STUDY ON THE PERFOMANCE IMPROVEMENT OF ELECTRICAL DOMESTIC APPLIANCE FACTORY

by

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Bachelor of Engineering in Electrical and Electronic Engineering (2006)
Nanyang Technological University

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

at the

Massachusetts Institute of Technology

[September 2007]
August 2007

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Abstract

This thesis has two objectives. First, it aims to help TECHSOL* electronics domestic appliance measure and analyze its current performance. Secondly, it is aimed to ascertain where a small improvement can result in significant gain.

A simulation model was used to model the factory in the abstract level. From the simulation model, areas of improvement for the factory are identified. It is also learned which stations constrain the factory production and which station performs badly.

The thesis concluded with a suggestion of improvement in a particular station. The way and methodology to improve that particular station become the focus study for my project partner in the company.

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

***Disclaimer**: The Company's name has been purposely disguised for the confidentiality.

Acknowledgements

I would like to thank Dr. Gerswin and Professor Sivakumar for the tremendous help, advice and guidance.

I would like to express my gratitude to Mr.Gan Thiam Boon, Mr Maartin Pelgrim, Mr Harold Kant, Mr Krisna Rao, Mr Tan Ngoh Huang, Mr Seah HT, Ms Melanie Sia, and Mr Ong Sin Huat from the attachment company for always giving us valuable data, support and opinion.

I would also like to thank Li Meng and Liu Ang who always worked side by side with me in this theme project.

Lastly, I would like to thank Fan Siyu,Minda, and Wilson Huang for the tremendous help during the course of my thesis writing.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Company Introduction

TECHSOL* is one of the largest Electronics companies in the world. Headquartered in Europe, TECHSOL had sales over $30 billion in 2006.

In 1951, TECHSOL Electronics Singapore was set up. With a current workforce of more than 3000 people, TECHSOL is one of the pioneer investors in Singapore and has been in the country for more than 5 decades.

TECHSOL Electronics Domestic Appliances began its operations in Singapore to assemble electrical appliances using kits supplied from the parent corporation in Europe. The factory became a Centre of Competence for electrical domestic appliances in 1987, supplying products around the world. Today in 2007, there are dozens of types and products that are produced everyday to cater to different consumer needs and preferences.

1.2 Project Background

For most of the factory's problems, there are always high interactions among each other. Having high change-over time may give rise to production in a big batch size. Producing in large batches usually results in high inventory level. Having Low efficiency may cause low production rates to the factory, and low production rates could result in the inability to satisfy peak demand.

Because of the interactions among problems and facilities in the factory, it is not easy to identify the right area to improve in the factory. Therefore, we want to model the whole factory at an abstract level to find out which improvements have to be the main priority. It is also desirable to find out where small improvements can result in high gains.

* The Client's company identity is protected.

The overall improvement project was done by a team of three students with everyone has his or her own specific area. Kasan Hidayat, the author of this report focused on the overall factory performance. Liu, on the other hand, focused on performance improvement on station 2 by looking at various methods and alternatives to improve that particular station's production rate. Li focused on alternative ways to build-up stock (including WIP) for demand satisfaction with the minimum costs.

Due to the high complexity of the factory flow and numerous parameters involved, a simulation model is chosen for the overall factory performance analysis.

2 Product Category and Flow

2.1 Factory Facilities

Production of TECHSOL product starts from station 1 and 2 in parallel then flows through the rest of the facilities.

Due to high labor costs, the factory in Singapore is machine intensive, in which labor usage is minimized. The overall factory is shown in figure 2.1.

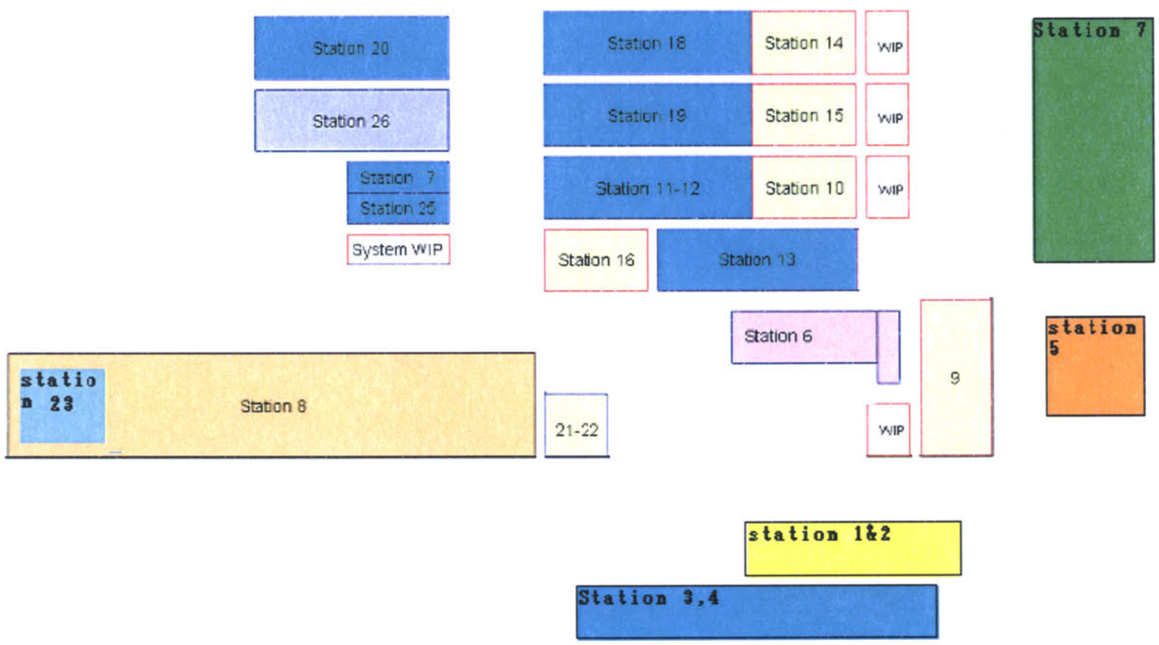

Figure 2-1 Overall Factory Layout

The facilities are differentiated into two categories: product driven stations and process driven stations. Stations 1 to 8 are process driven. This essentially means that they are shared among different types of the products. All products produced will always start from station 1 or 2, and then go to station 3. While almost all types of the products will go to station 4 and 6, there are various product types that will go through station 7 and 8. The remaining stations are the product driven facility. Only one or two types of the product family use those stations and they are not flexible to process other types of product families.

2.2 Product types and Category

Variation of products in TECHSOL results in more than 200 product types. They vary by voltage rating, complexity or functionality.

The major product categories are alpha, beta, and gamma. However, in each category, they also vary in terms of family, series and version.

Alpha is divided into families such as A, B, and C. The product types in B family, for example, are further divided into few series such as B1, B2, B3, etc. Lastly each of these series is categorized based on their finishing.

2.3 Process Flow

Although there are about 200 types of products, the whole production can be simplified according to their flow. The flow line of the products can be categorized into 13 different main groups. Figure 2-2 shows the flow of the product.

It can be seen from figure 2-2 that C-types product experiences re-entry in station 5 facilities as well as in station 12. On the other hand, type G and type H family have assembly with the plate that previously went through station 8 in station 14 and 15.

Things become more complex when there are also different processing rates for different product types in the same facilities. For example in the station 1, different type shapes are being produced depending on the required voltage rating. The shapes determine the cycle time of that particular line. Furthermore, there is also different change-over time that is required from one type to another. This results in certain preferably pattern in the change-over.

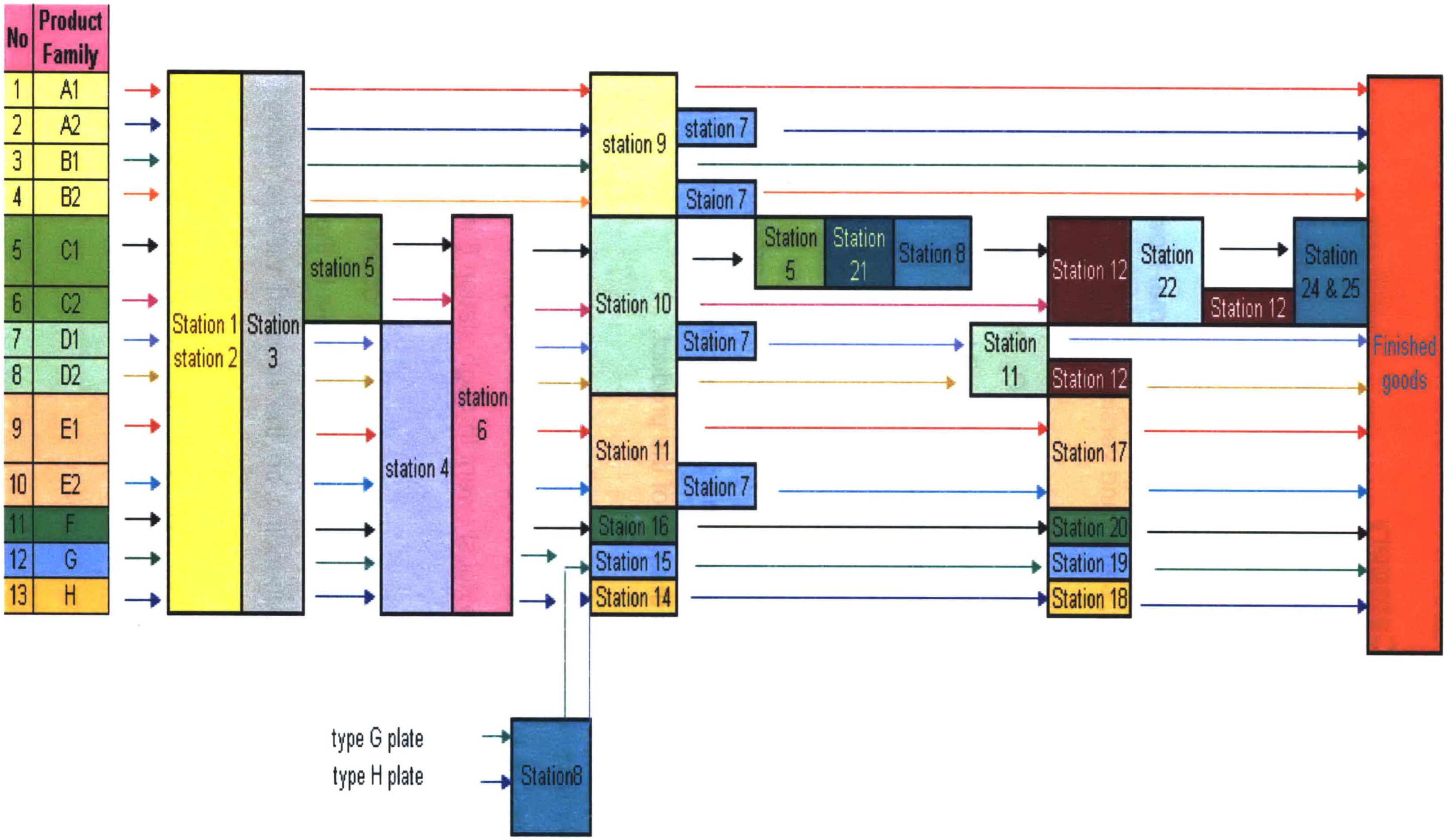

Figure 2-2 Simplified flow process of products

3 Theory Review

3.1 Infinite Buffer Theory

Figure 3-1 Long line machine model

According to Gershwin (1998), it is possible to model every chain of the processes as a group of machine/facilities with buffer in the middle of them. The buffer size can vary from zero to infinity.

For the infinite buffers case, it is easy to identify bottleneck machine/facilities by looking at the buffer trend. There will be an increasing trend of the buffer size accumulated just before the bottleneck machine/facility. Furthermore, in the infinite buffer case, the whole chain of production flow will be dictated by the lowest production rate machine (which is also referred as "bottleneck "machine/facility).

Gershwin (2006) also proved that improving the production rate capacity of the non bottleneck machine will not improve the overall production rate in the infinite-buffer case.

3.2 Machine parameter performance

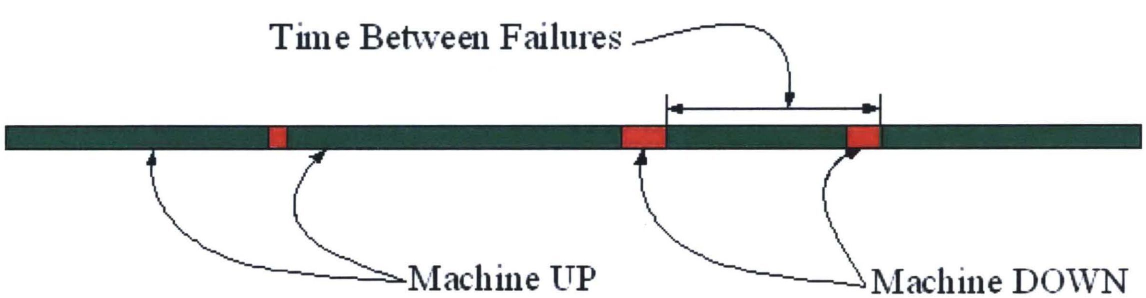

Figure 3-2 Machine performance parameters

MTTR (Mean time to repair) is defined as the average time taken to repair a machine while it is down. While MTTF (Mean time to failure) is defined as the average times the machine is operating before it breaks down. According to Gershwin (2006), MTTR + MTTF= MTBF (Mean time between failure), In TECHSOL as well as in Simul8 Software, MTTF is regarded as MTBF. Therefore, throughput this report, MTBF will be in used instead of MTTF to define the average time the machine is operating before it fails.

3.2 Operating Curve base on Queuing Theory

The operating curve is a description of the factory performance based on the cycle time performance and throughput. Aurand and Miller (1997) explained that the purpose of the operating curve is to provide an analysis methodology to understand and quantify these trades off and to measure and track a factory's performance over times.

Queuing theory provides the basis of the operating curve. Queuing theory is based on the customers that come into the service center. When the server is busy, the customers have to wait until the server is available. After the service is completed, the customer will leave the server. This provides the perfect analogy for what is happening in the factory floor. When a machine is busy, the parts have to wait before it can get into the machine to be processed. Based on the Pollaczek-Khinchin (P-K) formula, the steady state relation between throughput and cycle time is drawn as shown in figure 3-3.

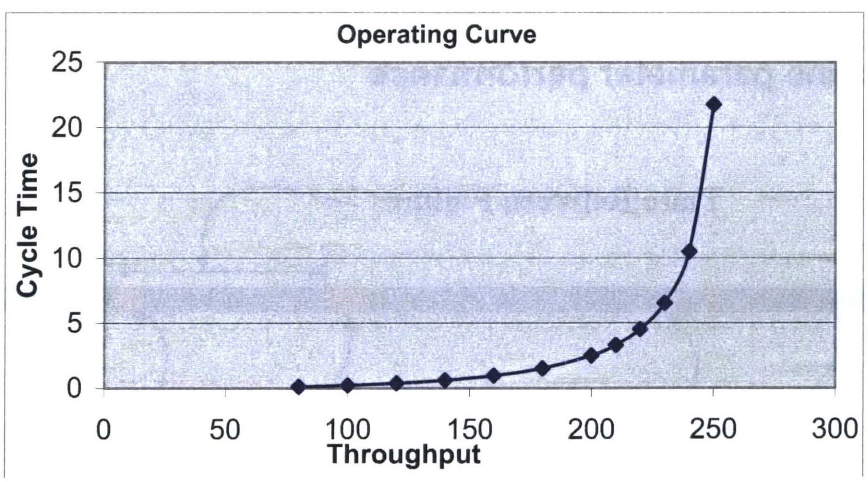

Figure 3-3 Operating Curve based on Cycle time and Throughput

Similarly based on Little's Law, $L = \lambda T$

$L =$ Queue Length

$\lambda =$ Arrival Rate

T = Time in the system

The cycle time/throughput time is directly related to the inventory level. Therefore the operating curve can also be drawn based on the inventory level and throughput as shown in figure 3-4.

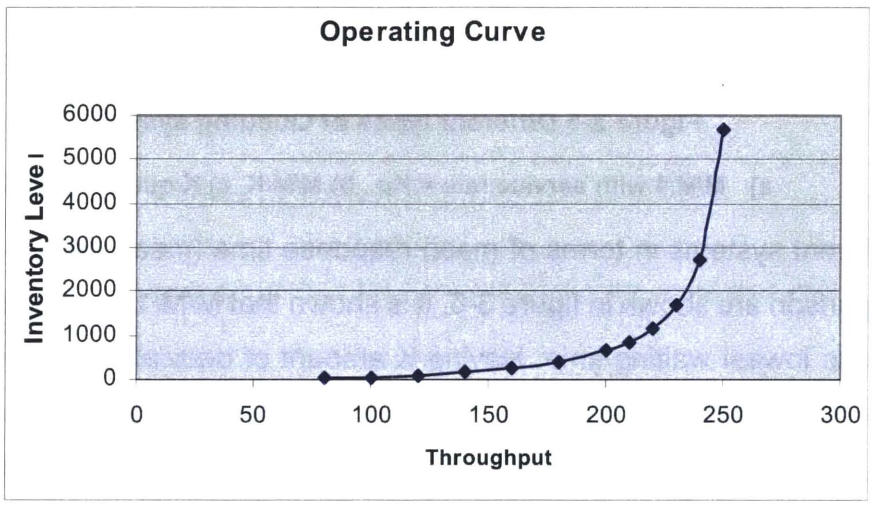

Figure 3-4 Operating Curve based on Cycle time and Throughput

It is noted that this whole queuing theory concept is new to the TECHSOL Engineering department.

3.3 A Comparison of Different Queuing System

Willig(1999) shows a comparison among a few types of queuing systems. He compared three different systems in terms of mean response time (mean delay) with the offered load. These are three systems compared by Willig :

1. M/M/1 with services rate of Kμ* = Markovian model for arrival and service process. There is only a single server with service rate K x μ.
2. M/M/K = Markovian model for arrival and service process, a single queue with K servers. Each server has service rate of μ*.
3. K queues of M/M/1 = Markovian model for arrival and service process, there are

K servers and each server have their own queue without allowing any queue switching. Each server has service rate of μ*

Three different types of systems are shown in figure 3-5.

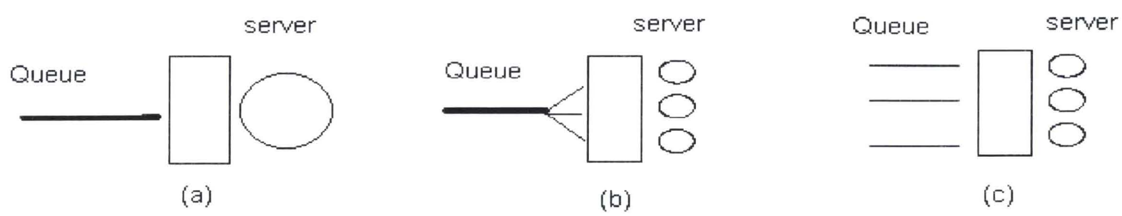

Figure 3-5 Different types of Queuing system

a) M/M/1 with service rate = Kμ , b) M/M/K, c) K queues of M/M/1

Three different systems in terms of mean response time (mean delay) with the offered load comparison are shown in figure 3-6. It is shown that M/M/1 system with high service rate leads to lowest waiting time. Having K amount of dedicated servers that can only serve one type of queue at one time, results in highest waiting time. Consequently, from previous discussion, it also results in high queuing level. This finding is very useful to explain why there are some stations in the factory that have higher average inventory level compare to the rest of stations.

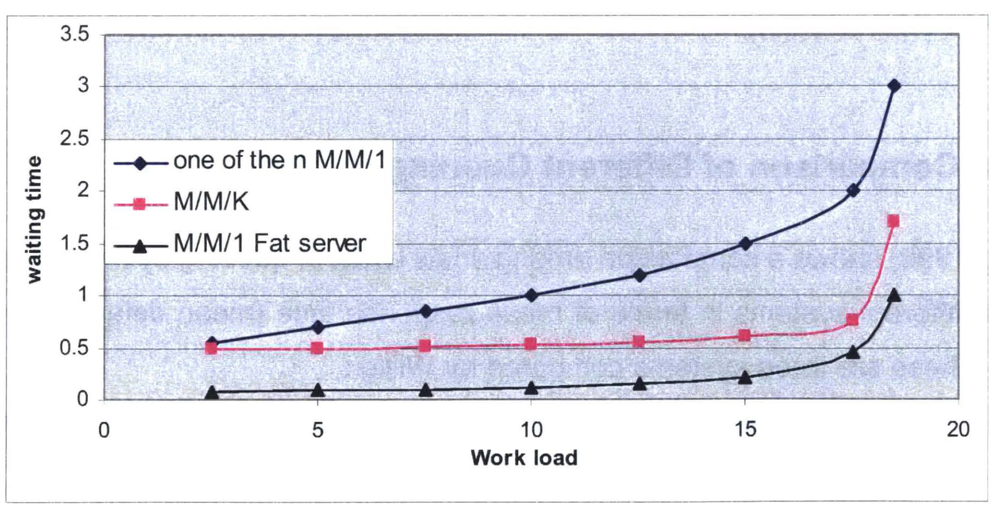

Figure 3-6 Comparison of operating curve of different types of queuing system

* μ is a common notation for service rate of a server in queuing theory

4 Simulation Model of the Overall Factory

4.1 Software used

The modeling software Simul8 was chosen as the tool to simulate the discussed model. Simul8 is powerful and easy-to-use discrete event simulation software. It allows most basic input such as setting of the work center, queue and its parameters such as cycle time, MTBF, MTTR, etc with minimum coding.

The flexibility of the Simul8 allows logic coding embedded in the simulation object for a more advance and specific usage of the model. They are including routing or heuristic policy and planning.

4.2 Simulation model building overview

In order to simulate the overall factory performance, it is unrealistic to go to the detailed level of every station due to very limited time of the project. Instead of simulating the machine level, we simulate the factory at the station level. Station 1 for example, comprises seven machines connected into one-line machine without buffer between them. For simplicity, it is modeled as only one work center in the simulation model.

However, it is not right to model station 3 as a single work center because unlike the first station where all the machine are connected with each other without any buffer between them, station 3 comprises of seven machines working in parallel. Furthermore, those 7 parallel machines most of the times are doing different types of the product family at one time. Therefore, specifically for station 3, the modeling is zoomed into the machine level.

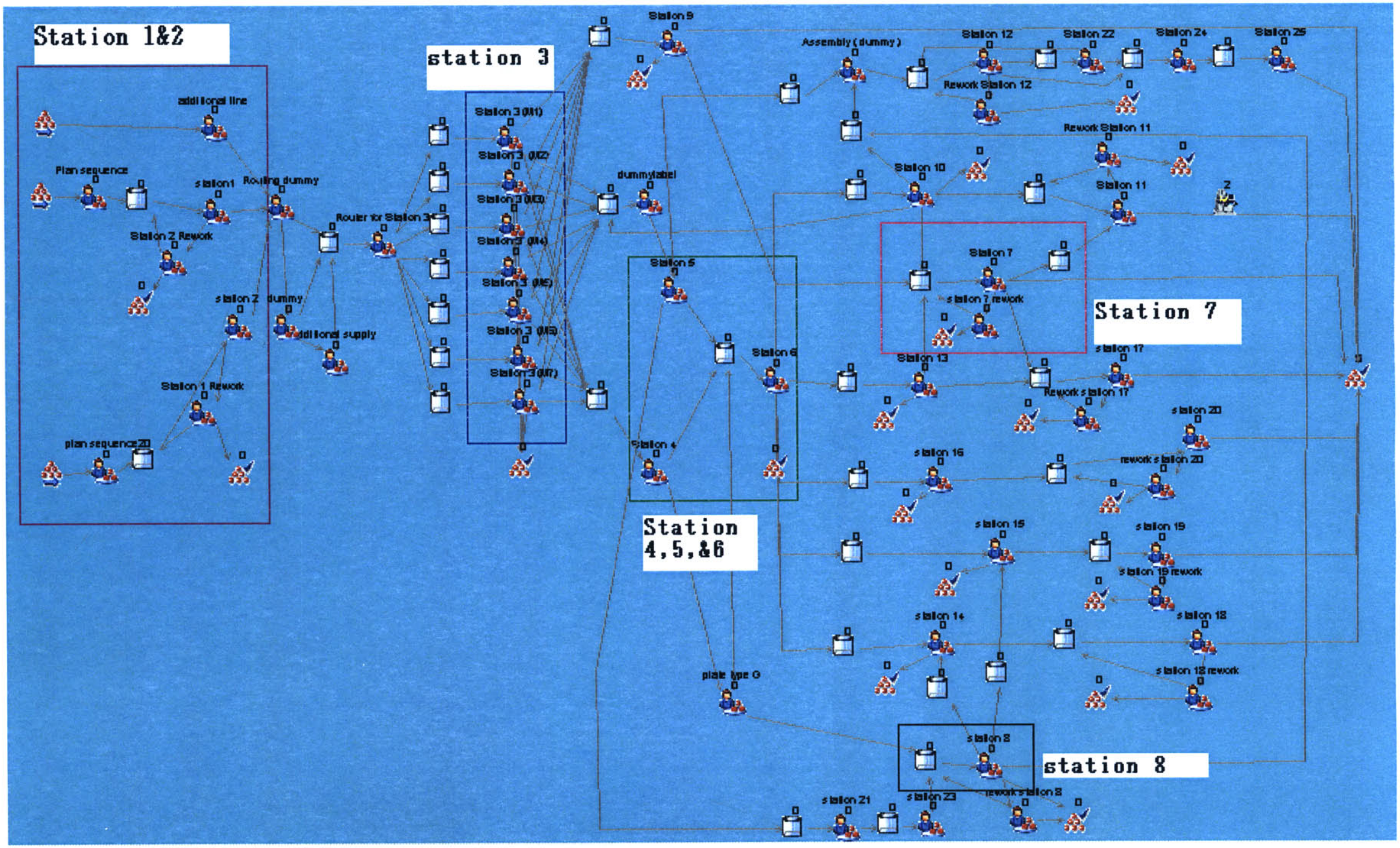

Figure 4-1 Simulation model of the overall factory

The simulation model layout is as shown in figure 4-1. It shows how each station is connected with the other stations. There are also numerous dummy zero cycle time work centers that are used to help the routing of the flow line as well as the flow or material rework. They are also used to do labeling for scheduling purposes.

Furthermore, in order to capture the change-over policy, the simulation was programmed such that the work center would try to finish the job with the same type/setting before it start s processing the other type of job to minimize change-over time.

For Station 3, machines work in parallel. In order to capture real scheduling activity which is minimizing the change-over time, a visual logic code is embedded to ensure that if a particular type of the product has already been assigned to a particular machine, that machine will try to take all same type of the job to its queue. However, when the queue in front of that particular machine is too high, another machine with the shortest queue will try to help that machine to finish that type of work-piece. The limit that determines the queue level is too high or not is also programmed to follow an adaptive logic. Based on the summation of all WIP (Work in progress) level in front of station 3, the logic set the limit as a percentage of it. This logic is programmed in this way to avoid the scenario where the WIP with same products will be routed to all 7 machines when these entire seven machines queue exceed certain static limit during high production period.

This scenario also happens in real factory situations, which the production floor operator and supervisor in station 3 always try to maximize the utilization of all their machines by having a minimum set up time during a high volume production. It could be achieved by assigning one machine to make one type of products as much as possible. However, during a low production season, the operators will not let any machine idle while there are accumulated jobs in queue in front of another. This logic results in some flexibility of the station 3 capacity.

4.3 Simulation Input data

The parameters of the simulation include product flow, downtime (MTTR/MTBF), stoppages, preventive maintenance, change-over time, percentage reject, percentage rework and planning/sequencing of the product.

The output of the Simulation is the production rate (defined as quantity / week) of every individual stations as well as finished goods, material reject, throughput time and buffer behavior which includes average buffer level and buffer trend. Because there is no limit in the current factory WIP space, infinite buffer size was used. A summary of input/output is shown in figure 4-2.

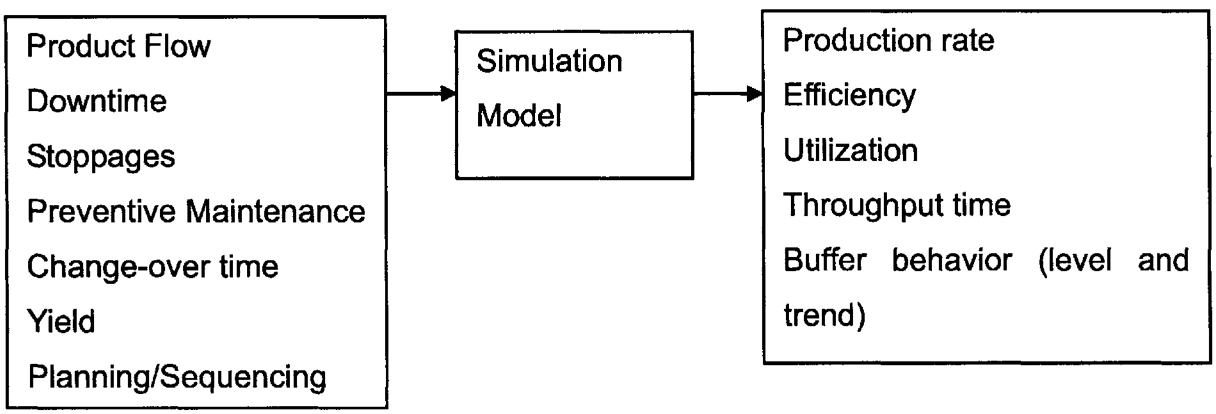

Figure 4-2 Simulation Input and Output

In the simulation model, although some factory performance such as assembly process cycle time depends on the operators, operators are excluded from the model. Furthermore, traveling time and traveling distance from one station to another are also not included in the model. In addition, the work flow is assumed to be continuously flow from upstream facilities to downstream facilities without purposely held for stock build up. In the factory floor, they may decide in which facilities they would like to hold particular stocks due to various reasons such as product differentiation, costing, or capacity availability.

4.3.1 Products flow

As explained in Chapter 2, product flow has the major complexity in the model that makes it difficult to model the whole factory. For simplicity, there will be only 14 types flow to follow in addition to the 13 types that have already been explained in chapter 2. This additional product type, C1-2 follows type C1 flow. However, its cycle time in the station 3 is twice as much as those for the rest of the products.

4.3.2 Breakdown and Stoppages

In TECHSOL, there are two types of unplanned downtime – breakdown and stoppage. Breakdown happens when the machine stops operating due to damaged machine parts. Breakdown usually takes longer time to repair and the frequency is quite low.

On the other hand, stoppage constitutes a frequent and shorter time machine disruption. It happens because some parts are stuck or jammed in the machine. Stoppages usually last less than a few minutes and it happens quite frequent in those stations that are built based on a connection of several machines. Due to the zero buffer space of most of the stations, the stoppage of one machine causes the rest of the machines in the same line to stop immediately. This is also known as "Interaction effects "in TECHSOL.

The difficulty in building the simulation model comes mostly from data collection process. Fortunately, the factory has records of the total break downs, stoppages, and fall off, etc. for every single station. However, they do not record the frequency of the stoppages or breakdowns. And to make matter worse, most of the data reported is merely a weekly total.

Some facilities, however, do have automatic computer collection of data for the frequencies of stoppages. And in some facilities there are manual daily reports where the operator will record down all types of machine down on that particular day.

A lot of time is spent trying to extract the lump-sum downtime based on the weekly report; computer recorded data, as well as manually recorded data to get a good estimation of the machine parameters for most of the facilities. However, there are still some facilities in the simulation model, where the change-over, break down, and stoppages are lumped into single parameters. Those facilities however are the finishing facilities that are currently only operating six days per week, as opposed to the rest of the facilities that are operating seven days per week. I.e. they are low utilized facilities.

For facilities that are impossible to get the detailed of their breakdown or stoppages time, the weekly reports of downtime are used. The frequency is estimated on the basis of the direct operators' estimation.

Using first 20 weeks data in 2007, The MTTR is estimated to be

$$= \frac{\text{total lost hour because of unplanned downtime (20 weeks)}}{\text{estimated frequency of breakdown (20 weeks)}}$$

Similarly, the MTBF is estimated to be

$$= \frac{\text{Total working hours - Total lost hour due to unplanned downtime (20 weeks)}}{\text{estimated frequency of break down (20 weeks)}}$$

For simplicity, the time to repair and the time until failure are also assumed to be exponentially distributed in the model.

The data was collected, starting from week 1 to week 20 in 2007. The accuracy of the modeling is, therefore, quite dependant on the accuracy of the information recorded by the operators/supervisor of each station.

For stations that do record of all information on the breakdown and stoppages, it is possible to use their data and make use of proper distribution pattern that follow the histogram of the down-time.

4.3.3 Preventive maintenance

Preventive maintenance is a scheduled maintenance for the machine that meant to keep the machine in a good condition. In TECHSOL, all facilities have their preventive maintenance every half-day on a weekly basis. Therefore, fixed distribution is a good estimation of preventive maintenance.

4.3.4 Change-over time

Change-over time is the time needed to change the machine setting so that it allows production of the machine from one type of product to the other. Change-over time only exists in the machine that has flexibility to produce different type of products.

The change-over time in the factory floor, however, does not exactly agree with the documentation of the target time. Sometimes it is slower and sometimes it is faster. The operators only could give an estimation of the timing. Therefore, change-over time is also estimated using an exponential distribution.

4.3.5 Yield

Yield consists of two parts, reject and rework. In TECHSOL the summation of reject and rework is called fall off rate. For simplicity, not all work centers is modeled with rework. Only those work centers with high rework percentage is added with rework and reject rate. Those work centers that have high reject percentage only modeled with reject rate.

4.3.6 Production planning/sequencing

The factory planner has the confirmed production demand for the following week, so she generates a weekly planning for selected production facilities, namely station 1, 2, 3, 7, 8, and 9 to 20. The rest of the production facilities will liaise with downstream and upstream stations to obtain their own production schedule.

As the demand fluctuates based on the seasonal pattern, the weekly production schedule can vary to a large extent. Moreover, as the factory tries to build up stock to tackle peak demand, there is a significant amount of inventory built up in various production stages that will not be passed down as finished good.

Therefore, for the planning schedule input to the simulation model, we took a weekly average of the total yearly production plan and later verify with the weekly average output for the first half a year. To simplify the planning input to the simulation model, we only input the planning schedule at the first production stage and assume that all quantity will flow down based on FIFO queue.

With respect to station 1 and 2 planning sequence, currently the factory can manage to keep the model changeover to a maximum of twice per week per line. The 14 major product families use five different types of models. Therefore, we took their average weekly production quantity and arrange in the same sequence as what the factory planner is doing with the same number of changeovers. We generate an average production schedule at the peak capacity of station 1 and 2 which also tallied with the factory production schedule.

4.5 Preliminary result

The preliminary result showed that there are accumulations of inventory before station 5 facilities, which caused non steady state of the system as shown in figure 4-3.

As the process that requires few re-entries which was caused by the quality, station 5 has been outsourced. In the real production floor, station 7 is frequently used to help station 5 in doing the job when it is not fully utilized. This behavior is also not included in the model since the model is assuming all the work/job should be done at the assigned work station.

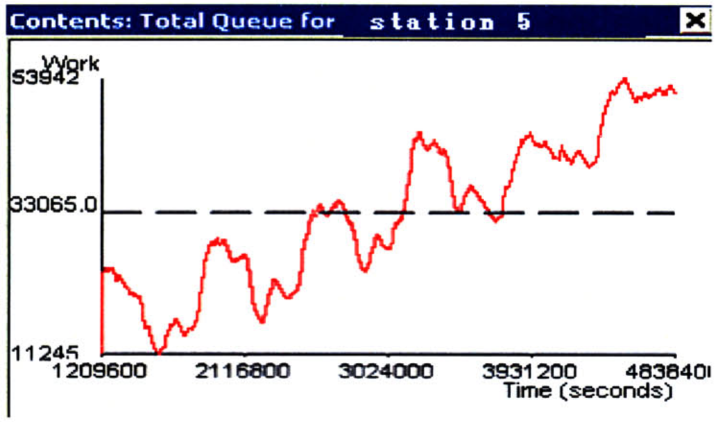

Figure 4-3 Accumulation of queue in front of station 5

The simulation model is therefore able to capture the factory performance. It is assumed that station 5 had already been replaced with the better machine which is planned to be brought in the near future.

4.6 Warm-up Period

The simulation result was collected from week 0 to week 20 to observe the inventory level behavior as shown in figure 4-4. It took approximately 5 weeks for the inventory to build up and reached the steady state. Therefore the result collection period started from week 5 onwards. In order to get a good estimation of the results, eight weeks period of data were collected for every simulation runs.

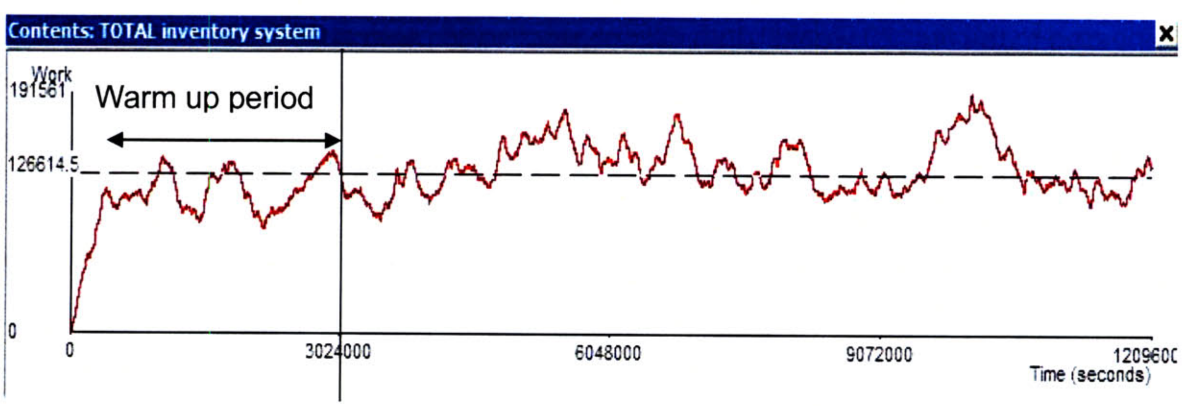

Figure 4-4 Total inventory level of the simulation model

4.7 Model Verification

During simulation modeling, it is known that the best practice requires a run for approximately 9 to 11 trials with different random seeds in order to obtain accurate results. It takes about 3 hours for one time simulation run including the warm up and result collection period for this simulation model. Because there is a very limited time for the project, the simulation-based model verification of the current factory performance was only run for 4 replications.

The verification of the main stations is shown in table 4-1

Facility	Model throughput /week	Factory throughput /week	Difference
Station 1	129611	125769	2.96%
Station 2	139191	133974	3.75%
Station 3	284122	264532	6.89%
Station 4,5,6	194357	181408	6.66%
Station 7	85463	88221	-3.23%
Station 8	98418	94192	4.29%

Table 4-1 Result comparison of the simulation throughput with the factory average throughput

The simulation model shows that there are 7% higher throughput of station 3 and 4 compared to the first 20 weeks' data collected from the production floor. During the first few months of the production, station 3 was only doing six-day shifts and later in the months, they operated seven-day shifts and started consuming inventory built-up. On the other hand, stations 4 had experienced reduction of the cycle time in the week 16 of production. In the simulation model, however, station 3 was modeled to do seven days shift work and the station 4 was modeled based on the new machine performance.

On the finishing process, which involves station 9 to 23, there were major differences between the simulation outputs and the real situation. Upstream stations purposely keep some inventory and do not release their output immediately to downstream stations. Therefore the output from the model is significantly different from the real output.

Comparing the real output with the average inventory built up in the various stage including station 2,station 6, station 8, station 9, station 10,and station 13 to 16, very little difference between the model and the real factory output was found. In the real situation, if all the inventories were pushed down to the downstream machine till finished good stage, the total output will not be as high as the sum of the current total output and the total stock build up due to non 100% yield of various stations. The real output and simulated model output comparison is shown in table 4-2.

As the simulation gap is small enough, it is verified that the model is close enough to the real situation. All the analysis will be based on this base model.

Real factory data / week							Simulation MODEL	Difference
		build up stock						
Family	Finished goods	Station 3	Station 6	Station 9-16	Station 7	Total		
A & B	64349.2	7614	0	720	1567	74250	69579	-6.29%
C	9649	2960	0	399	480	13488	12939	-4.07%
D	28783.4	-769	4369	5599	860	38842	38023	-2.11%
E	43621.7	-5410	6281	1046	2901	48440	51100	5.49%
F	733	370	370	0	0	1473	1570	6.59%
G	45608.7	40	9223	0	0	54872	52313	-4.66%
H	25222.3	2531	8376	0	0	36129	35612	-1.43%

Table 4-2 Comparison between finished good model with the real factory output

4.8 Current Factory Performance

Based on the verified model, the total WIP in the system on average was 131K and the distribution of the WIP was based of figure 4-5. WIP is highly accumulated in station 3. This is due to the logic implemented that when one type of product is already assigned to one of the machines in that station, that particular machine will take in all the same type of product to process, provided that the quantity does not exceed a certain limit.

The high accumulation of WIP at station 9 to 23 is caused by the product driven stations, where there is no process sharing between one type of product and another type of product. Due to the large batch production scheduling, those places are where most inventories would exist.

Both stations 3 and 9 to 23 (finishing station) are behaving in the one queue per server with multi server system as described in **section 3.3**. The high WIP results in station 9 to 23 due to the nature of the process, which is catered differently to different product types. While for station 3, it is because of the policy used to reduce the number of change-over.

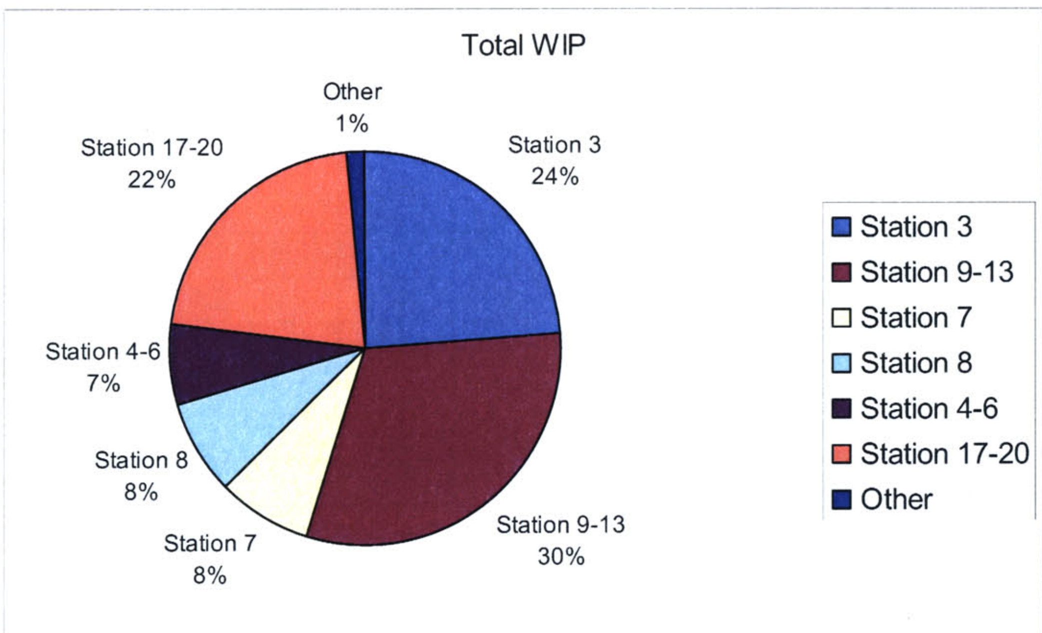

Figure 4-5 Inventory divisions of the simulated current factory performance

It is also possible to capture the average throughout the time of every product. As shown in table 4-3, it was noted that on average the throughput time of the products is about 3.2 days while there are very small quantity of products that takes about 8 days to finish due to the long chain of process flow.

While most of the facilities have 70 to 85% utilization, Station 1 and 2 are always fully utilized, based on real factory situation, where they always works for 24 hours. Station 3 has 94% utilization. Since both facilities (station 1 or station 2 and station 3) are the first and the second process that the work item has to go through, respectively, the factory production rate is limited by these two facilities.

Type	Throughput time (days)
A1	1.86
A2	3.06
B1	1.69
B2	2.82
C1-1	8.18
C2	8.68
C1-2	8.03
D1	4.68
D2	7.12
E1	1.94
E2	3.47
F	1.85
G	2.48
H	3.07
Average throughput Time	3.17 days

Table 4-3 Overall average Throughput time of the product

Based on the validated simulation model, it was observed that the maximum production rate / week of the finished product is only about 261K/week, which is about 4% lower than average demand of the positive scenario run by the production planning, which requires about 271K/week. It is also understood that in TECHSOL the most importance key performance is the demand fulfillment. The company is willing to build up high inventory in the low peak periods in order to satisfy the demand in the high peak periods.

We also observed that some facilities such as station 20 have a very long downtime compared to the working time. The return on investment of this station is not favorable. However, it does not limit the overall production rate due to the high installed capacity.

Current factory performance is summarized in table 4-4.

Facility	Prod rate/week	Fall off	net prod rate/week	Working %	Down %	Change -over %	Waiting %	Utilization
Station 1	133621	4010	129611	56.58	40.56	2.86	0.00	1.00
Station 2	143477	4285	139191	65.52	30.27	4.22	0.00	1.00
Manual line	20146	0	20146	100.00	0.00	0.00	0.00	1.00
Station 3	287283	3161	284122	74.83	15.73	4.28	5.16	0.94
Station 4	181863	0	181863	60.14	24.47	0.00	15.40	0.79
Station 5	41961	0	41961	34.69	45.53	0.00	21.78	0.64
Station 6	198331	3973	194357	65.25	13.44	8.18	13.13	0.85
Station 7	89287	3824	85463	54.64	26.76	7.32	11.28	0.86
Station 8	103146	4728	98418	51.27	36.78	3.47	8.48	0.91
Station 9	69117	220	68897	57.17	28.63	2.12	12.09	0.87
Station 10	52828	51	52777	56.79	36.26	N/A	6.95	0.90
Station 11	36507	101	36406	48.30	33.30	N/A	18.38	0.72
Station 12	15890	251	15639	52.59	33.26	N/A'	14.14	0.79
Station 13	50496	0	50496	54.27	33.36	N/A	12.37	0.81
Station 14	35389	73	35316	46.82	28.87	N/A	24.31	0.64
Station 15	53158	332	52827	57.12	32.52	N/A	10.36	0.85
Station 16	1545	11	1534	2.04	N/A	N/A	97.96	0.02
Station 17	49891	108	49783	53.62	33.20	N/A	13.17	0.81
Station 18	36108	903	35205	47.73	31.40	N/A	20.87	0.70
Station 19	53580	1125	52455	57.60	33.56	N/A	8.83	0.86
Station 20	1534	14	1520	38.77	59.45	N/A	38.77	0.04
Station 21	11894	0	11894	49.22	0.00	N/A	50.78	0.49
Station 22	12467	0	12467	51.47	0.00	N/A	48.53	0.51
Station 23	12617	0	12617	62.60	19.33	N/A	18.06	0.77

Table 4-4 Current stations performance based on the simulated result

The factory's current production is limited solely by station 1 and 2 production outputs, as seen from the non-fully utilized downstream facilities. The factory, therefore, can be modeled in a simpler way as shown in figure 4-6. In which station 1 and 2 is jobs arrival process that flow to the station 3 onwards.

The performances of the rest of the downstream facilities are limited on the station 3 in which the capacity is higher than the targeted production plan.

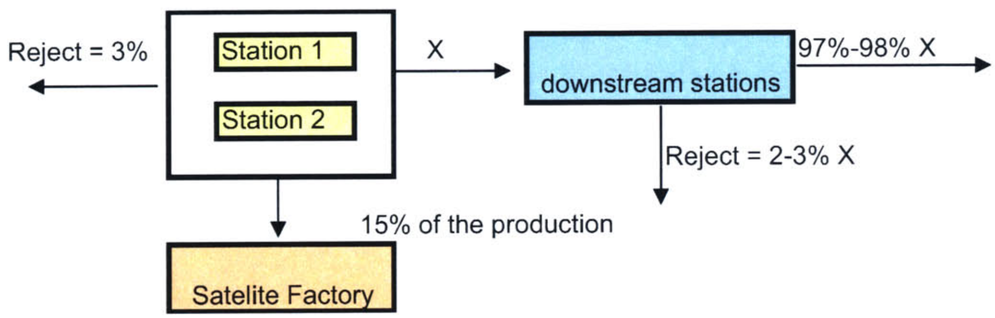

Figure 4-6 Simplified model of the Factory

Therefore, to achieve the targeted 271K/week production output, there are only two ways. Firstly, it is by improving the production rate of the station 1 or 2 and secondly is by improving all facilities' yield. Combinations of both will be effective too.

4.9 Sensitivity analysis

4.9.1 Effects on changing Batch Size

One way to increase production outputs of station 1 and 2 is by increasing the batch size of production to reduce change-over. However, it is also known that increasing batch size will increase the inventory level especially during the finishing part where all finishing lines have their own independent queues.

A few batch sizes have been simulated, starting with quarter, half, doubled and tripled of the current batch size to see the implication of the factory performance, especially production rates with the trade off of cycle time and inventory levels.

From the simulation run, doubling the batch size increased the production output/week by reducing the amount of lost hour due to change-over. The production rate was increased from 261K/week (base model) to 267k/week. The average WIP, however, increased from the base model 131k to 262k. Consequently, consistent with Little's Law, the cycle time of the product on average is also increased. It was increased from 3.17 days to 6.2 days

Further increase of the batch size to triple its original level brings the production output to the target production rate of 273K/week. However, the inventory level shot up significantly to 410K. In addition, average throughput time also increased to 9.5 days.

Cutting the batch size into half, on the other hand, resulted in the production rate of the factory to be 245k/week, a reduction of about 6.5% of the production rate compared to the base model.

The decrease of 6.5% production rate resulted in a 52.5% reduction of the total WIP. The half week's inventory change-over policy results in an average of 62K WIP while the current WIP of the factory is about 131K. Similarly, consistent with the Little's Law, the average product cycle time is also reduced from 3.1 days to 1.67 days.

Cutting the batch size further to a quarter of its current level results in a decrease of the production rate to 223k/week. The inventory and cycle time reduction is not very significant to those for the half batch size scenario, which is about 10K inventory reduction and 0.3 days cycle time reduction.

Based on the different batch size scenario of the inventory policy, operating curve of the current TECHSOL factory can be drawn as shown in figure 4-7 and figure 4-8. The higher the batch size, the higher the throughput of the factory; however, it has to be compensated by holding a high average inventory level in the factory and longer throughput time as well.

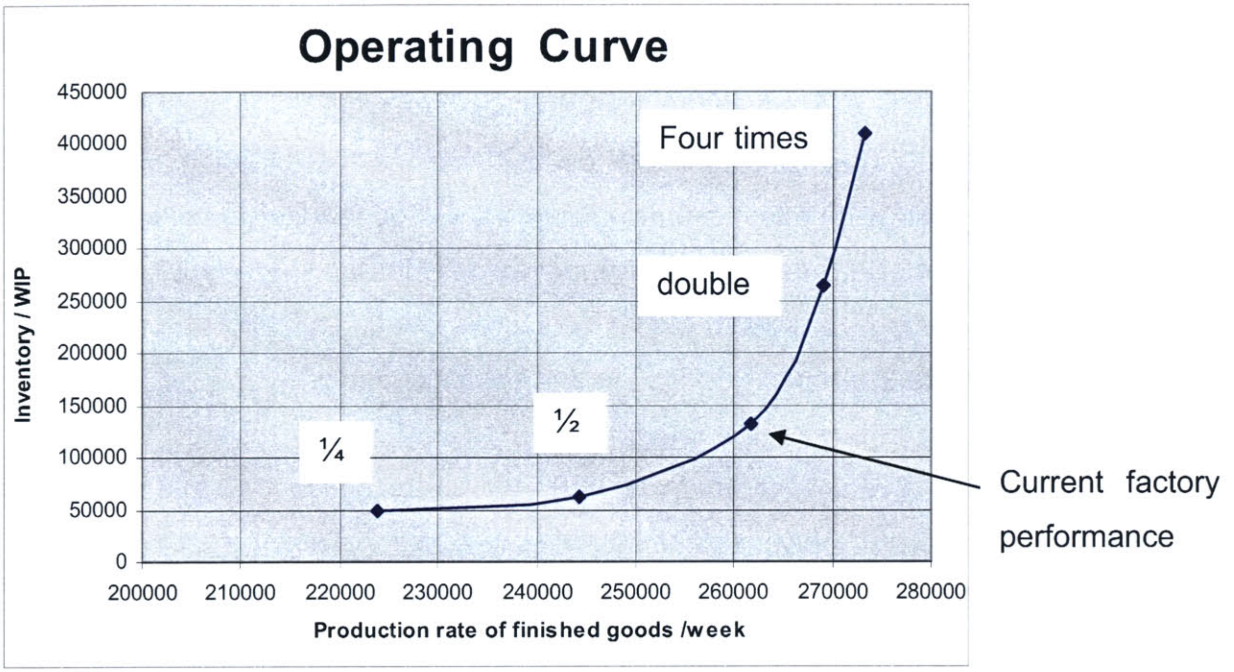

Figure 4-7 Operating curve of the factory based on the different production batch size-effect on the inventory level

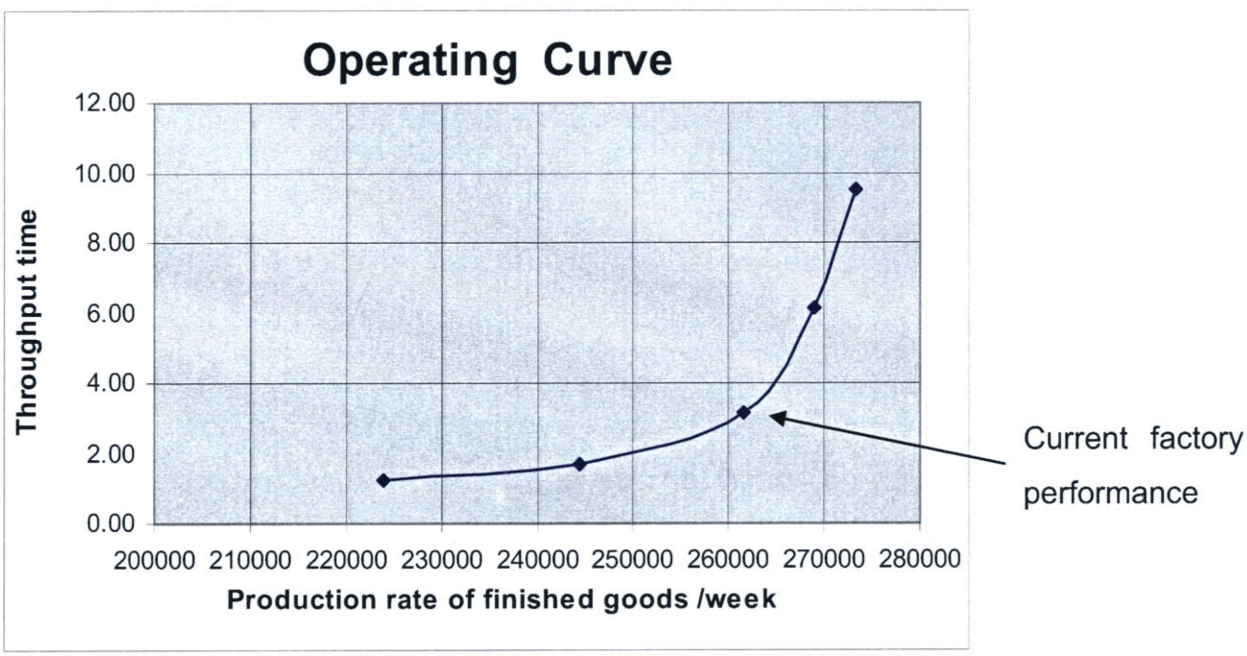

Figure 4-8 Operating curve of the factory based on different production batch size-effect on throughput time

4.9.2 Effects on Improving Production rate for Station 1 and 2

From figure 4-6, the simplified model of the factory, it can be estimated that every one unit increases in the capacity of station 1 and 2 will result in 0.8 increments in the final production output. The calculation can be estimated in the following way. For any 1 increment, 3% will go to reject/rework, while 15% will go to satellite factory and among all remaining parts that come into the downstream facilities, 2% will come out as a rejected part. Only 80% comes out as a finished good. This assumption will still be correct as long as the capacity of station 3 is not exceeded.

The base model (the current factory model) fully utilizes station 1, 2 and with additional help from manual line. However, manual line is very expensive to be used to improve the output of station 1. There are a few scenarios that are simulated to increase the production quantity of station 1 and 2 without using the manual line. They are:

a) Reduce the frequency of the stoppages by increasing MTBF of stoppages for station 1 and 2 to twice of their current performance.
b) In additional to a, reduce the breakdown frequency by doubling the MTBF of breakdown for station 1
c) In addition to b, reduce the breakdown frequency by doubling of the MTBF of breakdown for station 2.
d) Same as the base model, but manual line which used to help station 1 is removed.

The simulation run results showed that removing the manual line that is used to help production of station 1 (scenario d) resulting in the total production output of 242K/week while the average inventory level is about 110K. The cycle time during this scenario is approximately 2.8 days.

Reducing the frequency of the stoppages by increasing MTBF of stoppages for the station 1 twice of it current performance (scenario a) resulted in improvement of the production rate to 269K/week which is about 2.6% improvement compared to the base model or 11% compared to the scenario d. The inventory level is also increased to 160K, about 22% increment compared to the base model. Consequently, consistent with Little's law, the cycle time is also increased to 3.7 days.

In addition to scenario a, reducing breakdown frequency by doubling the MTBF of breakdown of station 1 (scenario b) resulted in an improvement of the production rate to 272k/week, a 4% increment of the current factory performance. The inventory level is also increased to 171k, which was 30% higher than the base model.

Lastly, in addition to scenario b, in order to reduce the breakdown frequency by doubling of the MTBF of breakdown for station 2 is simulated (scenario c), the results showed that the production rate is increased to 281k/week which is a 7.5% improvement as compared to the base model. Furthermore, the inventory level for this scenario is increased to a level of 254K.

Based on all the scenarios, the operating curve of the factory is drawn in figure 4-9.

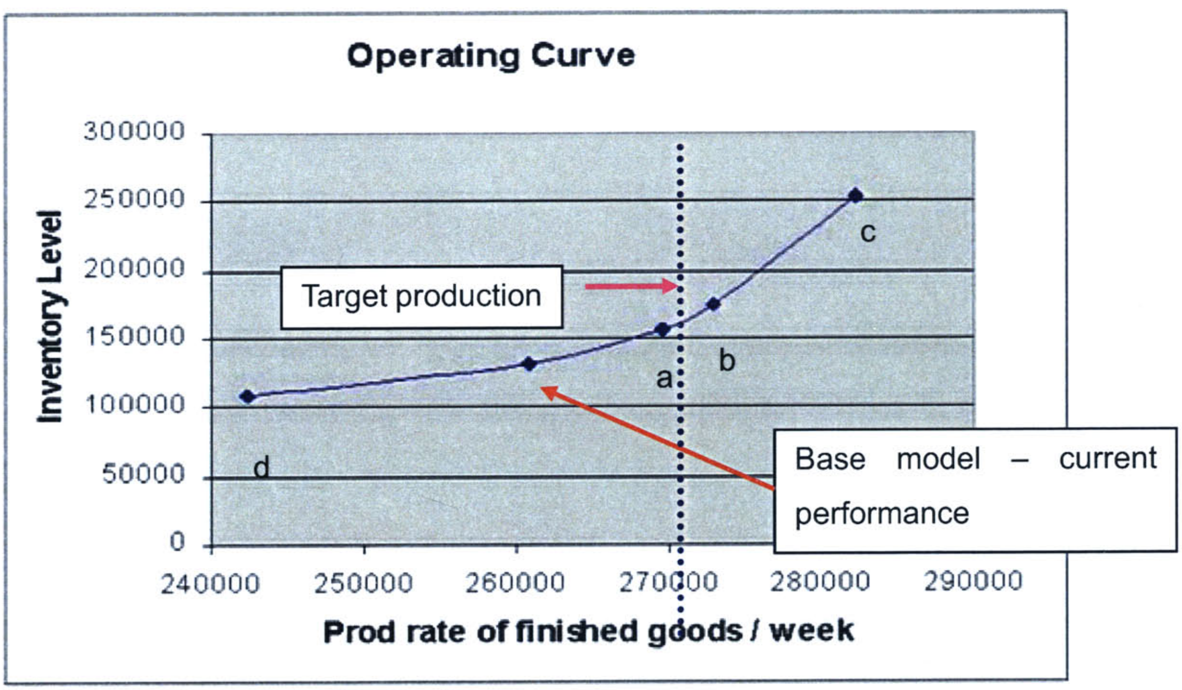

Figure 4-9 Operating curve based on Inventory and production rate for each scenario

Consistent with Little's Law, in which cycle time is directly proportional to the average inventory level, the cycle time for each scenario can also be plotted, as shown in figure 4-10.

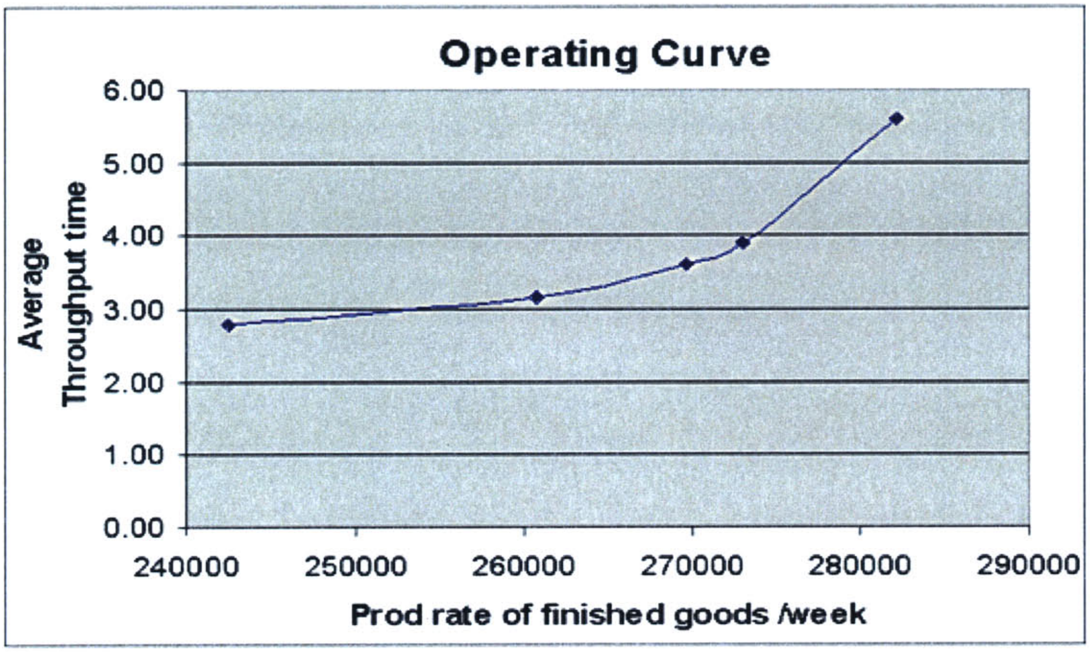

Figure 4-10 Operating curve based on average throughput time and production rate for each scenario

4.9.3 Effects on the Yield

The yield included rework and reject. However, facilities in the downstream of station 1 and 2 that limit the factory output are those with high reject rate. Facilities that have high rework rates did not contribute much to the factory overall throughput since their installed capacity is much higher than the requirement.

The reject rate of the overall factory station have been recorded down and listed in table 4-5. Those facilities not listed are those that have very little reject or do only rework most of the time.

Facilities	Reject rate	Facilities	Reject rate
Station 1	3.00%	Station 12	0.26%
Station 2	3.00%	Station 13	0.21%
Station 3	0.60%	Station 14	0.20%
Station 7	0.40%	Station 14	0.48%
Station 8	14.00%	Station 15	0.62%
Station 9	0.32%	Station 16	0.77%
Station 10	0.10%	Station 17	0.12%
Station 11	0.29%	Station 19	0.25%

Table 4-5 Reject rate of facilities

Increasing yield of station 1 and 2 will increase the production rate of that station and this will result in higher job arrival rate for the downstream stations.

Reject rate for station 8 is the highest among all of the stations in the factory. However, these reject rates only apply to product type C1 which accounts for only about 5% of the overall annual volume. Therefore, a 1% reduction of the reject rate in station 8 results in 5% x 1% incremental increase of overall production rate.

On the other hand, increasing station 3 yields could improve overall factory production rate. Since station 3 is flown through by every type of product, any percentage increment of the yield of station 3 will give same percentage increment of factory production rate. However, station 3 comprises 7 parallel machines with almost the same performance parameters. In order to improve the overall yield of station 3, changes have to be made to all the machines.

From all listed stations above, only station 3 is common for every product. Therefore, the impact of any percentage increment of other facilities yield will not be as high as that for the yield improvement of station 3.

Using a spread sheet as shown in figure 4-11, it can be calculated that the percentage volume of product that go through the facilities, the overall yield of the facilities starting from station 3 till finished goods is about 98%. The amount of the rejected parts is also shown in the spreadsheet. The highest amount rejected is from station 8 due to the highest reject rate of station 8.

The simulation runs are also performed on the four scenarios used in section **4.9.2,** but in these trials, station 3's reject rate has been improved to zero percent. Similar simulation runs are also conducted with station 8's yield set to zero. From the simulation runs, it can be seen that the previous operating curves shown in figure 4-9 have been shifted to the right with small increment to the upwards. This means the production rate is increased and at the same time the inventory level is also increased by a slower rate than the previous cases. The operating curve in which reject rate of station 3 has been nullified and when station 8's reject rate set to zero is shown in figure 4-12.

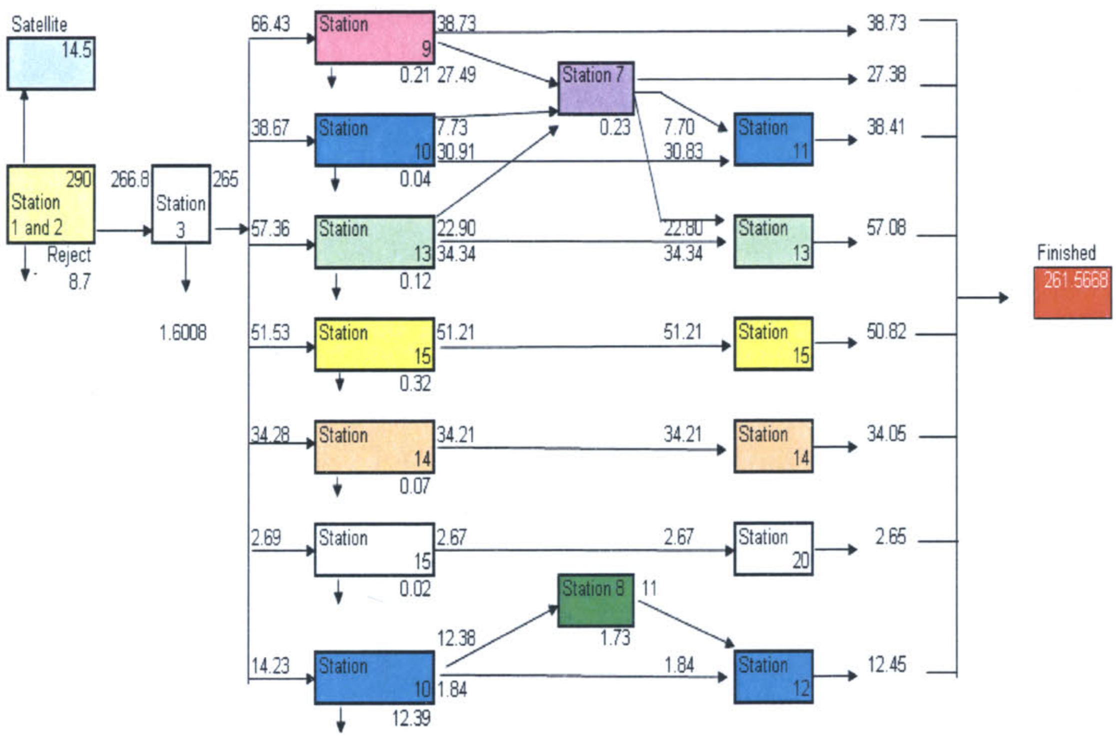

Figure 4-11 Spread sheet for reject rate analysis of the overall factory

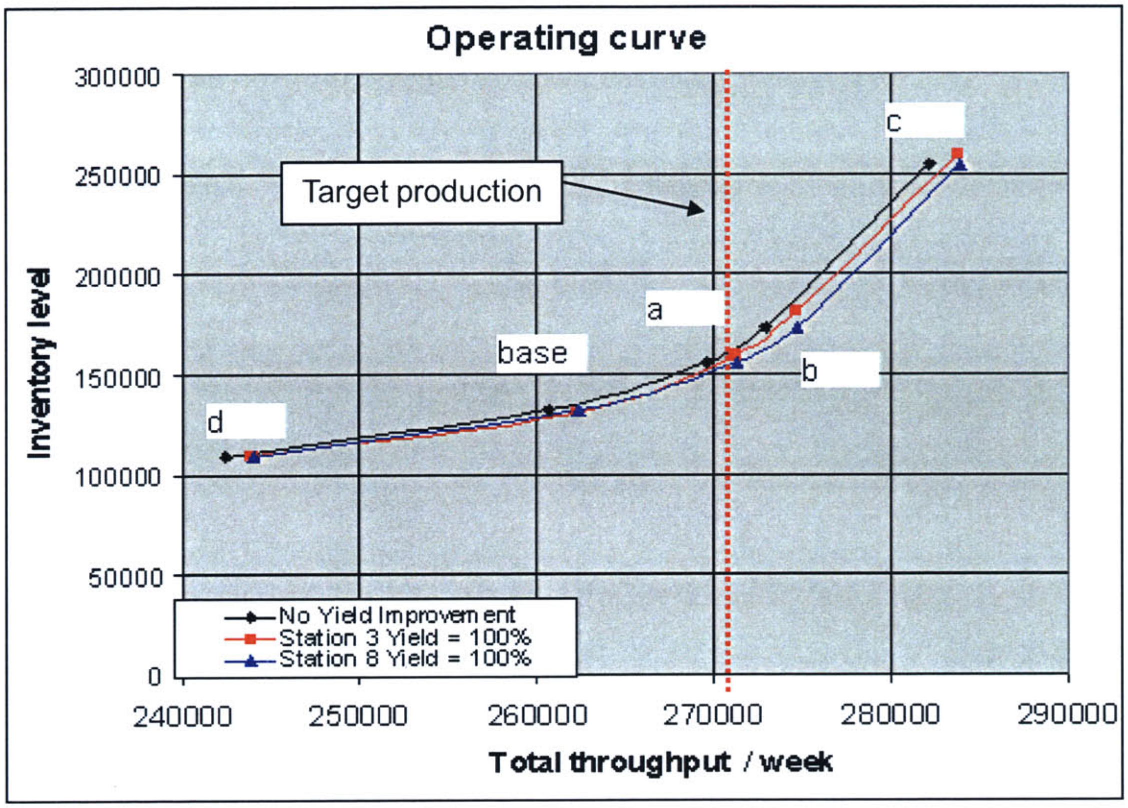

Figure 4-12 Comparison of the throughput and inventory level at different yield improvement

All scenario a,b,c and d are the same as in section **4.9.2** (without using manual line)

a) Reduce the frequency of the stoppages by increasing MTBF of stoppages for station 1 and 2 to twice of their current performance.
b) In additional to a, reduce the breakdown frequency by doubling the MTBF of breakdown for station 1
c) In addition to b, reduce the breakdown frequency by doubling of the MTBF of breakdown for station 2.
d) Same as the base model, but manual line which used to help station 1 is removed.

It is observed that for similar improvement of the overall factory production rate, the yield improvement of station 8 results in lower inventory holding compared to improvement of station 3. However, for the same increase of production rate, station 8 needs to be improved by 13% while station 3 needs to be improved by 0.6% on all seven machines in those stations. Similarly, throughput time of the products is proportional to the inventory level. The operating curve that shows the throughput time at different scenario with different yield improvement is shown in figure 4-13.

In order to reach targeted production rate of the finished goods, it is not enough only to improve the yield. It is still necessary to improve production rates of station 1 and 2.

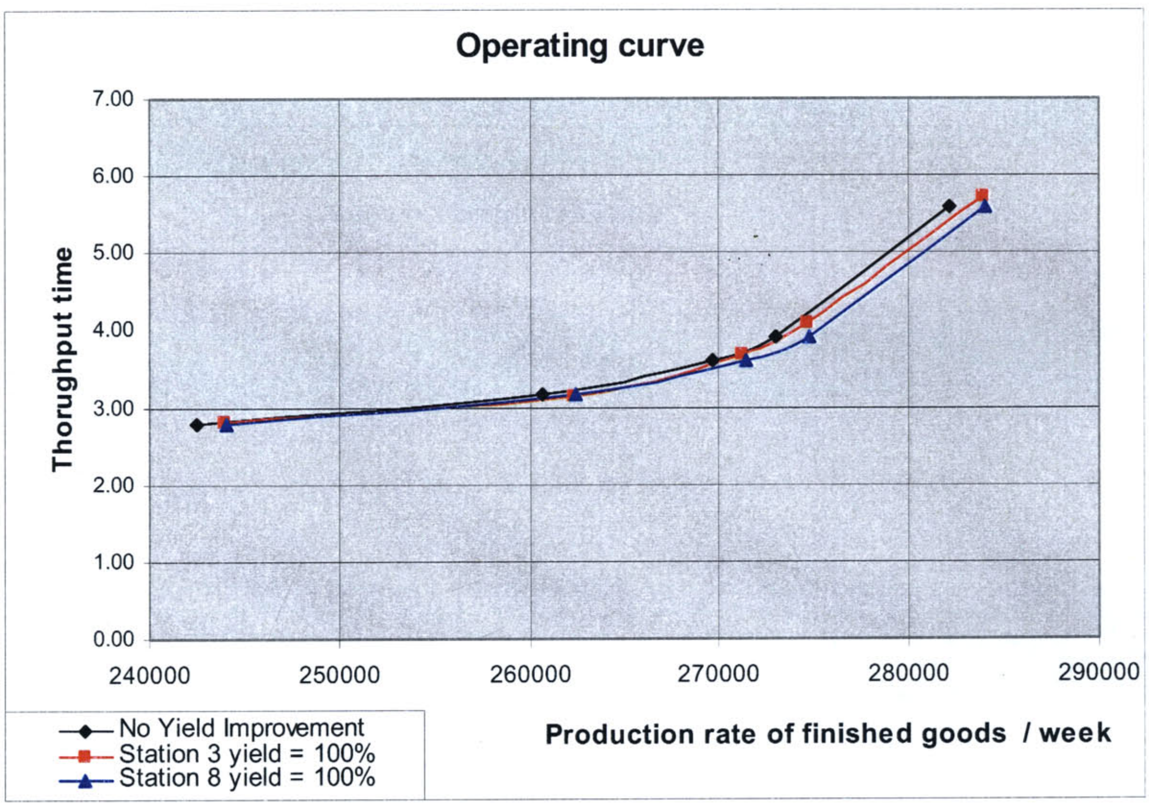

Figure 4-13 Comparison of the throughput and throughput time at different yield improvement

5 Conclusion and Recommendation

The project started with the goal of understanding the overall factory performance. The aim was to find where a small improvement can lead to a gain for the factory.

Due to the complexity of the factory, a simulation model was built to model the whole factory at an abstract level. Throughout the model building process, the understanding of the factory is enhanced together with the data collection. From the simulation model built, it was understood that a lot of factory facilities were operating in low efficiency, especially stations that are built by a long line machine with no buffer between them.

The simulation results also showed high average inventory level before station 3 and before product finishing processes which include station 9 to station 23. These high inventory levels at those particular areas are due to the systems that behave as a multiple server with multiple queues. The rest of the stations, on the other hand, have a behavior of single queue with a fat server.

Although most of the machines operate in low efficiency, the installed capacity is high enough so that they do not constrain the overall factory production. The current factory production rate is lower than the target level. It is also identified that the total production rate is dictated by the production rate of the first and second station multiplied by the yield of the downstream machine. The production rate of the overall factory can only be improved by increasing production capacity of the first and second station or reducing the reject rate of all facilities.

Any improvement of yield in station 3 will result in the same yield improvement in the factory as a whole. While 1% increases in yield on station 8 will result only in 0.05% improvement of the overall factory yield.

In the simulated results, the target throughput can be achieved by reducing stoppages of station 1 and 2 and reducing the downtime of station 1 into half. Another way to achieve the targeted production output is by reducing stoppages of the station 1 and 2 into half and at the same time reducing reject rate of the station 5 or station 8 to zero.

This project, however, did not consider human resources in the factory. The simulation model also did not take into account that every station can work on different types of jobs sequence instead of following FIFO convention.

In addition, it is also learnt that the factory has high demand variability every week. Based on the simulation model that we have built, it is possible to obtain the average lead time between stations. Therefore, a study on the stock policy using base stock or periodic review policy in each station will definitely provide great values.

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Appendix 1-Visual Logic code for Station 3

```
VL SECTION: Router Action Logic
  'See if there is already a queue assigned to this type
  IF NOT ( ss_work[1,family]  =  0 )
    'Create the pointer to the queue for this type
    SET ptr_sb  =  "Q "+ss_work[1,family]
    IF ptr_sb.Count Contents  >  gv_limit
      'Queue has reached maximum; find the shortest to use
      CALL ASUB Find Shortest
  ELSE
    'Type does not have a queue assigned to it; find the shortest and use it
    CALL ASUB Find Shortest queue
SET Routing  =  ss_work[1,family]
```

```
VL SECTION: ASUB Find Shortest
  'Start with assuming Q1 is the shortest

  SET lv_min  =  1
  SET lv_size  =  Q 1.Count Contents
  'Loop through the rest of the queues
  LOOP 2 >>> lv_i >>> gv_num_of_queues
    SET ptr_sb  =  "Q"+lv_i
    IF ptr_sb.Count Contents  <  lv_size
      SET lv_min  =  lv_i
      SET lv_size  =  ptr_sb.Count Contents
  'Shortest has now been found (lv_min); adjust spreadsheet entries
  'Check to see if this queue is already being used. If so, remove current assignment
and make a new one
  IF NOT ( ss_work[2,lv_min]  =  0 )
    SET ss_work[1,ss_work[2,lv_min]]  =  0
  SET ss_work[2,lv_min]  =  family
  SET ss_work[1,family]  =  lv_min
  'Keep count of the number of times the queue has changed and the work type caused
a change
  SET ss_work[3,family]  =  ss_work[3,family]+1
  SET ss_work[4,lv_min]  =  ss_work[4,lv_min]+1
```

Q1.Q2,Q3,...Q7 is the que in front of the 7 machines in station 3.

gv_limit = size limit of the que accumulated in front of a machine to give another machine to take the same types of the job.

Ss_work = spread sheet that used to store information

Routing, Family = label attached to each work peace for routing purpose