non-perishable nature. We identified 5 possible materials and they are: Raw Material 5, Raw Material 11, Raw Material 20, Raw Material 10 and Raw Material 14. Altogether they will take up an average of 87 pallets based on our recommendations. Therefore, only 212 pallet spaces will be occupied by the raw materials in this case.

However, the results are based certain assumptions mentioned in the models. Next, we discuss the key limitations and possible shortcomings of our recommendations:

3.4.4.1 Assumption #1: Order lead time is fixed and deterministic

We assume that the order lead times are fixed and deterministic when in fact both supplier lead time and quality test cycle time vary. Our calculations of the safety stocks are based on this assumption and an increase in lead time may result in stock out.

3.4.4.2 Assumption #2: Demand for raw material is normally distributed

We make the assumption that demand for each raw material is normally distributed in the continuous review model for B-items and periodic review model for C-items, so that we can determine a safety factor for a customer service level of 0.999. However, the demands for finished products are gradually increasing year-on-year. Therefore, although the safety factor used is high, the service level may be overestimated.

Furthermore, the monthly demand for each raw material is extracted from the demand of finished product based on the BOM. We did not take into consideration the production campaign in Train 1 of the API facility between Intermediate Product A1 and Intermediate Product B1, or the cleaning of the equipment in the manufacturing facilities which requires 2 weeks of production downtime. Therefore, the demand for each raw material may not be as random and well-behaved as we assumed it to be.

The implication of this assumption is that stock out may occur in periods when the real demand is high and too much stock may be sitting in the warehouse when the real demand is low.

3.4.4.3 Assumption #3: There is no extraordinary yield loss

As mentioned previously, the monthly demand for each raw material is extracted from the demand of finished product based on the BOM. The BOM has already taken into account the efficiency of the processes. However, the chances of atypical yield loss or failure of equipment are not factored into our analysis. We assume that the possibility of extraordinary yield loss is small and we count on the safety stocks to protect against these uncertainties.

3.4.4.4 Assumption #4: Forecast of demand is fairly accurate within the next 12 months

Our analysis of the forecast error concludes that the forecast is fairly accurate for demands within the next 12 months. Therefore, our inventory models are built on the forecast of demand for the next 12 months. However, this forecast is not 100% accurate and hence actual demands may be more or less than the figures we use in our models. If the actual demand happens to be more than forecasted, a stock out may occur; and if the actual demand is lower than forecasted, we may be keeping more stock than necessary.

Chapter 4: Conclusion

Thus far, we have made the following recommendations in this report:

1. Aggregate the demand for the 3 common items in both the API facility and PF1 (Raw Material 12, Plas-Ties Bag Closure and Raw Material 13) and order based on the aggregated demand.
2. Classify and rank the 36 different raw materials (excluding Raw Material 1 (P4) and Raw Material 2 (P4)) into A, B or C items using the 2-factor classification approach that is based on their procurement costs and average inventory space occupied. A-items comprise the top 7 items that need the most attention, B-items the next 11 items that need less attention and C-items the last 18 items that require the least attention. Raw Material 1 (P4) and Raw Material 2 (P4) are considered A-items too because their projected demands are comparable to the demands for the A-items.
3. Manage the A-items with timely orders so that each order will match closely to the demand based on the production schedule and arrives just in time for its usage. In addition, the suppliers should certify that the raw materials have passed all the quality tests before shipment, so that TCG can do away with the test at its production site and thus reduce the order lead times. Build a close relationship with the suppliers by sharing the production schedule with them and adopting VCP. A certain amount of safety stocks for the items can be kept in the initial stage of implementing this approach before getting used to the JIT approach.
4. Apply the continuous review inventory model on the B-items. The inventory level of each item is continuously reviewed and will be re-ordered when the level is at or below the re-order point. Each item is also given a certain number of orders per year.
5. Apply the periodic review inventory model on the C-items. The inventory level of each item is reviewed on a periodic basis and an amount equal to the demand since the last replenishment epoch will be order

6. Ship the inventory of Raw Material 1 (P3) to other TCG facilities since there is to be no demand for this raw material in the production schedule for the next 2 years. Other TCG plants can benefit by turning in it into sellable finished products.

4.1 Further Recommendation #1

Further to these recommendations, we would also recommend TCG to explore the possibility of making more materials common among the manufacturing facilities. Currently, there are only 3 common materials between the API facility and PF1, Raw Material 12, Raw Material 30 and Raw Material 13. All experienced significant reduction in inventory with our recommendation with reductions of 33%, 67% and 43% to their average inventory levels respectively. The effect of aggregating the demands from the 2 manufacturing facilities for each of these items therefore cannot be discounted. Although the demands for the items may be positively correlated, by aggregating the demands, the items do not need to be ordered individually and held separately in the warehouse for different facilities, thereby saving some pallet spaces.

One common material TCG may consider is the drums for storing finished products. There are currently 3 types of drums used separately for storing Product A, Product B and Product C. If they were able to use one common type of drum to replace the 3 drums, the drum demand can be aggregated and many fewer pallet spaces would be required.

4.2 Further Recommendation #2

In the inventory models we used in our analysis, we assume the order lead time for each item to be fixed. As mentioned previously, this assumption may not be entirely true because the lead time is a function of the supplier lead time and the time taken for quality testing; TCG mentioned that both these times are somewhat variable. However, we do not have the figures to discuss the variability of these lead times.

A fixed lead time is also important in the planning process as it decides when a future order can arrive and be available for the scheduled production. If the lead time is variable, orders may not arrive in time for the scheduled production or they may arrive too early and sit idle in the warehouse for longer periods of time. Either situation is undesirable. In many cases, the planners adopt a "rather early than late" ideology by adding a safety lead time to the orders. They feel that letting the stock sit idle in the warehouse and taking up valuable pallet spaces is a far better scenario than the stoppage of production due to the late arrival of the supplies.

On the other hand, if an order is found to be of poor quality, reordering the material will result in delay. Therefore, we recommend that TCG procure raw materials from reliable suppliers who can deliver orders with fixed lead times and with no defects or quality problems. A fixed lead time will also reduce the nervousness in planning.

4.3 Further Recommendation #3

Due to a lack of information on the components for Product D and its packaging methods, we are unable to give a quantitative analysis on the inventory management of the raw materials for this finished product. We can only recommend that TCG should attempt to adopt the ABC-classification approach we had identified for the 38 raw materials for the API facility and PF1. They should then apply the corresponding approaches to each classification of items, instead of using a pure MRP blanket approach. By doing so, they will give each raw material the right amount of attention and control the inventory to a level that suits their desired customer service level.

4.4 Further Recommendation #4

We mentioned previously that the Data3 system only shows the current inventory on hand but does not show the historic inventory level for each material. Therefore, the planners do not look at the inventory trend when planning the production schedule; for instance, the planners did not know that the inventory level actually went beyond the 2000 pallet spaces reserved for the 2 active production facilities in early '07.

We tried in vain to plot the graph for the historical inventory level for each material using the many different sets of data generated from the Data3 system. Our answers were either far from realistic (eg inventory level reaches a negative value) or the current inventory calculated did not match the current real data.

Currently, TCG is exploring the use of another inventory management system, SAP to replace the old Data3 system. We understand that SAP is a more powerful system that gives the users the visibility of the inventory trend. However, it is not until '09 or beyond that SAP will be used by TCG worldwide. We recommend that they switch to the more advanced system soon so that the planners do not plan blindly without considering the limitation of the warehouse.

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