Multiple-Part-Type Systems in High Volume Manufacturing: Kanban System Design for Automatic Production Scheduling

by

Kaizhao Lee

B.Eng, Electrical Engineering
National University of Singapore, 2007

Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Manufacturing

at the
Massachusetts Institute of Technology

September 2008

Signature of Author ....
Department of Mechanical Engineering
August 19th, 2008

Certified by..
Stanley B. Gershwin
Senior Research Scientist of Mechanical Engineering
Thesis Supervisor

Accepted by.................................
Lallit Anand
Professor of Mechanical Engineering
Chairman, Department of Committee on Graduate Students

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Abstract

A Kanban Production System is designed to help a factory line meet fluctuating demands for multiple part types. Based on the parameter settings of the Control-Point Policy, the optimum Kanban levels are obtained. The simulation software *Simul8* was used to model the factory line and the Kanban system. Using the optimum Kanban levels, the Kanban system will act as an automatic production scheduling system that will indicate clearly when and how much of each part-type should be produced. Use of this system will avoid unnecessary inventory and changeover cost incurred by the existing Kanban system used by the factory line.

Key words: Kanban, Control-Point Policy, Optimization

Disclaimer: The content of the thesis is modified to protect the real identity of the attachment company. Company name and confidential information are omitted.

Thesis Supervisor: Stanley Gershwin
Title: Senior Research Scientist of Mechanical Engineering

Acknowledgement

I would like to thank Professor Stanley Gershwin for his constant guidance and support during the project. He was always very willing to share his expertise in the field. Truly, his supervision helped made my project time much easier.

I would also to thank Gan Thiam Boon and Tjun Yan Mun, our supervisors from the attachment company, for their dedication and commitment to the project. They were always ready to answer our questions and willingly shared their knowledge about the production system in the company.

I am also indebted to Dr Brian Anthony, Harold Kant, Sia Lee Heng and Jennifer Craig for their guidance along the way.

Finally, this thesis would have been impossible to be completed without the unselfish help of my teammate, Hua Xia, whom I have been working closely with throughout the project.

Thank you everyone who has made this a truly enjoyable and memorable learning experience for me.

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Chapter 1 Introduction

1.1 Company Introduction

1.1.1 Company Background

The theme project is conducted in Pearly Electronics, a global electrical appliance company located in Singapore. It produces over 100 types of electrical appliances in six major product families and supplies to Asia, Europe and America.

The company aims to deliver world-class products to its customers and to operate with optimal resources in the most cost-effective manner. It constantly aspires to achieve a higher level of operational efficiency and better customer satisfaction. Its unique strength and in-house manufacturing competency has been recognized by a prestigious manufacturing award from the Singapore government.

1.1.2 Product Category

The electrical appliance company produces a large variety of final products, which can be classified into three major categories, namely Alpha, Beta, and Gamma as listed in Table 1-1. Under each category, the products are further grouped into nine families, based on their distinct functionalities and target markets. Within each family, there are version differences (L, C, S or I version) which require different manufacturing processes involved. In particular, India products belong to Beta category, while Sydney products belong to Gamma category. In addition, product variations also stem from different voltage ratings required for various countries or different colors of the final products.

Alpha Family contains low end products that are usually sold in developing countries and require simpler manufacturing processes than the other two product families. Beta Family products are mainly sold in Europe and America, and its demand indicates a seasonal pattern with Quarter 1, Quarter 2, and Quarter 4 of the financial year (financial year of this company starts from January) having low demand and Quarter 3 having high demand. Gamma Family is comprised of high end products which are sold mainly in Europe and America. The proportion of products within each of the 3 families is approximately 27% for Alpha Family, 65% for Beta Family, and 8% for Gamma Family.

Moreover, as the company emphasizes product innovation, the types of products designed and manufactured are constantly updated, with old products phasing out and new products taking over the market.

Table 1-1 Product Classification

Category	Family	I	L	S	C
Alpha	A1		√		√
	A2		√		√
Beta	B1	√			
	B2	√			
	B3	√			
	B4			√	√
	B5		√		√
Gamma	G1			√	√
	G2				√

1.1.3 Process Flow

The entire manufacturing process involves a complex sequence of flow constituted by 7 major stages in the Singapore factory and final assembly in foreign factories. However, as far as this project is concerned, only the Singapore factory will be studied, and the products from the Singapore factory will be considered as finished goods.

Although there are over 100 product types, their manufacturing processes can be simplified based on their production flows. As illustrated in Figure 1-1, all the products can be categorized into 13 main groups according to the flow lines that they have to go through. For instance, Type-A products go through stations 1, 2, 3, and 9 in a sequential order, while Type-C1 products experience re-entry at station 5 and 12.

Furthermore, there are different processing rates for different product types at the same facility, and different changeover times are involved when the production switches from one type to another.

1.2 Project Description

1.2.1 Project Motivation

As a manufacturer of domestic electrical appliances, the company faces a fluctuating demand curve, which peaks in the third quarter of the year. Currently it maintains an accumulated capacity higher than the accumulated demand; however, the short-term production volume is not able to fulfill all the customer orders during the peak demand period. In addition, being optimistic about sales, the management is interested in accomplishing an additional 15% production on top of the demand forecast to buffer against forecast inaccuracy.

On the other hand, the current production also incurs long product cycle times, frequent part failures, and features a wide range of products. In consequence, this complicates the scheduling of various manufacturing stages as well as in managing the entire supply chain. Therefore, through this project, the company intends to improve the existing scheduling policy so as to make optimal utilization of the important resources such as manpower, inventory storage space and holding time.

1.2.2 Project Scope

Various problems exist in this company, ranging from product design, process design to manufacturing. This project focuses on developing a strategy to deal with peak seasonal demands that exceed the short-term capacity of the factory.

Moreover, the outcomes of this project should be significant and feasible for implementation, so that they can be immediately tested and compared with traditional production scheduling policies through real plant execution. Therefore, the project started by understanding and mapping the process flow of the entire system. Next, the project group was divided into two teams to work on two critical production stations, namely, Stations 1 and 2, and Station 8 in Figure 1-1 (Station 8 is called the SC station for the rest of the thesis). Analysis of Stations 1 and 2 are done in [1] and [2] whereas analysis of Station 8 is done in [3] and this thesis.

At station 8, the cumulative capacity is larger than the cumulative demand over one year period; however, its short-term capacity is not able to fulfill all demands during the peak period. Currently this problem is treated by introducing extra labor cost in high demand season, which significantly increases the overall operation cost for this station. On the other hand, Kanban production system has been implemented at this station, to deal with demand fluctuation and high inventory problems. Nevertheless, the management is concerned about the effectiveness of the current system as well as the appropriateness of the Kanban levels.

Therefore, the team working on Station 8 had mainly two objectives: first to manage long-term capacity for 100% demand fulfillment without incurring extra operation cost and the second to design an effective Kanban system for automatic production scheduling.

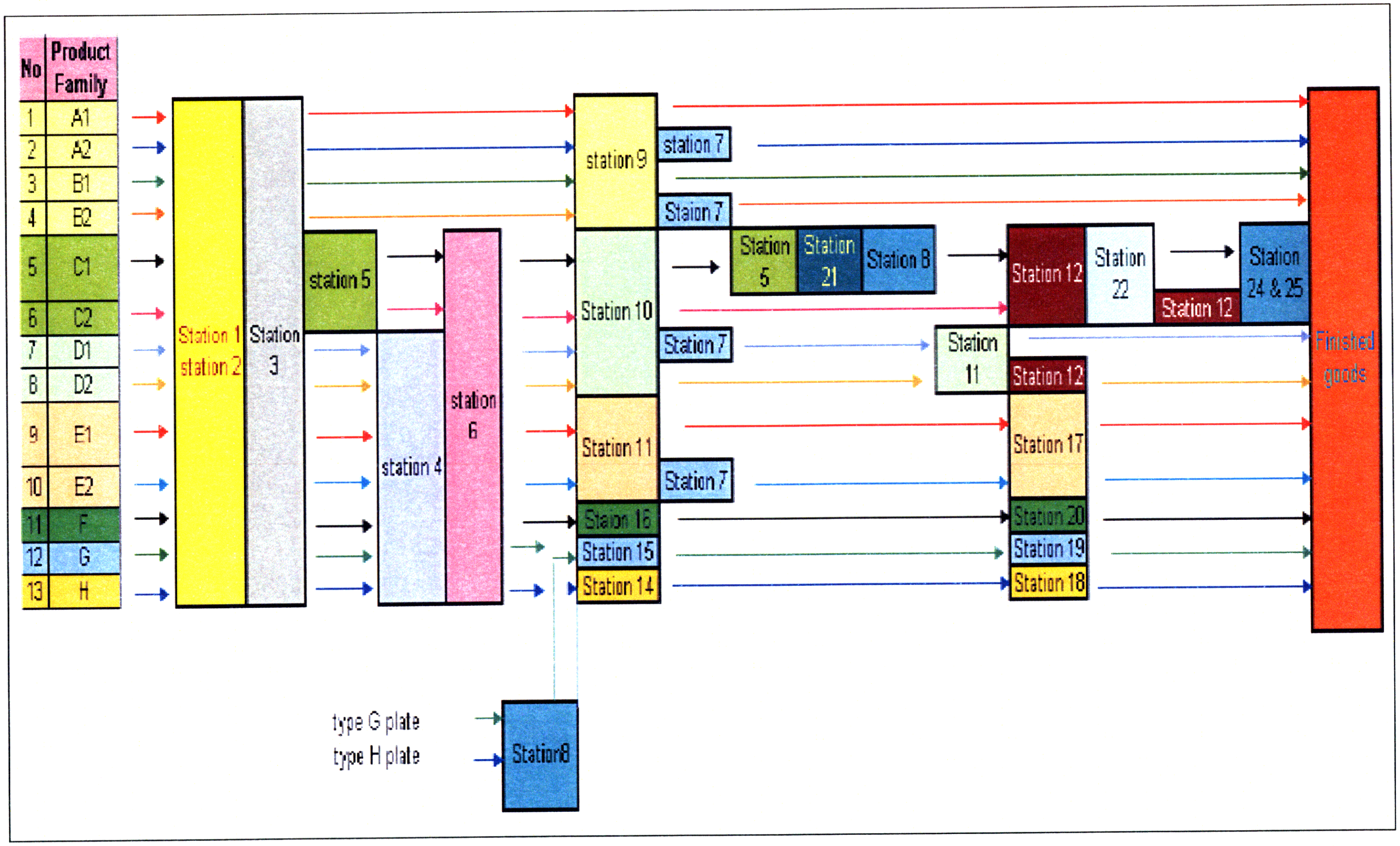

Figure 1-1 Process Flow

1.2.3 Thesis Outline

The first phase of the project, long-term capacity planning, was done in [3]. **This thesis focuses on the second phase** of the project i.e. designing the Kanban System.

Chapter 1 gives a brief introduction of the company and an overall description of the project; while Chapter 2 explains in detail the manufacturing problem that the team has investigated as well as the significance of the study at present. In Chapter 3, relevant literature on Manufacturing Systems, Kanban Production System and Control-Point Policy is presented. Chapter 4 elaborates the full project flow, from planning the new production schedule to constructing and verifying the software models for simulating the proposed production systems. The proposed method of calculating Kanban Levels is covered in Chapter 5. This method is tested using the simulation model in Chapter 6. Chapter 7 describes the outcomes from the simulation test and compares with the existing Kanban system used by the company. Finally, Chapter 8 contains recommendations for the company, summarizes the whole project in the conclusion and suggests possible future work.

Note that most sections in Chapter 1 to 4 are similar to [3]. The unique sections in this thesis are:

Section 1.2.3	Thesis Outline
Section 3.2	Kanban Production System
Section 3.4	Limitations in Previous Works
Section 4.3	Design of Kanban Production System
Section 4.4	Financial Analysis
Chapters 5 to 8	

Chapter 2 Problem Statement

2.1 Background of Problems

2.1.1 Peak Demand

The SC station normally operates for 6 days (more precisely 5 days 20h) per week. In this normal configuration, the SC station does not operate from Saturday 7pm to Sunday 11pm. This schedule gives a weekly maximum capacity of 125,000 items.

If the need arises, the SC station can operate for 7 days per week and increase its weekly maximum capacity to 150,000 items. However, there will be an extra labour cost of approximately $4,500 for operating from Saturday 7pm to Sunday 11pm. For this reason, Pearly generally tries to avoid this type of configuration unless absolutely necessary.

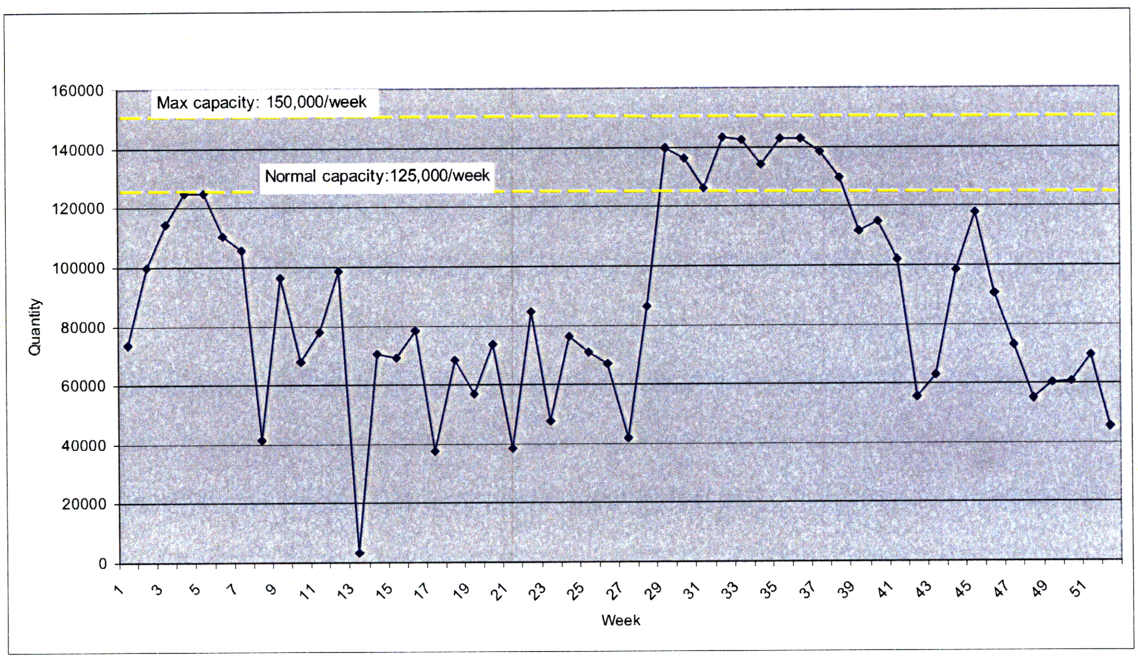

Figure 2-1 Demand per week in 2007 at SC station

Historically, in the third quarter of each year, the demand for the products at the SC station reaches their annual peak. Figure 2-1 shows the demand chart in 2007, which is a typical demand pattern at the SC station. As expected, there was a significant peak in demand in the third quarter. More specifically, the high demand in weeks 29 to 38 exceeded the normal capacity of the SC station (125,000 items per week). Thus, the management had no choice but to operate for 7 days per week from July to October (13 weeks) in 2007. This translated to an additional cost of $58,500 during that period.

2.1.2 Existing Kanban System in 2008

Before 2008, the SC station was treated as a 'push' system, whereby a weekly forecast order determined the quantity and versions of items to be produced. However, forecast inaccuracy sometimes resulted in inability to meet actual demand. Since a 'pull' system eliminates the problem of forecast inaccuracy, Pearly decided to implement Kanban system at the SC station at the beginning of 2008. Because production response at the SC station is unable to quickly meet actual demand fluctuations in various product versions, inventory is needed in the Kanban bins. Kanban cards were printed and distributed for each product version, and each Kanban card represents a pallet quantity of 1,500 units.

However, not all of the versions produced at the SC station use the Kanban system. For the versions that are supposed to be obsolescent soon, it does not make economic sense to build Kanban inventory for them. As such, the versions in Table 2-1 still use the 'push' system based on the weekly forecast order

Table 2-1 Versions on 'Push' System in 2008

Versions
A1
A2
E1
B1
B2

Table 2-2 shows the current Kanban levels for the 7 versions on the Kanban system. Note that the Kanban system currently has no minimum level to trigger production for a particular version. Instead, production is triggered whenever the inventory for a particular version is not at its maximum level. The version with the largest difference between the current inventory level and the maximum is selected to be produced first. Because of the possible danger of excessive changeovers, the production team tries to adhere to the 'changeover rule' set by management that the number of changeovers per week should not exceed the number of versions minus one. If the inventory level of any version drops to 4500, this is an emergency situation and management is informed immediately.

Table 2-2 Existing Kanban levels for Versions on Kanban System in 2008

Versions	Min level	Max level
A3	-.	21,000
A4	-	30,000
A5	-	21,000
A6	-	30,000
E2	-	21,000
E4	-	30,000
E5	-	21,000

However, the problem is that this method of production control is quite ambiguous, with no definite answer of when production of a version should start or when changeover should occur. In addition, the current 'changeover rule' may not be the best policy that the company should adopt since no analysis had been done to prove that the current 'changeover rule' would yield the minimum total cost of inventory and changeover.

2.2 Objective

The overall objective of this project is to determine a methodology for the SC station to meet its demand based on the current Kanban system. To meet this overall objective, the team will need to handle the following issues:

a. Understand the features of the SC station line and simulate its performance.
b. Determine a way to tackle the peak demand which is greater than the normal capacity of the SC station.
c. Understand and simulate the setup-based Control-Point Policy to achieve a production planning that gives minimum inventory and changeover frequency.
d. Determine the minimum and maximum Kanban levels and compare them with the existing levels used by Pearly.
e. Ensure that the proposed solutions are able to cope with a certain amount of variability in the demand forecast.

2.3 Significance

The project will enable the SC station to meet its demand without resorting to operating additional shifts every week during peak demand period. Moreover, the Kanban levels will be set methodically such that Pearly will know the appropriate Kanban levels to set in the future. Regardless of changing demands of current versions or release of new versions, Pearly will be able to adjust the Kanban levels accordingly based on the forecast demand. Once the appropriate minimum and maximum Kanban levels are set, the Kanban system will ensure that production is triggered only when necessary and in a systematic manner, instead of the current ambiguous manner.

By better managing the long-term capacity and avoiding unnecessary wastages, improvements in overall factory performance and savings in total operational cost are expected to be the potential outcomes of this project.

Chapter 3 Literature Review

This chapter summarizes the previous works on topics relevant to this project: Manufacturing Systems, Kanban Production System and Control-Point Policy.

3.1 Manufacturing Systems

In general, machines can be unreliable, and can incur unplanned breakdowns. Machine performance is usually characterized by parameters such as Average Operation Time τ, Mean Time To Repair (MTTR) and Mean Time To Fail (MTTF). τ is the average time used by a machine to finish one operation, and thus its maximum production rate is $1/\tau$ if the machine is perfectly reliable. MTTR refers to the average time taken to make the machine up when it is down, while MTTF refers to the average time passed by before the machine becomes down [4]. Figure 3-1 illustrates the definition of MTTR and MTTF, and based on the above three metrics, more performance parameters can be defined as follows:

Mean Time Between Failures:

$$MTBF = MTTR + MTTF \tag{1}$$

Repair Rate:

$$r = \frac{1}{MTTR} \tag{2}$$

Failure Rate:

$$p = \frac{1}{MTTF} \tag{3}$$

Machine Efficiency:

$$e = \frac{r}{r+p} \tag{4}$$

Average Production Rate:

$$P = \frac{e}{\tau} \qquad (5)$$

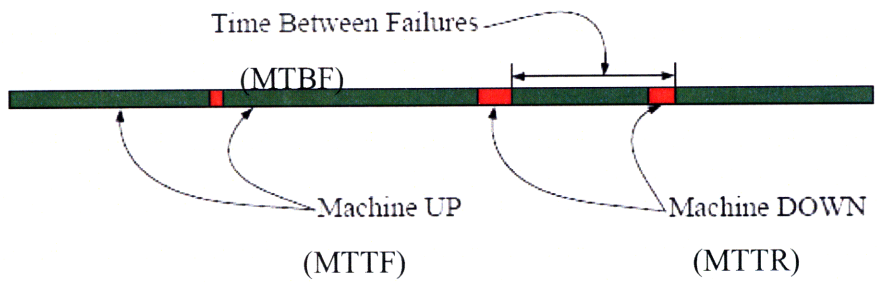

Figure 3-1 Illustration of MTTR & MTTF [4]

3.2 Kanban Production System

One of the renowned real-time manufacturing scheduling systems is the Kanban production system, which is token-based by nature. Kanban is a concept related to lean and just-in-time (JIT) production and is part of a pull system that determines the supply or production according the actual fluctuating demand. Being aware that supply or production lead-time is long and demand is difficult to forecast, the Kanban system has been used prevalently in factories to make the production respond quickly to the observed demand. Nonetheless, the response is usually not quick enough to meet the demand fluctuations, which causes significant lost orders. As such, stock building has become necessary in most Kanban systems applied in real manufacturing plants.

In the Kanban system, materials are held in Kanban bins with predetermined maximum levels to indicate the number of units for keeping on hand and the minimum levels at which replenishment need to start [5]. Hence, the Kanban system leads to spontaneous production scheduling by giving signals for replenishment when a stocked item is depleted to the minimum level and for discontinuing the production when the stocking quantity has reached the maximum level [6].

Hence, to design an effective Kanban system, it is essential to determine the appropriate maximum and minimum inventory levels. The setting of the minimum level is related to the average daily demand, the production lead-time, and a small buffer to account for forecast errors, demand fluctuation, and emergency situations [6]. On the other hand, the setting of the maximum level can be associated with the cost of changing-over too frequently and of holding too much inventory. Basically, the minimum level should ensure that the unit does not run out during restocking period, while the maximum level encourages a desirable degree of changeover frequency as well as inventory holding.

The key benefit of the Kanban system is that it guarantees an uninterrupted supply of parts to the downstream without requiring complicated ordering or production procedures [7]. It avoids the uncertainty of forecasting, the cost of reordering or changing-over production, and the risks of inventory [8] In addition, Kanban is able to limit or reduce the amount of Work-In-Process (WIP) inventory, which .generates further benefits as less opportunity cost, less inventory space, and shorter production lead-time [9].

3.3 Setup Enhanced Control-Point Policy

3.3.1 Overview on the Control-Point Policy

The Control-Point Policy (CPP) developed at MIT is useful in designing and analyzing the performance of manufacturing systems, as well as real-time scheduling of material flows [10]. It provides a set of rules for allocating production resources in real-time, so that the system reacts appropriately to random events. Figure 3-2 displays a general flow line containing machines and buffers, while Figure 3-3 shows the possible locations to place control points. The fundamental philosophy of CPP is to design control points and rules that limit the flow of material into and through the system.

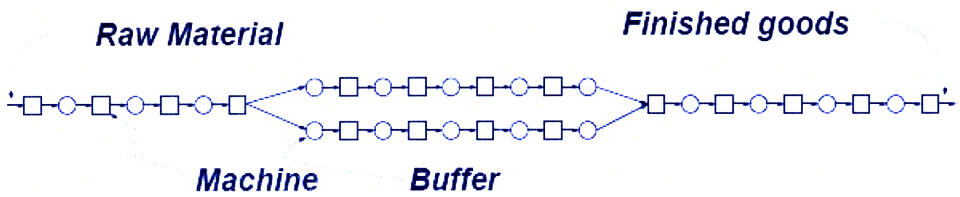

Figure 3-2 General Production Flow Line [4]

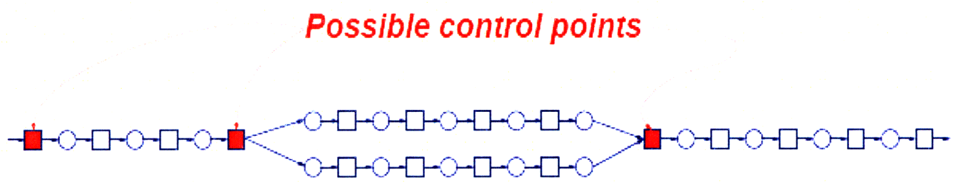

Figure 3-3 Possible Locations for Control Points in the Flow Line [4]

3.3.2 Time-Based Policy

The time-based CPP limits the flow of material into a system or downstream by limiting the earliness in production, which refers to how early the production will be completed before the due date, and the amount of in-process inventory. In particular, further production of a particular part-type is not allowed beyond a control point if the cumulative production at that point is greatly in excess compared to the cumulative demand, or if there are already too many of that part type in the system. The control points in the time-based version of the policy are Upper Hedging Time and Lower Hedging Time. In brief, production of the same part type is allowed until the Upper Hedging Time is reached, and production of a different part type is triggered when the Lower Hedging Time of that part type has been reached.

When there are more than one part type whose Lower Hedging Times has been reached, production decision is made by considering the rankings of the various product types. The highest ranking parts will be produced at the maximum production rate subject to capacity constraints and buffer constraints, whereas the lower ranking parts might not be produced if the capacity has been exhausted.

3.3.3 Token-Based Policy

Figure 3-4 demonstrates a multiple-part-type machine that is controlled according to the mechanism of the token-based version of CPP. Specifically, the white-colored square represents a physical machine in the production system, and the production flow at this machine is controlled by the Production Token Buffer. The upper buffer in this control structure performs the function of the hedging point, while the lower buffer represents a local backlog. For each increment of actual demand volume of a part type, the same amount of tokens is placed in that part's Demand Token Buffer. When one unit of that part type has been produced, the Synchronization Machine signals that one part has been produced and the order on that part has been fulfilled. Consequently, it takes one token out of both the Production Token Buffer and the Demand Token Buffer. As such, the production of one part type is allowed until either its Production Token Buffer or its Demand Token Buffer has become empty. This control concept is very similar to the time-based policy, which limits the production of the same part type when it has exceeded the predetermined hedging point.

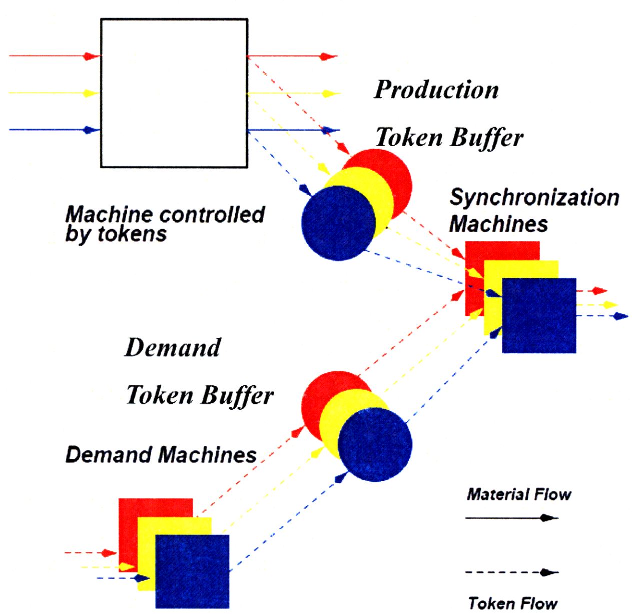

Figure 3-4 Material and Token Flow for a Single Part Type in the Token-Based Policy [4]

3.3.4 Setup-Change Policy

In manufacturing plants, there are usually multiple part types involved. One important aspect of production scheduling is to determine the production sequence for a variety of part types and the amount to produce before switching production to another type. With this need in real manufacturing practice, the Setup-Change Policy was developed and incorporated into the CPP so as to generate criteria for switching productions [11]. By means of limiting setup frequencies and making sure that capacity is available for production, this policy regulates production flow in a desirable sequence for multiple part types.

As such, one critical variable in the Setup-Change Policy is the Time Available for Setups, which is defined in Equation (6). In turn, dividing this Time Available for Setups by the total shift time, the Allowable Setup Fraction f_s can be obtained through Equation (7), where the machine performance parameters r, p, τ and e have been defined in Section 3.1.

Additionally, d in Equation (7) represents the demand rate, which is the average demand per time unit. Thus, this fraction f_s is determined by the machine efficiency and the demand rate. Moreover, it reveals that tokens, with the unit of time, are accumulated inside a Setup Token Buffer at the rate of f_s tokens per time unit. This accumulation continues all the time except when a setup occurs, in which case the Setup Token Buffer level decreases by the duration of the setup instead. Since the level is not allowed to be negative, a setup change can occur only when the Setup Token Buffer level is greater than the setup duration. In other words, the concept of accumulating and removing setup tokens effectively limit how frequently setups are allowed to occur.

Time available for setups = the total shift time – the total operation time – the total expected downtime (repairs and maintenance) – a safety time (6)

Allowable Setup Fraction:

$$f_s = 1 - \left(\frac{r+p}{r}\right)\sum_i \tau_i d_i = 1 - \sum_i \left(\frac{\tau_i}{e}\right) d_i \tag{7}$$

As a consequence of the Setup Enhanced CPP, the production at a single machine or at the system level will be spontaneously scheduled with favorable characteristics, namely, with the proper amount of the right part type produced at the proper time.

3.4 Limitations in Previous Works

Referring to the literature on the Token-Based CPP and the Kanban Production System, no clear and definite relationship has been established. However, it is observed that the Token-based CPP and the Kanban Production System are similar in the way that the Lower Hedging Point / Minimum Bin Level triggers production, while the Upper Hedging Point / Maximum Bin Level puts a limit on the WIP quantity by taking into account the changeover cost and the inventory holding cost. The current study attempts to link between the Token-Based CPP and the Kanban System. The CPP theories have provided meaningful guidelines and rules for designing an effective Kanban System, which is more feasible to implement in a plant or production line with existing Kanban production flows.

Chapter 4 Methodology

This section starts with an overview of the entire project flow and the various methodologies employed are elaborated in the following subsections.

4.1 Overall Project Flow

The entire project was carried out in several stages as laid out in Figure 4-1, where the rectangles represent the major project stages, and the ovals indicate the intermediate and final achievements. At the initial stage, information on overall Factory Layout, Manufacturing Process Flow, as well as specific Line Performance Measures were acquired through observations and interviews in the plant. Particularly, with Year 2007 Demand Forecast for the SC station, further investigation was achieved in two key steps named Long-Term Capacity Planning and Short-Term Resource Management in the Project Flow. The theoretical bases for accomplishing these two goals were mainly total cost optimization, Setup Enhanced CPP, and design of Kanban Production System.

The two key deliverables for this study were Long-Term Planning Strategy and Kanban-System Design Policy. The designed rules mainly consist of scheduling guidelines for the SC station. These rules could also be generalized and adapted for the application on other production stations or lines.

Definition of Symbols

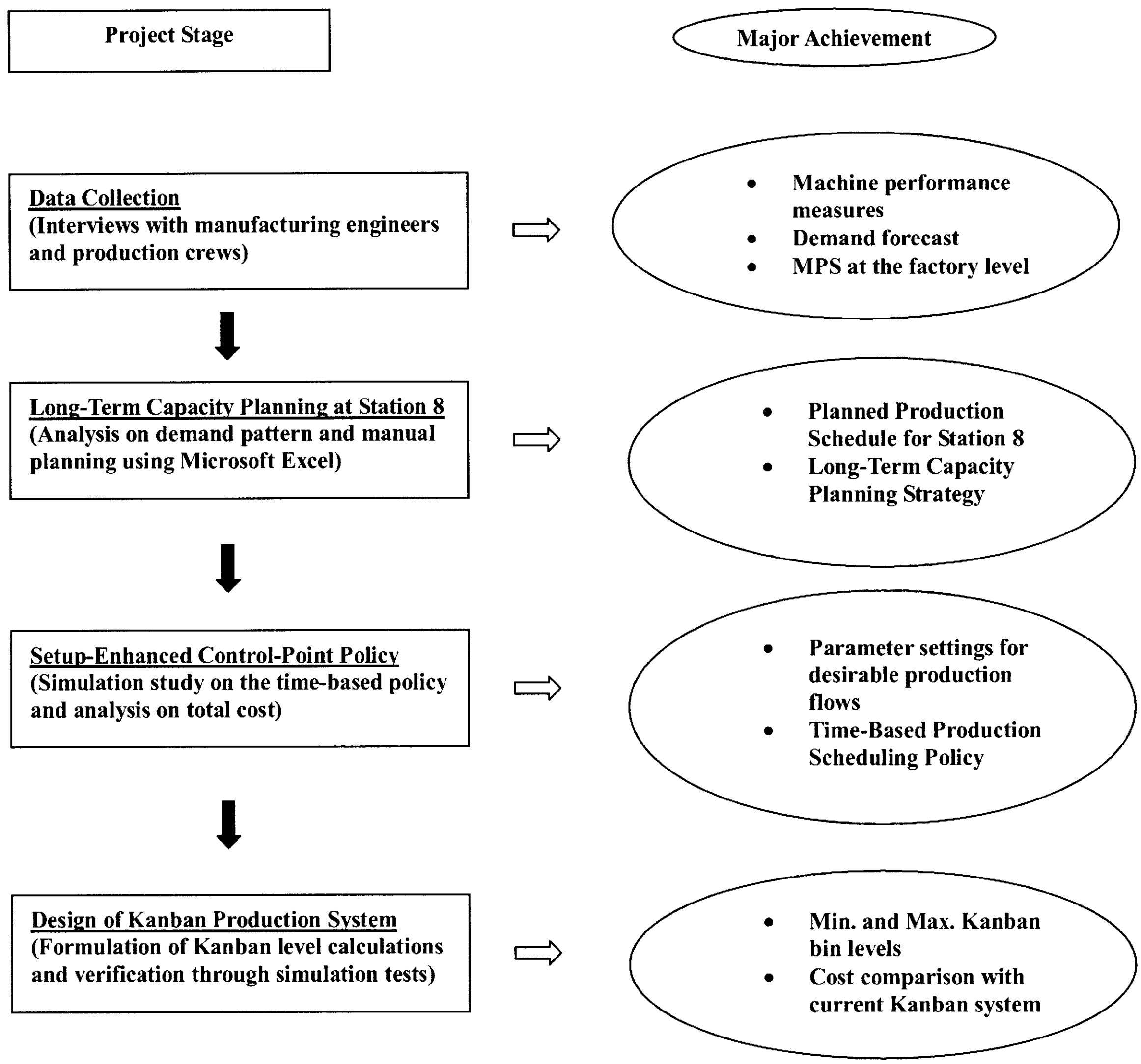

Figure 4-1 Overall Project Flow

4.1.1 Similarities & Differences of the two teams' strategies

As mentioned in 1.2.2, there are two teams in the project group: one team working on Stations 1 and 2 ([1], [2]) and one team working on the SC station ([3] and this thesis). Reviewing the characteristics of Stations 1 and 2 and the SC station, as well as the analysis strategies used by the two teams, the similarities and differences can be summarized as follows:

<u>Similarities</u>

A. Characteristics of the Station

(1) The station faces a seasonal demand pattern with peak period in Quarter 3 of the year.

(2) Weekly production follows factory plan and the minimum changeover rule.

B. Strategy for Analysis

(1) The weekly effective capacity of the station was first evaluated.

(2) Long-term planning aided in making capacity building decisions and providing weekly production targets.

(3) Time-based and token-based production scheduling policies were developed with the study on CPP.

<u>Differences</u>

A. Characteristics of the Station

(1) Yearly capacity exceeds yearly demand for SC station, whereas the total capacity of auto-lines is insufficient to meet yearly demand at Stations 1 and 2.

(2) Multiple product types are involved in one line at the SC station, while multiple lines are operated concurrently to process multiple product types at Stations 1 and 2.

(3) A Kanban production system is already in execution at the SC station.

B. Strategy for Analysis

(1) Resource allocation needs to be optimized among multiple production lines at Stations 1 and 2, while analytical calculation is sufficient to optimize the capacity building process at the SC station.

(2) The team working on Stations 1 and 2 investigated the time-based and token-based CPP, whereas the SC team probed more on improving the existing Kanban system and justifying the beneficial outcomes.

4.2 Data Collection

Through plant observation and interviews with the management, general process information and production problems were understood at the beginning of the attachment. Upon finalizing the project topic, more specific data associated with the SC station were gathered, such as historical Machine Performance Records, Demand Forecast, Planned Production, Actual Production Output and so forth. Indeed, various interviews were conducted with factory planners, line operators, manufacturing engineers, and the management.

4.2.1 Line Performance Measures

Since the SC station in this study is actually a simplification of the SC station coating processing line connected by one conveyor belt and without any significant buffer between machines, the methods of recording and computing line performance data were noted down in the following equations. The number of stoppages was obtained by the real-time recording software at the station. Additionally, it should be noticed that the definition of MTBF in Pearly is equivalent to the parameter MTTF. The factory performance is measured using the Equations (8) to (10).

$$Line\ MTBF = \frac{\text{Line operating time (min)}}{\text{Number of stoppages}} \tag{8}$$

$$Line\ MTTR = \frac{\text{Machine stoppages time (min)}}{\text{Number of stoppages}} \tag{9}$$

$$Line\ Efficiency = \frac{MTBF}{MTBF + MTTR} \tag{10}$$

4.2.2 Factory Planning Cycle

At present, factory planning is done in three levels in Pearly. During September of the previous year, a forecast for next year's commercial demand is provided to the factory planner by the marketing department of Pearly. Thus, the highest level of production planning begins at this stage, and an MPS is generated by taking into consideration the weekly production level, manpower requirement, and critical sub-assemblies for each production line.

The second level planning is on a monthly basis, because the commercial demand for the subsequent month is confirmed in the third week of the previous month. Up to this stage, the planning is still only conducted to the resolution of weeks. Next, the marketing department confirms the commercial demand for next week each Wednesday of the current week, which indicates the actual commercial demand for the factory. Taking the actual demand and factory-wise stock building into account, the third level production planning is performed every Thursday. In consequence, daily production plans for various lines are generated based on the daily capacity of each line. Although this stage of planning gives production details on a daily basis, a variety of manufacturing resources are not well-utilized in this manner.

Hence, this project seeks opportunity for operation improvement by long-term as well as short-term resource management at the local production line level.

4.3 Design of Kanban Production System

As mentioned in Section 3.2, the key to an effective Kanban system is to determine the appropriate maximum and minimum inventory levels. This is not an easy task, especially since the SC station has to produce many product versions of fluctuating demand every week (multi-part, single line system).

Because the Kanban system behaves like a token-based version of Control-Point Policy (CPP), which is similar to the time-based version of CPP, the time-based version of CPP can be used to help determine the Kanban levels. As such, from the most desirable production schedule obtained from the Setup-Enhanced CPP study [3], the parameter settings of Upper Hedging Time and Lower Hedging Time are employed to decide the minimum and maximum levels of the Kanban bins.

To use the Upper Hedging Time and Lower Hedging Time, the average demand rate of each product version must be obtained. There is no need to add buffer to cater for variability due to forecast errors, upstream supply not on time, sudden increases in demand, etc. This is because the hedging time obtained in CPP has already included the buffer. Thus, the Kanban levels are formulated in Equations (11) and (12). Note that the Kanban levels and the demand rate are unique for each production version.

$$Min.\ Kanban\ Level = Demand\ Rate \times Lower\ Hedging\ Time \tag{11}$$

$$Max.\ Kanban\ Level = Demand\ Rate \times Upper\ Hedging\ Time \tag{12}$$

Since the finished goods of the SC station are stored in pallets of holding size 1500 items, the Kanban levels obtained are rounded to the nearest multiple of 1500. These rounded numbers will be the final minimum and maximum Kanban levels that the company should adhere to.

From the implementation point of view, Kanban cards are used for each production version. Each Kanban card represents a pallet quantity of 1500 units. Hence, the number of Kanban cards can be computed according to Equations (13) and (14).Note that the number of Kanban cards is unique for each production version.

$$Min.\ Number\ of\ Kanban\ Cards = \frac{Min\ Kanban\ Level}{Pallet\ size\ of\ 1500} \tag{13}$$

$$Min.\ Number\ of\ Kanban\ Cards = \frac{Max\ Kanban\ Level}{Pallet\ size\ of\ 1500} \tag{14}$$

4.4 Financial Analysis

After designing the new Kanban levels, there is a need to calculate how much it will cost to maintain the Kanban levels. The total cost of production at the SC station is made up of two components---inventory holding cost and changeover cost. If the designed Kanban levels are very large, the changeover cost will be small but the inventory holding cost will be large; if the Kanban levels are very small, the inventory holding cost will be small but the changeover will be large. Hence, the Kanban levels must be designed considering both the inventory holding cost and the changeover cost such that total cost is minimized.

4.4.1 Inventory Holding Cost

Between the raw materials and the SC station (inclusive), the costs of manufacturing of each India and Sydney are \$5 and \$7 respectively. After the item is processed in the SC station, the inventory holding cost of each item in a year is assumed to be 15% of the cost of manufacturing of the piece. This includes both the actual cost of physically storing the inventory and the opportunity cost of investments.

Since the inventory level of each version usually fluctuates between the minimum and the maximum Kanban level, the mean inventory level of that version is taken to be the average of the minimum and maximum Kanban level. Hence, the inventory holding cost for the Kanban levels can be calculated using Equations (15) and (16)

$$\begin{aligned} &\textit{Inventory holding cost of IP / year} \\ &= \frac{\min \textit{Kanban level} + \max \textit{Kanban level}}{2} \times \$5 \times 15\% \end{aligned} \tag{15}$$

$$\begin{aligned} &\textit{Inventory holding cost of SP / year} \\ &= \frac{\min \textit{Kanban level} + \max \textit{Kanban level}}{2} \times \$7 \times 15\% \end{aligned} \tag{16}$$

4.4.2 Changeover Cost

When the SC station switches producing one to another version of item, the changeover time results in loss of productive hours. This approximates to be \$1,200 per hour or \$20 per minute. Hence, the changeover cost can be calculated using Equation (17).

$$Changeover\ \cos t = Changeover\ time(\text{min}) \times \$20 \tag{17}$$

Chapter 5 Proposed Method of Calculating Kanban Levels

5.1 How to calculate the Optimum Kanban Level

In [3], the most desirable production schedule for the SC station has already been studied and obtained. The parameter settings of Upper Hedging Time and Lower Hedging Time that will yield this most desirable production schedule are reflected in Table 5-1.

Table 5-1 Hedging Time settings that will give the optimum production schedule

Hedging Times for Low-runners		Hedging Times for High-runners	
Lower (weeks)	Upper (weeks)	Lower (weeks)	Upper (weeks)
1.5	3	1	2

Using Equations (11) and (12) in Section 4.3 to convert the hedging times to Kanban levels, the formulae for calculating the optimum Kanban level are given in Table 5-2. The next section will explain the method to calculate mean demand rate.

Table 5-2 Formulae for calculating the Optimum Kanban level

Kanban Levels for Low-runners		Kanban Levels for High-runners	
Minimum	Maximum	Minimum	Maximum
1.5* mean demand rate	3*mean demand rate	1*mean demand rate	2*mean demand rate

5.2 How to calculate the mean Demand Rate

The demand rate of a version varies every week. This means that the version's Kanban level will have to change every week, which is impractical to implement in Pearly and defeats the purpose of having a Kanban production system. Hence, it would be more practical to assign a demand rate for a few weeks so that the Kanban level would remain constant during these few weeks.

High-runners are defined as versions that have large order quantities throughout the year such that their annual demand make up more than 15% of the total annual demand of all versions. The other versions that do not fall into this category are defined as low-runners. In general, it is observed that the demand for low-runners is consistently low throughout the year. This is shown in Figure 5-1 which plots the demands for three low-runners in 2007. On the other hand, the demand for high-runners is consistently high except in Quarter 3 when it is significantly higher. This is shown in Figure 5-2 which plots the demands for three high-runners in 2007.

Hence, it is most likely necessary to assign just one mean demand rate to low-runners throughout the year but two different demand rates to high-runners---one mean demand rate for Quarter 1, 2 and 4 and one mean demand rate for Quarter 3.

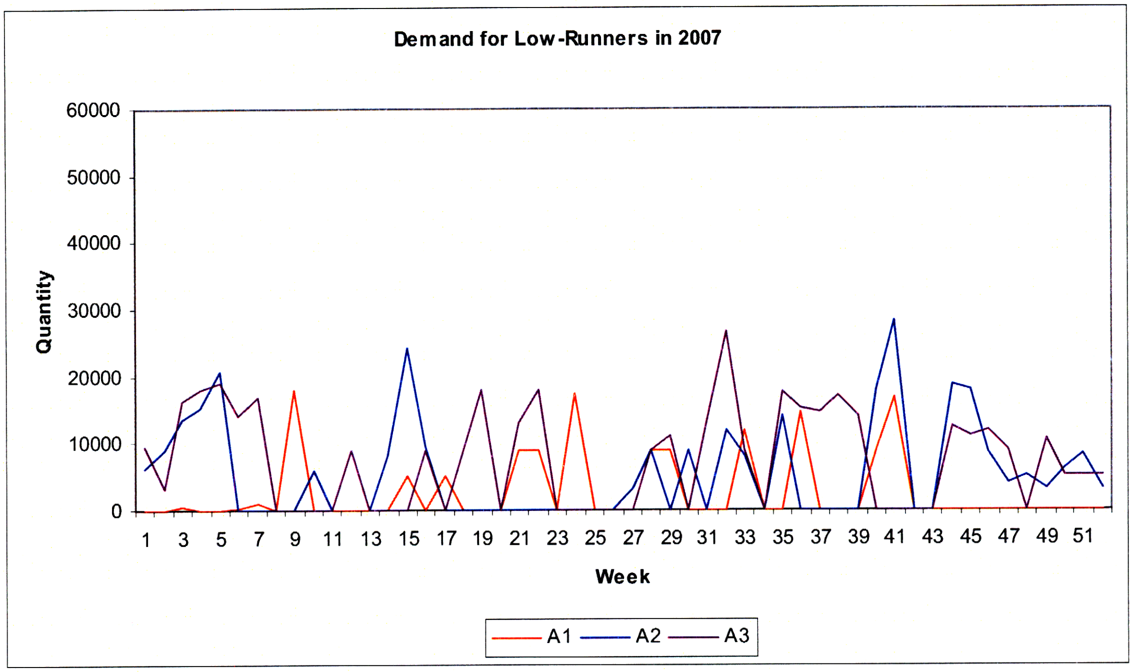

Figure 5-1 Demand for three Low-Runners in 2007

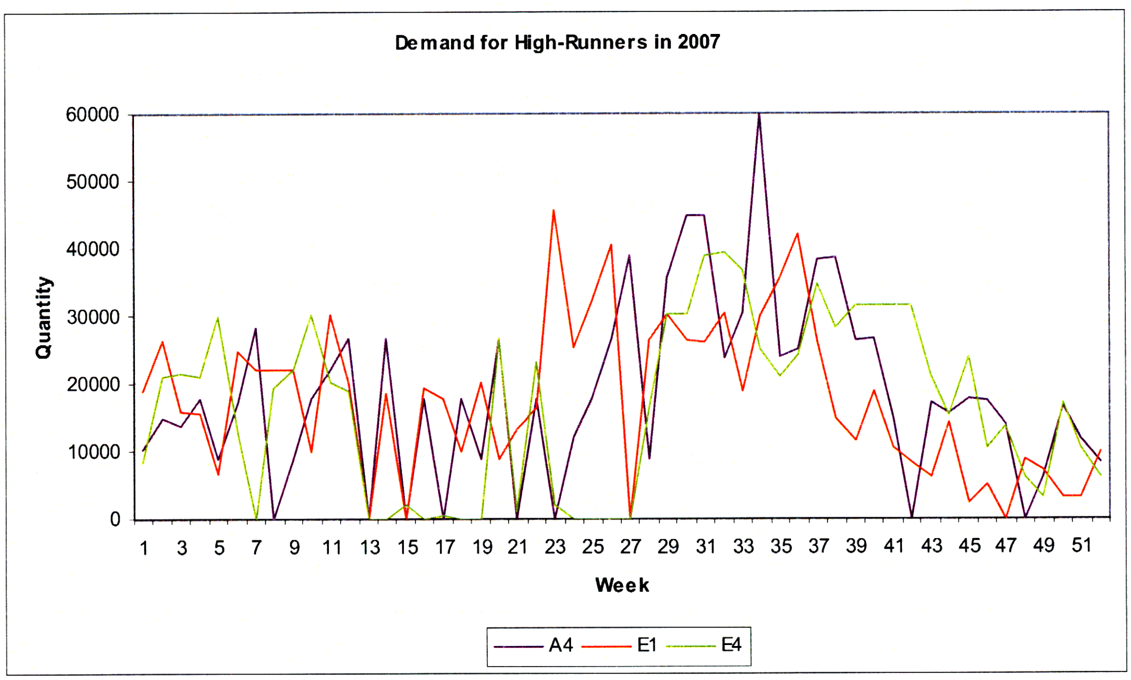

Figure 5-2 Demand for three High-Runners in 2007

Hence, the mean demand rates for the low-runners and high-runners can be calculated using Equations (18) to (20).

Low-runners:

$$\begin{aligned} &\textit{Mean Demand Rate throughout year} \\ &= \textit{Average weekly demand in year} \\ &= \frac{\textit{Total demand in year}}{\textit{Number of weeks with demand in year}} \end{aligned} \tag{18}$$

High-runners:

$$\begin{aligned} &\textit{Mean Demand Rate in } Q1, Q2 \,\&\, Q4 \\ &= \textit{Average weekly demand in } Q1, Q2 \,\&\, Q4 \\ &= \frac{\textit{Total demand in } Q1, Q2 \,\&\, Q4}{\textit{Number of weeks with demand in } Q1, Q2 \,\&\, Q4} \end{aligned} \tag{19}$$

$$\begin{aligned} &\textit{Mean Demand Rate in } Q3 \\ &= \textit{Average weekly demand in } Q3 \\ &= \frac{\textit{Total demand in } Q3}{\textit{Number of weeks with demand in } Q3} \end{aligned} \tag{20}$$

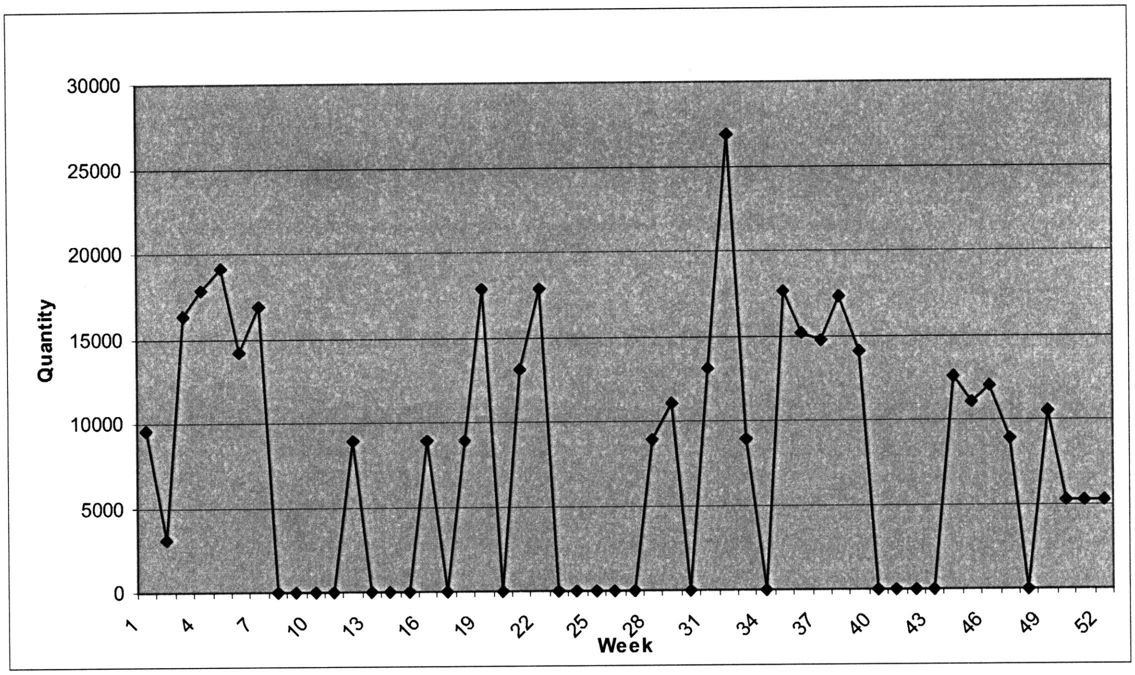

Figure 5-3 Demand for A3 in 2007

For instance, for the low-runner A3 (Figure 5-3), the mean demand rate in 2007 can be calculated as follows from Equation (18)

$$\begin{aligned} &\textit{Mean Demand Rate throughout year} \\ &= \frac{\textit{Total demand in year}}{\textit{Number of weeks with demand in year}} \\ &= \frac{39{,}1750}{31} \\ &= 12{,}637\ \textit{items / week} \end{aligned}$$

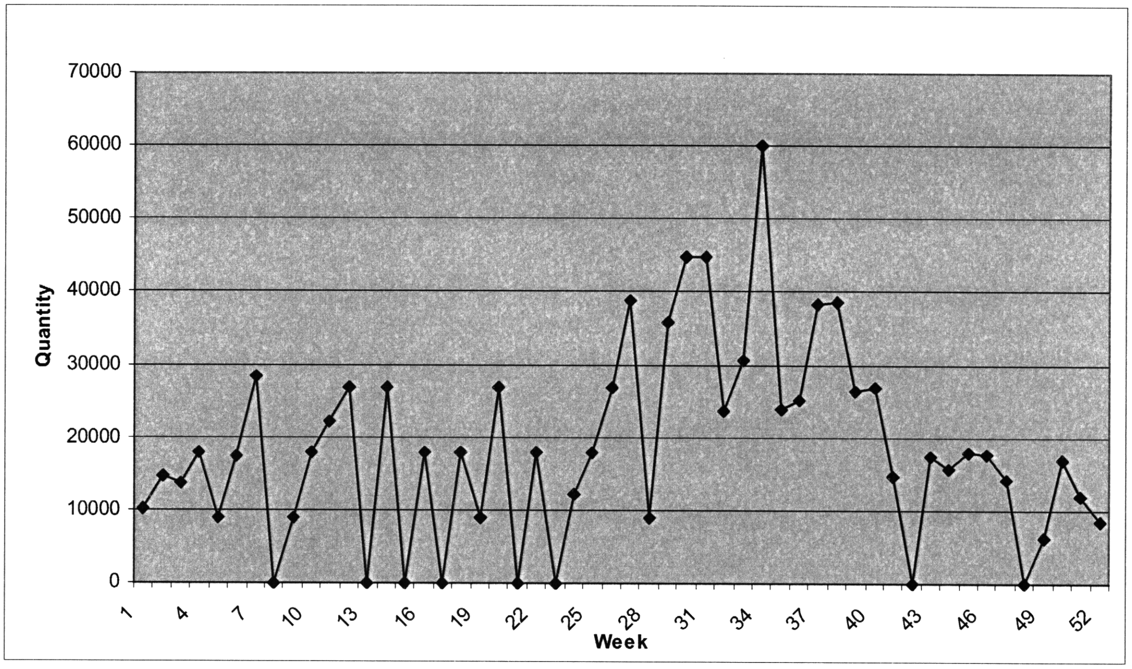

Figure 5-4 Demand for A4 in 2007

For the high-runner A4 (Figure 5-4), there are 2 different mean demand rates---1 for Quarter 1, 2 and 4; 1 for Quarter 3. They can be calculated as follows from Equations (19) and (20). Note the large difference between the values obtained for the 2 demand rates.

$$\begin{aligned}
&\textit{Mean Demand Rate in } Q1, Q2 \,\&\, Q4\\
&= \frac{\textit{Total demand in } Q1, Q2 \,\&\, Q4}{\textit{Number of weeks with demand in } Q1, Q2 \,\&\, Q4}\\
&= \frac{528{,}106}{31}\\
&= 17{,}036
\end{aligned}$$

$$\begin{aligned}
&\textit{Mean Demand Rate in } Q3\\
&= \frac{\textit{Total demand in } Q3}{\textit{Number of weeks with demand in } Q3}\\
&= \frac{439{,}883}{13}\\
&= 33{,}837
\end{aligned}$$

Chapter 6 Kanban Simulation

6.1 Considerations

Owing to the fact that the SC station processes are connected by the conveyor belt without any dedicated buffer space in between, the entire SC station line is simulated as one station with the following considerations:

- *Variety of Versions*

The SC station has to produce a variety of versions as shown in Table 6-1. These versions can either be categorized into India or Sydney types. Moreover, one color of the SC station coat is dedicated to one version -- either gold or silver.

Table 6-1 Classification of Product types, Versions and SC station Coat Colors

Type	Version	SC station Coat Color
India	A1	Gold
	A2	Gold
	A3	Silver
	A4	Silver
	A5	Silver
	A6	Silver
	E1	Gold
	E2	Gold
	E3	Silver
	E4	Silver
	E5	Silver
Sydney	B1	Silver
	B2	Silver

- *Capacity*

As mentioned in Chapter 2.1.1, the SC station can either have a normal capacity of 125,000 items per week with 6-day operation, or a maximum capacity of 150,000 items per week with 7-day operation. However, with proper long-term capacity planning prior to testing through the simulation model, the SC station is able to maintain 6-day operation with the normal capacity throughout the year. Therefore, the simulation model should assume that the SC station only has a normal capacity of 125,000 items per week so that the SC station does not need to work on Sundays which incurs unreasonably high labour costs.

- *Efficiency*

According to the line productive hours recorded to be 125h/week, the efficiency of the SC station line is 0.744. Mean Time To Repair (MTTR) is 8 minutes and Mean Time to Failure (MTTF) is 23.25 minutes, which are based on the average performance data in 2007.

- *Yield*

From historical data, the yield for India fluctuates between 95% and 97%, while the yield for Sydney fluctuates between 90% and 92%. In the simulation, the yield rates for India and Sydney are assumed conservatively to be 95% and 90% respectively.

- *Production Rate*

Without considering any machine breakdown, it should ideally take 3 seconds for each item to be processed at the SC station. Note that machine breakdown has already been considered in efficiency

- *Priority*

Orders consisting of Sydney are preferred over orders consisting of India because there is no stock-keeping for Sydney at the factory level.

- *Supply*

Referring to Figure 1-1, the supplies for the SC station are not from in-house manufacturing but procured directly from India and Sydney suppliers. Hence, it could be assumed that there is no supply problem for the SC station.

- *Changeover Time*

If the arriving order is the same version as the previous order produced, there will be no changeover time required. Nevertheless, if it is a different version, there will be loss of production time due to the setup change needed. Since every version has unique decorative paint, every version change involves a changeover time of 20 minutes. Moreover, if the next order to be produced is of a different type or different color from the previous order, there will be an additional 10 minutes needed for basecoat (BC) and topcoat (TC) changes. The variety changeover times for production version, type and color changes are summarized in Table 6-2.

Table 6-2 Changeover Time

		Changeover time (min) due to			Total Changeover Time (min)
		BC	Decoration	TC	
Same Version		0	0	0	0
Different Version	Same type & Same colour	0	20	0	20
	Others	5	20	5	30

- *Batch Size*

Since India and Sydney are loaded into the SC station using a carrier that can hold 35 pieces, the batch size has to be a multiple of 35. Moreover, from production experience one tank of basecoat paint or one tank of topcoat paint can last for painting about 2800 pieces. Thus, the batch size is assumed to be 2800 pieces for SC station processes. This means that the SC station will always round up the order quantity to the nearest 2800 for production. In turn, the surplus produced will be used to fulfill subsequent orders.

- *Demand Forecast*

Demand forecast was based on daily production schedule at downstream F station. The due dates for each job in the *SF Planned Production Schedule* was adjusted one day earlier to be the due dates for the *SC station Demand Schedule* and the quantity to be produced was adjusted larger to account for yield issues..

6.2 Kanban Pseudo Code

The Kanban production system is used on a multi-part single-line system. As such, the simulation of the Kanban production system is quite complex and must be able to satisfy the following scenarios. Note that versions A and B can be any product version, as long as they are different.

Scenario 1: The SC station is currently not producing anything and there is an order for version A.

If version A's Kanban level is above minimum, do nothing; else produce version A until version A's Kanban level is at maximum.

Scenario 2: The SC station is currently producing version A and there is an order for version A.

Continue producing version A until version A's Kanban level is at maximum.

Scenario 3: The SC station is currently producing version A and there is an order for version B.

Continue producing version A until version A's Kanban level is at maximum. Next, if version B's Kanban level is above minimum, do nothing; else produce version B until version B's Kanban level is at maximum. Note that if there are other versions needed to be produced beside version B, they will be ranked according to the priority mentioned in the Section 6.1.

Hence, the following Pseudocode is derived to satisfy the above scenarios and the flowchart is depicted in Figure 6-1.

Iterative Pseudocode

Use current Kanban inventory to fulfill orders that are due (*Simulation time* > *Due Date*)
If currently Station idle
    If there are Sydney versions whose Kanban level is less than or equal to min level
        Choose version with largest difference between its current Kanban level and min level
        Start to fill Kanban level back to max level
    Else if there are India versions whose Kanban level is less than or equal to min level
        Choose version with largest difference between its current Kanban level and min level
        Start to fill Kanban level back to max level
    Else
        Station idle
Else
    Continue to fill Kanban level back to max level

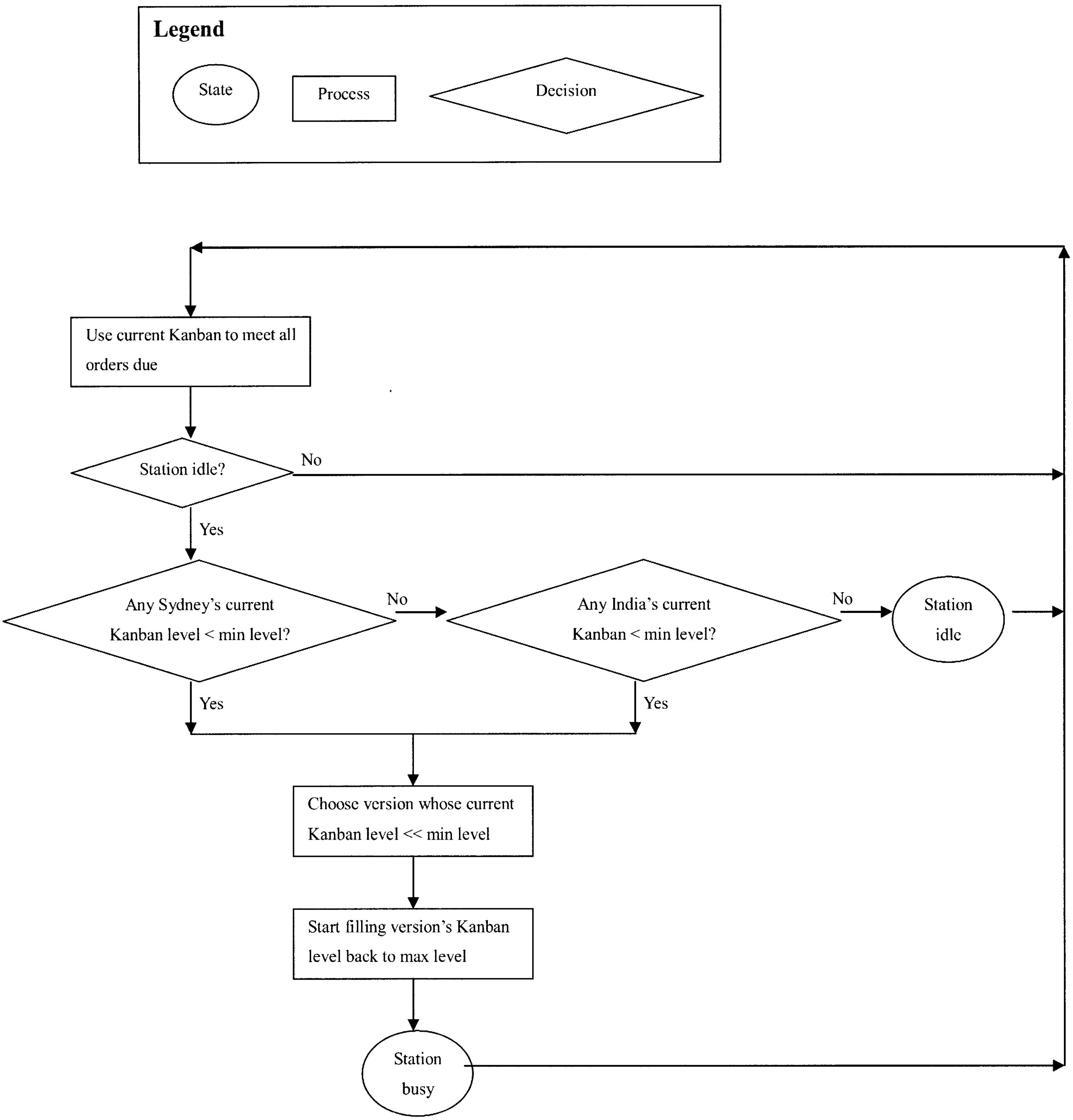

Figure 6-1 Kanban simulation Pseudocode flowchart

6.3 Kanban Simulation Model

Model Layout

Simul8 was chosen as the modelling software to simulate the SC station. The powerful and user-friendly software allowed simple entry of basic factory parameters (e.g. cycle time, MTBF, MTTR, routing). For more advanced tasks such as the Kanban method, they are coded using the Visual Logic embedded in the simulation objects. The Kanban simulation model layout is shown in Figure 6-2 and the Visual Logic codes are attached in the appendix.

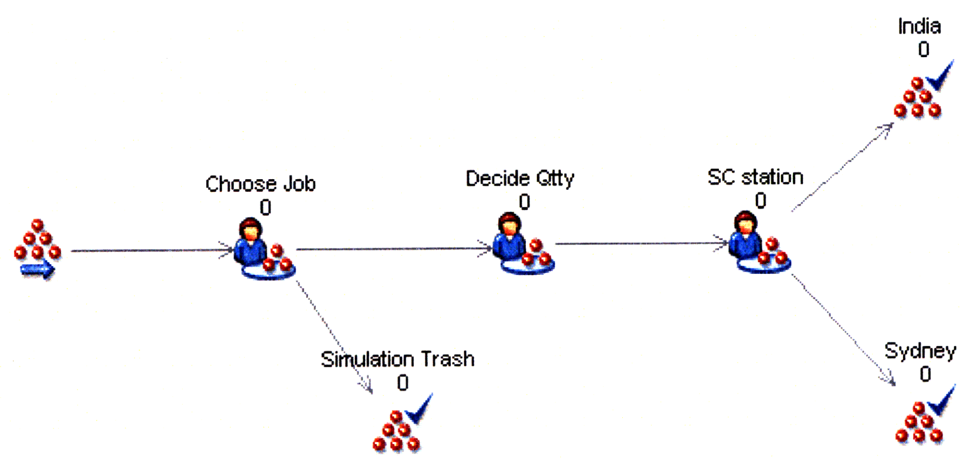

Figure 6-2 Kanban simulation model layout

Sample Input

To illustrate how the simulation works, as well as to verify the correctness of the model, the Planned Production Schedule of the downstream F station in Week 5 of 2007 was used as an example. As listed in Table 6-3, on 29 Jan., the F station would start working on 8,500 pieces of A2 and 11,000 pieces of E5. This meant that by the end of 28 Jan., 8500 defect-free pieces of A2 and 11,000 defect-free pieces of E5 would have to be manufactured in the SC station and delivered to the F station.

Table 6-3 Production Schedule at downstream F station in Week 5 (2007)

	Sat	Sun	Mon	Tue	Wed	Thu	Fri
	29-Jan	30-Jan	31-Jan	1-Feb	2-Feb	3-Feb	4-Feb
A2	8,500	8,500	2,800	0	0	0	0
A3	0	0	5,700	8,500	4,000	0	0
A4	0	0	0	0	4,500	4,000	0
E1	0	0	0	0	0	6,500	0
E2	0	0	0	0	10,500	5,000	0
E3	0	0	0	6,500	0	0	0
E4	0	150	7,500	5,000	0	0	0
E5	11,000	11,000	6,500	0	0	0	0
B1	0	0	0	2,500	0	0	0

Since the due date for each job in the *F station Planned Production Schedule* was adjusted one day earlier to be the due dates for the *SC station Demand Schedule* and the quantity to be produced was adjusted larger to account for yield issues. In consequence, based on Table 6-3, the *SC station Demand Schedule* was generated in Table 6-4. With historical yield factors as 95% for India and 90% for Sydney, to yield 8500 defect-free pieces of A2 and 11,000 defect-free pieces of E5 by 28 Jan., the SC station should be scheduled to manufacture 8,947 pieces of A2 and 11,579 pieces of E5 on that day.

Table 6-4 Demand Forecast of SC station in Week 5 (2007)

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	28-Jan	29-Jan	30-Jan	31-Jan	1-Feb	2-Feb	3-Feb
A2	8,947	8,947	2,947	0	0	0	0
A3	0	0	6,000	8,947	4,211	0	0
A4	0	0	0	0	4,737	4,211	0
E1	0	0	0	0	0	6,842	0
E2	0	0	0	0	11,053	5,263	0
E3	0	0	0	6,842	0	0	0
E4	0	158	7,895	5,263	0	0	0
E5	11,579	11,579	6,842	0	0	0	0
B1	0	0	0	2,778	0	0	0

Subsequently, the *SC station Demand Schedule* was converted to an input spreadsheet to the Setup-Enhanced CPP simulation model for the SC station. Table 6-5 displays the sample input spreadsheet, in which the orders on the two product types India and Sydney are listed separately. For each product type, the record for input orders contains four categories of information: due date, product version, color, and order quantity. Although the orders seemed to be recorded in accordance with the product version in Table 6-5, any sequence of recording orders is acceptable for the input spreadsheet. For instance, from this table, it can be seen that 8,947 pieces of A2 were demanded with the due date 28 Jan., and the color of this particular version is gold.

Table 6-5 Input Spreadsheet to Simulation Model for Week 5 (2007)

India					Sydney			
Due Date	Version	Color	Order Quantity		Due Date	Version	Color	Order Quantity
28-Jan	A2	Gold	8,947		31-Jan	B1	Silver	2,778
29-Jan	A2	Gold	8,947					
30-Jan	A2	Gold	2,947					
30-Jan	A3	Silver	6,000					
31-Jan	A3	Silver	8,947					
1-Feb	A3	Silver	4,211					
1-Feb	A4	Silver	4,737					
2-Feb	A4	Silver	4,211					
2-Feb	E1	Gold	6,842					
1-Feb	E2	Gold	11,053					
2-Feb	E2	Gold	5,263					
31-Jan	E3	Gold	6,842					
29-Jan	E4	Silver	158					
30-Jan	E4	Silver	7,895					
31-Jan	E4	Silver	5,263					
28-Jan	E5	Silver	11,579					
29-Jan	E5	Silver	11,579					
30-Jan	E5	Silver	6,842					

Sample values for the Kanban Variables

Varying the Kanban bin levels would affect when the SC station would start manufacturing each version and whether the orders would be satisfied. In this example, for each version, the minimum Kanban level is 1 week of the version's average weekly demand and the maximum Kanban level is 2 weeks of the version's average weekly demand. The current inventory level is set to be exactly halfway between the minimum and the maximum level. Hence, the Kanban level for each version is shown in Table 6-6.

Table 6-6 Sample values for the Kanban bin levels

Version	Current Level	Min Level	Max Level
A2	16,641	11,094	22,188
A3	18,956	12,637	25,274
A4	25,554	17,036	34,072
E1	25,148	16,765	33,530
E2	16,907	11,271	22,542
E3	8,627	5,751	11,502
E4	25,251	16,834	33,668
E5	13,388	8,925	17,850
B1	12,756	8,504	17,008

Sample Output

Using the input spreadsheet in Table 6-5 and the sample values for the Kanban variables in Table 6-6, the simulation output is the production sequence in Table 6-7 (in actual order of production). Production of a version is triggered when the current inventory falls below the minimum inventory. The Kanban bin is then filled back to the maximum level. For instance, after 11,579 pieces of E5 were removed from the Kanban bins to fulfill demand on 28 January, production is triggered, causing 16,800 pieces of E5 to be produced on 29 Jan. Not all versions are triggered. For instance, since only 2,778 pieces of B1 were removed on 31 January, the current inventory level of B1 is still more than the minimum level. Hence, no B1 was produced in Table 6-7. Note the last column in Table 6-7 indicates whether there is any shortages when a demand is due. In this case, as there no shortages, the samples values for Kanban bin levels are appropriate for implementation.

Table 6-7 Sample Production Sequence (in actual order of production)

Version	Production Quantity	Setup Time (min)	Start Date	End Date	Shortage?
E5	16,800	30	29-Jan	29-Jan	
A2	16,800	30	29-Jan	29-Jan	
A2	8,400	0	30-Jan	30-Jan	
A2	2,800	0	30-Jan	30-Jan	
E5	19,600	30	30-Jan	31-Jan	
A3	22,400	20	31-Jan	01-Feb	
A3	5,600	0	01-Feb	02-Feb	
E2	22,400	30	02-Feb	03-Feb	
E4	22,400	30	03-Feb	04-Feb	
E3	11,200	20	04-Feb	05-Feb	
A4	19,600	20	05-Feb	06-Feb	

Chapter 7 Verification of Proposed Method of Calculating Kanban Levels

In this chapter, the proposed method of calculating Kanban levels in Chapter 5 is put to the test using the historical demand data in years 2007 and 2008 (weeks 1 to 30). In each year, the Kanban levels are first determined for all the versions using the proposed method. Next, the historical demand data and the Kanban levels are input into the simulation model defined in Chapter 6. The Kanban levels would have to meet all historical demands without any shortage in meeting any demand.

Since Pearly prefers to implement the Kanban system for only 'non-obsolescing' versions, the proposed Kanban levels for 'non-obsolescing' versions in 2008 are then compared with the current Kanban levels to examine the cost benefits. Finally, sensitivity analysis is done to examine how much demand variability the proposed Kanban levels can hedge against.

7.1 Using Year 2007 Data

For the year 2007, since this demand forecast exceeds the normal 6-day capacity of the SC station in quarter 3, it is smoothed out to obtain the planned production (Figure 7-1). This method of long-term capacity planning is covered in [3]. A comparison of the demand forecast and the planned production is shown in Figures 7-1 and 7-2. As shown in Figure 7-1, the planned production is within normal weekly capacity of the SC station. The planned production is then input into the Kanban simulation.

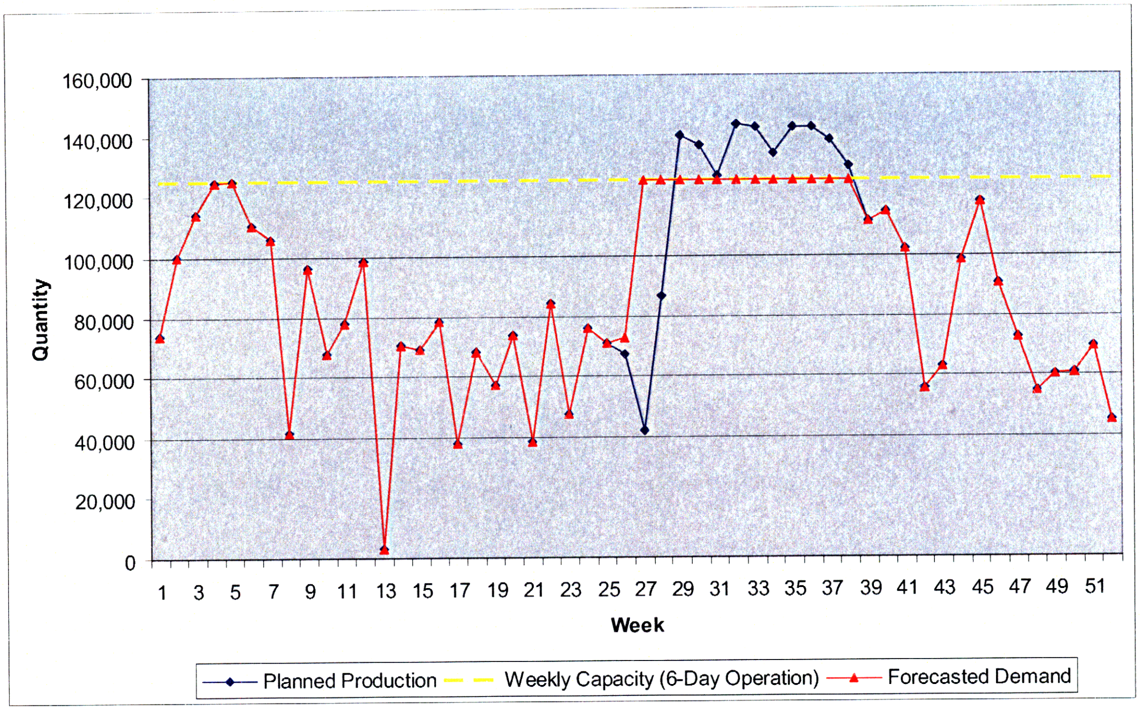

Figure 7-1 Demand & Planned Production for All Versions in 2007

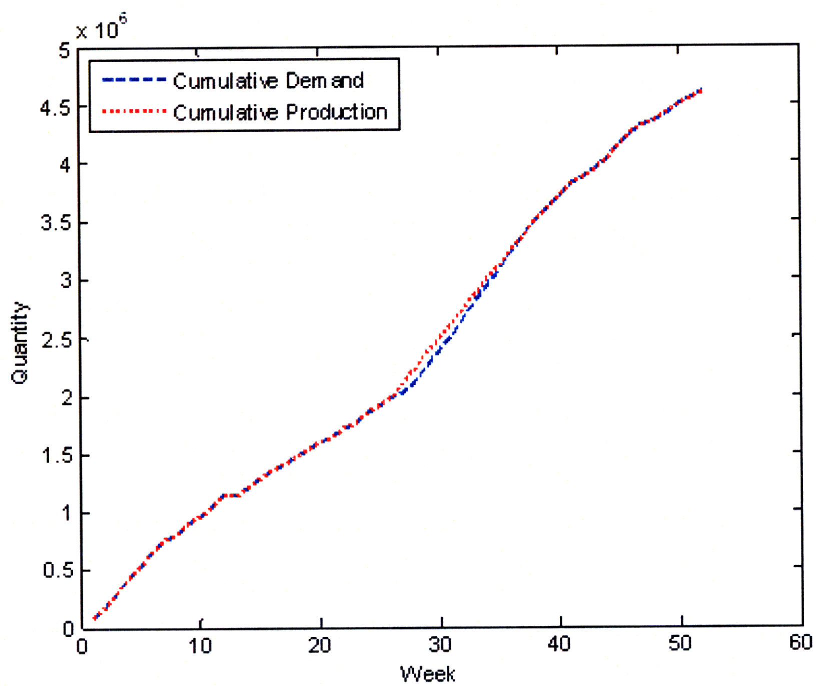

Figure 7-2 Cumulative Demand & Cumulative Planned Production for All Versions in 2007

7.1.1 Mean Demand Rate in 2007

In 2007, the SC station manufactures 11 versions and there is an average of 6.1 versions in each week's demand. The demand proportion for all the 11 versions have been sorted in Pareto format as displayed in Figure 7-3. The high-runners are A4, E1 and E4 while the rest are low-runners.

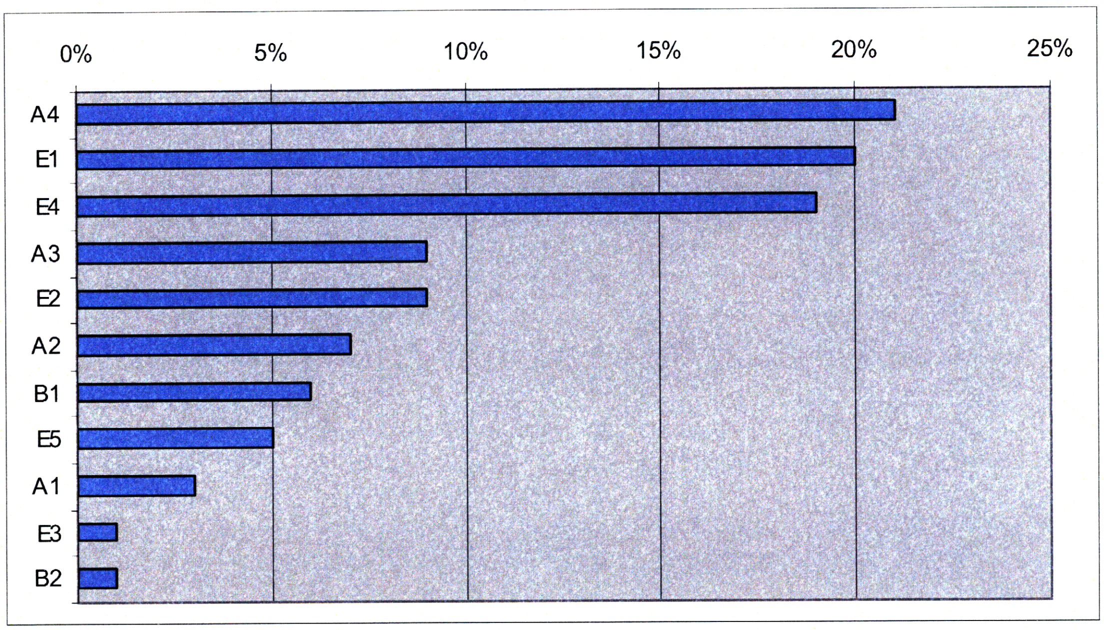

Figure 7-3 Version Proportion of Demand at SC station in 2007

The mean demand rates of each version in 2007 are calculated using Equations 18 to 20 (Chapter 5) and shown in Table 7-1 and 7-2

Table 7-1 Demand Rate each version in 2007 Q1, Q2 and Q4 (Q=Quarter)

Versions	Mean Demand Rate
A1	8,604
A2	10,540
A3	12,005
A4*	16,184
E1*	15,927
E2	10,708
E3	5,463
E4*	15,992
E5	8,479
B1	7,654
B2	6,380

*: *High-Runner*

Table 7-2 Demand Rate each version in 2007 Q3 (Q=Quarter)

Versions	Mean Demand Rate
A1	8,604
A2	10,540
A3	12,005
A4*	32,145
E1*	25,283
E2	10,708
E3	5,463
E4*	28,283
E5	8,479
B1	7,654
B2	6,380

*: *High-Runner*

7.1.2 Proposed Kanban Levels for 2007

Using the formulae in Table 5-2, the demand rates in Tables 7-1 and 7-2 are converted to the respective proposed Kanban levels for 2007 in Table 7-3 and 7-4. Note that the Kanban levels are rounded off to the nearest multiple of 1500 (explained in Section 4.3).

Table 7-3 Proposed Kanban levels for 2007 Q1, Q2 and Q4 (Q=Quarter)

Version	Min Level	Max Level
A1	13,500	25,500
A2	16,500	31,500
A3	18,000	36,000
A4*	16,500	33,000
E1*	16,500	31,500
E2	16,500	31,500
E3	7,500	16,500
E4*	16,500	31,500
E5	12,000	25,500
B1	12,000	22,500
B2	9,000	19,500

*: *High-Runner*

Table 7-4 Proposed Kanban levels for 2007 Q3 (Q=Quarter)

Version	Min Level	Max Level
A1	13,500	25,500
A2	16,500	31,500
A3	18,000	36,000
A4*	31,500	64,500
E1*	25,500	51,000
E2	16,500	31,500
E3	7,500	16,500
E4*	28,500	57,000
E5	12,000	25,500
B1	12,000	22,500
B2	9,000	19,500

*: *High-Runner*

7.1.3 Simulation Results using the Proposed Kanban Levels for 2007

Using the proposed Kanban levels for all versions for 2007 in Tables 7-3 and 7-4, the proposed Kanban levels can satisfy all the demands in 2007. To meet the average demand of 6.1 versions every week, using the proposed Kanban levels would result in only 3.0 versions produced every week. The production output from the planned production is illustrated in Figure 7-4.

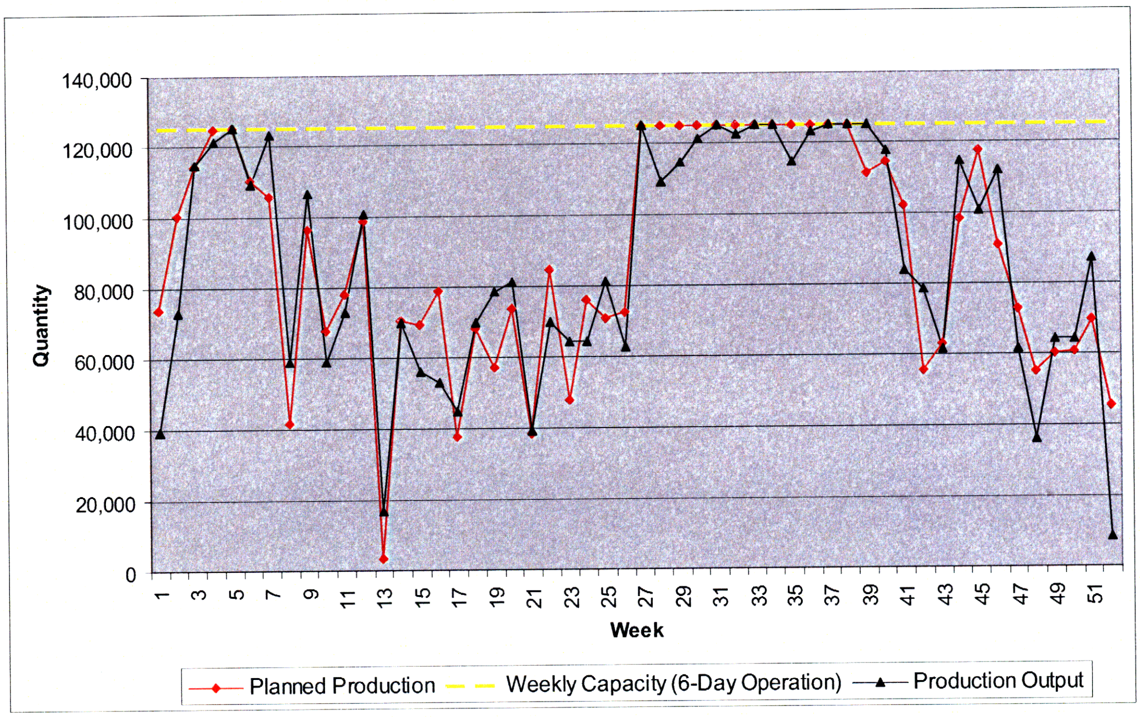

Figure 7-4 Planned Production & Production Output at SC station in 2007

As shown by Figure 7-5, the cumulative production output is always above the cumulative planned production. Throughout the weeks, the total Kanban inventory of all the versions, which is the difference between the cumulative production output and the cumulative planned production, varies but remain approximately constant.

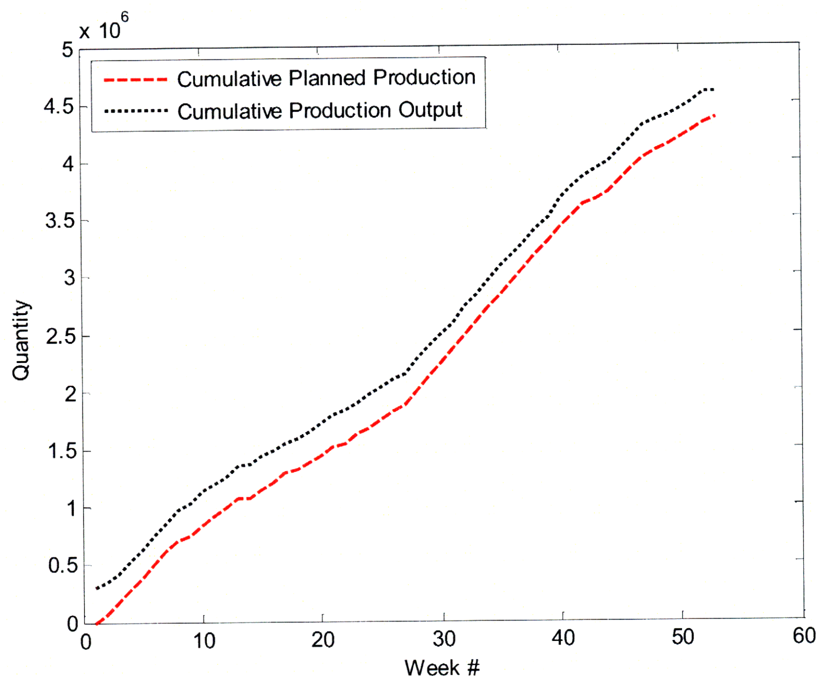

Figure 7-5 Cumulative Production Output & Cumulative Planned Production for All Versions in 2007

To determine whether there is any shortage, it is necessary to plot the cumulative production output and planned production for each version separately. For instance, all the orders of E5 are met since its cumulative production output is always above its cumulative planned production as illustrated in Figure 7-6. This is also true for all the other versions.

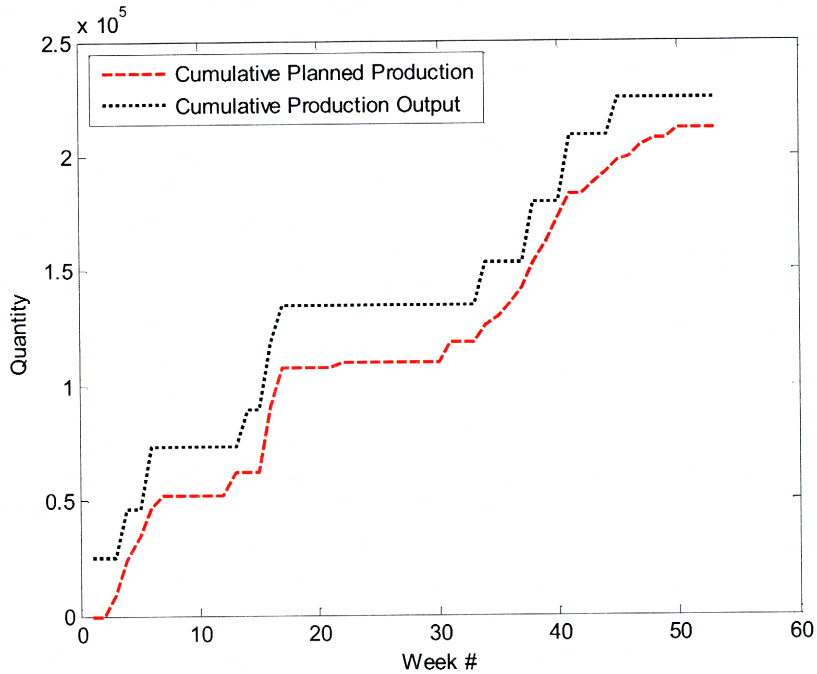

Figure 7-6 Cumulative Production Output & Cumulative Planned Production for E5 in 2007

7.2 Using Year 2008 (Week 1 to 30) Data

For the year 2008, only the data from week 1 to 30 is available. Since this demand forecast does not exceed the 6-day capacity of the SC station, there is no need to smoothen out the demand via long-term capacity planning. Hence the planned production is equal to the demand forecast and is input into the Kanban simulation (Figures 7-7 and 7-8).

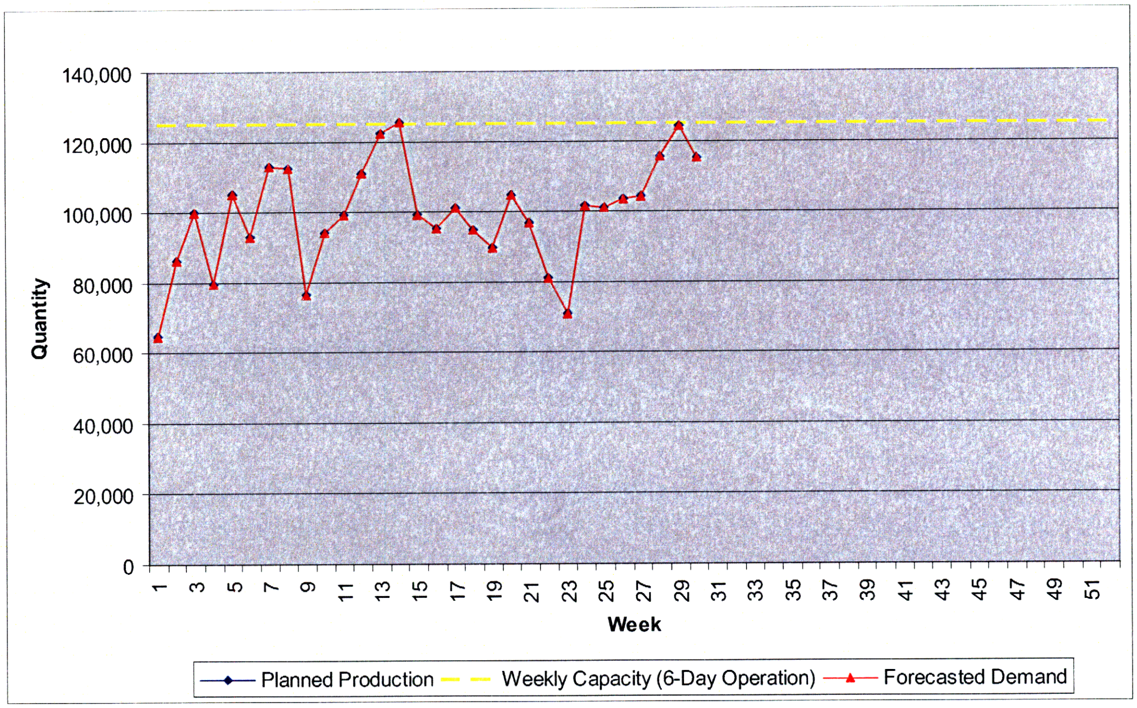

Figure 7-7 Demand & Planned Production for All Versions in 2008

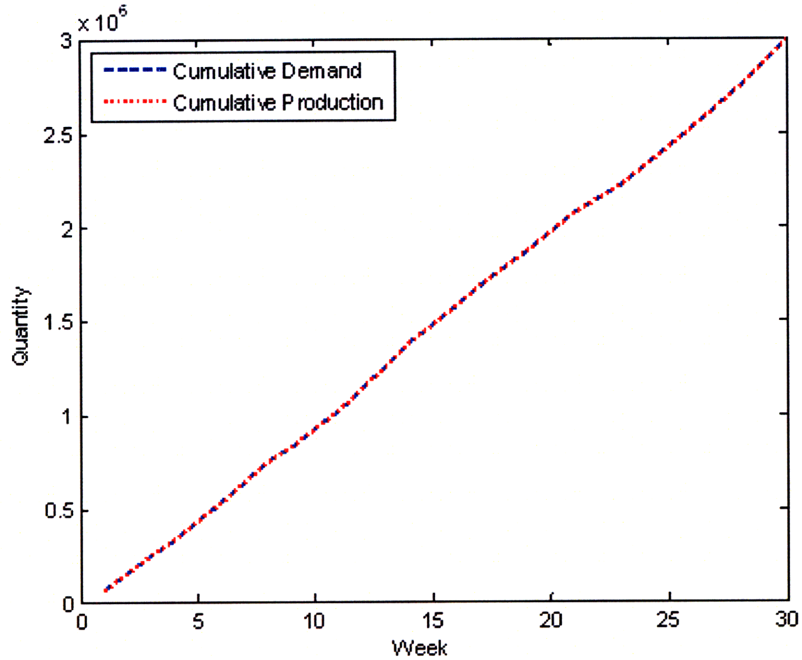

Figure 7-8 Cumulative Demand & Planned Production for All Versions in 2008

7.2.1 Mean Demand Rate in 2008

In 2008, the SC station manufactures 12 versions and there is an average of 9.1 versions in each week's demand. The demand proportion for all the 12 versions have been sorted in Pareto format as displayed in Figure 7-9. The high-runners are E4 and A6 while the rest are low-runners.

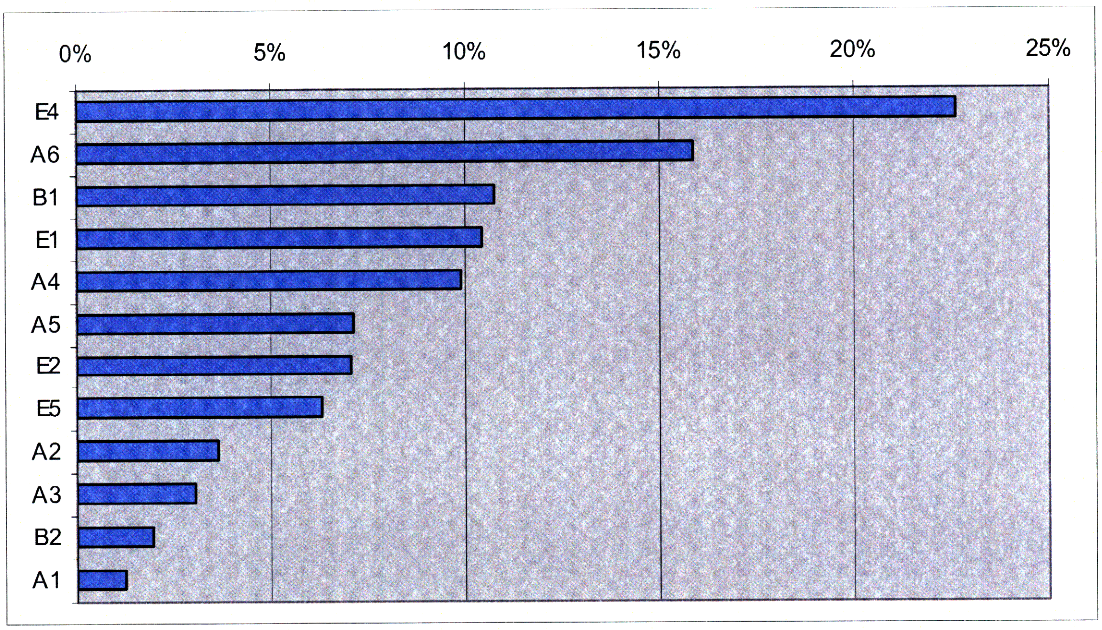

Figure 7-9 Version Proportion of Demand at SC station in 2008

Similarly to Table 6-3, the demand rates of each version in 2008 (week 1 to 30) are calculated using Equations 18 to 20 (Chapter 5) and shown in Table 7-5.

Table 7-5 Demand Rate for each version in 2008

Versions	Demand Rate
A1	5,134
A2	6,492
A3	5,068
A4	9,986
A5	7,475
A6*	16,075
E1	11,384
E2	8,713
E4*	21,377
E5	6,623
B1	9,954
B2	3,702

*: *High-Runner*

7.2.2 Proposed Kanban Levels for 2008

Using the formulae in Table 5-2, the demand rates in Table 7-5 are converted to the respective the proposed Kanban levels for 2008 will be Table 7-6. Note that the Kanban levels are rounded off to the nearest multiple of 1500 (explained in Section 4.3).

Table 7-6 Proposed Kanban levels for all versions for 2008 Q1, Q2 and Q4

Version	Min Level	Max Level
A1	7,500	15,000
A2	9,000	19,500
A3	7,500	15,000
A4	15,000	30,000
A5	10,500	22,500
A6*	16,500	31,500
E1	16,500	34,500
E2	13,500	25,500
E4*	21,000	43,500
E5	10,500	19,500
B1	15,000	30,000
B2	6,000	10,500

*: *High-Runner*

7.2.3 Simulation Results using the Proposed Kanban Levels for 2008

Using the proposed Kanban levels for all versions for 2008 in Tables 7-6, the proposed Kanban levels can satisfy all the demands in 2008. To meet the average demand of 9.1 versions every week, using the proposed Kanban levels would result in only 4.1 versions produced every week. The production output from the planned production is illustrated in Figure 7-10.

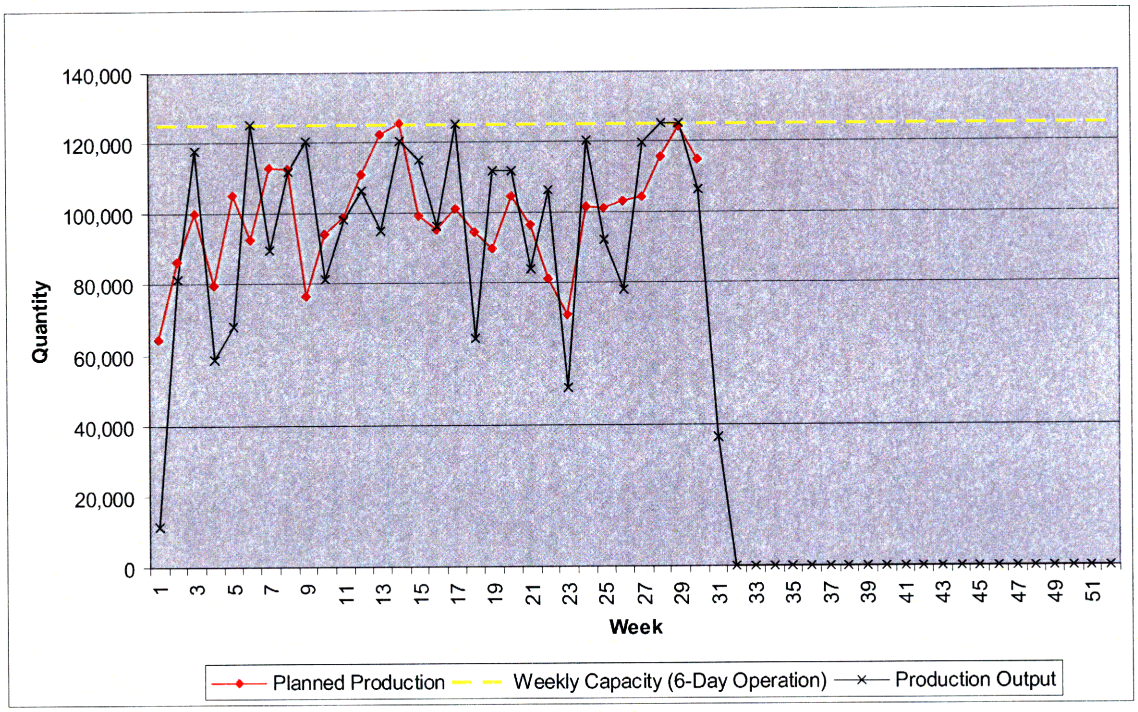

Figure 7-10 Planned Production & Production Output at SC station in 2008

As shown by Figure 7-11, the cumulative production output is always above the cumulative planned production. Throughout the weeks, the total Kanban inventory of all the versions, which is the difference between the cumulative production output and the cumulative planned production, varies but remain approximately constant.

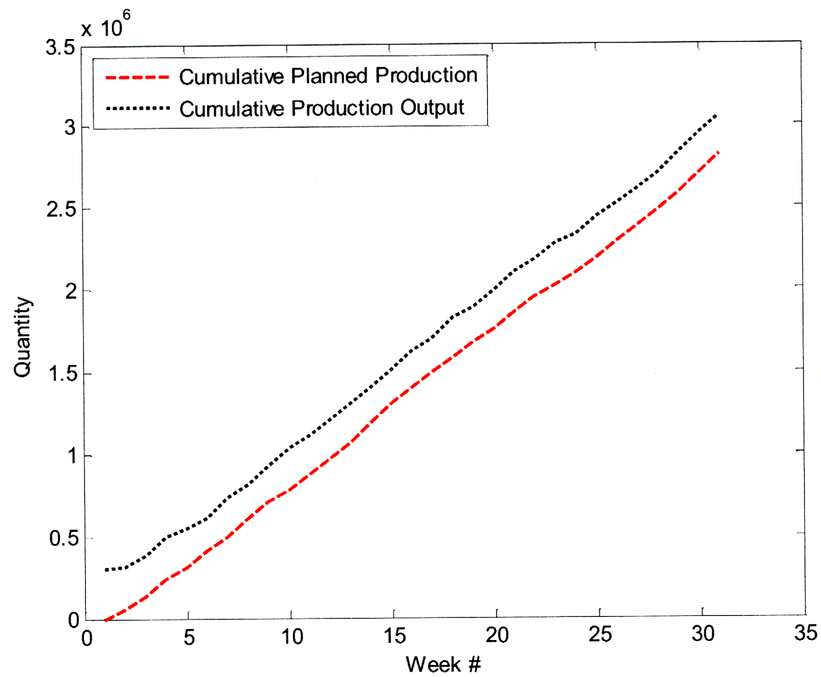

Figure 7-11 Cumulative Production Output & Cumulative Planned Production for All Versions in 2008

To determine whether there is any shortage, it is necessary to plot the cumulative production output and planned production for each version separately. For instance, all the orders of E5 are met since its cumulative production output is always above its cumulative planned production as illustrated in Figure 7-12. This is also true for all the other versions.

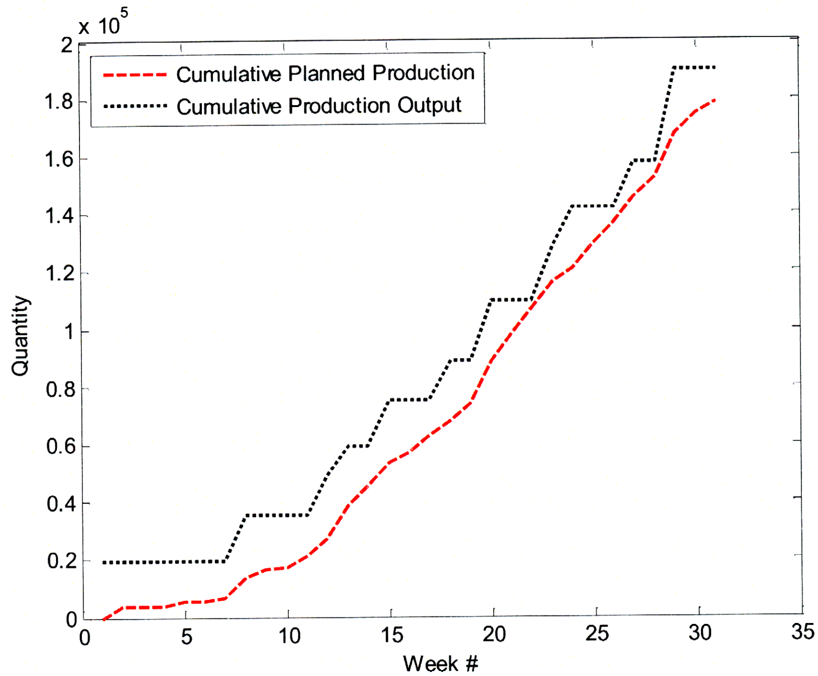

Figure 7-12 Cumulative Production Output & Cumulative Planned Production for E5 in 2008

7.3 Comparison between Existing and Proposed Kanban levels for 2008 (week 1 to 30)

7.3.1 Existing Kanban Levels for 2008

As explained in Section 2.1.2, Pearly currently uses the Kanban levels in Table 2-2 for the 7 versions on the Kanban system. Note that the existing Kanban system has no minimum level to trigger production for a particular version. Instead, production is triggered whenever the inventory for a particular version is not at its maximum level, subjected to the 'changeover rule'.

Using this method of production, the minimum level of each version in the existing Kanban system can be approximated to be the difference between the maximum level and the average demand rate. Hence, the approximated existing Kanban levels are given in Table 7-7.

Table 7-7 Approximated Existing Kanban levels for Kanban versions in 2008

Versions	Min level	Max level
A3	16,500	21,000
A4	19,500	30,000
A5	13,500	21,000
A6	13,500	30,000
E2	12,000	21,000
E4	9,000	30,000
E5	15,000	21,000

7.3.2 Proposed Kanban Levels for 2008

As explained in Section 2.1.2, the existing Kanban system is not applied to all versions produced at the SC station. Only 7 versions have Kanban levels as shown in Table 2-2. The rest of the versions in Table 2-1 are still on the 'push' system. Hence, in order to make a fair comparison between the existing and proposed Kanban levels in Section 7.2, it is necessary to only compare the 7 versions that are currently on the Kanban system.

Thus, the proposed Kanban system in Table 7-6 is only implemented for the 7 versions to give Table 7-8.

Table 7-8 Proposed Kanban levels for Kanban versions for 2008 Q1, Q2 and Q4

Version	Min Level	Max Level
A3	7,500	15,000
A4	15,000	30,000
A5	10,500	22,500
A6*	16,500	31,500
E2	13,500	25,500
E4*	21,000	43,500
E5	10,500	19,500

**: High-Runner*

7.3.3 Comparison between Existing and Proposed Kanban Levels for 2008

Using the Planned Production in Figure 7-5 and the existing Kanban levels in Table 7-7 as input into the Kanban Simulation Model in Chapter 5, a certain production sequence is obtained. The changeover cost, inventory cost and total cost can then be calculated using Equations (15) to (17) in Section 4.4 to obtain Table 7-9.

Table 7-9 Financial Analysis of Existing Kanban Levels for 2008 (wk 1-30)

Ave # of Versions produced/wk	Changeover Cost	Ave Total Inventory	Inventory Cost	Total Cost
6.00	$90,000	136,500	$60,775	**$150,775**

Similarly, the changeover cost, inventory cost and total cost can be calculated for using the

Proposed Kanban Levels in Table 7-8 to obtain Table 7-10.

Table 7-10 Financial Analysis of Proposed Kanban Levels for 2008 (wk 1-30)

Ave # of Versions produced/wk	Changeover Cost	Ave Total Inventory	Inventory Cost	Total Cost
2.77	$41,500	141,000	$62,779	**$104,279**

By comparing Tables 7-9 and 7-10, it is observed that the proposed Kanban levels can greatly reduce the average number of versions produced per week from 6 to 2.77 versions. This results in a 54% reduction in changeover cost from $90,000 to $41,500. In spite of the slightly larger inventory cost in the Proposed Kanban levels, the total cost for using the Proposed Kanban levels is 30% lower than the total cost for using the existing Kanban levels.

There are other benefits in addition to the lower total cost of using the proposed Kanban levels. By defining the minimum levels in the proposed Kanban levels to trigger production, the sequence of production is no longer ambiguous and has clear indications of when production of a version should start or when changeover should occur. Moreover, using the proposed method of calculating Kanban levels gives a more structured way of determining Kanban levels that will change accordingly with the demand rate.

7.4 Sensitivity Analysis to increased demands

As demonstrated by Table 5-2, the proposed Kanban levels are calculated based on the mean demand rate. This mean demand rate is actually an estimate because the total demand for the version in Equations (18) to (20) (Section 5.2) is an estimate. To examine how much increase in demands the estimated demand rate or the proposed Kanban levels can hedge against, sensitivity analysis is done.

The demands for all the Kanban versions in 2008 are increased by a certain percentage such that the mean modified demand rate is larger than the mean original demand rate (Figure 7-13). Note since only the demands of the Kanban versions are simulated, the increased demands of the Kanban versions are still within the normal weekly capacity of the SC station. Next, the proposed Kanban levels in Table 7-8 are tested to see whether they are sufficient to meet the modified demand.

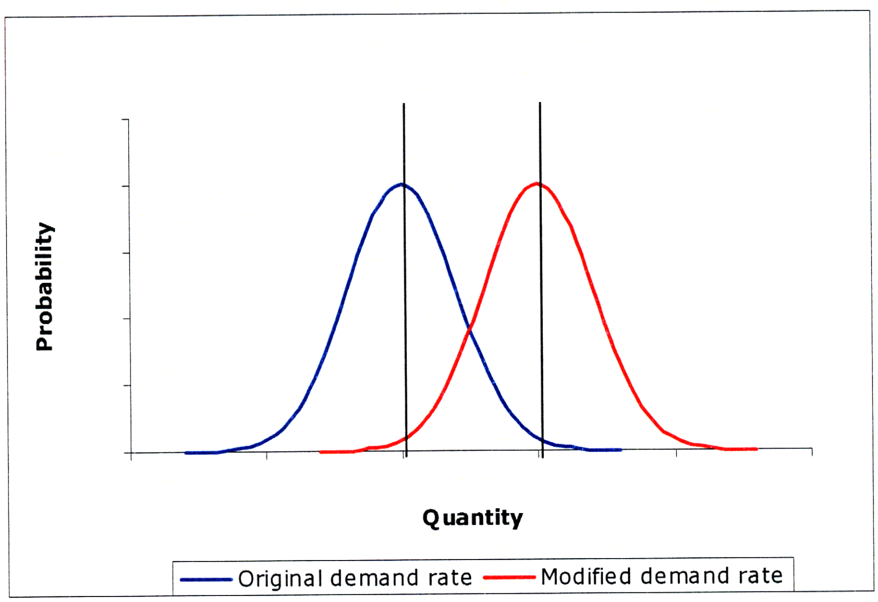

Figure 7-13 Probability distribution curves of original demand rate vs modified demand rate

As indicated in Table 7-11, when the demands for all the versions are increased by up to 50%, the proposed Kanban levels can still meet the increased demand. However, when the demands for all the versions are increased by more than 60%, there is shortage in meeting the increased demand.

. .

Table 7-11 Impact of Increased demands on ability of Proposed Kanban levels to cope

Increase in demands	Proposed Kanban levels able to Cope with increased demand?
10%	Yes
20%	Yes
30%	Yes
40%	Yes
50%	Yes
60%	No
70%	No

The significance of this result is that the proposed Kanban levels, which are initially calculated from the estimated mean demand rates, can satisfy up to a 50% increase in demand rates for all versions. If the actual mean demand rate for a version exceeds beyond 50% of the estimated mean demand rate, it would be safer to adjust the mean demand rate and recalculate the Kanban level for that version.

On the other hand, when the existing Kanban levels are tested to see whether they are sufficient to meet the modified demand, it is observed in Table 7-12 that the existing Kanban levels can only satisfy up to a 30% increase in demand rates for all versions.

Table 7-12 Impact of Increased demands on ability of existing Kanban levels to cope

Increase in demands	Existing Kanban levels able to Cope with increased demand?
10%	Yes
20%	Yes
30%	Yes
40%	No
50%	No
60%	No
70%	No

Chapter 8 Recommendations and Conclusion

8.1 Recommendations for the company

To set the minimum and maximum Kanban levels for any version at the SC station, Pearly should use the formulae in Table 5-2, whereby the mean demand rates are estimated using Equations (18) to (20) (in Section 5.2).

Hence, for the remaining quarter 4 of the year 2008, it is recommended for the company to use the proposed Kanban levels in Table 7-8. Production for the particular version is triggered whenever the inventory for that version drops below the minimum level. Production continues until the inventory for that version reaches the maximum level.

However, the company strongly prefers to define the minimum Kanban level as a range of values. The upper bound of the minimum Kanban level is defined as the level whereby that particular version is queued for production; the lower bound of the minimum Kanban level is defined as the dangerously low level whereby management is informed. Ideally, the Kanban level for each version is allowed sometimes to drop below the upper bound of the minimum Kanban level but never to the lower bound of the minimum Kanban level. Since the average order quantity for a particular version in a day in 2008 is 5674, the lower bound of the minimum Kanban level is set to be 6000 (rounded to the nearest pallet size of 1500). Thus, the proposed Kanban levels for the remaining quarter 4 of the year 2008 are shown in Table 8-1.

Table 8-1 Proposed Kanban levels (range of values as min level) for Kanban versions for 2008 Q1, Q2 and Q4

Version	Min Level	Max Level
A3	6,000 - 7,500	15,000
A4	6,000 - 15,000	30,000
A5	6,000 - 10,500	22,500
A6	6,000 - 16,500	31,500
E2	6,000 - 13,500	25,500
E4	6,000 - 21,000	43,500
E5	6,000 - 10,500	19,500

The number of Kanban cards to be used for each version is calculated using Equations (13) and (14) (in Section 4.3) to obtain Table 8-2.

Table 8-2 Proposed Number of Kanban cards (range of values as min level) for Kanban versions for 2008 Q1, Q2 and Q4

Version	Min Level	Max Level
A3	4 - 5	10
A4	4 - 10	20
A5	4 - 7	15
A6	4 - 11	21
E2	4 - 9	17
E4	4 - 14	29
E5	4 - 7	13

8.2 Conclusion

Overall, this project has successfully identified and studied the two problems that the SC station has. Solutions have been proposed to solve these two problems. For the problem of the peak demand exceeding the normal capacity, a long-term capacity planning methodology is proposed in [3]. For the problem of the existing Kanban system having inappropriate Kanban levels, a method to determine the Kanban levels has been proposed in this thesis.

For the year 2008, although this proposed Kanban system will result in approximately equal amount of inventory with the existing Kanban system, there will be a 54% reduction in changeover cost. This leads to a 30% reduction in total cost, which is about $46,000 cost savings. The proposed Kanban system will also be able to hedge against 50% variability in demand forecast of each version.

In general, this proposed Kanban system will be able to help the SC station to meet fluctuating demands for different versions throughout the year. Unlike the existing Kanban system, the minimum and the maximum Kanban levels in the proposed Kanban system are clearly defined such that there is no longer any ambiguity in the sequence of production. Use of this system will indicate clearly when to start or stop production, as well as how much quantity to produce for each version.

8.3 Future work

In this thesis, it is assumed that there are no supply issues to the SC station. This may not be true for Sydney versions. Hence, it is necessary to simulate the upstream stations for the Sydney versions, to understand the availability of supply of Sydney versions to the SC station.

In addition, the Kanban system is designed for only the SC station. Further research can be done to design the Kanban system for the other stations in the process flow. This will help the entire manufacturing process better react to demand. After the Kanban system is implemented for the whole process flow, the Constant Work in Process (CONWIP) [12] system can be studied in its application in the whole process flow to potentially lower inventory levels.

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Appendix

Visual Logic Code for Kanban Simulation Model

VL SECTION: Choose Job Route-In After Logic

```
'Reset (Labelling)Found=0 means no job found
SET (Labelling)Found = 0
'Set Label Ready =1-->Route to simulation trash if not ready to produced yet; Set Label Ready =2-->Route to
SC station pdtn
SET Ready = 1
'Reset Current_Lateness to 0 so as to find max due later
SET (Labelling)Current_Lateness = 0
'Copy previous pdtn data to temp cos will be updating 'current' variables with next pdtn data (note: initial run,
current_color=current_worktype=3 so initial job Sij=30)
SET (Labelling)Temp_Previous_Version = (Labelling)Current_Version
SET (Labelling)Temp_Previous_Color = (Labelling)Current_Color
SET (Labelling)Temp_Previous_Worktype = (Labelling)Current_Worktype
SET (Labelling)Temp_LoopWorktype = 2
'If SC station stopped pdtn
IF Decide Qtty.State = 0
  'Deduct demand from inventory
  WHILE (Labelling)Temp_LoopWorktype >= 1
    SET (Labelling)Forecast_Column = [(Labelling)Temp_LoopWorktype-1]*5
    SET (Labelling)Forecast_Row = 3
    'If color=0 -> end of queuelist in forecast
    SET (Labelling)Temp_CheckEndQueue =
(Dispatch)Forecast[(Labelling)Forecast_Column+3,(Labelling)Forecast_Row]
    WHILE (Labelling)Temp_CheckEndQueue <> 0
      IF (Dispatch)Forecast[(Labelling)Forecast_Column+4,(Labelling)Forecast_Row] <> 0
        IF (SC station)Total_Sij+Simulation Time >=
(Dispatch)Forecast[(Labelling)Forecast_Column+1,(Labelling)Forecast_Row]
          'Look thru all surplus-on-hand
          SET (Labelling)Temp_SurplusListQueue = 2
          WHILE (Decide Qtty)SurplusList[1,(Labelling)Temp_SurplusListQueue] <> (Decide
Qtty)Temp_Blank
            IF (Dispatch)Forecast[(Labelling)Forecast_Column+2,(Labelling)Forecast_Row] = (Decide
Qtty)SurplusList[1,(Labelling)Temp_SurplusListQueue]
```

SET (Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue] = (Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]-(Dispatch)Forecast[(Labelling)Forecast_Column+4, (Labelling)Forecast_Row]

'Edit demand excel sheet so that qtty=0 to show that job done

SET (Dispatch)Forecast[(Labelling)Forecast_Column+4,(Labelling)Forecast_Row] = 0

'If inventory lvl < 0, Indicate '1' in Shortage column

IF (Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue] < 0

'Increase # Shortage by 1

SET (Decide Qtty)SurplusList[7,(Labelling)Temp_SurplusListQueue] = (Decide Qtty)SurplusList[7,(Labelling)Temp_SurplusListQueue]+1

'Record max shortage

IF (Decide Qtty)SurplusList[8,(Labelling)Temp_SurplusListQueue] < ABS[(Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]]

SET (Decide Qtty)SurplusList[8,(Labelling)Temp_SurplusListQueue] = ABS[(Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]]

Break

SET (Labelling)Temp_SurplusListQueue = (Labelling)Temp_SurplusListQueue+1

SET (Labelling)Forecast_Row = (Labelling)Forecast_Row+1

SET (Labelling)Temp_CheckEndQueue = (Dispatch)Forecast[(Labelling)Forecast_Column+3,(Labelling)Forecast_Row]

SET (Labelling)Temp_LoopWorktype = (Labelling)Temp_LoopWorktype-1

'if previous version not filled to max, then fill previous version to max

IF (Decide Qtty)SurplusList[4,(Labelling)Current_Row]-(Decide Qtty)SurplusList[2,(Labelling)Current_Row] > 0

SET (Labelling)Current_Quantity = (Decide Qtty)SurplusList[4,(Labelling)Current_Row]-(Decide Qtty)SurplusList[2,(Labelling)Current_Row]

SET (Labelling)Found = 1

IF (Labelling)Found <> 1

SET (Labelling)Temp_SurplusListQueue = 2

WHILE (Decide Qtty)SurplusList[1,(Labelling)Temp_SurplusListQueue] <> (Decide Qtty)Temp_Blank

'If min lvl >> inventory lvl, do this job

IF (Decide Qtty)SurplusList[3,(Labelling)Temp_SurplusListQueue]-(Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue] > (Labelling)Current_Lateness

SET (Labelling)Current_Lateness = (Decide Qtty)SurplusList[3,(Labelling)Temp_SurplusListQueue]-(Decide Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]

```
            SET (Labelling)Current_Version  =  (Decide
Qtty)SurplusList[1,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Color  =  (Decide
Qtty)SurplusList[6,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Quantity  =  (Decide
Qtty)SurplusList[4,(Labelling)Temp_SurplusListQueue]-(Decide
Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Row  =  (Labelling)Temp_SurplusListQueue
            IF (Labelling)Temp_SurplusListQueue  >=  13
              SET (Labelling)Current_Worktype  =  2
            ELSE
              SET (Labelling)Current_Worktype  =  1
            SET (Labelling)Found  =  1
          SET (Labelling)Temp_SurplusListQueue  =  (Labelling)Temp_SurplusListQueue+1
        'Look thru Sydney surplus-on-hand and replace with Sydney order if necessary cos Sydney higher
priority
        SET (Labelling)Temp_SurplusListQueue  =  13
        WHILE (Decide Qtty)SurplusList[1,(Labelling)Temp_SurplusListQueue]  <>  (Decide
Qtty)Temp_Blank
          'If min lvl >> inventory lvl, do this job
          SET (Labelling)Current_Lateness  =  0
          IF (Decide Qtty)SurplusList[3,(Labelling)Temp_SurplusListQueue]-(Decide
Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]  >  (Labelling)Current_Lateness
            SET (Labelling)Current_Lateness  =  (Decide
Qtty)SurplusList[3,(Labelling)Temp_SurplusListQueue]-(Decide
Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Version  =  (Decide
Qtty)SurplusList[1,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Color  =  (Decide
Qtty)SurplusList[6,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Quantity  =  (Decide
Qtty)SurplusList[4,(Labelling)Temp_SurplusListQueue]-(Decide
Qtty)SurplusList[2,(Labelling)Temp_SurplusListQueue]
            SET (Labelling)Current_Row  =  (Labelling)Temp_SurplusListQueue
            SET (Labelling)Current_Worktype  =  2
            SET (Labelling)Found  =  1
          SET (Labelling)Temp_SurplusListQueue  =  (Labelling)Temp_SurplusListQueue+1
```

```
IF (Labelling)Found = 1
  'Calculate Sij
  IF (Labelling)Current_Version = (Labelling)Temp_Previous_Version
    SET (Labelling)Sij = 0
  ELSE
    SET (Labelling)Sij = 30
    IF (Labelling)Current_Worktype = (Labelling)Temp_Previous_Worktype
      IF (Labelling)Current_Color = (Labelling)Temp_Previous_Color
        SET (Labelling)Sij = 20
  SET Ready = 2
  'Label with the type that is the most late (i.e. largest lateness)
  SET Version = (Labelling)Current_Version
  SET Color = (Labelling)Current_Color
  SET Quantity = (Labelling)Current_Quantity
  SET Worktype = (Labelling)Current_Worktype
  SET Sij = (Labelling)Sij
```

VL SECTION: Decide Qtty Route-In After Logic

```
SET (Decide Qtty)Temp_Version = Version
'Round quantity to be produced to nearest multiple of 2800
SET Quantity = [TRUNC[Quantity/2800]+1]*2800
'Indicate Overall Job Sequence Queue # on 'ball'
SET SequenceQueue = (Decide Qtty)Temp_Pdtn_SequenceQueue-1
'Output Sequence of Production
SET (Decide Qtty)Pdtn_Sequence[1,(Decide Qtty)Temp_Pdtn_SequenceQueue] = (Decide Qtty)Temp_Version
SET (Decide Qtty)Pdtn_Sequence[2,(Decide Qtty)Temp_Pdtn_SequenceQueue] = Quantity
SET (Decide Qtty)Pdtn_Sequence[3,(Decide Qtty)Temp_Pdtn_SequenceQueue] = Sij
SET (Decide Qtty)Temp_Pdtn_SequenceQueue = (Decide Qtty)Temp_Pdtn_SequenceQueue+1
```

VL SECTION: SC station Route-In After Logic

```
'Set start time of production in (Decide Qtty)Pdtn_Sequence
IF (SC station)Temp_SequenceQueue <> SequenceQueue
  SET (Decide Qtty)Pdtn_Sequence[4,SequenceQueue+1] = ROUND[Simulation Time+(SC station)Total_Sij]
  SET (SC station)Total_Sij = (SC station)Total_Sij+Sij
```

SET (SC station)Temp_SequenceQueue = SequenceQueue