The Production Planning and Inventory Management of Intermediate Products for a Pharmaceutical Company

By

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Master of Engineering in Manufacturing

ABSTRACT

TCG is a multinational pharmaceutical company. As part of its drive to stay lean and competitive, TCG hopes to effectively maximize its capital assets by reducing warehouse inventory. This thesis aims to reduce the inventory of intermediate products through the use of fixed demand rate production planning and inventory controls. The production planning model attempts to derive the optimal production cycle time based on demand rates, production rates and setup times to prevent stock outs. The optimal cycle time should provide the optimal inventory levels for the intermediate products. The production planning model stabilizes the fluctuations in inventory levels and outperforms TCG's production plan in 2008 by 115 pallet spaces. With an order-up-to policy, the inventory level is capped at a maximum level, preventing uncontrolled accumulation of inventory of the intermediate products. This will prevent stock outs and stabilize inventory levels. Using an order-up-to policy to minimize the inventory, a reduction of up to 1.8% can be achieved.

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API	Active Pharmaceutical Ingredient
MPS	Master Production Schedule
MRP	Materials Requirements Planning
JV	Joint Venture
PF2	Pharmaceutical Facility 2
PF1	Pharmaceutical Facility 1

Chapter 1: Introduction

1.1 Introduction

1.1.1 The Company

TCG 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 TCG's Manufacturing Facilities

The plant has 3 separate manufacturing facilities, each located in different buildings. The Active Pharmaceutical Ingredient (API) facility produces both Product A and Product B; the active ingredients that are needed to produce certain finished goods. In Pharmaceutical Facility 1 (PF1), Product C is produced using about 60% of the Product A manufactured in the API facility. Product D will be produced in its Pharmaceutical Facility 2 (PF2) by 2008; this product will also use Product A as one of its active ingredients.

1.1.3 TCG's Warehouse

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 goods 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 (Raw materials, intermediate products, packaging components)	1000
PF1 (Raw materials, packaging components)	1000
TOTAL	**2000**
PRODUCT D Requirements	**Pallet Spaces**

Raw materials, packaging components	0
Active Ingredient	300
Finished Goods	1200
TOTAL	**1500**

Table 1-1: Projected Warehouse Space Distribution

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 Product D's 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 35 kg drums and at least 60 pallet spaces for materials waiting for quality inspection results. In addition, TCG 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 production of Product D 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 C is jointly produced by TCG and a partner company. The partner company supplies some of the raw materials to TCG to produce the finished goods. The Joint Venture (JV) is a company that bridges communication between the 2 large pharmaceutical companies. Every month, JV will forecast the monthly demand for each product that is jointly produced for the next 2 years.

TCG produces Product A and Product B for sister plants that requires these active ingredients as raw materials for other TCG products. TCG receives the monthly forecast for Product A and Product B from its own Global Chemical Planning (GCP) group. TCG has 6 main customers for Product C and they are all 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 JV and GCP to plan the production schedules for the coming months and to make sure that customers can receive the right amount of products on time.

1.1.5 Planning and Scheduling Infrastructure

The demand forecasts are 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 goods. 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 these 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 for Thesis

Based on TCG's long range operating plan, product demand for the current products will increase steadily. Therefore, if TCG continues its current way of operation, it may need an addition of 1500 pallet spaces for the API facility and Pharmaceutical Facility 1 (PF1), and another 4100 pallet spaces for the Pharmaceutical Facility 2 (PF2) at the start of year 2009. With the projected 8600 – 9100 pallet spaces needed in the next two years, the current warehouse space is definitely not able to support the whole plant's operation.

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 goods they want to ship out soon. The intermediate products that is kept in the warehouse should also be reduced.

TCG would also like to explore the benefits of air versus sea shipments for the finished goods. Currently, all finished goods are shipped by air freight, but sea shipment may be more cost effective. On the other hand, although finished goods are now shipped only after quality tests are passed, the possibility of shipping finished goods while waiting for the quality tests 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 three separate areas and is tackled by three 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 materials inventories and ordering methods. The second area covers the intermediate products inventories and campaigning activities when one of the production lines switch from one product to another. The last area covers the handling of finished goods inventories and shipment.

This thesis focuses only on the second area of the project. I study and analyze the management of the intermediate products inventory and the campaigning activities in the Active Pharmaceutical Ingredient (API) Facility. I investigate methods on improving production planning and inventory control. The results will be compared with the current situation and recommendations will be proposed.

1.5 Organization of Thesis

Chapter 2 will describe the operational conditions in TCG, an overview of the manufacturing facilities in TCG and its production capacities, the products produced, good manufacturing practices, customer service level, and current inventory level. Chapter 3 will attempt to provide an overview of the inventory, demand and production of the intermediate products made in the API facility. Chapter 4 proposes two models to improve the inventory levels of three intermediate products. Chapter 5 will summarize the results and highlight some of the possible recommendations.

Chapter 2: Operations in TCG

2.1 Manufacturing Facilities

2.1.1 Active Pharmaceutical Ingredient (API) Facility

2.1.1.1 Product Flow

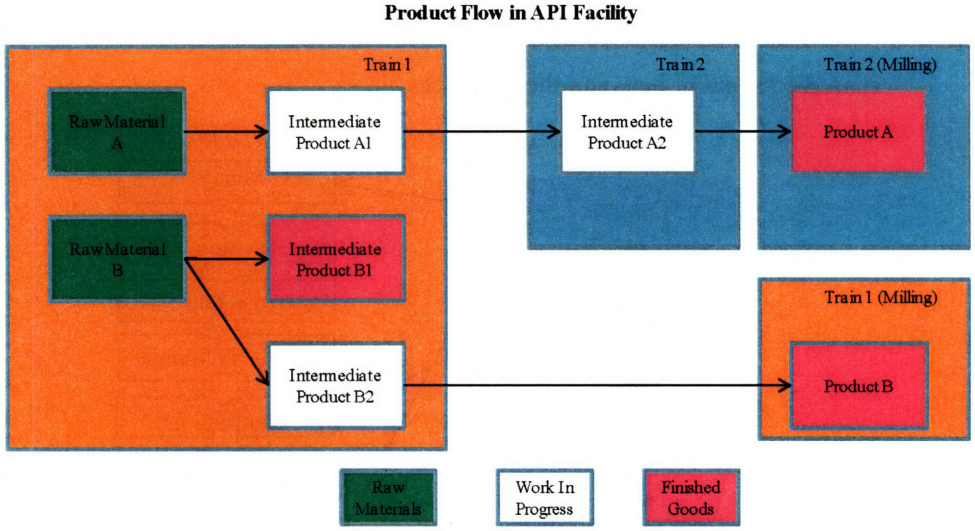

Figure 2-1: Product Flow in API Facility

The API facility produces 3 finished products for its customers, 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 the diagram above, there is also a Milling Train, which separates into Train 1 (Milling) and Train 2 (Milling).

Train 1 produces the intermediate products: Intermediate Product A1 and Intermediate Product B2 from Raw Material A and Raw Material B respectively. Intermediate Product B1 is also produced in Train 1 from Raw Material B. Although Intermediate Product B1 is chemically equivalent to Intermediate Product B2, 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 called Product B. Product B is produced to

be reused as a seed to stimulate future production of Intermediate Product B1. Collectively, Intermediate Product A1, Intermediate Product A2 and Product A can be referred to as products of Product A and Intermediate Product B1, Intermediate Product B2 and Product B can be referred to as products of Product B.

In Figure 2-2, I show the process steps for producing Intermediate Product A1 and Intermediate Product B1. In the figure, we indicate the steps for which there is shared equipment between the processes.

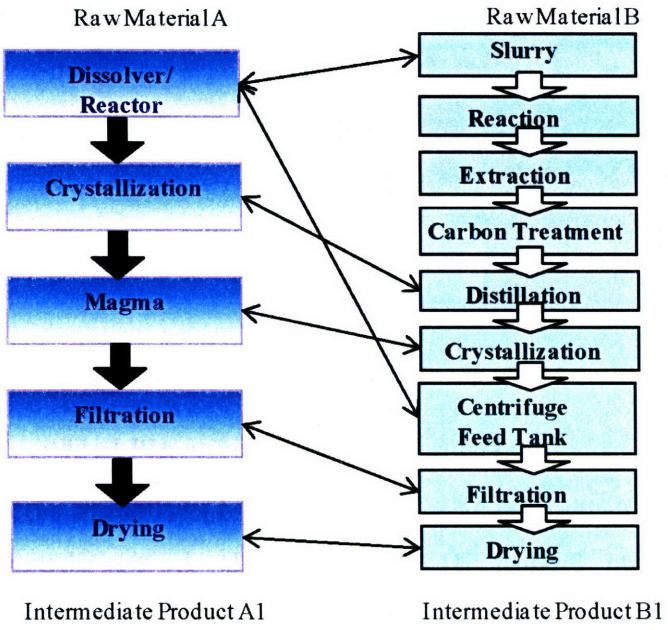

Figure 2-2: Shared Equipment for Train 1

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 account the fact that switching between Intermediate Product A1 and Intermediate Product B1 requires two 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 is required for Intermediate Product B1. During this period, both products are stored in the warehouse.

In Train 2, the Intermediate Product A1 from Train 1 is converted into Intermediate Product A2. Intermediate Product A2 is a concentrated and purer 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 up to a certain fixed level of inventory of Intermediate Product A2; 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 on the left. The figure on the right shows the process steps in the Milling Train.

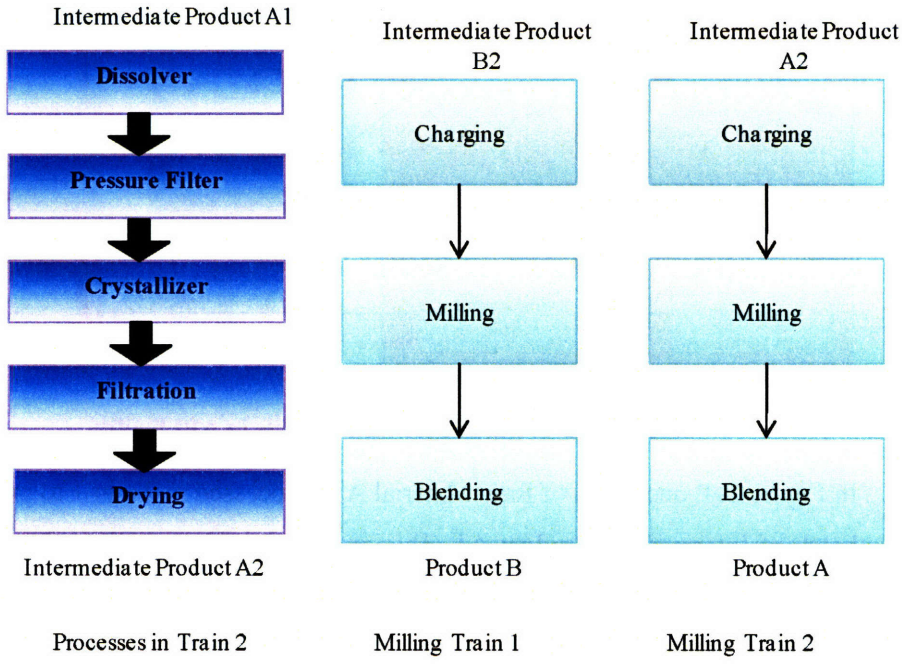

Figure 2-3: Processes in Train 2 and Milling Train

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 two products can be processed separately without conflict. Both products undergo similar processes of charging, milling and blending.

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. There is the same need for coordination of schedules between Intermediate Product B2 and Product B; however, the demand for Product B is small, so we are not concerned with this in this study.

2.1.1.2 Process Capability

The batch flow of products through the API facility is shown below in Figure 2-4.

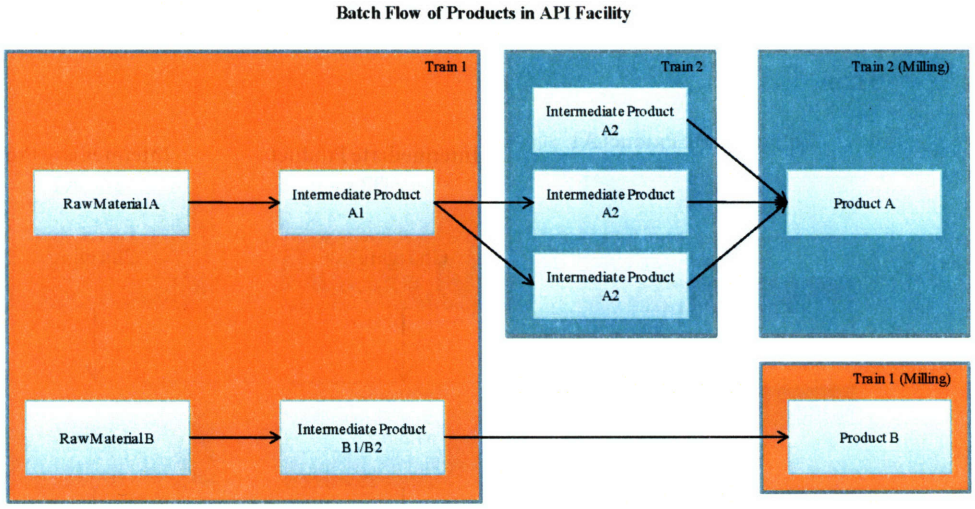

Figure 2-4: Batch Flow of Products in API facility

In Figure 2-4, one batch of Raw Material A 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 quantities. The smaller quantity of Intermediate Product A1 is then processed in Train 2 to yield one batch of Intermediate Product A2. Three batches of Intermediate Product A2 are then used as input to Train 2 (Milling) to produce one batch of Product A. Thus, a one and one half batch of

Intermediate Product A1 is approximately required for each batch of Product A. A similar production scenario occurs in the API facility for Product B.

In Table 2-1 we show the production capacity for each product when only one product is produced at one time. For Train 1, producing 6 batches of Intermediate Product A1 per week implies that zero batches of Intermediate Product B1 are produced. Product B utilizes Train 1 (Milling) and is not affected by the equipment constraints of Train 1. For Train 2, 9 batches of Intermediate Product A2 and 3.5 batches of Product A can be produced concurrently.

Production Line	Product	Production Capacity (batches per week)
Train 1	Intermediate Product B1	10
Train 1 (Milling)	Product B	5+
Train 1	Intermediate Product A1	6
Train 2	Intermediate Product A2	9
Train 2 (Milling)	Product A	3.5

Table 2-1: Production Capacity of API

Given that one and one half batches of Intermediate Product A1 is required to produce one batch of Product A, a production capacity for Intermediate Product A1 of 6 batches a week would translate to 4 batches of Product A per week. By adjusting the batch sizes in terms of Product A and taking into account their respective production capacity shown in Figure 2-4, the standardized production capacity for Product A products is shown below in Table 2-2.

Production Line	Product	Adjusted Production Capacity (batches per week of Product A)
Train 1	Intermediate Product A1	4
Train 2	Intermediate Product A2	3
Train 2 (Milling)	Product A	3.5

Table 2-2: Standardized Production Capacity of Product A products

The process capacity of the API facility indicates that the production of Intermediate Product A2 from Intermediate Product A1 is the bottleneck if production was coordinated so that no step is ever blocked or starved. To improve the overall efficiency, buffer space should be allocated to decouple the processes.

2.1.1.3 Processing Times

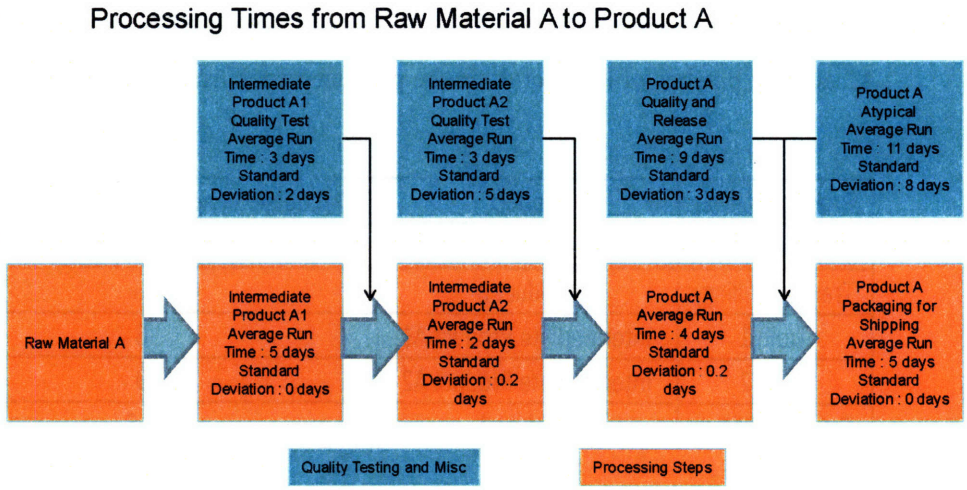

Figure 2-5: Processing Times for Product A

The above processing time diagram for Product A assumes that all production in the API facility is coordinated so that no process step is ever starved or blocked from operating. Figure 2-5 shows that it takes an average of 5 days to produce one batch of Intermediate Product A1 from start to finish, 2 days to produce one batch of Intermediate Product A2 and 4 days to produce one batch of Product A. Each production step is followed by an accompanying quality testing step. Quality testing takes an average of 3 days to process one batch of Intermediate Product A1 or Intermediate Product A2. However, as Product A is a finished good to the API facility, the quality department applies more stringent quality tests. It takes TCG on average 9 days before one batch of Product A is released for further use. In the event that the batch of Product A fails a quality test, the batch is declared as an Atypical. TCG will then conduct an investigation to determine if the Atypical Product A is fit to be used or has to be discarded. This investigation takes an average time of 11 days and up to a maximum of 19 days. Every batch of Product

A for its external customers, regardless of quality deviations requires 5 days to package for shipment. Each batch of Product A which is used internally in Pharmaceutical Facility 1 does not require any time for packaging and shipment.

By adding up all the average start to finish run times shown in Figure 2-5, TCG will take about 30 days to convert Raw Material A to Product A when there are no quality deviations. TCG requires up to an additional 19 days to process an Atypical Product A batch. The total processing time for an Atypical Product A batch is less than the 3 months lead time which TCG uses for planning the production in the API facility and for confirming orders from customers for Product A.

The processing time diagram in Figure 2-5 shows that producing Product A from Intermediate Product A1 can use a make to-order system. However, due to the sharing of equipment in Train 1, it alternates between production campaigns for Intermediate Product B1 and for Intermediate Product A1; consequently, the API facility has to pre-build a certain quantity of Intermediate Product A1 based on forecasted customer demand.

If the API facility were to use a coordinated production line, it would be able to operate under a make to order system as it will only produce when customers place their orders.

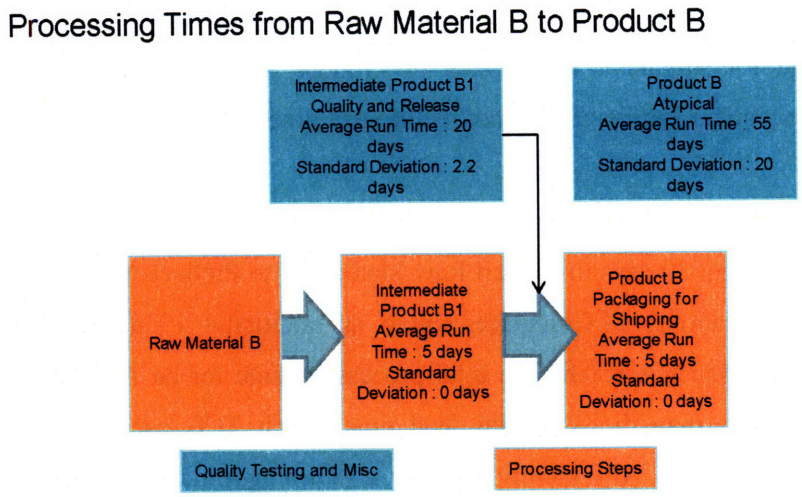

Figure 2-6: Processing Times for Intermediate Product B1

The above processing time diagram for Intermediate Product B1 is similar to Figure 2-5 and assumes that all production in the API facility is coordinated and not starved. It takes TCG on average 5 days to produce one batch of Intermediate Product B1, and quality testing requires an average of 20 days before one batch of Intermediate Product B1 with no quality deviations is released for packaging. Every batch of Intermediate Product B1, regardless of quality deviations requires 5 days to package for shipment.

By adding up all the average start to finish run times shown in Figure 2-6, TCG will take 30 days to convert Raw Material B to Intermediate Product B1 when there are no quality deviations. TCG requires up to an additional 75 days to process an Atypical Intermediate Product B1. The total processing time for an Atypical Intermediate Product B1 batch would exceed the 3 months lead time, which TCG uses for planning the production in the API facility and for confirming orders from customers for Intermediate Product B1, by five days.

The processing time diagram in Figure 2-6 shows that producing Intermediate Product B1 from Raw Material B can use a make to-order system. However, due to the sharing of equipment in Train 1, the API facility has to build a certain quantity of Intermediate Product B1 based on forecasted customer demand to prevent stock outs.

If the API facility were to reduce quality testing time and use a coordinated production line, it would be able to operate under a make to order system as it will only produce when customers place their orders.

2.1.1.4 Preventive Maintenance

The API facility does preventive maintenance on all its equipment during its annual shutdown. Each Train in the API facility has a different shutdown period and duration. Train 1 shuts down for one week during December. Train 2 shuts down for two consecutive weeks during November and the Milling Train shuts down for one week during January and one week during December. These preventive maintenance periods are usually decided in advance between the manufacturing staff and the planners to prevent the loss of production during critical periods.

2.1.2 Pharmaceutical Facility 1

The production of Product C in Pharmaceutical Facility 1 (PF1) is a serial process where the main ingredient is Product A. From the warehouse perspective, there are no intermediate products in this process.

Finished goods from PF1 consist of Product C in 4 different tablet forms, Tablet W, Tablet X, Tablet Y and Tablet Z. Tablet W is the weakest and Tablet Z is the strongest in terms of strength. The difference in the 4 strengths of tablet lies in the amount of Product A each tablet carries.

2.1.3 Pharmaceutical Facility 2

Pharmaceutical Facility 2 (PF2) will produce Product D. There are 2 variants of Product D: Product D1 and Product D2. Product D1 and Product D2 will begin production in 2008. The Bill of Materials (BOM), packaging methods and actual

production capacity for Product D is not known to us at the point in time when this report is written.

2.2 Product Classification

Besides classifying Product C based on the tablet's strength, all finished goods are classified in terms of the markets they serve. Basically, the market each product serves is dictated by the active ingredient's raw materials approved by that market. The raw materials of concern are Raw Material A and Raw Material B. They are obtained from four locations; Production Site 1 (P1), Production Site 2 (P2), Production Site 3 (P3) and Production Site 4 (P4). This means that each customer will order a finished good with specific demand on the source of Raw Material A or Raw Material B contained in the product. In order to differentiate the products, affixes are added to their names to indicate the origin of the active ingredient.

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 their sister plants and they will only demand for a certain proportions of the different types of finished products.

2.3 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 goods to ensure 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 goods are tested before shipment. The sampled materials will sit in the warehouse while waiting for the test 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 that experiences a deviation 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.

2.4 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 tries to meet the customer demand. 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.

In order to meet customer demand and not starve productions downstream, TCG keeps a certain level of safety stocks for most of the raw materials and finished products.

Customers (i.e., TCG's sister plants) have to send their order for Product C three months in advance so that the PF1 can have enough time to meet these orders. The maximum cycle time for producing Product A from the raw material of Raw Material A is 50 days. It takes a maximum of 105 days to convert Raw Material B to Intermediate Product B1. Therefore, the three months of lead time is practical for TCG to plan the production schedule.
These 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 observe that the customer orders are pretty fixed with less than 10% of the orders having their quantities increased; for the orders that are changed, the changes are usually small.

2.5 Current Warehouse Inventory Level

The start-of-the-month inventory level for each raw material, intermediate products and finished good is compiled from June 2006 to May 2007. Only materials kept in the warehouse are included in the data, some intermediate products and solvents are ignored since they are kept in a separate facility. The inventory level is then converted into the amount of pallet spaces the material occupies.

Chapter 3: **Intermediate Products at TCG**

3.1 Intermediate Product Inventory Level

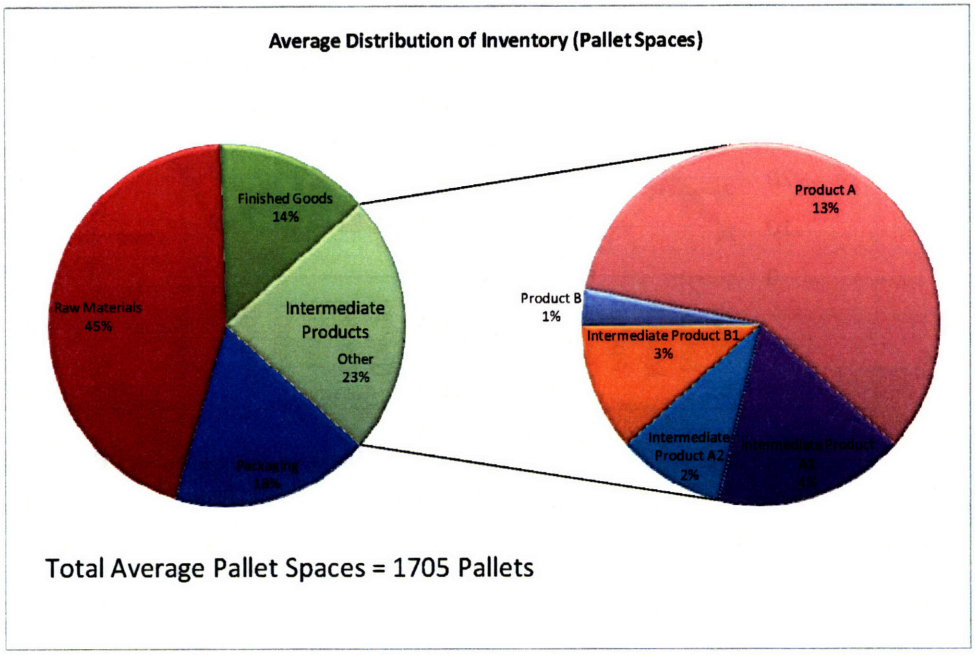

Figure 3-1: Average Distribution of Inventory

In Figure 3-1 we show the average inventory distribution for TCG, which was computed from January 2006 to May 2007. In this study, I consider all products produced by the API facility as intermediate products. The intermediate products are Intermediate Product A1, Intermediate Product A2, Product A, Intermediate Product B1 and Product B. Intermediate Product A2 is not stored in the warehouse but in the API facility and we are not concerned about its impact on the overall warehouse pallet space. Intermediate products accounts for 23% of the total average inventory found in the warehouse, this translates to about 393 pallet spaces. Product A represents 13% of the total average inventory; this translates to about 222 pallet spaces or 22 batches. We expect that TCG can achieve substantial inventory reduction if we can determine safety and cycle stock levels analytically and we can plan campaign activities taking into account the demand variability.

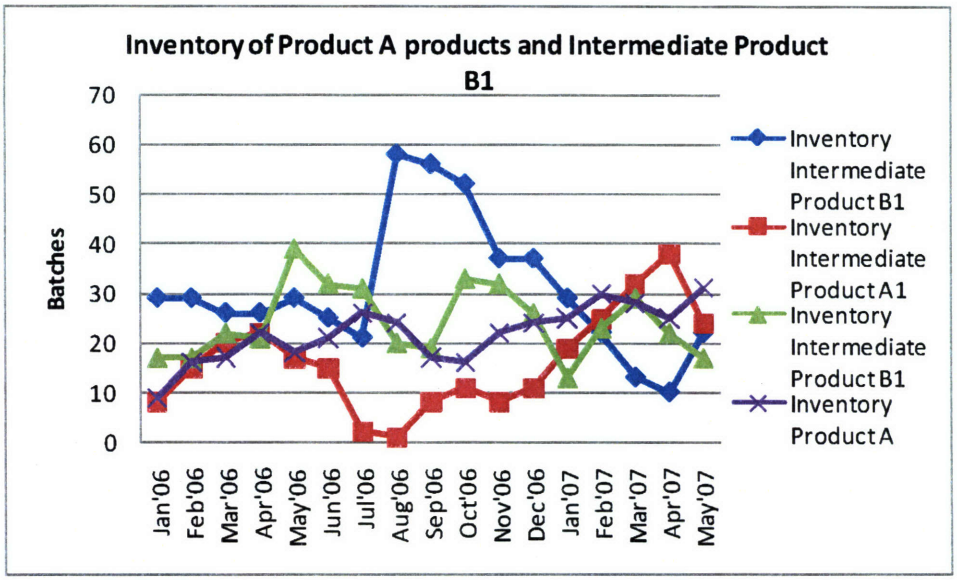

Figure 3-2: Inventory of Product A and Intermediate Product B1 Products

In Figure 3-2, we present the actual inventory levels of all intermediate and finished products for Product A and Intermediate Product B1 from January 2006 to May 2007. The inventory level for Intermediate Product B1 shown in Figure 3-2 is that of Intermediate Product B1 and Product B combined for easy analysis. From the Figure 3-2, Intermediate Product A1 has highly variable inventory levels due to the production campaigns. The inventory level of Intermediate Product A2 seems to vary around about 25 batches, where its demand is affected by the production scheduling of Product A. The inventory level for Product A is increasing from around 10 batches to 30 batches, as of May 2007. The inventory levels for Product B are highly dependent on its campaign scheduling.

3.2 API Facility Production and Ordering Methods

TCG receives forecasted monthly demand data for the next 24 months from the Global Chemical Planning group for Product A and Intermediate Product B1. The planners input the forecast into the Materials Requirement Planning (MRP) software in the Data3 system. The Data3 system will generate a Master Production Schedule (MPS) based on the lead time and capacity of the API facility. Based on the production schedule for Product A, the planners will time

lag the production schedule of Intermediate Product A2 and Intermediate Product A1 based on the production lead times. Since the production of Intermediate Product A2 is the bottleneck for the API facility, as long as the production capability of Intermediate Product A2 is not exceeded, the production capability of Intermediate Product A1 and Product A will be feasible. The planners try to keep a minimum amount of safety stock for both products such that stock outs do not occur. Confirmed customers orders are known only for the month when the products are required and production begins one month before the customer order. Typically the customer order and forecasted demand do not differ by much, on the order of one to two batches each month.

A typical customer ordering scenario is shown in Figure 3-3.

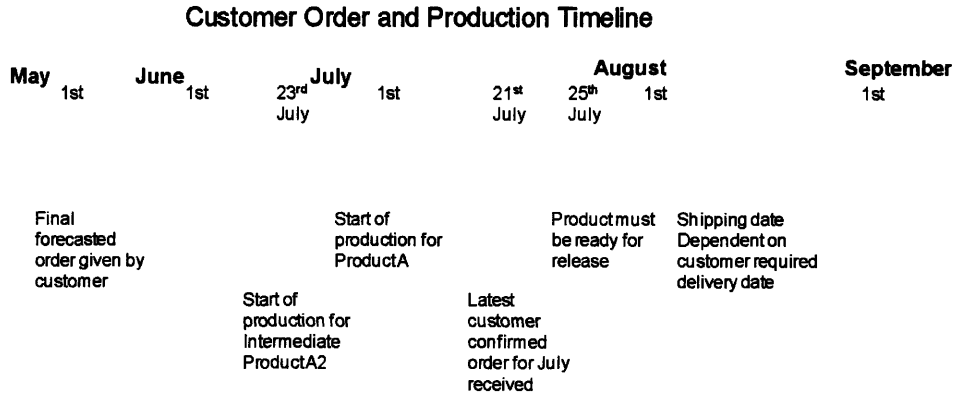

Figure 3-3: Customer Order and Production Timeline

If the customer wants Product A delivered in August, the customer will place a confirmed order at the latest by the 21st of July. TCG would have produced the order in the beginning of July based on the forecasted order given by the customer in May, three months before the actual delivery date. Should the confirmed order be larger than the forecasted order, it is up to the planner's discretion as to whether to accept the order. If the confirmed order is smaller than the forecasted order, the excess stock is absorbed by TCG into its inventory.

3.3 Inventory and Production for products of Product A and Product B

3.3.1 Inventory and Production Campaigns for Intermediate Product A1 and Intermediate Product B1

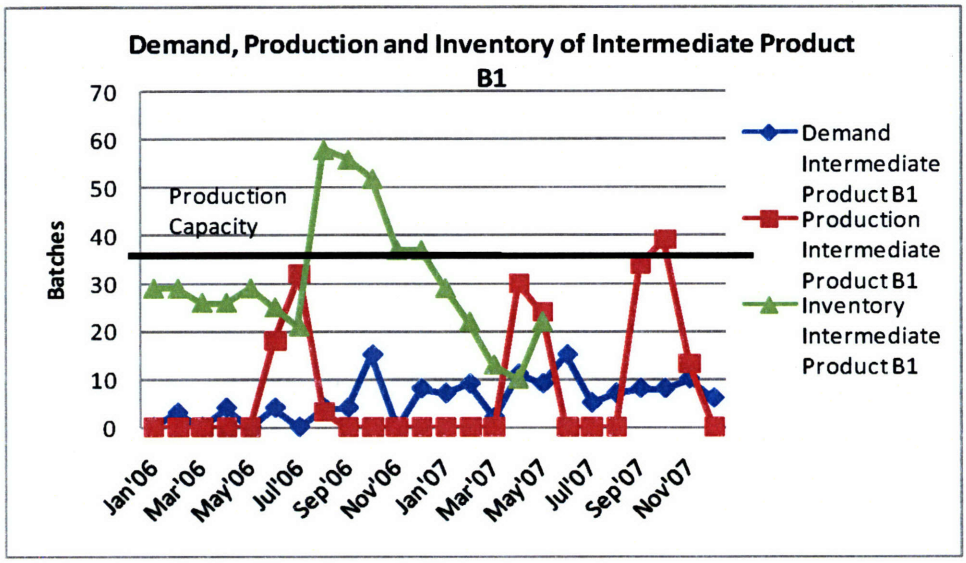

Figure 3-4: Demand, Production and Inventory of Intermediate Product B1

In Figure 3-4, we present the actual demand, production and inventory levels for Intermediate Product B1 from January 2006 to May 2007 and the latest forecasted demand and planned production values from June 2007 to December 2007 that was obtained in May 2007. Based on the weekly production capacity shown in Table 2-1, and assuming that there are 4 weeks in a month, the production capacity of Intermediate Product B1 is indicated by the black line in the above figure.

Train 1 of the API facility needs to schedule production between Intermediate Product A1 and Intermediate Product B1. In a pharmaceutical company, the time spent in producing only one product (i.e. Intermediate Product A1 or Intermediate Product B1) is called a campaign.

From the Figure 3-4, the inventory for Intermediate Product B1 rises sharply after each campaign as inventory is built up to satisfy demand until the next campaign. The average monthly inventory from Jan 2006 to May 2007 is 30.5 batches, while the average monthly demand is 5 batches. From Figure 3-4, the inventory level of Intermediate Product B1 never drops below 10 batches. The maximum monthly production capacity for Intermediate Product B1 is 40 batches, this is 8 times greater than demand. Thus, inventory can be built up over a short period of time.

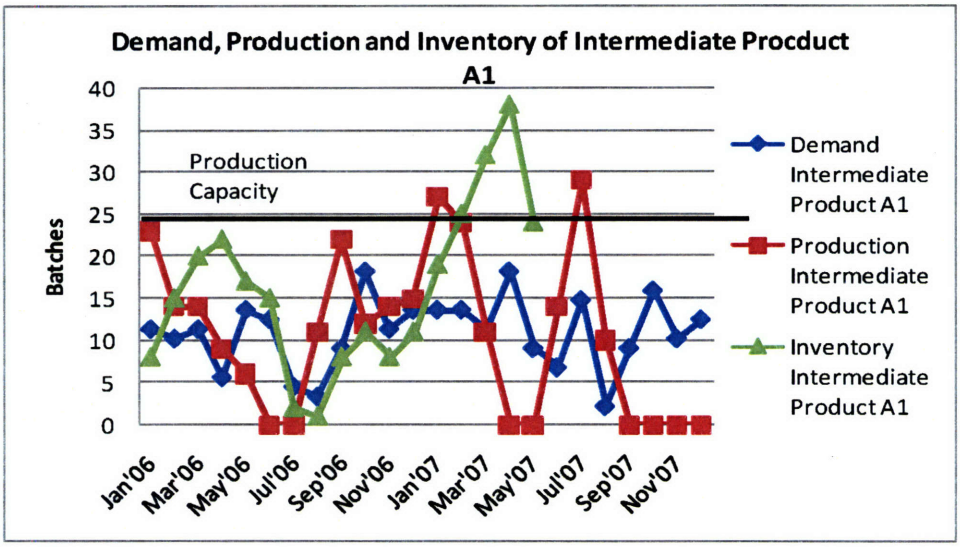

Figure 3-5: Demand, Production and Inventory of Intermediate Product A1

In Figure 3-5, we present the actual demand, production and inventory levels for Intermediate Product A1 from January 2006 to May 2007 and the latest forecasted demand and planned production values from June 2007 to December 2007 that was obtained in May 2007. Based on the weekly production capacity shown in Table 2-1, and assuming that there are 4 weeks in a month, the production capacity of Intermediate Product A1 is indicated by the black line in the above figure.

From the Figure 3-5, the inventory level of Intermediate Product A1 drops sharply during the Intermediate Product B1 campaign as only 1 to 1.5 months of demand is kept. The average monthly demand is 13.3 batches, while the maximum monthly production capacity for Intermediate Product A1 is 24, which is 2 times

greater than demand. As compared to Intermediate Product B1, inventory for Intermediate Product A1 has to be built up over a longer time period.

Currently, the planners choose to produce Intermediate Product B1 for two months before switching over to Intermediate Product A1. The production of Intermediate Product B1 will resume for another two months when its inventory level reaches zero. This method of planning gives rise to variable production time periods. Sometimes the campaign for Intermediate Product A1 goes for 7 months, while at other times it only goes for 2.5 or 4 months. The scheduling of production between Intermediate Product A1 and Intermediate Product B1 could be better managed by a fixed time period production cycle based on the demand and production capacity. From Figure 3-4 and Figure 3-5, the cumulative demand and production graphs for Intermediate Product B1 and Intermediate Product A1 are plotted to illustrate the variable production cycle time periods.

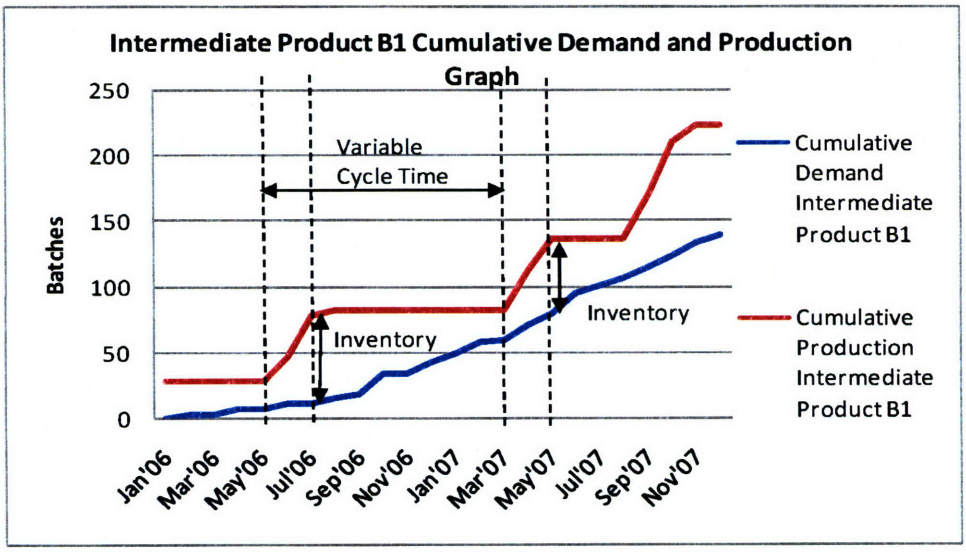

Figure 3-6: Intermediate Product B1 Cumulative Demand and Production Graph

From Figure 3-6, Intermediate Product B1's production rate is much larger than its demand. This is due to the longer production time period allocated to Intermediate Product A1. Thus there is the need to build up stock quickly when production begins.

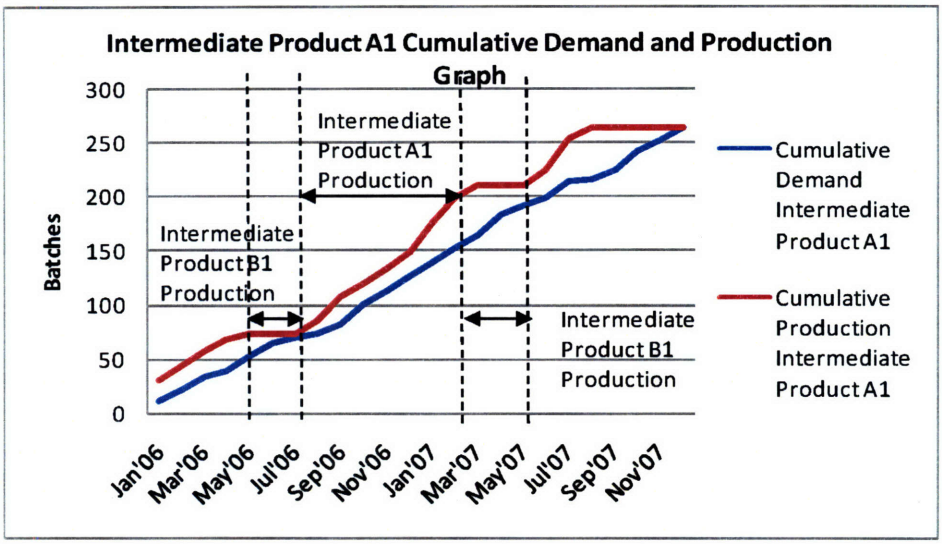

Figure 3-7: Intermediate Product A1 Cumulative Demand and Production Graph

From Figure 3-7, Intermediate Product A1 production lasted for 7 months from mid-August 2006 to mid-March 2007, while Intermediate Product B1 production lasted for 2-3 months from April to May 2007. Typically, a Intermediate Product A1 campaign is expected to last 2-3 months, however when Intermediate Product B1 demand is less than forecast, this allowed the last campaign of Intermediate Product A1 to continue for 7 months. From Figure 3-5, the inventory of Intermediate Product A1 starts to build up immediately after the Intermediate Product B1 campaign. In April 2007, TCG had 39 batches of Intermediate Product A1 inventory, about three times the average monthly demand. In light of the knowledge that the Intermediate Product A1 campaign would continue for 7 months, the planners could have matched the demand rate with the production rate for Intermediate Product A1, and only built up stock about three to four months before the campaign changes over to Intermediate Product B1. This method of scheduling would allow the planners to keep low Intermediate Product A1 inventory during the first three months of its available production time. In the last quarter of 2007, TCG's plan is to import Intermediate Product A1 from TCG's sister plants, and thus to not produce Intermediate Product A1 is produced in the API facility.

3.3.2 Inventory and Production for Intermediate Product A2

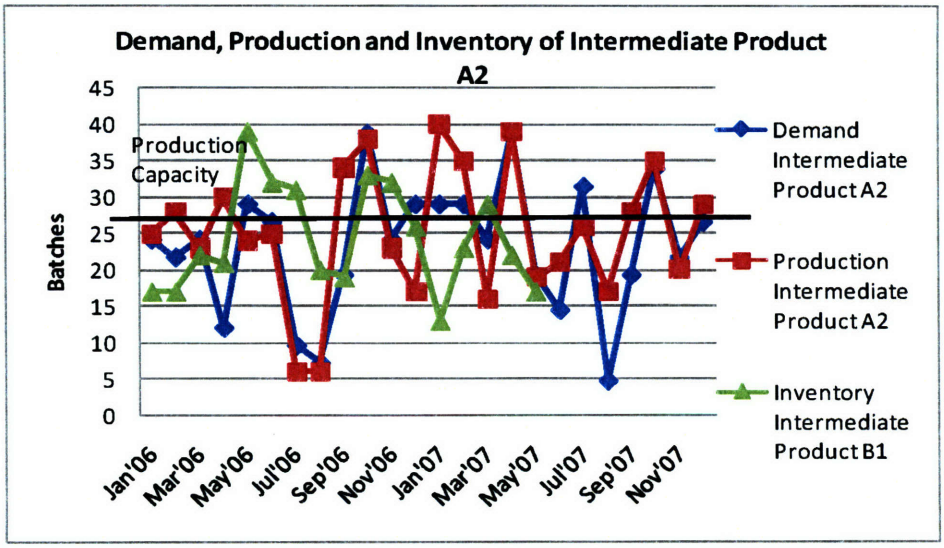

Figure 3-8: Demand, Production and Inventory of Intermediate Product A2

In Figure 3-8, we present the actual demand, production and inventory levels for Intermediate Product A2 from January 2006 to May 2007 and the latest forecasted demand and planned production values from June 2007 to December 2007 that was obtained in May 2007. Based on the weekly production capacity shown in Table 2-1, and assuming that there are 4 weeks in a month, the production capacity of Intermediate Product A2 is indicated by the black line in the above figure.

The monthly production capacity of Intermediate Product A2 is 36 batches when there is sufficient manpower available. This figure takes into consideration the individual machine downtimes in the production line. The average monthly demand is 29.6 batches. Although the production of Intermediate Product A2 is the bottleneck of the API facility, the production capacity is sufficient to accommodate the demand.

The past inventory fluctuations for Intermediate Product A2 can be attributed to two reasons, 1) production was based on demand and its variability, 2) the difference in batch sizes between Intermediate Product A2 and Product A.

As of June 2007, the inventory for Intermediate Product A2 is not stored in the warehouse but in the API facility. In addition, TCG has switched over from producing Intermediate Product A2 based on a forecast of future demand to production controlled by kanban cards available. Thus, now the production of Intermediate Product A2 will be based on replenishing its inventory level as it is used to meet downstream demand. TCG has set the maximum number of Intermediate Product A2 kanban cards to be kept at 12 batches. This is primarily due to space considerations in the API facility as it is unable to hold more than 12 batches. In the subsequent months, the inventory should stabilize around 12 batches of Intermediate Product A2, which translates to 1 weeks worth of supply for Product A production.

3.3.3 Inventory and Production for Product A

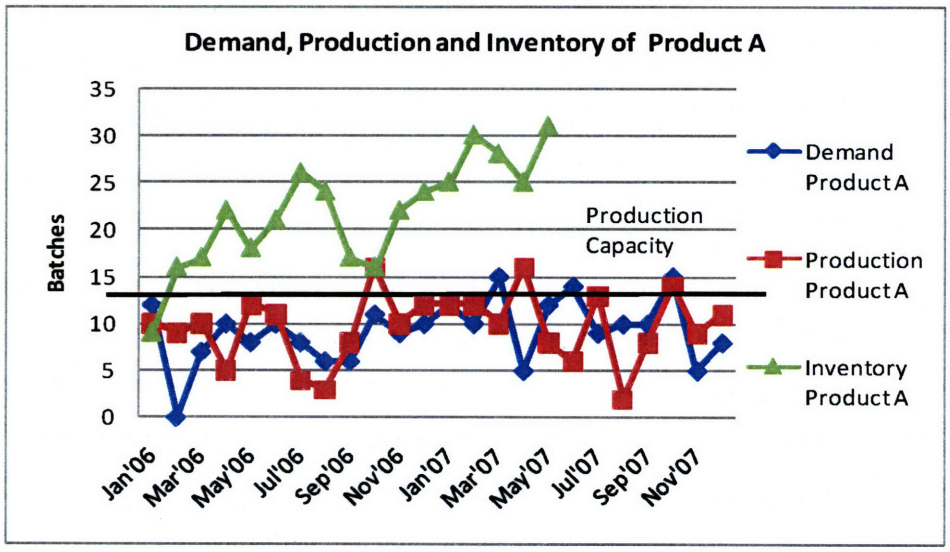

Figure 3-9: Demand, Production and Inventory of Product A

In Figure 3-9, we present the actual demand, production and inventory levels for Product A from January 2006 to May 2007 and the latest forecasted demand and planned production values from June 2007 to December 2007 that was obtained in May 2007. Based on the weekly production capacity shown in Table 2-1, and assuming that there are 4 weeks in a month, the production capacity of Product A is indicated by the black line in the above figure.

The maximum monthly production capacity of Product A is 13.5 batches when there is sufficient manpower available; the average monthly demand is 10.5 batches. Even if the API facility produced at the rate of the bottleneck, its production capacity is still 12 batches per month; this capacity is sufficient to accommodate the average monthly Product A demand.

The inventory level fluctuates between 10 and 30 batches. The MRP system has set the safety stock level for Product A to be 5 batches. The past data indicates that a minimum of 10 batches or one month's average demand is kept from January 2006 to May 2007.

Figure 3-9 clearly shows that the inventory level might be decreased as demand variability has been minimal and production capacity is not fully utilized. The planners rationalize the buildup of Product A inventory as necessary due to the following reasons:

1) Pre-scheduled train cleaning and campaign turnaround downtime require more manpower than available at the API facility. Manpower is diverted from other trains and this reduces the overall production capacity in affected trains.

2) Due to manpower constraints, all trains cannot run at maximum capacity simultaneously. Building up Product A inventory will allow production capacity in all trains to be level loaded. Product A is preferred over other intermediate products because it is closest to the customer, thus reducing lead time.

3) Economic/production performance measures. TCG conducts annual profit planning, which attempts to set production and performance targets to be achieved in the following year. These targets are based on a variety of factors such as demand, capacity, manpower, current performance, strategic decisions, etc. Any deviation from the profit plan will be thoroughly investigated and could impact the overall site performance. In the event of reduced product demand, planners are reluctant to produce less than the profit plan as it could have negative implications on site performance. This results in stocking up of certain products despite poor demand.

The planners at TCG try to match the monthly demand to the monthly production when generating their master production schedule as long as the capacity limit is not reached. In the event that demand is greater than capacity, the planners will build up stock in the previous months to meet the excess demand. Due to the lack of manpower and reduced production capacity during an annual plant shutdown or campaign turnaround in other Trains, the planners will build up stock of Product A beforehand.

3.4 Demand of Product A products and Intermediate Product B1

3.4.1 Characterization of Demand of Product A products

The demand for Product A drives the demand and production for its intermediate products such as Intermediate Product A1 and Intermediate Product A2. Characterizing the demand of Product A would allow me to characterize the demand of its intermediate products.

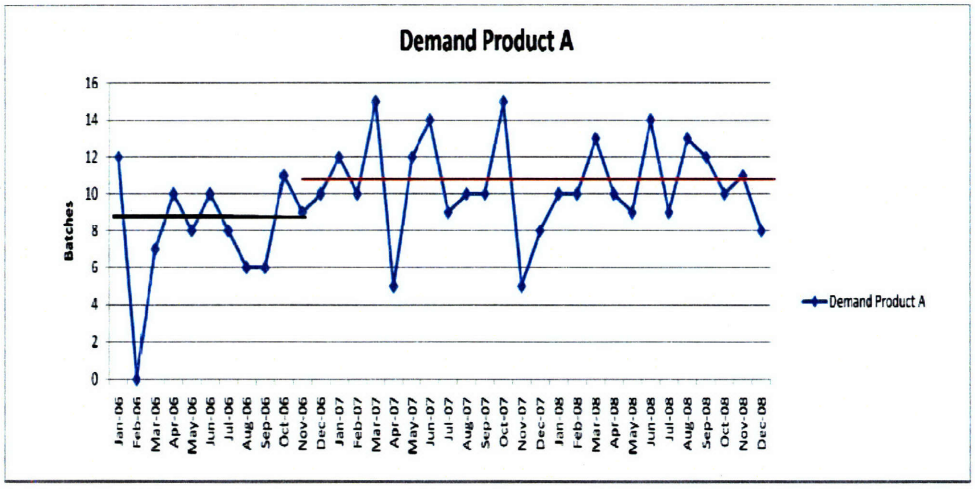

Figure 3-10: Demand for Product A

In Figure 3-10, we present the actual demand for Product A from January 2006 to May 2007 and the latest forecasted demand from June 2007 to December 2008 that was obtained in May 2007. The red and black line represents an initial estimate of the mean demand through observation. From this initial observation, the demand for Product A does not appear to be stationary. To determine if the

demand of Product A over 36 months is stationary about a mean value, I applied a single factor ANOVA to determine if there is any mean shift in demand. Characterizing the mean demand for Product A is important to determine if the average demand rate is constant or linearly increasing over time as the proposed campaign planning model in Chapter 4.1 assumes a constant demand rate.

A single factor ANOVA with the following hypotheses was tested at a 95% confidence level.

H_0 : Mean Demand from 2006 to 2008 is equal

H_1 : Mean Demand from 2006 to 2008 is not equal

The following ANOVA table summarizes the results of the test.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2006 Demand	12	97	8.083333	10.08333
2007 Demand	12	125	10.41667	11.53788
2008 Demand	12	129	10.75	3.477273

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	50.66667	2	25.33333	3.028071	0.062031	3.284918
Within Groups	276.0833	33	8.366162			
Total	326.75	35				

From the ANOVA table at a 95% confidence level, there is no mean shift in the demand. However, as the F test statistic from the ANOVA table is close to the critical F value, I chose to select another period which can be better characterized by a constant demand rate. The campaign planning model is sensitive to the demand rate, having an average demand rate which is lower than the actual demand rate will result in stock outs when it is implemented. The monthly averages in 2007 and 2008 are quite close and another single factor ANOVA was applied to this period. A second single factor ANOVA with the following hypotheses was tested at a 95% confidence level.

H_0 : Mean Demand from 2007 to 2008 is equal

H_1 : Mean Demand from 2007 to 2008 is not equal

The following ANOVA table summarizes the results of the test.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2007 Demand	12	125	10.41667	11.53788
2008 Demand	12	129	10.75	3.477273

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.666667	1	0.666667	0.088799	0.768505	4.300949
Within Groups	165.1667	22	7.507576			
Total	165.8333	23				

From the ANOVA table, the F statistic indicates that the 2007 and 2008 monthly demand can be better characterized as stationary. The average monthly demand for Product A during this period is 10.58 batches with a standard deviation of 2.68 batches.

3.4.2 Characterization of Demand of Intermediate Product B1

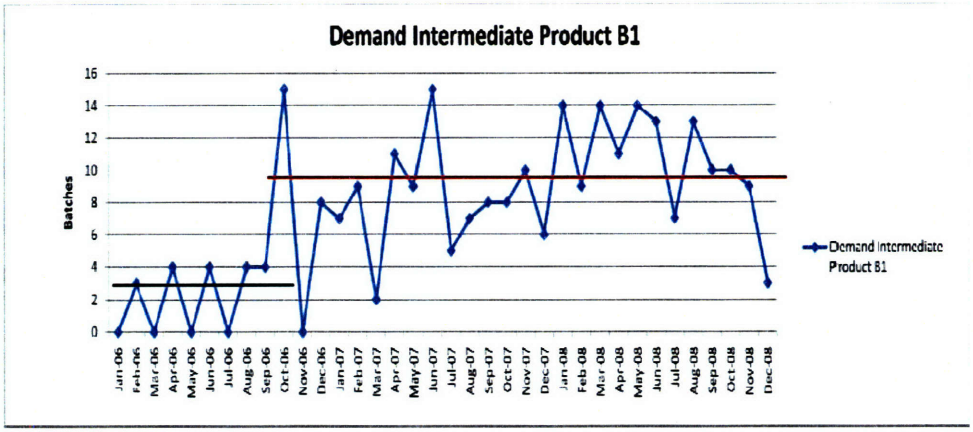

Figure 3-11: Demand for Intermediate Product B1

In Figure 3-11, we present the actual demand for Intermediate Product B1 from January 2006 to May 2007 and the latest forecasted demand from June 2007 to December 2008 that was obtained in May 2007. The red and black lines represent an initial estimate of the mean demand through observation. From this initial observation, the demand for Intermediate Product B1 does not appear to be

stationary. To determine if the demand of Intermediate Product B1 over 24 months; from 2007 to 2008, is stationary about a mean value, I applied a single factor ANOVA to determine if there is any mean shift in demand. Characterizing the mean demand for Intermediate Product B1 is important to determine if the average demand rate is constant or linearly increasing over time as the proposed campaign planning model in Chapter 4.1 assumes a constant demand rate.

A single factor ANOVA with the following hypotheses was tested at a 95% confidence level.

H_0 : Mean Demand from 2007 to 2008 is equal

H_1 : Mean Demand from 2007 to 2008 is not equal

The following ANOVA table summarizes the results of the test.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2007 Demand	12	97	8.083333	10.44697
2008 Demand	12	127	10.58333	11.17424

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	37.5	1	37.5	3.468816	0.075945	4.300949
Within Groups	237.8333	22	10.81061			
Total	275.3333	23				

From the ANOVA table, the F statistic indicates that the 2007 and 2008 monthly demand can be characterized as stationary. The average monthly demand for Intermediate Product B1 during this period is 9.33 batches with a standard deviation of 3.45 batches.

Chapter 4: Improvement models

In Chapter 3, we presented the intermediate products produced by the API facility. Of the five intermediate products, the inventory of Intermediate Product A2 does not have any impact on warehouse space while the inventory of Product B is insignificant occupying about 1% of the total warehouse inventory. I will describe two models to control the inventory of the three remaining intermediate products. I propose a fixed time period production cycle to better plan and control the inventory of Intermediate Product A1 and Intermediate Product B1. I propose using an order-up-to policy to manage the increasing inventory trend of Product A.

4.1 Fixed Time Period Production Cycle Campaigning Model

Using the model, we can determine the shortest feasible production cycle for Intermediate Product A1 and Intermediate Product B1. The shortest production cycle will result in the least amount of inventory to be kept for both products and prevent stock outs. The current production planning method depends on the demand of Product A; fluctuations in that demand are magnified in the demand for Intermediate Product A1 as one and one half batches of Intermediate Product A1 is required for one batch of Product A. To prevent stock outs in the current planning method, there is a tendency by the planners to produce more than required.

We can model Train 1 of the API facility as a single-stage two part type system. In this model, a cycle T refers to the sum of time taken to setup and produce one campaign of Intermediate Product A1 and one campaign of Intermediate Product B1 sequentially. A cycle takes into account the setup times, product demand rates, unit production times and preventive maintenance times for both products. The system will produce a product at its maximum rate such that the inventory is sufficient to last until the next production campaign for the product in the next cycle.

The model takes into account Train 1's one week preventive maintenance period during December. The model takes the demand for Intermediate Product B1 and

Intermediate Product A1 during that particular week and redistributes the demand across the remaining fifty-one weeks of a year.

The model aims to simplify the production planning process and determine the shortest production cycle time which would yield the least amount of inventory to be held.

Figure 4-1 illustrates a typical production cycle for two products using the campaigning model. The production for product 1 and product 2 begins when their cumulative production line hits their respective cumulative demand line and the setup for a particular product begins immediately after the production of the previous product ends. For the scenario when product 1 is in production, production will stop when the time between the start of production for product 2 and end of production for product 1 is equal to the setup time for product 2. The above scenario also applies when product 2 is in production.

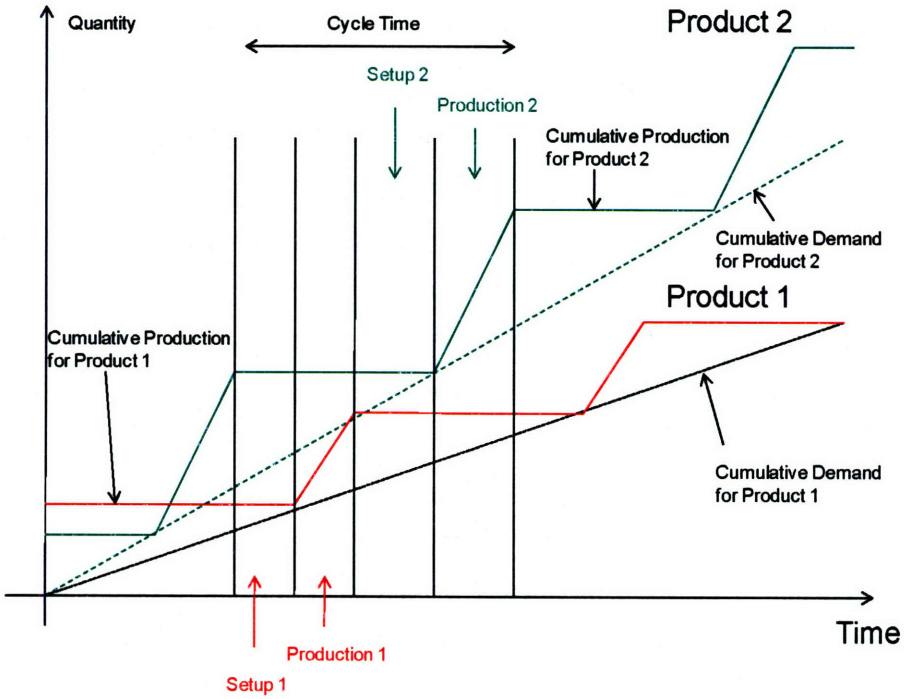

Figure 4-1: Fixed Production Time Campaigning Model for Two Products

The cycle time T can be modeled as

$S_1 + \tau_1 Q_1 + S_2 + \tau_2 Q_2 = T$ where $Q_i = d_i T$

d_i is the demand rate for product i

Q_i is the quantity produced for product i during a campaign

τ_i is the production time to produce one unit of product i

S_i is the setup times for product i

Assumptions

1. Demand is constant. Demand for Intermediate Product A1 and Intermediate Product B1 can be modeled as a constant as shown in the previous chapter.
2. Deterministic setup times. Any variability in the setup times is smaller than one time unit of one week.
3. Deterministic production times. The production times used for Train 1 takes into account the individual machine down times and can be achieved if there is sufficient manpower available.
4. Production rate of product i is greater than the demand rate.

4.1.1 Simulation

Using the proposed campaigning model described above, I used the projected future demand and current production capacity to calculate the minimal cycle time that will reduce the inventory holdings due to the production campaigns. In addition, by changing the setup times and production capacity, I explore its effects on cycle time and the overall inventory.

The following table shows the recommended cycle time T based on the current demand, setup times and production capacity.

4.1.1.1 Current Production Scenario

In Chapter 3.4, we showed that both Intermediate Product A1 and Intermediate Product B1 can be modeled as having a constant average demand rate over the 2007 and 2008 period. However, the average demand rate for both Intermediate Product A1 and Intermediate Product B1 is higher in 2008 than in 2007. When an average demand rate is used, the campaigning model will predict higher average

inventory in 2007 as it is building up stock to accommodate the higher demand in 2008. Thus, a separate demand rate is used for Intermediate Product A1 and Product B for 2007 and 2008 to lower the predicted inventory level.

		Intermediate Product B1	Intermediate Product A1
Demand Rate (Batches/Week)	d(i)	1.91	2.71
Unit Production Time (Batches/Week)	$\tau(i)$	0.10	0.17
Setup Time (Weeks)	S(i)	2.00	2.00
Production Size (Batches)	Q(i)	21.38	30.34
Campaign Production Time (Weeks)	$\tau(i)Q(i)$	2.14	5.06
Inventory during No Production(Batches)	$Q(i)-d(i)\tau(i)Q(i)$	17.30	16.63
Inventory during No Production(Pallets)	$Q(i)-d(i)\tau(i)Q(i)$	32.69	71.08
Cycle Time (Weeks)	T	11.19	

Table 4-1: 2007 Current Production Scenario and Predicted Inventory

In Table 4-1, we present the current production parameters for Intermediate Product A1 and Intermediate Product B1 to be used to model production in 2007. The weekly demand rate for both Product A and Intermediate Product B1 is obtained by taking the total demand from 2007 and dividing by the total number of weeks available for useful production. The formula used is:

$$\text{Weekly Demand} = \frac{\text{Sum of 2007 Monthly Demand}}{51\,\text{Weeks}}$$

Train 1 undergoes preventive maintenance for one week every year. Thus, in a 52 week year, only 51 weeks are available for useful production.

The inventory level when a product is not in production is shown in the table to provide a rough estimate on the minimum number of pallet spaces required.

Using the production capacity found in Table 2-1, the API facility can produce up to 10 batches of Intermediate Product B1 per week and 6 batches of Intermediate Product A1 per week. Thus, the corresponding unit production time for one batch

is 0.1 weeks for Intermediate Product B1 and 0.17 weeks for Intermediate Product A1.

The model proposes a cycle time of about 11 weeks. In this model, TCG would produce Intermediate Product A1 for 5.06 weeks, then switch over to producing Intermediate Product B1 for 2.14 weeks. The changeover time from Product A to Intermediate Product B1 is 2 weeks and vice versa. Thus, the total cycle time is 5.06 weeks for Product A, followed by 2 weeks for setup, followed by 2.14 weeks for Intermediate Product B1, and followed by 2 weeks for setup, for a total of 11.19 weeks.

		Intermediate Product B1	Intermediate Product A1
Demand Rate (Batches/Week)	d(i)	2.70	3.00
Unit Production Time (Batches/Week)	$\tau(i)$	0.10	0.17
Setup Time (Weeks)	S(i)	2.00	2.00
Production Size (Batches)	Q(i)	41.21	43.00
Campaign Production Time (Weeks)	$\tau(i)Q(i)$	4.12	7.17
Inventory during No Production(Batches)	$Q(i)-d(i)\tau(i)Q(i)$	30.10	22.84
Inventory during No Production(Pallets)	$Q(i)-d(i)\tau(i)Q(i)$	56.89	97.62
Cycle Time (Weeks)	T	15.29	

Table 4-2: 2008 Current Production Scenario and Predicted Inventory

In Table 4-2, we present production parameters for Intermediate Product A1 and Intermediate Product B1 to be used to model production in 2008. The weekly demand rate for both Product A and Intermediate Product B1 is obtained by taking the total demand from 2008 and dividing by the total number of weeks available for useful production. The formula used is:

$$\text{Weekly Demand} = \frac{\text{Sum of 2008 Monthly Demand}}{51\,\text{Weeks}}$$

There is only 51 weeks available for useful production as Train 1 undergoes preventive maintenance for one week every year. The rest of the parameters such as setup times, unit production times remain unchanged from the model used for 2007.

The model proposes a cycle time of about 15 weeks for 2008. In this model, TCG would produce Intermediate Product A1 for 7.17 weeks, then switch over to producing Intermediate Product B1 for 4.12 weeks. The changeover time from Product A to Intermediate Product B1 is 2 week and vice versa. Thus, the total cycle time is 7.17 weeks for Product A, followed by 2 week for setup, followed by 4.12 weeks for Intermediate Product B1, and followed by 2 week for setup, for a total of 15.29 weeks.

The subsequent figure shows the possible monthly master production schedule from 2007 to 2008 based on the proposed campaigning model using the parameters in Table 4-1 for 2007 and Table 4-2 for 2008. A detailed weekly master production schedule is available in the Appendix A-1.

Current Production for 2007-2008

		Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
Gross Demand (Batches)	Intermediate Product B1	7	9	2	11	9	15	5	7	8	8	10	6
	Intermediate Product A1	14	14	11	18	9	7	15	2	9	16	10	13
Production (Batches)	Intermediate Product B1	0	19	2	0	21	0	15	6	0	21	0	11
	Intermediate Product A1	30	0	11	20	0	22	9	8	22	0	19	5
Inventory (Batches)	Intermediate Product B1	29	22	20	32	26	34	19	18	28	20	19	24
	Intermediate Product A1	19	35	32	21	28	18	28	31	28	41	38	34
Inventory (Pallet Spaces)	Intermediate Product B1	55	42	37	61	49	65	36	34	53	38	35	45
	Intermediate Product A1	81	151	138	92	122	78	121	134	122	177	163	147
	Total	136	193	175	153	171	143	157	168	175	215	198	191

		Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08
Gross Demand (Batches)	Intermediate Product B1	14	9	14	11	14	13	7	13	10	10	9	3
	Intermediate Product A1	11	11	15	11	10	16	10	15	14	11	13	9
Production (Batches)	Intermediate Product B1	10	0	8	33	0	0	25	16	0	3	39	0
	Intermediate Product A1	6	24	13	0	16	27	0	3	24	11	0	19
Inventory (Batches)	Intermediate Product B1	21	36	16	10	32	18	8	24	30	18	11	32
	Intermediate Product A1	34	24	34	40	24	27	38	28	24	28	30	15
Inventory (Pallet Spaces)	Intermediate Product B1	40	67	30	20	61	34	15	45	57	35	22	61
	Intermediate Product A1	147	103	146	172	102	115	164	118	102	121	130	66
	Total	187	170	176	192	163	150	178	162	159	156	152	126

Figure 4-2: Proposed MPS using Current Parameters and Campaigning Model

In Figure 4-2, the starting inventory level for January 2007 was obtained from TCG and is highlighted in red. The inventory level for 2007 fluctuates between 136 to 215 pallet spaces and in 2008, the inventory level fluctuates between 126 to 192 pallet spaces. Figure 4-3 is a graphical representation of the pallet space requirement for Intermediate Product A1 and Intermediate Product B1 based on the MPS shown in Figure 4-2. In Figure 4-3, the total pallet space appears to fluctuate between 150 to 200 pallet spaces. However, the peak periods of high total pallet space appears to coincide with the periods where Intermediate Product A1 requires high volumes of pallet spaces. As compared to Intermediate Product A1, Intermediate Product B1 appears to have a more stable inventory level.

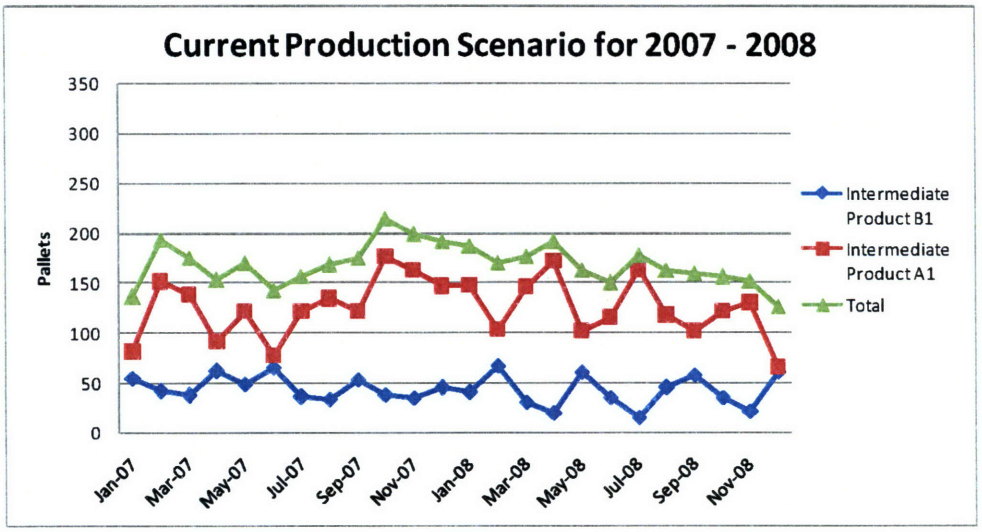

Figure 4-3: Graphical Representation of Inventory Level using the Campaigning Model with the Current Production Scenario

The following figure shows the actual inventory values for Intermediate Product A1 and Intermediate Product B1 over the first 5 months of 2007 (highlight in blue) and the predicted inventory level (highlight in pink) based on the forecasted demand and TCG's production plan.

Actual and Predicted Inventory for 2007

		Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
Gross Demand (Batches)	Intermediate Product B1	7	9	2	11	9	15	5	7	8	8	10	6
	Intermediate Product A1	14	14	11	18	9	7	15	2	9	16	10	13
Production (Batches)	Intermediate Product B1	0	0	0	30	24	0	0	0	34	39	13	0
	Intermediate Product A1	27	24	11	0	0	14	29	10	0	0	0	0
Inventory (Batches)	Intermediate Product B1	29	22	13	10	22	37	22	17	10	36	67	70
	Intermediate Product A1	19	25	32	38	24	15	22	36	44	35	19	9
Inventory (Pallet Spaces)	Intermediate Product B1	55	42	25	19	42	70	42	32	19	68	127	132
	Intermediate Product A1	81	107	137	162	103	64	94	155	188	149	81	37
	Total	136	148	161	181	144	134	136	187	207	217	207	169

		Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08
Gross Demand (Batches)	Intermediate Product B1	14	9	14	11	14	13	7	13	10	10	9	3
	Intermediate Product A1	11	11	15	11	10	16	10	15	14	11	13	9
Production (Batches)	Intermediate Product B1	0	0	0	0	20	36	28	10	0	0	0	0
	Intermediate Product A1	20	21	25	13	0	0	0	0	20	16	9	29
Inventory (Batches)	Intermediate Product B1	64	50	41	27	16	22	45	66	63	53	43	34
	Intermediate Product A1	9	29	50	60	61	51	35	25	10	17	21	18
Inventory (Pallet Spaces)	Intermediate Product B1	121	95	77	51	30	42	85	125	119	100	81	64
	Intermediate Product A1	37	122	212	256	263	219	151	107	44	71	90	75
	Total	158	217	290	307	293	260	236	232	163	171	172	140

Figure 4-4: Current and Predicted Inventory Level in 2007 and 2008

In Figure 4-4, the inventory level in 2007 fluctuates between 134 to 217 pallet spaces and between 140 to 307 pallet spaces in 2008. There is no production in December 2007 as TCG plans to order Intermediate Product A1 from its sister sites until March 2008 to cover the demand requirements. Figure 4-5 is a graphical representation of the pallet space consumption for Intermediate Product A1 and Intermediate Product B1 based on the MPS shown in Figure 4-4. In Figure 4-5, the peak periods of high total pallet space consumption appear to coincide with the period where Intermediate Product A1 consumes high volumes of pallet spaces. Both Intermediate Product A1 and Intermediate Product B1 have highly variable inventory level fluctuations.

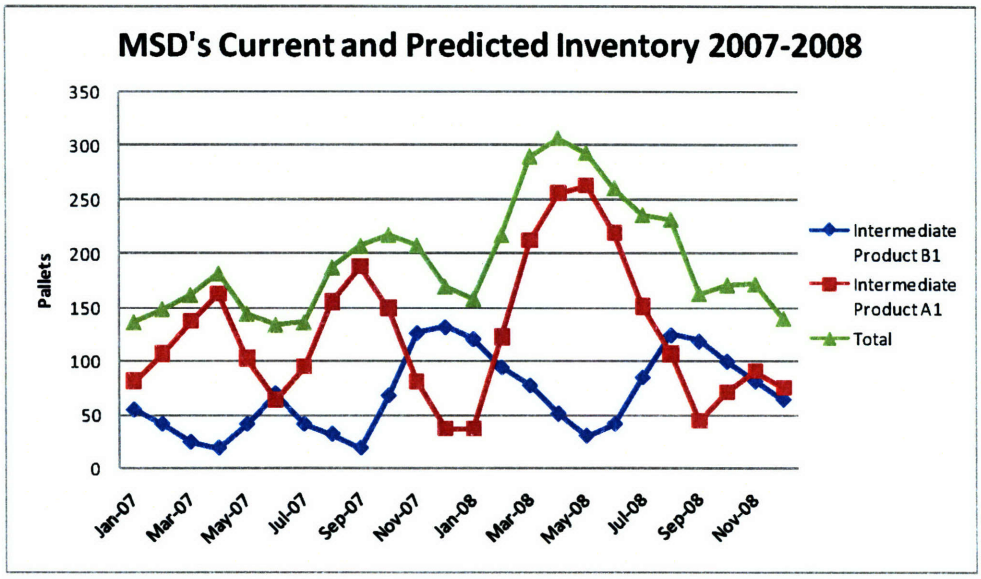

Figure 4-5: Graphical Representation of Inventory Level using TCG's Production Plan

By comparing Figure 4-2 and Figure 4-4, the maximum and minimum pallet space occupied by the warehouse in 2007 is approximately equal for both the campaigning model and TCG's production plan. However, in 2008, the campaigning model predicts a lower level for both the maximum and minimum pallet space than for TCG's production plan. By comparing the maximum pallet spaces consumed in 2008 between both production plans, the campaigning model reduces the pallet space consumption by 115 pallet spaces. By comparing the graphical representation of inventory levels in Figure 4-3 and Figure 4-5, the campaigning model stabilizes the inventory fluctuations over a smaller number of pallet spaces.

4.1.1.2 Future Production Scenario

The following table shows the recommended cycle time T based on the demand, future setup times and production capacity. Production capacity is unlikely to change over the next two years because this would usually involve additional capital spending. TCG has recently completed the Pharmaceutical Facility 2, and there is no indication that more capital will be spent on new equipment. Any increase in machine efficiency using the current capacity would result in minor

capacity increments, for example, the increase of 0.5 batches a month for Intermediate Product A1.

For the future production scenario, we assume that TCG can reduce its setup times by half, from the current 14 days to 7 days.

		Intermediate Product B1	Intermediate Product A1
Demand Rate (Batches/Week)	d(i)	1.91	2.71
Unit Production Time (Batches/Week)	τ(i)	0.10	0.17
Setup Time (Weeks)	S(i)	1.00	1.00
Production Size (Batches)	Q(i)	10.69	15.17
Campaign Production Time (Weeks)	τ(i)Q(i)	1.07	2.53
Inventory during No Production(Batches)	Q(i)-d(i)τ(i)Q(i)	8.65	8.32
Inventory during No Production(Pallets)	Q(i)-d(i)τ(i)Q(i)	16.35	35.54
Cycle Time (Weeks)	T	5.60	

Table 4-3: 2007 Production Scenario and Predicted Inventory

In Table 4-3, we present the future production parameters for Intermediate Product A1 and Intermediate Product B1 to be used to model production in 2007. The weekly demand rate for both Product A and Intermediate Product B1 is obtained by taking the total demand from 2007 and dividing by the total number of weeks available for useful production. The formula used is:

$$\text{Weekly Demand} = \frac{\text{Sum of 2007 Monthly Demand}}{51\,\text{Weeks}}$$

Train 1 undergoes preventive maintenance for one week every year. Thus, in a 52 week year, only 51 weeks are available for useful production.

Using the production capacity found in Table 2-1, the API facility can produce up to 10 batches of Intermediate Product B1 per week and 6 batches of Intermediate Product A1 per week. Thus, the corresponding unit production time for one batch is 0.1 weeks for Intermediate Product B1 and 0.17 weeks for Intermediate Product A1.

The model proposes a cycle time of about 5 weeks for 2007. In this model, TCG would produce Intermediate Product A1 for 2.53 weeks, then switch over to producing Intermediate Product B1 for 1.07 weeks. The changeover time from Product A to Intermediate Product B1 is 1 week and vice versa. Thus, the total cycle time is 2.53 weeks for Product A, followed by 1 week for setup, followed by 1.07 weeks for Intermediate Product B1, and followed by 1 week for setup, for a total of 5.6 weeks.

		Intermediate Product B1	Intermediate Product A1
Demand Rate (Batches/Week)	d(i)	2.70	3.00
Unit Production Time (Batches/Week)	$\tau(i)$	0.10	0.17
Setup Time (Weeks)	S(i)	1.00	1.00
Production Size (Batches)	Q(i)	20.61	21.50
Campaign Production Time (Weeks)	$\tau(i)Q(i)$	2.06	3.58
Inventory during No Production(Batches)	$Q(i)-d(i)\tau(i)Q(i)$	15.05	11.42
Inventory during No Production(Pallets)	$Q(i)-d(i)\tau(i)Q(i)$	28.45	48.81
Cycle Time (Weeks)	T	7.64	

Table 4-4: 2008 Production Scenario and Predicted Inventory

In Table 4-4, we present production parameters for Intermediate Product A1 and Intermediate Product B1 to be used to model production in 2008. The weekly demand rate for both Product A and Intermediate Product B1 is obtained by taking the total demand from 2008 and dividing by the total number of weeks available for useful production. The formula used is:

$$\text{Weekly Demand} = \frac{\text{Sum of 2008 Monthly Demand}}{51\,\text{Weeks}}$$

There is only 51 weeks available for useful production as Train 1 undergoes preventive maintenance for one week every year. The rest of the parameters such

as setup times, unit production times remain unchanged from the model used for 2007.

The model proposes a cycle time of about 7 weeks for 2008. In this model, TCG would produce Intermediate Product A1 for 3.58 weeks, then switch over to producing Intermediate Product B1 for 2.06 weeks. The changeover time from Product A to Intermediate Product B1 is 1 week and vice versa. Thus, the total cycle time is 3.58 weeks for Product A, followed by 1 week for setup, followed by 2.06 weeks for Intermediate Product B1, and followed by 1 week for setup, for a total of 7.64 weeks.

The subsequent figure shows the possible monthly master production schedule from 2007 to 2008 based on the proposed campaigning model using the parameters in Table 4-3 for 2007 and Table 4-4 for 2008. A detailed weekly master production schedule is available in the Appendix A-2.

Future Production for 2007-2008

		Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
Gross Demand (Batches)	Intermediate Product B1	7	9	2	11	9	15	5	7	8	8	10	6
	Intermediate Product A1	14	14	11	18	9	7	15	2	9	16	10	13
Production (Batches)	Intermediate Product B1	11	0	11	11	11	1	10	10	11	11	0	11
	Intermediate Product A1	15	15	11	12	8	15	15	9	7	15	15	10
Inventory (Batches)	Intermediate Product B1	29	26	26	32	30	30	22	25	27	25	25	25
	Intermediate Product A1	19	26	25	21	22	19	24	22	29	32	32	31
Inventory (Pallet Spaces)	Intermediate Product B1	55	50	49	61	57	56	42	48	52	48	48	48
	Intermediate Product A1	81	109	105	92	95	79	101	95	122	138	136	132
	Total	136	159	154	153	152	136	144	143	174	186	183	180

		Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08
Gross Demand (Batches)	Intermediate Product B1	14	9	14	11	14	13	7	13	10	10	9	3
	Intermediate Product A1	11	11	15	11	10	16	10	15	14	11	13	9
Production (Batches)	Intermediate Product B1	20	0	21	0	21	11	10	15	6	21	0	21
	Intermediate Product A1	6	18	6	20	4	17	12	9	14	1	21	7
Inventory (Batches)	Intermediate Product B1	29	24	25	22	23	31	20	28	25	28	36	27
	Intermediate Product A1	28	30	28	29	29	22	29	25	27	22	12	18
Inventory (Pallet Spaces)	Intermediate Product B1	54	45	47	42	44	59	37	53	47	52	68	51
	Intermediate Product A1	118	130	121	124	122	95	124	105	115	96	52	79
	Total	172	175	168	166	167	154	160	158	161	148	121	130

Figure 4-6: Proposed MPS using Future Parameters and Campaigning Model

In Figure 4-6, the starting inventory level for January 2007 was obtained from TCG and is highlighted in red. The inventory level for 2007 fluctuates between 136 to 186 pallet spaces and in 2008, the inventory level fluctuates between 121 to 175 pallet spaces. Figure 4-7 is a graphical representation of the pallet space consumption for Intermediate Product A1 and Intermediate Product B1 based on the MPS shown in Figure 4-6. In Figure 4-7, the total pallet space consumption appears to be relatively stable, and fluctuates between 150 to 180 pallet spaces. The pallet space consumption for Intermediate Product B1 appears to be relatively flat from 2007 to 2008.

Thus, the fluctuations in total pallet space consumption appear to be dominated largely by fluctuations in Intermediate Product A1's pallet space consumption.

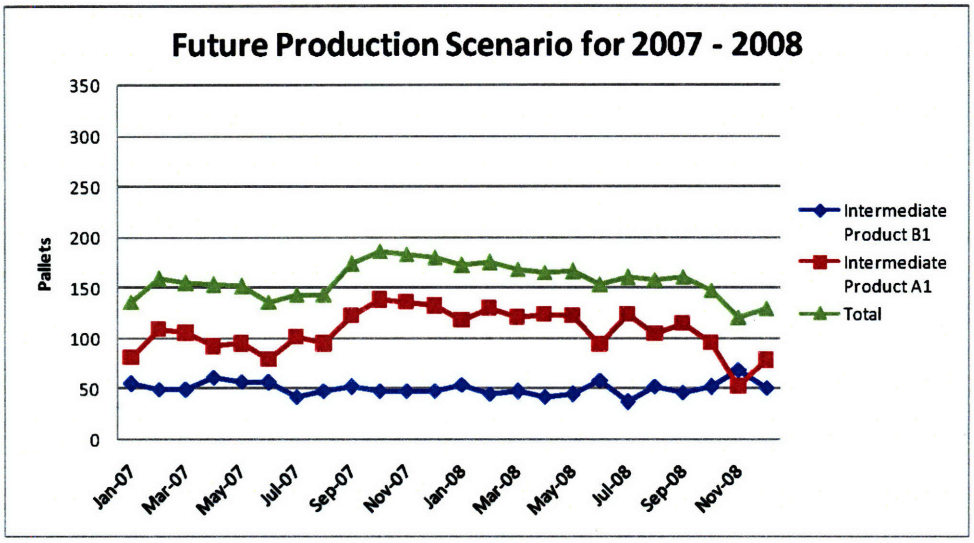

Figure 4-7: Graphical Representation of Inventory Level using the Campaigning Model with the Future Production Scenario

By comparing Figure 4-4 and Figure 4-6 for 2007, the maximum pallet space consumption is reduced by 31 pallet spaces when the campaigning model is used over TCG's production plan. In 2008, the campaigning model predicts a lower maximum and minimum pallet space consumption than TCG's production plan. By comparing the maximum pallet spaces required in 2008 between both production plans, the campaigning model reduces the pallet space requirements by 130 pallet spaces. By comparing the graphical representation of inventory levels in Figure 4-5 and Figure 4-7, the campaigning model stabilizes the inventory fluctuations over a smaller number of pallet spaces.

4.1.2 Limitations

The campaigning model assumes that every batch of Intermediate Product A1 or Intermediate Product B1 does not have quality deviations, so every batch produced can be used to satisfy the demand for a particular week. A batch with quality deviation takes a longer than average time to be released from the quality testing department and additional inventory must be available to satisfy the demand for that particular week. Thus, a safety stock level could be kept to guard

against quality deviations in the production of Intermediate Product A1 and Intermediate Product B1.

4.2 Order-up-to Policy for Product A

Product A inventory acts as a buffer between the API facility and PF1 facility to prevent starvation at the PF1 facility.

	Demand (Batches/Month)		Production (Batches/Month)	
Year	Average	Std Dev	Average	Std Dev
2006	8.08	3.18	9.17	3.71
2007	10.42	3.43	10.08	3.70
2008	10.75	1.86		

Table 4-5: Monthly Demand and Production for Product A

In Table 4-5, we present the average and the standard deviation of the demand and production of Product A from 2006 to 2008. The values in Table 4-5 are derived by using a combination of actual data from January 2006 to May 2007 and the forecasted data from June 2007 to December 2008. From Table 4-5, the average values and standard deviations for both demand and production in 2006 and 2007 appear to be closely matched. However, the average production quantity is still higher than the average demand quantity. This difference in average quantity over time is shown in Figure 4-8 as an increasing inventory trend for Product A from January 2006 to May 2007. Despite the planners' decision to produce according to demand, the inventory follows an increasing trend. Thus, there is reason to believe that there is no inventory policy managing Product A.

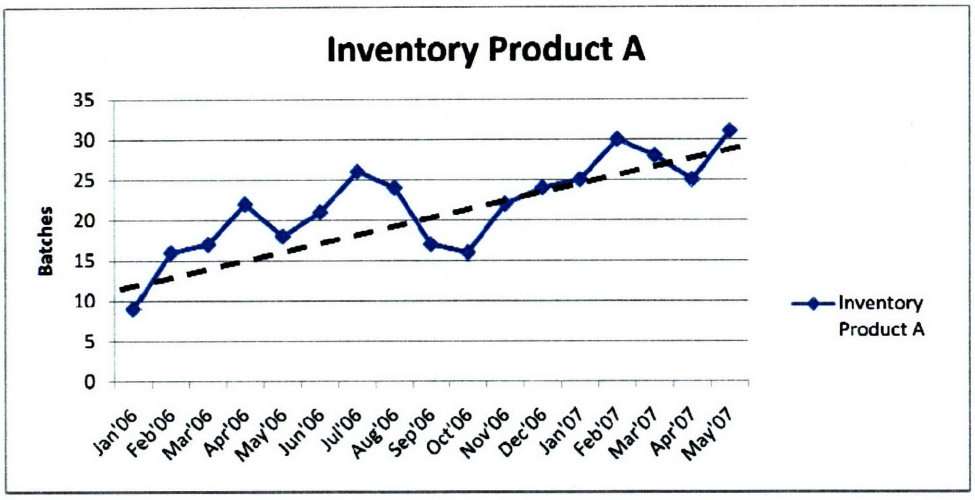

Figure 4-8: Inventory of Product A

We will assume that production of Product A is never starved of its raw material Intermediate Product A1 and Intermediate Product A2. We then suggest and examine an order-up-to policy to determine the target inventory level required to prevent a stock out at PF1. With the order-up-to policy, TCG will produce Product A in each week as long as the inventory level is below a set target inventory level. When the target level is reached, TCG will only produce Product A at that week's demand to maintain the inventory at the target inventory level. In the event that the demand for Product A is greater than the production capacity, the excess demand is satisfied by inventory. The objective of the order-up-to policy is to stabilize the inventory at a target inventory level such that there is a limited probability of stock out at the PF1.

4.2.1 Simulation

I will use an Excel simulation to simulate the weekly demand and production capacity of Product A at the API facility in order to determine the target inventory level for an order-up-to policy.

To develop the simulation, we will make use of the following notation:

D_i = Demand for week i

I_i = Inventory for week i

I_{target} = Target Inventory

P_i = Production for week i

μ_D = Mean weekly demand

σ_D = Weekly standard deviation of demand

$Rand_i$ = Random number for week i from a Normal Distribution, $X \sim N(0,1)$

$MaxCap$ = Maximum weekly production capacity

We generate random demand in week i as

$$D_i = \mu_D \pm Rand_i * \sigma_D$$

The production for the week i is given by

$$P_i = \begin{cases} MaxCap & \text{if } D_i > MaxCap \\ D_i & \text{if } D_i < MaxCap \;\&\; I_{i-1} = I_{target} \\ D_i + (I_{target} - I_{i-1}) & \text{if } D_i < MaxCap \;\&\; D_i + (I_{target} - I_{i-1}) < MaxCap \;\&\; I_{i-1} \neq I_{target} \\ MaxCap & \text{if } D_i < MaxCap \;\&\; D_i + (I_{target} - I_{i-1}) > MaxCap \;\&\; I_{i-1} \neq I_{target} \end{cases}$$

The change in inventory between week i-1 and week i is given by

$$I_i = I_{i-1} + P_i - D_i$$

Due to TCG's policy of meeting all of its customer demand, I set the probability of not stocking out with a particular target inventory level at a minimum of 99% up to a maximum of 100%. I generate over 1000 random numbers to simulate the random demand over 1000 periods. Using the above formulas, I simulate the change in inventory levels and search through a range of target inventory levels for Product A to determine the appropriate target inventory level.

Based on TCG's past demand and production schedule as well as planning behavior, I made the following assumptions.

1. The maximum production capacity for Product A is 3 batches per week and there is no uncertainty in production. This assumption will hold if the API facility has sufficient manpower
2. The quality department takes a fixed time to release a batch of Product A for use in the PF1 facility. This assumption will hold if the quality department does not detect any Atypical Product A batch.

In Table 4-6, we present the parameters used to model the order-up-to policy for Product A using the actual and forecasted demand for 2007.

	Average	Std Dev
Demand (Batches/Week)	2.50	1.68
Target Inventory (Batches)	17.00	
Max Production (Batches/Week)	3.00	

Table 4-6: 2007 Model Parameters and Results

The actual weekly demand data is unavailable because the demand received by the API facility is the monthly demand. The weekly demand shown in Table 4-6 can be determined from the monthly demand by:

$$\text{Weekly Demand} = \frac{\text{Sum of 2007 Monthly Demand}}{\text{50 Weeks}}$$

The weekly demand is obtained by taking the total Product A demand in 2007 and dividing over the number of weeks of useful production. The Milling Train of the API facility shuts down for two weeks for preventive maintenance. The demand during these two weeks is redistributed over the remaining fifty weeks of the year.

The standard deviation shown in Table 4-6 is obtained by:

$$\text{Weekly Std. Dev.} = \sqrt{\frac{\text{12 Months}}{\text{50 Weeks}} * (\text{Monthly Std. Dev.})^2}$$

To obtain the weekly standard deviation, I assume that the each week's demand is mutually independent of the next week's demand. Thus, the monthly standard deviation is the sum of the weekly standard deviation.

In

Production Line	Product	Adjusted Production Capacity (batches per week of Product A)
Train 1	Intermediate Product A1	4
Train 2	Intermediate Product A2	3
Train 2 (Milling)	Product A	3.5

Table 2-2, the maximum weekly production capacity for Product A is 3.5 batches. However, the planners at the API facility usually use 3 batches as the production capacity of Product A per week.

Using the Excel spreadsheet, when the target inventory level is set at 18 batches, the probability of stocking out over the 1000 random numbers generated is 0.

Target Inventory (Batches)	Probability of No Stock Out
1	55.82%
2	67.04%
3	61.72%
4	82.24%
5	86.92%
6	89.94%
7	92.44%
8	94.30%
9	96.06%
10	97.46%
11	98.46%
12	99.14%
13	99.52%
14	99.72%
15	99.82%
16	99.92%
17	99.96%
18	100.00%

Table 4-7: Target Inventory and No Stock Out Probability with 2007 Demand

In Table 4-7, I use the Excel spreadsheet to tabulate the probability of not stocking out against the target inventory level. By setting the target inventory level between 12 to 18 batches, the probability of not stocking out is between the accepted range of 99% and 100%.

The following figure shows the first 10 values and last 10 values of the Excel spreadsheet used in this simulation as well as the parameters seen in Table 4-6.

	Demand Mean		2.5	Target Inventory			18	
	Demand Std Dev		1.68	Max. Production			3	
Trial	Rand	Demand	Production	Change in Inventory	Max Inventory	Positive / Negative	# of Positive Inventory	# of Negative Inventory
	0	0	0	0	18	1	1000	0
1	0.427819	3	3	0	18	1	1	0
2	0.044192	3	3	0	18	1		
3	-0.19426	2	2	0	18	1		
4	-1.67717	0	0	0	18	1		
5	-0.04174	2	2	0	18	1		
6	0.728575	4	3	-1	17	1		
7	-1.37068	0	1	1	18	1		
8	-0.59191	2	2	0	18	1		
9	0.841119	4	3	-1	17	1		
10	0.92132	4	3	-1	16	1		
990	-0.81035	1	1	0	18	1		
991	0.89429	4	3	-1	17	1		
992	0.27313	3	3	0	17	1		
993	-0.83135	1	2	1	18	1		
994	0.201358	3	3	0	18	1		
995	-0.84658	1	1	0	18	1		
996	1.175604	4	3	-1	17	1		
997	-0.35333	2	3	1	18	1		
998	-0.20901	2	2	0	18	1		
999	-2.31803	-1	-1	0	18	1		
1000	0.442199	3	3	0	18	1		

Figure 4-9: Excel Simulation Spreadsheet

In Table 4-8, we present the parameters used to model the order-up-to policy for Product A using the forecasted demand for 2008.

	Average	Std Dev
Demand (Batches/Week)	2.58	1.68
Target Inventory (Batches)	16.00	
Max Production (Batches/Week)	3.00	

Table 4-8: 2008 Model Parameters and Results

The monthly demand has increased from 10.42 batches per month in 2007 to 10.75 batches per month in 2008. Using the equation to determine the weekly demand, the weekly demand for 2008 is 2.58 batches. As a simplifying estimate, I

assume that the standard deviation in demand for 2008 will be the same as in 2007, thus the standard deviation for 2008 remains at 1.68 batches. I assume that there will be no increase in the production capacity of Product A as TCG does not plan to buy new equipment to increase its production capacity.

Using the Excel spreadsheet, when the target inventory level is set at 19 batches, the probability of stocking out over the 1000 random numbers generated is 0.

Target Inventory (Batches)	Probability of No Stock Out
1	49.38%
2	60.72%
3	69.94%
4	77.38%
5	83.08%
6	87.18%
7	89.48%
8	91.70%
9	93.58%
10	95.54%
11	96.96%
12	97.76%
13	98.50%
14	99.00%
15	99.30%
16	99.46%
17	99.72%
18	99.90%
19	100.00%

Table 4-9: Target Inventory and No Stock Out Probability with 2008 Demand

In Table 4-9, I use the Excel spreadsheet to tabulate the probability of not stocking out against the target inventory level. By setting the target inventory level between 14 to 19 batches, the probability of not stocking out is between the accepted range of 99% and 100%.

As seen previously in Chapter 3.1 , Figure 3-1 shows that the inventory level of Product A is 13% of the total average inventory from January 2006 to May 2007; this translates to an average of 22 batches of Product A. By implementing the

order-up-to policy using Table 4-9 and the demand for 2008, I suggest a target inventory level of 14 to 19 batches in order for the no stock out probability to be between 99% to 100%. This will result in a reduction of 3 to 8 batches or 31 to 82 pallets of Product A.

4.2.2Limitations

I assume that the API facility is able to produce 3 batches per week in this model as the uncertainty in production is ignored. The API facility currently faces a manpower shortage when either Train 1 or Train 2 undergoes preventive maintenance or campaign turnaround cleaning. The production capacity during these periods can drop to as low as 1 batch per week.

In addition, this model has ignored the occurrence of Atypical Product A batches. An Atypical Product A batch is usually caused by an error in production. This affects the model by adding uncertainty into the time taken by the quality department to release a normal batch of Product A for use in the PF1 facility. A safety factor which considers the probability of an Atypical Product A batch occurring could be added to the target inventory level. TCG is currently unable to quantify the frequency of quality deviations for Product A.

Chapter 5: Recommendations and Conclusion

5.1 Recommendations

The campaigning model in Chapter 4.1 using the current production parameters performs as well as TCG's current campaigning plan in 2007. In 2008, the proposed campaigning model outperforms TCG's current campaigning plan by stabilizing the inventory level fluctuations; this leads to a reduction of 115 pallet space. In addition, TCG should reduce the setup time from 14 days to 7 days to further stabilize the inventory fluctuations. The reduction in setup time reduces the cycle time and reduces the inventory by 31 pallets in 2007 and by 130 pallets in 2008. TCG should adopt the proposed campaigning model in 2008. In addition, TCG should reduce the setup time from 14 days to 7 days to stabilize the inventory fluctuations.

An order-up-to policy should be used to control the inventory of Product A. The policy can stabilize the inventory at a fixed level and prevent stock outs. By setting the target Product A inventory at 19 batches for 2008, TCG can achieve a reduction of 4 batches (31 pallets). This is a 1.8% reduction in TCG's total average inventory levels

5.2 Conclusion

I explore a model to schedule the campaigning activities of Intermediate Product A1 and Intermediate Product B1. The model determines the minimal campaign cycle time to reduce the inventory levels. For 2008, a minimum reduction of 115 pallet spaces is achieved when the campaigning model is used over TCG's current campaigning plan.

Product A has a growing inventory trend, accounting for 13% of the total average warehouse inventory, and there is no obvious inventory control policy. Using an order-up-to policy, TCG can stabilize the inventory level of Product A at a fixed level of 19 batches without compromising the probability of stock out. TCG can

achieve a reduction to 1.8% of the total average warehouse inventory by keeping the target inventory level at 19 batches. The order-up-to policy is similar to TCG's kanban policy used for Intermediate Product A2 as both policies attempt to maintain the inventory at a fixed level.

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Appendix

Appendix A-1

Current production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	January					February				March				April				
					1	8	15	22	29	5	12	19	26	5	12	19	26	2	9	16	23	30
Demand Rate	Batches	Intermediate Product B1			1.40	1.40	1.40	1.40	1.40	2.25	2.25	2.25	2.25	0.50	0.50	0.50	0.50	2.20	2.20	2.20	2.20	2.20
	Batches	Intermediate Product A1			2.73	2.73	2.73	2.73	2.73	3.42	3.42	3.42	3.42	2.85	2.85	2.85	2.85	3.65	3.65	3.65	3.65	3.65
Production	Batches	Intermediate Product B1	10									9.40	10.00	2.00								
	Batches	Intermediate Product A1	6		6.00	6.00	6.00	6.00	6.00	0.36						4.80	6.00	6.00	6.00	6.00	1.56	
Inventory	Batches	Intermediate Product B1		29	27.60	26.20	24.80	23.40	22.00	19.75	17.50	24.65	32.40	33.90	33.40	32.90	32.40	30.20	28.00	25.80	23.60	21.40
	Batches	Intermediate Product A1		19	22.27	25.53	28.80	32.06	35.33	32.27	28.86	25.44	22.02	19.17	16.33	18.28	21.43	23.79	26.14	28.50	26.41	22.77
Total	Pallets				147.32	158.63	169.94	181.25	192.56	175.25	156.39	155.30	155.35	146.01	132.90	140.29	152.82	158.73	164.63	170.54	157.47	137.74

Current production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	May				June				July					August			
					7	14	21	28	4	11	28	25	2	9	16	23	30	6	13	20	27
Demand Rate	Batches	Intermediate Product B1			2.25	2.25	2.25	2.25	3.75	3.75	3.75	3.75	1.00	1.00	1.00	1.00	1.00	1.75	1.75	1.75	1.75
	Batches	Intermediate Product A1			2.28	2.28	2.28	2.28	1.71	1.71	1.71	1.71	2.96	2.96	2.96	2.96	2.96	0.57	0.57	0.57	0.57
Production	Batches	Intermediate Product B1	10		7.40	10.00	4.00									5.40	10.00	6.00			
	Batches	Intermediate Product A1	6						3.60	6.00	6.00	6.00	6.00	2.76						2.40	6.00
Inventory	Batches	Intermediate Product B1		29	26.55	34.30	36.05	33.80	30.05	26.30	22.55	18.80	17.80	16.80	15.80	20.20	29.20	33.45	31.70	29.95	28.20
	Batches	Intermediate Product A1		19	20.49	18.21	15.93	13.65	15.55	19.84	24.13	28.42	31.46	31.26	28.30	25.33	22.37	21.80	21.23	23.06	28.49
Total	Pallets				137.73	142.65	136.22	122.23	123.23	134.48	145.73	156.98	168.07	165.32	150.78	146.44	150.79	156.39	150.65	155.16	175.06

Current production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	September				October					November				December				
					3	10	17	24	1	8	15	22	29	5	12	19	26	3	10	17	24	31
Demand Rate	Batches	Intermediate Product B1			2.00	2.00	2.00	2.00	1.60	1.60	1.60	1.60	1.60	2.50	2.50	2.50	2.50	1.20	1.20	1.20	1.20	1.20
	Batches	Intermediate Product A1			2.28	2.28	2.28	2.28	3.19	3.19	3.19	3.19	3.19	2.56	2.56	2.56	2.56	2.51	2.51	2.51	2.51	2.51
Production	Batches	Intermediate Product B1	10							3.40	10.00	8.00						Plant			1.40	10.00
	Batches	Intermediate Product A1	6		6.00	6.00	6.00	3.96						1.20	6.00	6.00	6.00	Shutdown	5.16			
Inventory	Batches	Intermediate Product B1		29	26.20	24.20	22.20	20.20	18.60	20.40	28.80	35.20	33.60	31.10	28.60	26.10	23.60	22.40	21.20	20.00	20.20	29.00
	Batches	Intermediate Product A1		19	32.22	35.94	39.66	41.34	38.15	34.96	31.77	28.58	25.39	24.03	27.47	30.91	34.34	31.84	34.49	31.98	29.48	26.97
Total	Pallets				187.19	199.31	211.44	214.84	198.19	187.96	190.21	188.68	172.02	161.47	171.44	181.40	191.36	178.38	187.46	174.48	164.15	170.07

Current production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	January				February				March					April			
					7	14	21	28	4	11	18	25	3	10	17	24	31	7	14	21	28
Demand Rate	Batches	Intermediate Product B1			3.50	3.50	3.50	3.50	2.25	2.25	2.25	2.25	2.80	2.80	2.80	2.80	2.80	2.75	2.75	2.75	2.75
	Batches	Intermediate Product A1			2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.96	2.96	2.96	2.96	2.96	2.85	2.85	2.85	2.85
Production	Batches	Intermediate Product B1	10		10.00												8.30	10.00	10.00	10.00	2.90
	Batches	Intermediate Product A1	6					6.00	6.00	6.00	6.00	6.00	6.00	6.00	1.02						
Inventory	Batches	Intermediate Product B1		29	35.50	32.00	28.50	25.00	22.75	20.50	18.25	16.00	13.20	10.40	7.60	4.80	10.30	17.55	24.80	32.05	32.20
	Batches	Intermediate Product A1		19	24.13	21.28	18.43	21.58	24.73	27.89	31.04	34.19	37.23	40.27	38.33	35.37	32.40	29.56	26.71	23.86	21.01
Total	Pallets				170.19	151.41	132.62	139.48	148.70	157.92	167.13	176.35	184.04	191.74	178.15	160.20	157.94	159.47	161.01	162.54	150.65

Current production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	May				June					July				August			
					5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25
Demand Rate	Batches	Intermediate Product B1			3.50	3.50	3.50	3.50	2.60	2.60	2.60	2.60	2.60	1.75	1.75	1.75	1.75	3.25	3.25	3.25	3.25
	Batches	Intermediate Product A1			2.56	2.56	2.56	2.56	3.19	3.19	3.19	3.19	3.19	2.56	2.56	2.56	2.56	3.70	3.70	3.70	3.70
Production	Batches	Intermediate Product B1	10												5.40	10.00	10.00	10.00	5.80		2.52
	Batches	Intermediate Product A1	6			4.26	6.00	6.00	6.00	6.00	6.00	6.00	2.76								
Inventory	Batches	Intermediate Product B1		29	28.70	25.20	21.70	18.20	15.60	13.00	10.40	7.80	5.20	3.45	7.10	15.35	23.60	30.35	32.90	29.65	26.40
	Batches	Intermediate Product A1		19	18.45	20.15	23.58	27.02	29.83	32.64	35.45	38.26	37.83	35.27	32.71	30.15	27.58	23.88	20.18	16.48	15.30
Total	Pallets				133.09	133.72	141.80	149.87	156.97	164.06	171.16	178.26	171.51	157.25	153.19	157.83	162.48	159.41	148.41	126.45	115.26

Current production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	September					October				November				December				
					1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Demand Rate	Batches	Intermediate Product B1			2.00	2.00	2.00	2.00	2.00	2.50	2.50	2.50	2.50	2.25	2.25	2.25	2.25	0.60	0.60	0.60	0.60	0.60
	Batches	Intermediate Product A1			2.73	2.73	2.73	2.73	2.73	2.85	2.85	2.85	2.85	3.13	3.13	3.13	3.13	1.82	1.82	1.82	1.82	1.82
Production	Batches	Intermediate Product B1	10						Plant Shutdown				2.50	10.00	10.00	10.00	8.70		0.78	6.00	6.00	6.00
	Batches	Intermediate Product A1	6		6.00	6.00	6.00	6.00		6.00	4.50											
Inventory	Batches	Intermediate Product B1		29	24.40	22.40	20.40	18.40	16.40	13.90	11.40	8.90	8.90	16.65	24.40	32.15	38.60	38.00	37.40	36.80	36.20	35.60
	Batches	Intermediate Product A1		19	18.56	21.83	25.09	28.36	25.63	28.78	30.43	27.58	24.74	21.60	18.47	15.34	12.21	10.38	9.34	13.52	17.70	21.87
Total	Pallets				125.43	135.61	145.79	155.97	140.51	149.25	151.59	134.69	122.52	123.79	125.05	126.31	125.11	116.19	110.60	127.32	144.04	160.76

Appendix A-2

Future production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	January					February				March				April				
					1	8	15	22	29	5	12	19	26	5	12	19	26	2	9	16	23	30
Demand Rate	Batches	Intermediate Product B1			1.40	1.40	1.40	1.40	1.4	2.25	2.25	2.25	2.25	0.50	0.50	0.50	0.50	2.20	2.20	2.20	2.20	2.20
	Batches	Intermediate Product A1			2.73	2.73	2.73	2.73	2.73376	3.4172	3.4172	3.4172	3.4172	2.85	2.85	2.85	2.85	3.65	3.65	3.65	3.65	3.65
Production	Batches	Intermediate Product B1	10					4.70	6.00					8.70	1.90				2.80	7.90		
	Batches	Intermediate Product A1	6		6.00	6.00	3.18			2.40	6.00	6.00	0.78			4.86	6.00	4.32			1.26	6.00
Inventory	Batches	Intermediate Product B1		29	27.60	26.20	24.80	28.10	32.70	30.45	28.20	25.95	23.70	31.90	33.30	32.80	32.30	30.10	30.70	36.40	34.20	32.00
	Batches	Intermediate Product A1		19	22.27	25.53	25.98	23.24	20.51	19.49	22.08	24.66	22.02	19.17	16.33	18.34	21.49	22.17	18.52	14.88	12.49	14.85
Total	Pallets				147.32	158.63	157.89	152.44	149.45	140.85	147.64	154.42	138.90	142.23	132.71	140.36	152.89	151.61	137.17	132.37	118.02	123.92

Future production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	May				June				July					August			
					7	14	21	28	4	11	28	25	2	9	16	23	30	6	13	20	27
Demand Rate	Batches	Intermediate Product B1			2.25	2.25	2.25	2.25	3.75	3.75	3.75	3.75	1.00	1.00	1.00	1.00	1.00	1.75	1.75	1.75	1.75
	Batches	Intermediate Product A1			2.28	2.28	2.28	2.28	1.71	1.71	1.71	1.71	2.96	2.96	2.96	2.96	2.96	0.57	0.57	0.57	0.57
Production	Batches	Intermediate Product B1	10				6.80	3.90				0.80	9.90					4.90	5.10		
	Batches	Intermediate Product A1	6		6.00	1.92			3.66	6.00	5.52			0.06	6.00	6.00	3.06			2.52	6.00
Inventory	Batches	Intermediate Product B1		29	29.75	27.50	32.05	33.70	29.95	26.20	22.45	19.50	28.40	27.40	26.40	25.40	24.40	27.55	30.90	29.15	27.40
	Batches	Intermediate Product A1		19	18.57	18.21	15.93	13.65	15.61	19.90	23.71	22.00	19.04	16.14	19.18	22.21	22.31	21.74	21.17	23.12	28.55
Total	Pallets				135.58	129.79	128.66	122.04	123.29	134.54	143.74	130.87	135.03	120.74	131.84	142.93	141.46	144.98	148.88	153.91	173.81

Future production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	September				October					November				December				
					3	10	17	24	1	8	15	22	29	5	12	19	26	3	10	17	24	31
Demand Rate	Batches	Intermediate Product B1			2.00	2.00	2.00	2.00	1.60	1.60	1.60	1.60	1.60	2.50	2.50	2.50	2.50	1.20	1.20	1.20	1.20	1.20
	Batches	Intermediate Product A1			2.28	2.28	2.28	2.28	3.19	3.19	3.19	3.19	3.19	2.56	2.56	2.56	2.56	2.51	2.51	2.51	2.51	2.51
Production	Batches	Intermediate Product B1	10				8.90	1.80										7.00	3.70			
	Batches	Intermediate Product A1	6		6.00	0.66								1.32	6.00	6.00	1.80			3.78	Plant Shutdown	6.00
Inventory	Batches	Intermediate Product B1		29	25.40	23.40	30.30	30.10	28.50	26.90	25.30	26.60	32.80	30.30	27.80	25.30	22.80	28.60	31.10	29.90	28.70	27.50
	Batches	Intermediate Product A1		19	32.28	30.66	28.38	26.10	27.83	30.64	31.71	28.52	25.33	24.09	27.53	30.97	30.20	27.70	25.19	26.46	23.96	27.45
Total	Pallets				185.93	175.24	178.54	168.43	172.80	181.79	183.34	172.17	170.25	160.22	170.18	180.14	172.16	172.41	166.43	169.60	156.63	169.29

Future production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	January				February				March					April			
					7	14	21	28	4	11	18	25	3	10	17	24	31	7	14	21	28
Demand Rate	Batches	Intermediate Product B1			3.50	3.50	3.50	3.50	2.25	2.25	2.25	2.25	2.80	2.80	2.80	2.80	2.80	2.75	2.75	2.75	2.75
	Batches	Intermediate Product A1			2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.96	2.96	2.96	2.96	2.96	2.85	2.85	2.85	2.85
Production	Batches	Intermediate Product B1	10			0.40	10.00	10.00	0.20					4.00	10.00	6.60					
	Batches	Intermediate Product A1	6		5.76					5.88	6.00	6.00	3.60				2.04	6.00	6.00	6.00	1.50
Inventory	Batches	Intermediate Product B1		29	24.00	20.90	27.40	33.90	31.85	29.60	27.35	25.10	22.30	23.50	30.70	34.50	31.70	28.95	26.20	23.45	20.70
	Batches	Intermediate Product A1		19	30.37	27.52	24.67	21.82	18.97	22.01	25.16	28.31	28.95	25.99	23.03	20.07	19.14	22.30	25.45	28.60	27.25
Total	Pallets				175.12	157.09	157.21	157.32	141.28	149.99	159.21	168.42	165.86	155.47	156.42	150.95	141.72	149.99	158.27	166.54	155.58

Future production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	May				June					July				August			
					5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25
Demand Rate	Batches	Intermediate Product B1			3.50	3.50	3.50	3.50	2.60	2.60	2.60	2.60	2.60	1.75	1.75	1.75	1.75	3.25	3.25	3.25	3.25
	Batches	Intermediate Product A1			2.56	2.56	2.56	2.56	3.19	3.19	3.19	3.19	3.19	2.56	2.56	2.56	2.56	3.70	3.70	3.70	3.70
Production	Batches	Intermediate Product B1	10		7.50	10.00	3.10					1.10	10.00	9.50						4.70	10.00
	Batches	Intermediate Product A1	6					4.14	6.00	6.00	5.34				0.30	6.00	6.00	6.00	3.18		
Inventory	Batches	Intermediate Product B1		29	24.70	31.20	30.80	27.30	24.70	22.10	19.50	18.00	25.40	33.15	31.40	29.65	27.90	24.65	21.40	22.85	29.60
	Batches	Intermediate Product A1		19	24.69	22.13	19.56	21.14	23.95	26.76	28.91	25.72	22.53	19.97	17.71	21.15	24.58	26.88	26.36	22.66	18.96
Total	Pallets				152.19	153.53	141.82	141.94	149.04	156.13	160.41	143.95	144.30	148.00	135.02	146.40	157.78	161.46	153.09	140.01	136.95

Future production scenario for 2007 to 2008

			Production Capacity	Initial Inventory	September					October				November				December				
					1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Demand Rate	Batches	Intermediate Product B1			2.00	2.00	2.00	2.00	2.00	2.50	2.50	2.50	2.50	2.25	2.25	2.25	2.25	0.60	0.60	0.60	0.60	0.60
	Batches	Intermediate Product A1			2.73	2.73	2.73	2.73	2.73	2.85	2.85	2.85	2.85	3.13	3.13	3.13	3.13	1.82	1.82	1.82	1.82	1.82
Production	Batches	Intermediate Product B1	10		5.90				Plant		8.20	10.00	2.40					1.80	10.00	8.80		
	Batches	Intermediate Product A1	6			2.46	6.00	6.00	Shutdown	1.08				4.56	6.00	6.00	4.92				0.72	6.00
Inventory	Batches	Intermediate Product B1		29	33.50	31.50	29.50	27.50	25.50	23.00	28.70	36.20	36.10	33.85	31.60	29.35	27.10	28.30	37.70	45.90	45.30	44.70
	Batches	Intermediate Product A1		19	16.22	15.95	19.21	22.48	19.75	17.98	15.13	12.28	9.44	10.86	13.73	16.60	18.39	16.56	14.74	12.92	11.82	15.99
Total	Pallets				132.63	127.68	137.86	148.04	132.58	120.30	118.90	120.91	108.55	110.40	118.40	126.40	129.79	124.27	134.25	141.96	136.11	152.83