Qualification of the IBM CSC Factory in Singapore:
Resource Estimation and Allocation in Software and Hardware Services

by
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Bachelor of Engineering in Management and Industrial Engineering
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SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Submitted to the Department of Mechanical Engineering
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ABSTRACT

The CSC department of IBM Singapore has been established two years ago. It provides a variety of hardware and software services for its customers. Due to the complex mix of products and the different ways of completing the tasks at each section of the factory, it is difficult to estimate the resources needed to complete a set of similar jobs. It is also difficult to put the resources at the right place at the right time and not create under or overcapacity.

A quick way of estimating and allocating resources (qualification) is necessary to predict the cost that will incur for a certain job. This is useful during the negotiation process for a new contract and improves decision making of management. Resource allocation allows smooth workflow within the sections of the factory. This can increase factory capacity.

This thesis shows the mistakes made by management during former resource estimation and allocation. It shows the step-by-step examination of the factory operations and the model derived through quantitative and qualitative analysis.

It demonstrates the new resource estimation and allocation process and provides thoughts on future areas of development.

Thesis Supervisor: Stanley B. Gershwin
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Introduction[1] [2]

This thesis project was completed at the Customer Solution Center (CSC) of IBM International Holdings, Singapore. This chapter provides background on IBM, IBM in Singapore, and the Customer Solution Center in particular. It states the internship motivation and gives a non-technical problem statement as well as the outline for the following chapters.

1.1 IBM

1.1.1 Overview

International Business Machines Corporation (also known as 'IBM' or 'Big Blue') is the world's largest information technology company headquartered in Armonk, New York, USA.

IBM was founded in 1889 as Tabulating Machine Company. It was incorporated as Computing-Tabulating-Recording Company (C-T-R) in the state of New York in 1911 and formally changed its name to International Business Machines Corporation in 1924.

IBM had revenue of US$91.4 billion, net income of US$9.5 billion, and over 355,000 employees in 2006. These are increases of 0.3%, 19.1%, and 8.0% compared to 2005 respectively. IBM has managed to continuously increase its earnings per share for the last 16 quarters.

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[1] Siyu Fan, "Field Deployment Process Transformation in IBM PC Services", MIT ME Department Thesis, Aug. 2007

[2] Jie Zuo, "Pre-engagement Process Improvement in IBM PC Services", MIT ME Department Thesis, Aug. 2007

IBM has employees in over 170 countries. The geographical distribution of revenue is listed in Fig.1. IBM Singapore falls into Asia Pacific which makes up the third largest region in terms of generated revenue.

FOR THE YEAR ENDED DECEMBER 31:	2006	2005
Geographies:		
Americas	$39,511	$38,817
Europe/Middle East/Africa	30,491	30,428
Asia Pacific	17,566	18,618
OEM	3,856	3,271
Total	$91,424	$91,134

Fig. 1: Geographical distribution of revenue (from the IBM Annual Report 2006)

1.1.2 Business Segments

The company's operations comprise the following business segments:

- Global Technology Services (GTS)
- Global Business Services (GBS)
- Systems and Technology Group
- Software
- Global Financing

Global Technology Services and Global Business Services are both part of Global Services. The main objective of Global Services is to provide solutions to clients. This is usually done using IBM software and hardware. Global Technology Services mainly deals with infrastructure services. It includes outsourcing, integrated technology, and maintenance services. Global Business Services mainly deals with professional services. It includes consulting, systems integration, and application management services.

Systems and Technology Group provides business solutions that require advanced computing power and storage capabilities. That includes server and storage sales, semiconductor technology and products, packaging solutions, and engineering technology services.

Software consists primarily of middleware and operating systems software. Middleware is a standard software platform that allows clients to integrate systems, processes, and applications. Operating software is designed to run computers.

The mission of Global Financing is to generate return on equity and to facilitate clients' acquisition of mainly IBM hardware, software, and services.

Fig. 2 shows the revenue from continuing operations.

YEAR IN REVIEW

RESULTS OF CONTINUING OPERATIONS

Revenue

(Dollars in millions)

FOR THE YEAR ENDED DECEMBER 31:	2006	2005
Statement of Earnings Revenue Presentation:		
Global Services	$48,247	$47,407
Hardware	22,499	24,343
Software	18,204	16,830
Global Financing	2,379	2,407
Other	94	147
Total	$91,424	$91,134

(Dollars in millions)

Fig. 2: Revenue from continuing operations (from the IBM Annual Report 2006)

1.1.3 IBM Worldwide Organizations

There are three companywide organizations at IBM:

- Sales & Distribution

- Research, Development, and Intellectual Property
- Integrated Supply Chain (ISC)

Employees at the Sales & Distribution organization work in integrated teams with IBM consultants and technology representatives to deliver high-value solutions that address the clients' critical needs.

Research, Development, and Intellectual Property has the main objective to produce high impact hardware and software products as well as service solutions for the company's clients. IBM spends approximately US$6 billion annually for R&D. It has managed to be awarded more U.S. patents than any other company in 2006. This is the 14th year in a row. These innovations have been able to generate direct intellectual property income of around US$1 billion annually.

Integrated Supply Chain works to transform its clients' supply chains for greater efficiency and responsiveness to global market conditions. It also continuously improves the IBM supply chain. Around US$36 billion are spent through the IBM supply chain annually[3].

1.1.4 IBM in Singapore

IBM established its first branch office in Singapore in 1953. The aim was to market and service its range of data processing equipment. Today, Singapore is a regional hub for several thousand employees.

Singapore is the region's leading nation to adopt e-business and e-government. This has been attributed to both strong government support and presence of large number of multinational companies. IBM Singapore, as one of the major IT solution providers, is

[3] Adapted from the 2006 IBM Annual Report and www.ibm.com

striving to play a major role in the development of IT in Singapore. IBM's technological capability, as well as its extensive experience in the sector has made IBM a strong player in the IT sector nation-wide. IBM's influence of everyday life in Singapore can also be seen in the IT infrastructures that are based on IBM technology – more than half the ATMs in Singapore use IBM technology[4].

1.1.5 IBM International Holdings Singapore

IBM International Holdings (IIH) was formed to meet the overall manufacturing strategy for IBM Integrated Supply Chain (ISC). In 1994, ISC IIH Singapore began operations as a hard drive and network peripheral assembly site. In 2000, the unit added on facilities to provide microelectronics testing. Overall, there were 4000 employees in the Manufacturing and Development (M&D) community in Singapore in 2002. As Asia Pacific becomes the center of growth for many sectors, IBM has been continuously expanding and adjusting its position in the region.

Today, the areas of IBM International Holdings include:

- Disk storage system manufacturing
- Tape storage system manufacturing
- Global Customer Solution Center
- Asia Pacific Integrated Supply Chain Configuration Centre of Competence
- Procurement Engineering, Southeast Asia
- Retail Store Solution (hardware & software)
- Software Development Lab
- Product Introduction (Software)
- Business Transformation and IT Deployment
- On Demand Supply Chain Lab (partnership with National University of Singapore)

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4 Adapted from www.ibm.com.sg

1.1.6 Global Customer Solution Center (CSC)

Overview

IBM Customer Solution Center (CSC) is part of the IBM Integrated Supply Chain organization (ISC). Globally, there are eight such customer solution centers. CSC Singapore was established in 2005, and currently has around 25 employees.

CSC does not negotiate and develop business directly with the final recipients or end customers of the services. It communicates primarily with IBM internal customers. CSC possesses contracts with IBM internal customers, but provides services directly for the end customers. The end customers of CSC in Singapore are companies, educational institutions, and government bodies.

Fig. 3 illustrates the relationship between CSC, internal customer, and end customer.

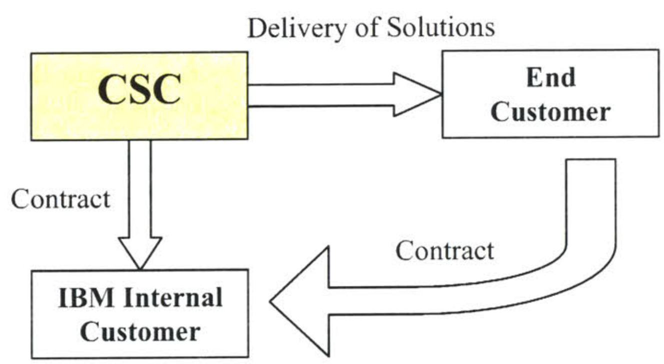


Fig.3: Relationship between CSC, internal customer and end customer

Services

CSC provides a set of IT services. They include the update, reconfiguration, and testing of hardware and software of the end customer among others.

Currently, CSC provides service for 5000-6000 units annually and has a cost recovery of US$800,000 per year. Units in this context are PCs and servers. CSC Singapore is looking to further expand its business in Southeast Asia.

Organization

Organizationally, CSC has three functional components: business, technology, and factory as illustrated in Fig. 4.

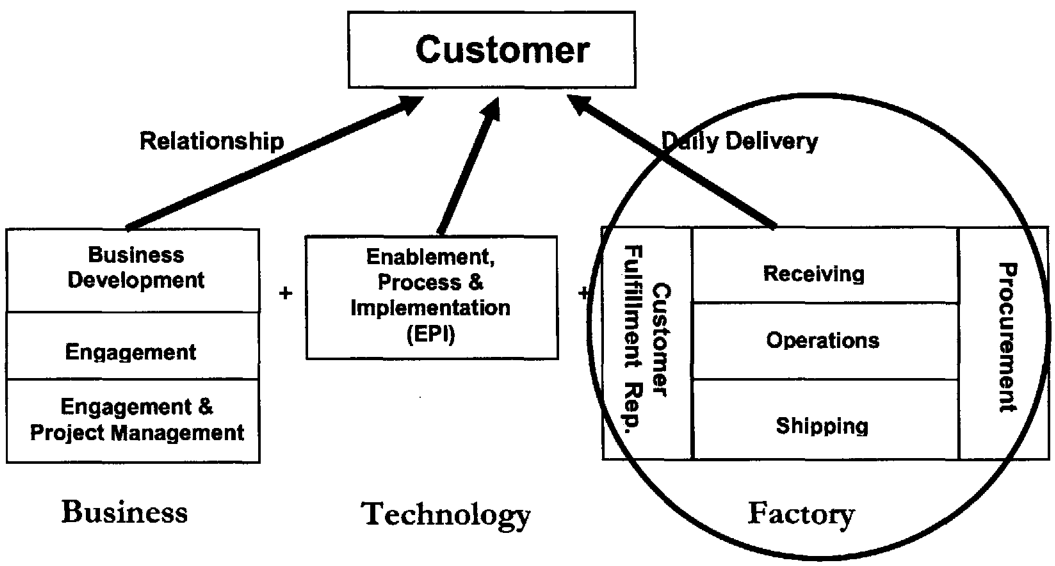


Fig. 4: CSC Organizational Structure

Business includes Business Development, Engagement and Engagement& Project Management. They develop and maintain relationships with existing and potential customers.

Technology includes Enablement, Process & Implementation (EPI) Team. They design the process and develop solutions with the Engagement team. They also implement the solutions with the factory teams.

Factory includes Customer Fulfilment Representatives (also known as planners), procurement, receiving, operations, and shipment. Planners are in direct contact with end customers for order management, planning and scheduling. Procurement is in charge of finding vendors for delivery and field deployment services which CSC outsources to smaller IT service providers. Receiving, operations and shipping makes up the core of the factory. They are directly involved in providing service to the PCs and servers. This thesis will focus on receiving, operations, and shipping and will refer to them simply as factory.

1.2 Internship Motivation

IBM Singapore CSC was established just two years ago. Its operations have been running since then and a variety of service processes have been established. Management has overcome many challenges while new ones have appeared on the agenda.

The goal for the three internship students is to qualify the end-to-end delivery process. This process is divided into three parts: pre-engagement, factory, and on-site. This thesis will focus on the CSC factory.

1.3 Non-technical Problem Statement

Management of the Customer Solution Center (CSC) department of IBM Singapore needs a way to understand and predict the requirements of its factory to provide the necessary IT services for its customers.

A quick and simple way of finding out what the requirements of the factory for a task will be is necessary for management to understand what they want in return from their customers. This is also necessary to add or reduce headcount for different responsibilities within the factory, so that an overload or lack of tasks for the employees is prevented.

Such a process already exists. It is the job of the internship student to verify or disprove the process and to develop a better one if necessary.

1.4 Outline

The problem is described in detail in section 2. The analysis of the problem and the result of the analysis are shown in section 3. The proposed solution in the form of a new qualification template is discussed in section 4. Section 5 concludes and discusses areas of potential future development.

Chapter 2:
Problem Statement

2.1 Objective

The main objective during the internship is to develop a new qualification template for the IBM CSC factory in Singapore.

The second goal is to make suggestions to improve the factory if possible.

The term 'qualification template' is used at IBM CSC to describe the evaluation of resources needed that allow the required tasks to be done.

The two main reasons why such a template is developed for the CSC factory are:

1. Cost proposal and
2. Planning.

Cost proposal takes place when management is estimating the necessary resources needed to complete a certain set of incoming jobs. This is necessary during the negotiation process before a contract is signed. It also plays a role when reporting to upper management. Resources are headcount, time, space, and equipment among others. The critical resource is headcount or the number of operators required.

Planning in this context means anticipating and adjusting to future incoming jobs by shifting resources. This is necessary to avoid over and under capacity at the different sections of the factory. These sections are also called sites. Changes at the sites due to resource allocation do not occur on a regular basis. They can be necessary and can lead to improvements in overall factory capacity.

An older version of the qualification template exists. The first task is to find out whether that version accurately functions as a template. The second step is to make suggestions to improve that template or develop a new version if necessary.

2.2 Description of Operations at the Factory

2.2.1 Overview

The IBM Customer Solution Center (CSC) factory in Singapore is the center piece of the entire department. Over 80% of the work directly performed for the client is done in the factory. The rest is completed at the client.

In the factory software and hardware services are performed for the customer. Software services are updates of existing software, installation of new software, and reconfiguration of computer systems among others. Hardware services are removal or installation of memory cards, etc.

The factory consists of three physical sections with their respective boundaries. These sections are called sites. The three sites are:

1. Receiving Site,
2. Operations Site,
3. Shipping Site.

Each site has its own supervisor, operators, and tasks. The supervisors of the receiving and shipping sites have desks in the control room. That room is for administrative work only. Security at both entrances/exits makes sure that parts remain where they are supposed to be. One shift is 7.2 hours. Usually there is only one shift per day, five days a week. During peak season operators might need to come in during the weekends or perform multiple shifts per day. The factory layout is shown in Fig. 5.

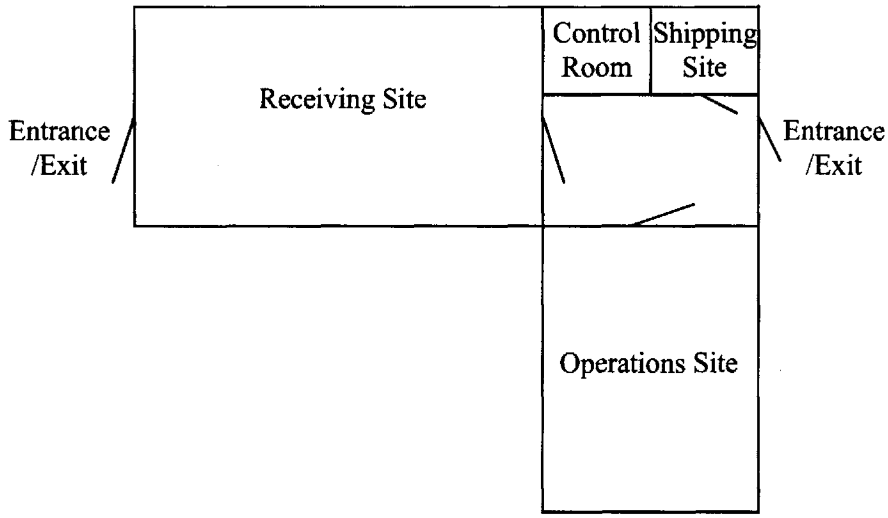


Fig. 5: Factory layout

Units enter the receiving site and are registered. They are passed to the operations site. At the operations site software and hardware services are performed. The units are then brought to the shipping site and are ready to be transported to the customer.

Units are discrete pieces of hardware that include laptops, desktops, servers, printers, and monitors. Laptops and desktops are often called PCs.

2.2.2 Receiving Site

The main job of the receiving site is to register incoming hardware and to pass them to the operations site.

Registration of hardware means updating the IBM inventory system. The internal IBM inventory system is also called RIIS. The operator manually types in the serial number into a computer that has access to the internal network.

The operator also has to verify the incoming hardware with what is written on the report. This is done by counting the pieces of hardware and comparing their unit serial numbers. If there are any discrepancies the mistake is reported. Then the origin of the error has to be found. This is done by calling the customers and CSC internal personnel to let them check their data. Everyone involved in creating and passing the data has to be talked to until the mistake is found.

If there are no discrepancies in the first place or after eliminating the errors, the operator will move the pallet on a manual forklift to the operations site.

Two operators work at this site permanently. More employees can be added during peak season. The receiving site covers the largest physical area of the entire CSC factory. Units are placed and stored on pallets. The units are placed onto the storage area at random. There are no designated places for certain customers or types of units.

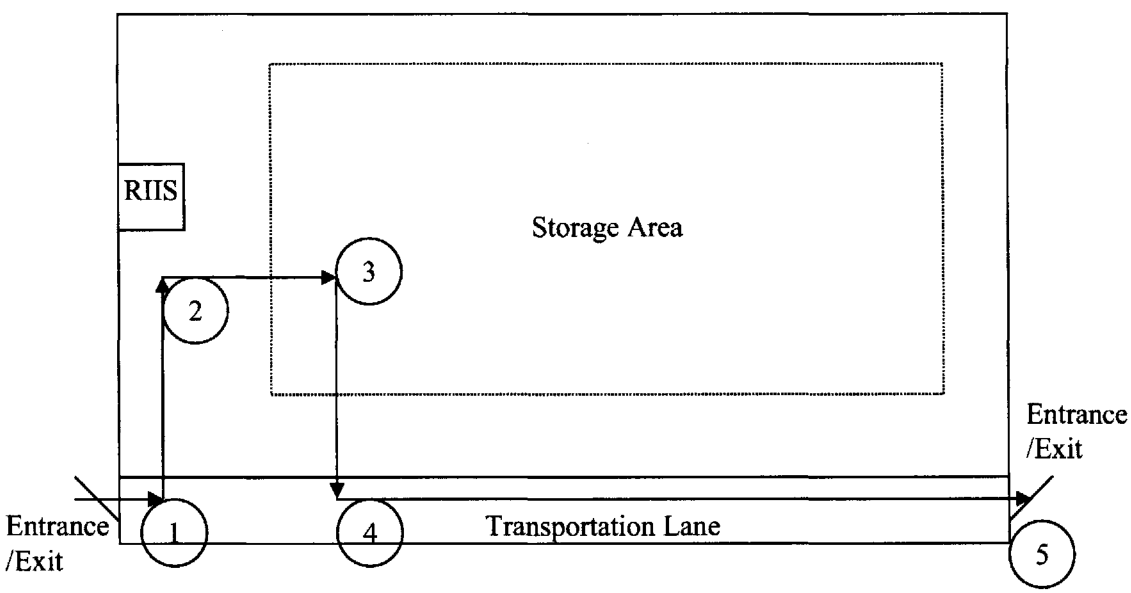


Fig. 6: Receiving Site Layout

Fig. 6 shows the physical layout of the receiving site. Units enter at '1' and are registered at the RIIS computer at '2'. Then they are stored at '3'. When it is time they will be moved to '4' and exit the receiving site via '5'. The units are then brought to the operations site.

The largest variation in completion time of the registration process occurs due to discrepancies between the actual hardware and the report.

2.2.3 Operations Site

The main job of the operations site is to perform hardware and software services.

Hardware services involve the addition or removal of hardware components. These include memory chips, CD drives, etc. Hardware services only take up a small amount of total time spent on a unit PC – laptop or desktop. Sometimes no hardware services are performed at all. In very rare cases only hardware services are performed. These types of services occur more frequently when dealing with servers.

Software services involve the update of existing software with newer versions, the installation of completely new software, and the configuration of computer systems. Usually the time for the configuration process is being reduced by customized software, so that the operator does not have to perform each configuration step him- or herself. Software services take up the largest amount of time when dealing with PCs.

5 operators work at the operations site permanently. More operators can be added during peak season. Each operator possesses the same set of skills to perform every task handed to him or her. The operations site covers the second largest area of the factory. The layout of the operations site is shown in Fig. 7.

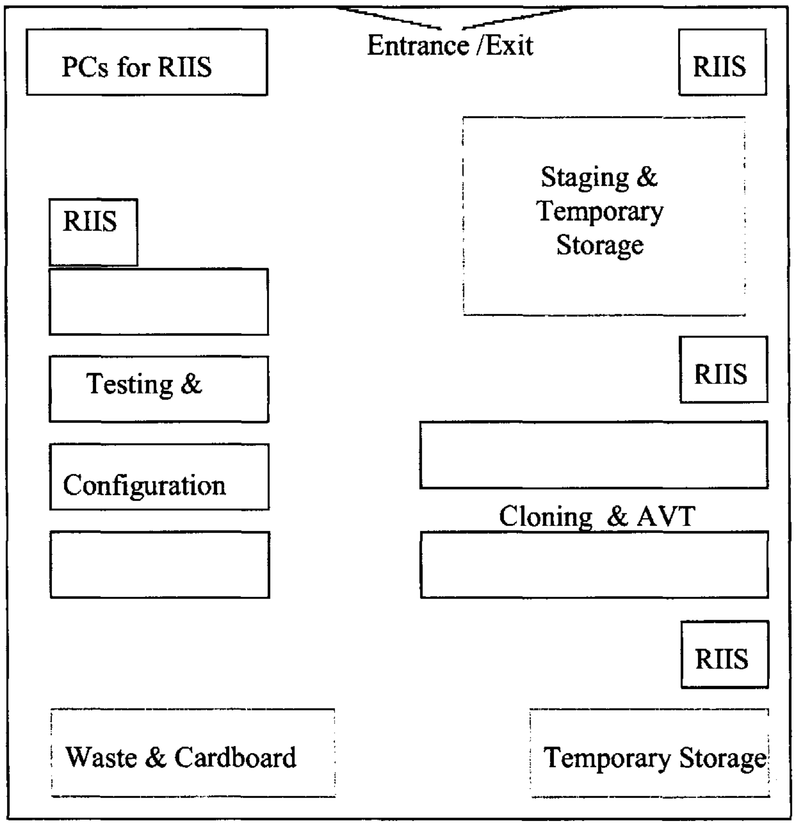


Fig. 7: Operation site layout

Units enter the operations site and are kept at the temporary storage area. This area is unmarked space without clear separation to the other places of the site.

Units arrive on pallets and are moved with manual forklifts. Smaller transportation carts are available to move a batch of units to the subsequent working areas for the actual hardware and software services. *A batch is a number of units that one operator will work on simultaneously. In this text the word batch is used as a synonym for process batch.* Usually these units belong to the same customer and are almost equal in hardware features and service requirements.

Three different types of services are performed at the operations site:

1. Cloning & AVT,

2. Testing & Configuration,
3. Assembly

These services are performed at their designated areas (Fig. 7).

1. Cloning & AVT

Cloning & AVT is solely done for PCs. During cloning a base image is being installed onto the hardware unit. During Asset Verification and Testing (AVT) the functionality of the hardware units are checked by the operator.

Multiple base images are stored at the IBM server. A cable connects the PC unit to a socket that has access to the server. The base image is then uploaded to the PC. A base image is a preconfigured state of a computer hard disk with its respective software installations and configurations. It serves as the standard template that needs to be installed onto multiple PCs typically for the same customer.

2 racks are available for this service. A rack is a table with two platforms (Fig. 8). The PC units are placed on the lower platform. The upper platform is reserved for monitors that display the current progress of the units.

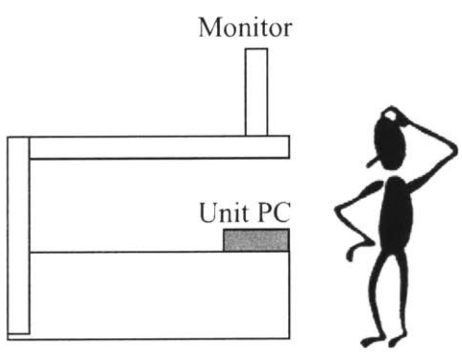


Fig. 8: Cloning & AVT rack

Each Cloning & AVT rack has 12 sockets that are connected to the internal IBM server. There is physical space on the lower platform for at least 12 PCs – desktops or laptops. Usually there is one operator working on each rack. This can change however, depending on the workload.

2. Testing & Configuration

Testing & Configuration is solely done for servers. It is essentially the same type of service as in Cloning & AVT. During testing the functionality of the unit is checked; during configuration, hardware and software services are performed.

4 racks are reserved for this service. These racks are smaller in size and only have 6 sockets. These racks also do not have a lower platform (Fig. 9). Servers are placed on transportation carts. These carts serve as lower platforms.

Usually one operator is responsible for two racks at the Testing & Configuration area. This can change depending on workload.

The Cloning & AVT and Testing & Configuration racks are very similar. The sockets are the same in terms of model and functionality. When there is a large imbalance of servers and PCs that need to be processed, PCs can end up at the Testing & Configuration racks and vice versa.

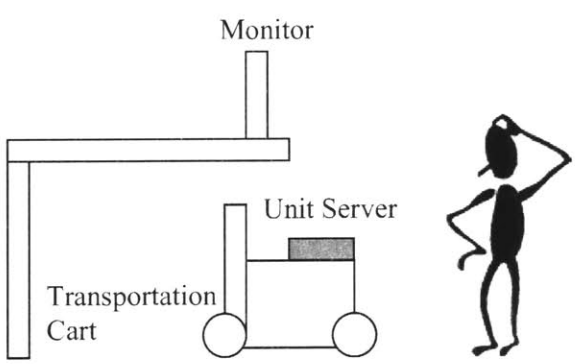


Fig. 9: Testing & Configuration rack

The reason for a mostly clear separation of racks is for reference and administrative purposes. This way operators have an easier time finding their units and customers can see where there units end up at the operations site.

3. Assembly

Assembly in this context means the addition or removal of hardware components. This includes replacing older hardware components with newer parts.

Assembly can be done anywhere at the operations site. There is no one in particular responsible for this set of tasks.

If the only required operation is assembly, it is typically done at the Staging & Temporary Storage area. This is usually the case for servers. If assembly is required in combination with software services, they are usually done at the respective Cloning & AVT or Testing & Configuration racks by the same operator who performs the software services.

Comments on Operations Site

Overall processes and people are very flexible at the operations site. Although designated work space exists, operators can make necessary adjustments whenever circumstances require.

The sequence of operating steps on one piece of hardware cannot be changed for the vast majority of cases.

There is no algorithm or heuristic in which incoming jobs are being processed. Operators will start with any job and support other operators whenever they have time. It usually works on a FIFO basis. The lack of systematic work does not seem to pose a major problem due to the limited size of the operations site. Since the beginning of the factory virtually no jobs have left the factory late.

There are over a dozen customers each with multiple customer segments. Each segment requires a different set of service to be performed. The registration process does not change a lot for the receiving site. The type of tasks for the operations site varies significantly. This makes the operations site the most complex site of the entire factory to describe. Each task requires something unique. Usually the amount of time spent on each task can vary quite a bit.

The variation in lead time due to errors during the service processes for the same type of job is not as large as in the receiving site. The impact on lead time of the site is significantly smaller.

2.2.4 Shipping Site

The main objective of the shipping site (Fig. 10) is to hold the units until they are transported out of the factory to the customer.

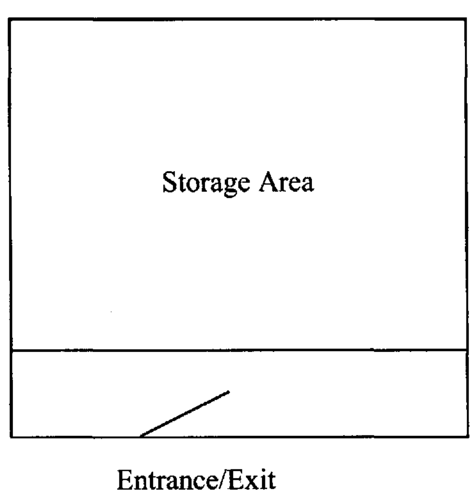


Fig. 10: Shipping Site Layout

There is a registration process involved. This process is a more formal one and rarely ever delays the shipment due to discrepancies between the report and the actual hardware.

One operator is responsible for the shipping site. The pallets with the units are being moved to the site with the help of manual forklifts. The shipping site covers the smallest area of the CSC factory. This can be explained because the average holding time is the smallest at this site.

If a shipment has been shipped but cannot be delivered, it will not be put back to the shipping site immediately. The units will enter the receiving site and need to go through the entire registration process again. This can occur if there are coordination difficulties with the customer. In rare cases units are immediately brought back because of problems with the hardware or software. Usually administrative issues cause the return of goods.

2.3 Description of Old Template

The old template is an excel file consisting of multiple worksheets. The entire value adding service for one unit of a certain customer is broken down into discrete steps. These steps represent software services, hardware services, or administrative tasks. The user types in the time estimates for these steps. The excel sheet sums up these times individually for the receiving, operations, and shipping site. The resulting time is the cycle time to complete one unit at each site.

All cycle times are operator times. Operator times are times the operator directly spends on a unit. During this time the operator cannot do anything else. There is also time the unit does not need the operator's attention. These times are called bench times. During bench time software is usually being installed. During short bench times, the operator remains at the rack. During longer bench times, the operator might still be dealing with the units, e.g. by registering the units during the installation process. This is true for most cases. Thus operator time is approximately the total cycle time the unit requires to be processed. Idle times are period of times, when the operator is not working on a unit and that unit is not processing anything. They are not explicitly considered in the old template.

t_i: operator time for step #i [min],

t_{agg}: total operator time for one unit [min],

n: total number of steps at site j,

d: total demand [units],

j: site j (j=1, 2, 3 for receiving, operations and shipping)

$$t_{j,agg} = \sum_{i=1}^{n} t_{i,j}, \quad (1)$$

$$t_{t,total} = d * t_{j,agg}, \quad (2)$$

The rate or wage per time for an operator at site j is then used to calculate the cost for the cost proposal process.

r_j: rate or wage per minute at site j [S$/min],

c_j: cost at site j [S$],

$$c_j = r_j * t_{t,total}, \quad (3)$$

The final result of the old template is a cost estimation. This estimation is solely based on the previous cycle time estimation. The cost estimation shows how much the customer should be charged in order to cover labor cost involved in delivering that particular service. The cycle time estimation shows how much time the operator has to spend on the units. The more time an operator has to spend on a job, the more it will cost.

This template is derived through common sense. It has not been verified.

The old template is based on three key assumptions:

1. Addition of step cycle times

Equation (1) assumes that the total cycle time is the sum of all cycle times for the individual steps. This is true, if the individual steps are done in sequence.

2. Proportional increase in overall time

Equation (2) assumes that the overall cycle time to complete x parts is the product of x and the cycle time to complete one part. This is true, if the individual units are worked on in sequence. This assumption is thoroughly discussed in the next sections.

3. Infinite capacity

The template does not take into account how much time there is to complete a number of units. This period of time is called SLA (service level agreement) at IBM CSC Singapore. The template assumes that it is possible to complete any type of jobs in any given timeframe. This is only true if the factory has a very large capacity. This assumption can only be made if the factory capacity does not reach its limit.

Chapter 3:
Analysis for Qualification

3.1 Overview

The first task is to find out whether the old template accurately estimates the resources of the factory. If it does not, an improved version or an entirely new template has to be created.

The following sections will discuss the data collection process, the data analysis, and the model used for the new template.

3.2 Data Collection

In order to verify or disprove the old template the proposed results have to be compared with the real situation. Cost values are not available. Thus only the cycle time estimation is being analyzed.

Cycle times at the receiving, operations, and shipping site were collected for two consecutive weeks. The number of similar jobs being processed is very small. Five sets of the same job arrived at the factory during these two weeks. It is very hard to forecast when the new jobs will arrive at the receiving site. It is also hard to forecast when the jobs will be processed at the shipping site. This made the operations site the main focus. This focus is desirable because service operations at the operations site are the most complex.

The reason to focus on the same job is to be able to compare the change in resources for varying demand. The same job in this context means the same service done on the same type of units – laptops, desktops, or servers – for the same customer. The service requirements have to be the same, while the hardware performance can vary slightly.

5 different batches of laptops have been analyzed. These PCs all had the same CPU (1.8GH Pentium Dual Core). They had different RAM and hard disk sizes – ranging from 256MB to 1024MB and 40GB to 80GB respectively. That did not have an impact, because the individual process steps were completed at almost the same time for all laptops.

The individual cycle times for each operator step were collected for the operations site. A common stopwatch was used. The total cycle time were collected for all five jobs. That is the period of time from the beginning of the first step for the first unit until the end of the operation for the last step of the last unit in the same batch. Two units are in the same batch if one operator performs service operations on them in parallel or close sequence and returns them to the shipping site at the same time.

At first every single discrete set of tasks was treated as a new step. This led to 19 individual steps. Some of these steps took only 10 seconds to be completed.

The 19 steps were aggregated for two reasons:

1. If two steps are performed on the same unit in sequence it does not make sense to separate them. Each of these steps could have been divided into multiple smaller steps as well.

2. An aggregation of steps reduces overall variation. This is the variation in accuracy of the manual cycle time collection process.

5 individual cycle times remain after the aggregation (Fig. 11). These are 3 operator times and 2 processing times. Processing time is equivalent to bench time. It is the time a process takes place without the attendance of the operator.

	Description
1. Operator Step	Unpacking, Setting up cable connections
2. Processing Step	Image cloning, registration
3. Operator Step	Configuration of PC
4. Processing Step	Safeguard installation, registration
5. Operator Step	Packing

Fig. 11: Description of aggregated steps

Idle times did not occur for the five cycle times taken. Idle time is the time the operator is not working on the unit and the unit is not in process of anything neither. Idle time is neither operator time nor processing time. Two more cycle times were taken for other jobs. For those idle times did exist. There might have been some bias due to the bystander/author who was constantly observing the process. That way the operator might have left out some potential idle time.

Step #	Type	1 PC	2 PCs	5 PCs	4 PCs	5 PCs
1	Operating Time	00:03:35	00:05:45	00:07:15	00:07:00	00:09:15
2	Processing Time	00:24:25	00:23:15	00:29:45	00:28:00	00:27:45
3	Operating Time	00:11:05	00:10:30	00:10:45	00:10:00	00:10:00
4	Processing Time	01:46:30	01:45:00	01:45:30	01:51:00	01:58:00
5	Operating Time	00:07:15	00:13:17	00:11:45	00:10:00	00:10:00
	Total Time	02:32:50	02:37:47	02:45:00	02:46:00	02:55:00

Fig. 12: Cycle times for each step in units: [hsr:min:sec]

The cycle times collected are listed in Fig. 12. The first row shows the batch size. One operator was responsible to work on 1PC, 2PCs, 5PCs, 4PCs, and 5PCs in a batch on 5 different days.

3.3 Data Analysis

3.3.1 Overview

In this section the estimation results of the old template and the actual times are compared.

If the discrepancies are significant, an improved or a completely new template needs to be developed.

3.3.2 Statistical Analysis

The inputs for the old template are the individual step cycle times. There is little incentive to collect time estimations for jobs that are already being processed. It is assumed that management can accurately estimate the individual step cycle times with the help of the site supervisors. In addition, there is no method of knowing the exact step cycle time before running a set of operations. By then, the contract has already been signed. The resource and cost estimation for the cost proposal process would make more sense before the signing of the contract.

The individual operator steps are done in sequence. They cannot be done by one operator in parallel by definition. There is no need to question whether the total cycle time for one unit is the sum of all step cycle times. Equation (1) appears to be valid. As long as the initial estimation is accurate the overall cycle time for one unit will be accurate.

Equation (2) states that by doubling the number of units being processed the overall processing time will double as well. This is true if they are done in sequence. The actual result shows no such increase when done in a batch. Fig. 13 shows the estimated value in comparison with the actual value.

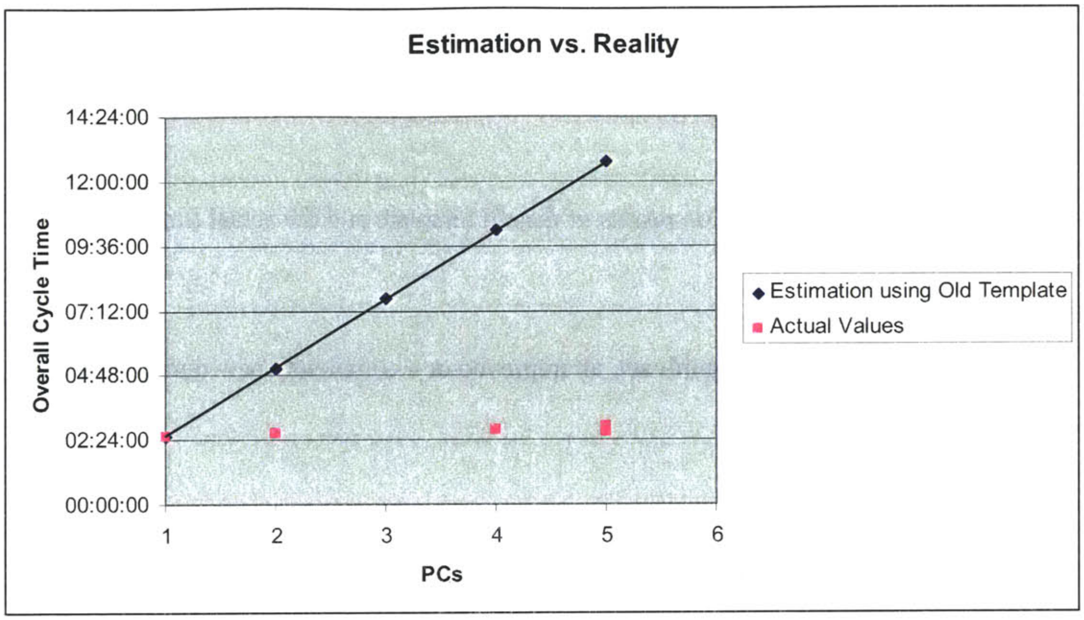


Fig. 13: Estimation vs. Reality

It is clear for this case that the difference between the estimated value and the actual value increases with larger batch sizes.

Fig. 14 gives an overview of the percentage overestimation of the estimated value and the actual one. The estimated overall cycle time can take on values 4 times larger than reality for a batch size of 5 PCs.

Batch Size	1	2	5	4	5
Overestimation [%]	0	94	363	268	337

Fig. 14: Overestimation

If the units are done in sequence equation (2) is valid. This did not happen once during the two weeks at the factory. Thus, the only time equation (2) would be valid is for the batch size of one.

Equation (2) is definitely not valid on a large scale when considering the entire demand for a long period of time of a certain customer. Another way of estimating cycle times for multiple units has to be developed. The proportional increase in time does not represent the true situation. Another relationship has to be found.

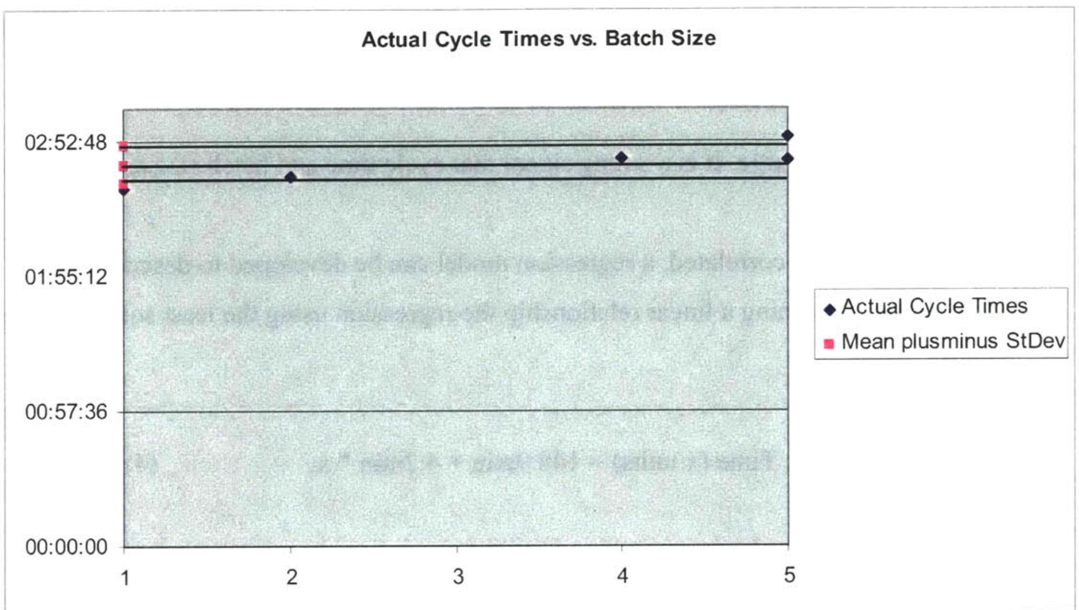


Fig. 15: Mean and Standard Deviation of Cycle Times

Fig. 13 shows the rather small difference in overall cycle time for different batch sizes in comparison to the overall cycle time. This can be pure variation.

If this is a case of pure variation around a mean, the mean and standard deviation will be:

$$\text{Mean} = 163.3 \text{ min},$$
$$\text{Standard deviation} = 8.4 \text{ min},$$

These values are shown in Fig. 15 along with the actual cycle times.

Taking a closer look at Fig. 15, it is possible to see a slight increase of cycle time with larger batch sizes. It makes sense to analyze whether a different relationship between cycle time and batch size exists than pure variation.

The correlation factor between cycle time and batch size for the existing data set is:

$$\text{Correlation (cycle time, batch size)} = 0.91,$$

This value is very large. It is a strong signal that cycle time and batch size are correlated.

Assuming they are correlated, a regression model can be developed to describe the relationship. Assuming a linear relationship the regression using the least square method yields:

$$\text{Cycle Time (x units)} = 148.9\text{min} + 4.2\text{min} * x, \qquad (4)$$

The result is displayed in Fig. 16.

The linear regression model seems to represent reality very well for the existing data set. Because of the high correlation it seems reasonable to create a new template based on the linear model.

There were only five cycle times taken during the two weeks. This is a rather small number to give a definite relationship based on statistical studies alone. A qualitative analysis can help to support or reject the statistical findings.

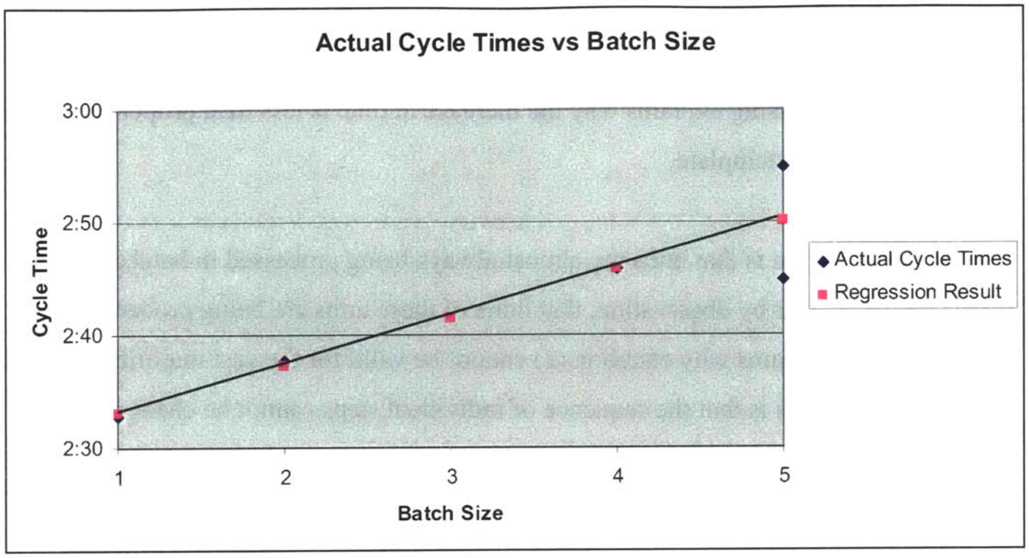


Fig. 16: Regression Model

3.3.3 Qualitative Analysis

By observing the operation processes at the factory site, a couple of valuable things for the qualification template can be noticed. They can be helpful in explaining and interpreting the results of the statistical analysis. The observations took place during the understanding phase of the factory processes before data collection, during the two weeks of data collection, and after the statistical analysis.

Two phenomena are described and discussed in this section. They are:

- Near-parallel processing
- Overhead times

Near-Parallel Processing

Near-parallel processing explains why the increase in time is less than proportional as is suggested in the old template.

The first observation is that units are almost always being processed in batches at all three sites. It is clear by observation, that none of these units are being processed in sequence. This explains why equation (2) cannot be valid for the vast majority of cases. Another observation is that the sequence of individual steps cannot be changed for the vast majority of cases.

The units in a batch are processed almost in parallel. This is possible due to the processing times or bench times. These times allow the operator to work on other units without delaying the entire process by a lot while the previous units are still in progress of having software installed. This is explained next.

A breakdown of the three types of times involved gives some insight on how to estimate overall cycle time.

The three types of times are:

- Operator Time
- Processing or Bench Time
- Idle Time

Fig. 17 illustrates the times of an operator who is performing the same service for a batch of three identical units and does not leave that batch during the process. The entire process is broken down into the three types of times.

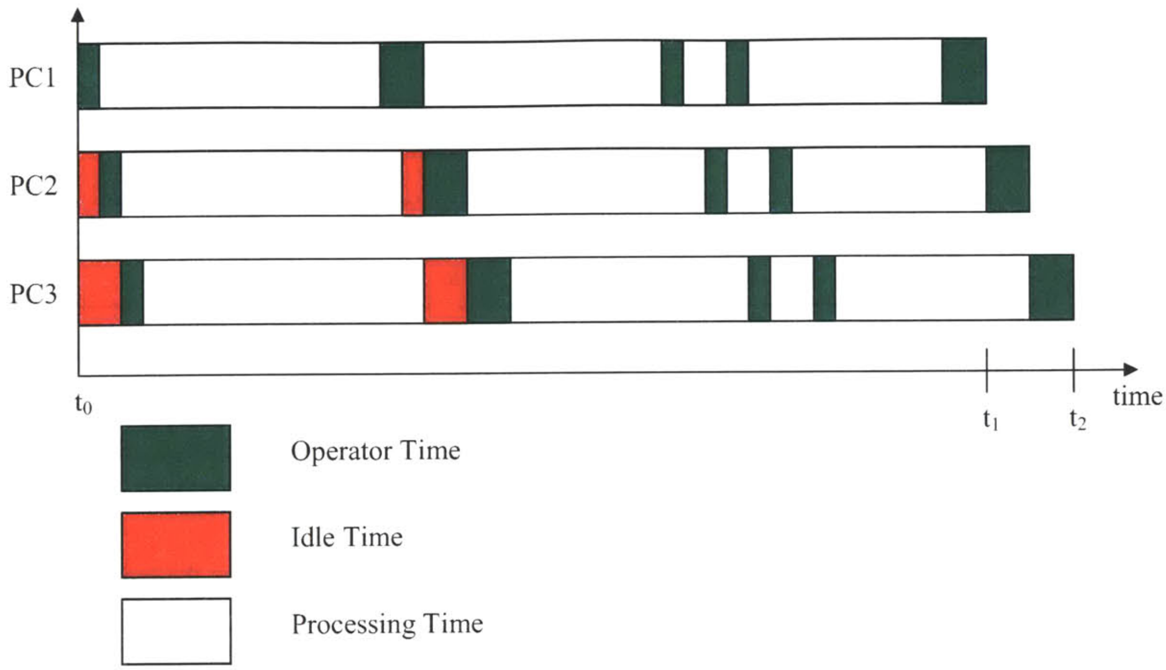


Fig. 17: Near-parallel processing of identical parts by single operator

The operator finishes an operating step and immediately moves on to the next unit. While the operator is busy with one unit, the other units can only be in process or remain/become idle.

The first step for any unit can only be an operator step or idle time. The first step for the first unit is always an operator step. This means idle time for all the other units in the same batch. If there are no more idle times for any unit in the batch, the increase in overall processing time will be the product of the cycle time of the first operator step and the batch size less one.

To find out whether there are more idle times, the following process is considered. Fig. 18 lists the cycle times of the n steps done for one single unit. The notation is $T_{i,,j}$ with step i and type of time j. (j=1: operator time; j=2: processing time)

Because only one unit is considered, no idle time exists.

Step #	Cycle Time
1	$T_{1,1}$
2	$T_{2,2}$
…	…
K	$T_{k,1}$
…	…
n-1	$T_{n-1,2}$
N	$T_{n,1}$

Fig. 18: Processing Plan for a unit with n steps

The total time needed to complete that unit is the sum of all times for the individual steps.

Now, more units are being processed simultaneously. The fastest all units can be completed is the completion time for one unit and the product of the largest operator time and the batch size less one:

$$T_{min}\,(x \text{ units}) = (x-1)*\max\{T_{i,1}\} + T_{1agg} + T_{2agg}, \qquad (i = 1, 2, 3, \ldots, n) \qquad (5)$$

with $T_{xagg} = \sum_{i}^{n} T_{i,x}$, (6)

Equation (5) states that the increase in total cycle time is by the largest operator time anywhere in the process. This makes sense. If the largest cycle time lasts $T_{i,,1}$ for every unit, the increase per unit will be at least by this margin.

Theoretically, the increase in total cycle time for a batch can be larger. One way this could happen is if the processing time following an operator time is smaller than that operator time (Fig. 19).

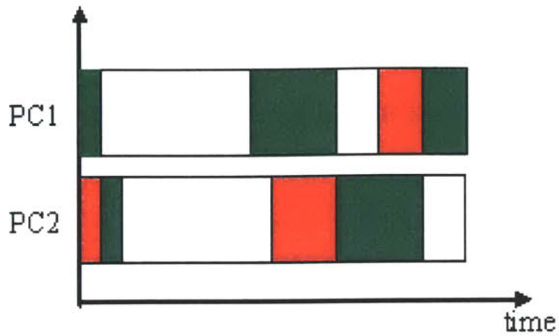


Fig. 19: Idle times due to operator-processing time ratio for two PC batch

This does not happen in most cases. In the case analyzed before, the processing times far outweigh the operator times (Fig. 20).

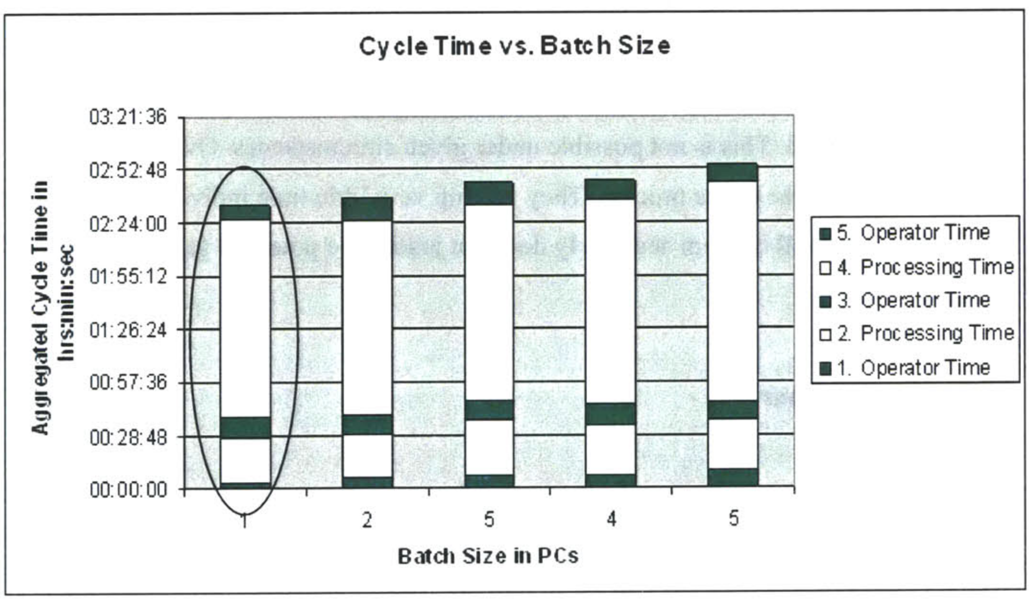


Fig. 20: Operator time vs. processing time

This means the increase in additional time is the maximum operator time. In the analyzed case that would be approximately 11min. The regression model indicates an increase of around 4min. The difference seems to be too large to be a statistical outlier.

Overhead Times

Overhead times explain why the additional increase in total cycle time for every extra unit in a batch is less than the largest operator time.

Overhead times are part of operator times. Overhead times occur when the operator is performing an operation that is needed for all units in the same batch. This operation is only performed once and takes the same amount of cycle time, whether done for one unit or for multiple units.

Overhead times can be transportation times for cables, documents, cutters, etc. They occur when the operator switches on the RIIS computer for inventory registration. These steps do not have to be repeated for the following units of the same batch.

To accurately predict the increase in total cycle time, the exact amount of overhead times has to be measured. This is not possible under given circumstances. Overhead times occur throughout the entire process. They take up very little time individually. The effort spent to measure all of them accurately does not justify the potential gain in accuracy for the new template.

Other Observations

There are other observations made, that can influence total cycle time.

Skilled operators can perform certain operations at two computers at the same time. This is rather rare, but can reduce total cycle time.

Sometimes a unit is added to a batch after the entire operation has already begun. This is very rare. It can happen, if there are some issues with that unit. If it does happen, and this unit actually belongs to the same batch, the operator may choose to wait until that unit has been completed before taking the entire batch to the shipping site. This can increase total cycle time.

3.3.4 Results from Analysis

The results from the quantitative/statistical and the qualitative analysis show that the old template poorly describes the actual process. A new way of estimating results has to be developed.

The three key insights are:

- Batch Size
- Small Increase
- Linear Relationship

Batch Size

Performing service for a batch of units allows near-parallel processing. The larger the batch the bigger the discrepancy becomes between the estimation of the old template and the actual value.

Small Increase

The increase in total cycle time for every additional unit in a batch is very small. It is even smaller than the largest operator time, which usually makes up a small part of the overall process itself.

Linear Relationship

A linear model can accurately describe the relationship between cycle time and batch size for the data set analyzed. This might not be the true underlying relationship, but it is accurate enough; it is a lot more accurate than the model used in the old template.

These results will be used to develop a new model for the new template.

3.4 Model

3.4.1 Overview

In this section the previous findings will be used to create the new template. The template can be used to estimate resources for the cost proposal process. The template can also be used to analyze resource allocation needed for planning.

The assumptions are stated first. The models and equations used for the resource estimation and allocation process are discussed afterwards.

3.4.2 Assumptions

It is assumed that the user can provide the necessary cycle times for the individual steps. It is assumed that these times are accurate enough.

The linear relationship stated in equation (4) for the data set analyzed is assumed to represent reality accurate enough. The linear relationship between total cycle time and batch size is used for all other cycle time estimations.

There are enough units at the beginning of every shift, so that the operators can work on their batch without delay. This assumption is not always true. Sometimes operators at either site can face periods of waiting. This happens, when the units are still at the previous sites or when the units haven't arrived at the factory in time at all.

It is assumed that operators work on any batch from the beginning of their shift until the end. They start at the end of the current shift and continue during the next shift. This is not always the case. If there is only half an hour left, operators may choose to not start another batch that takes over two hours to be completed. This can be compensated by adjusting the working hours per day in the template.

3.4.3 Resource Estimation

The inputs needed to estimate the required resources are:

- Demand or total number of units being processed
- Individual step cycle times
- Average batch Size
- Incremental Increase or additional time per extra unit

Demand 'D' in this context is the total number of units for a customer segment. They are undergoing the same service performed for the same customer. The units are equal or very similar in hardware features. Demand is given in every contract. There should be no problem acquiring this number. Sometimes a range is given. For this case the minimal, maximal, average value or any other value can be inserted to estimate the required resources respectively.

Individual cycle times for each step t_i are estimated based on experience. Management or operators can fill in these times.

The average batch size 'b' is the arithmetic mean of all batch sizes for the units of that contract. This is a new input requirement for the user. The batch size can be estimated based on experience or past data. The larger the batch size, the less resources are required under the given limitations in rack space. Batch sizes can be different for each site. The reason to choose the arithmetic mean is explained later.

The incremental increase or additional time per extra unit 'I' is another new input. This number can be estimated based on experience or a set of experiments. So far, after taking multiple times for a variety of customer segments, it seems that times between 5-10 min. are accurate and safe values for most cases.

The resource calculation is done using the following set of equations:

D: Total demand of customer segment,

t_i: step cycle time for step i,

n: total number of steps to complete one unit,

t_{total}: total cycle time to complete one unit,

b: average batch size,

I: incremental increase,

$t_{resource}$: time to complete all units or time one operator will spend to complete the demand,

$$t_{total} = \sum_{i=1}^{n} t_i, \qquad (7)$$

$$t_{resource} = \frac{D \bullet (t_{total} + I \bullet (b-1))}{b}, \qquad (8)$$

Choosing the arithmetic mean of the batch sizes

Proof that equation (8) is valid with varying batch sizes throughout the entire operation:

b_i: batch size #i,

$D = b_1+b_2+\ldots+b_m = \sum_{i=1}^{m} b_i$, let $m=\frac{D}{b}$,

$$\Rightarrow t_{resource} = (t_{total}+I\bullet(b_1-1))+(t_{total}+I\bullet(b_2-1))+\ldots+(t_{total}+I\bullet(b_m-1)) =$$

$$=\frac{D}{b}\bullet t_{total}+I(b_1+b_2+\ldots+b_m-m)=\frac{D}{b}\bullet t_{total}+I\bullet(D-m)=$$

$$\frac{D\bullet(t_{total}+I\bullet(b-1))}{b},$$

Variation

Variation of cycle time is not considered in the equations described above.

Variation exists due to inherent variation of the process as well as errors that occur during the process due to defective parts. Also, breaks that operators take can be a source of cycle time variation.

Analysis of variation can help predict the probability of completing a batch of units within the given time frame. Units from the same customer segment are limited. This did not allow an extensive analysis of cycle time variation.

To compensate the lack of consideration of cycle time variation the value 'V' is added to equation (8). This value represents the percentage increase in cycle time that management expects the process to have.

The new equation for resource estimation is:

$$t_{resource}=\frac{D\bullet(t_{total}+I\bullet(b-1))}{b}\bullet(1+V), \quad (9)$$

If the rate or wage per unit time for a site is known, the cost can be estimated by multiplying this value with the estimated time:

$$\text{cost} = r \cdot t_{resource}, \qquad (10)$$

3.4.4 Resource Allocation

Equation (9) is the basis for the new template and allows resource or time estimation for a customer segment. This can be used for the cost proposal process by management.

The previous model does not consider whether it is possible to complete the required jobs. It also does not consider whether there is under or overcapacity at the three sites. This is necessary to allow smooth workflow between the receiving, operations, and shipping site and maximize factory capacity.

Maximizing factory output by resource allocation is not possible without considering the current set of incoming jobs. Because of the large variety of customer segments it is not possible to calculate a single value for throughput at each site independent from the specific jobs. Some units might take longer at one site, others longer at another site. Resource in the context of resource allocation means headcount or number of operators.

The best way to determine the amount of resources needed at each site is by aggregating the necessary amounts of resources for every customer segment at every site.

In order to do that, the following additional inputs are needed:

SLA: period of time in which jobs must be done, time until deadline is called SLA at IBM

T_{day}: working time per day, usually one 7.2 hours-shift per day

$$t_{resource} = \frac{D \cdot (t_{total} + I \cdot (b-1))}{b \cdot SLA \cdot T_{day}} \cdot (1+V), \qquad (11)$$

Equation (11) gives a prediction of the required headcount at the respective site to complete the customer segment. The recommended headcount per site cannot be determined, if one customer segment alone is considered.

In contrast to resource estimation discussed in the previous section, resource allocation only makes sense when all customer segments are considered. This can be done after equation (11) has been used on all customer segments for each site.

Chapter 4:
Proposed Solution – New Qualification Template

4.1 Overview

The final qualification template is a set of excel worksheets that allow resource estimation and resource allocation based on equations (9) and (11).

The sheets are:

- User Manual
- Customer Segment
- Summary Sheet
- Incremental Increase

Every sheet is described in the following sections. Illustrations are provided.

4.2 User Manual

The first worksheet is called "user manual". It is intended to guide first time users through the worksheet. It also provides some theory and underlying assumptions made to create the template.

The user manual consists of the sections:

General information, How to use it, What the template does, Explanation of different cells, Error messages, Theory behind the sheet, Limitations and Caution.

The worksheet is shown in Fig. 21.

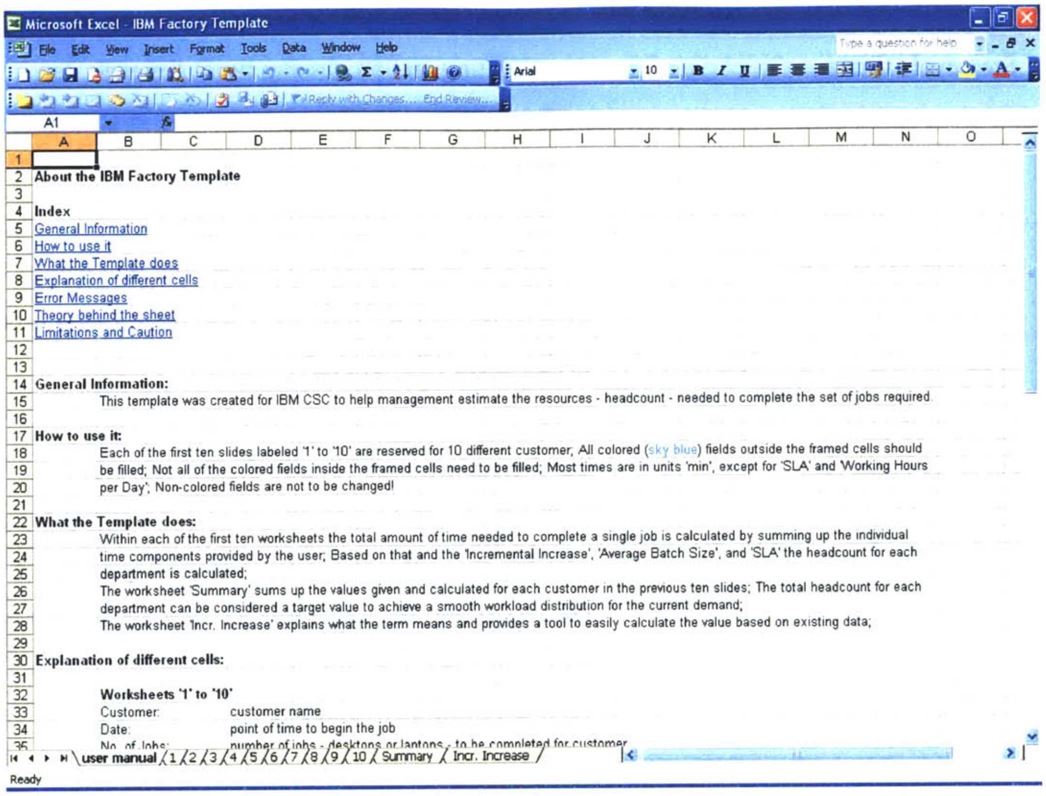


Fig. 21: User manual of the qualification template

4.3 Customer Segments

Following the user manual are 10 worksheets for 10 different customer segments (Fig. 22). The number of worksheets can be increased if necessary.

The inputs needed for each sheet are:

Demand	the total number of PCs or servers that need to be completed for a customer segment; D as is used in equations (7) – (11)
SLA	period of time given to fulfil the required tasks;

Step cycle times	the operating and processing times for each step performed on one unit; t_{total} as is used in equations (7) – (11);
Incremental Increase	the additional time needed for another unit being worked on parallel to the previous ones; I as is used in equations (7) – (11);
Average batch size	the average number of units that an operator can work on simultaneously; this number will depend on whether the units are available at the beginning of the day or not; the larger this number for the current rack size, the higher the output of the site; b as is used in equations (7) – (11);
Working hours per day	is set to be 7.2 hours; however, if for example overtime needs to be considered, the user of the template can change this time to a different value; T_{day} as is used in equations (7) – (11);
Variation	this number is designed to increase the time needed to complete a batch of units; this is necessary to provide a buffer for variation in processing and operating time, idle time, and time needed to fix problems that occur during the service processes; V as is used in equations (7) – (11);

These inputs are for PCs – desktops and laptops – and are separated accordingly. However servers and other hardware can be easily added.

The outputs are:

Total cycle time for the receiving site;
Total cycle time for the operations site;
Total cycle time for the shipping site;
$t_{resource}$ as is used in equation (8);

Headcount for the receiving site;
Headcount for the operation site;
Headcount for the shipping site;
$t_{resource}$ as is used in equation (11);

Outputs are also separated into laptops and desktops.

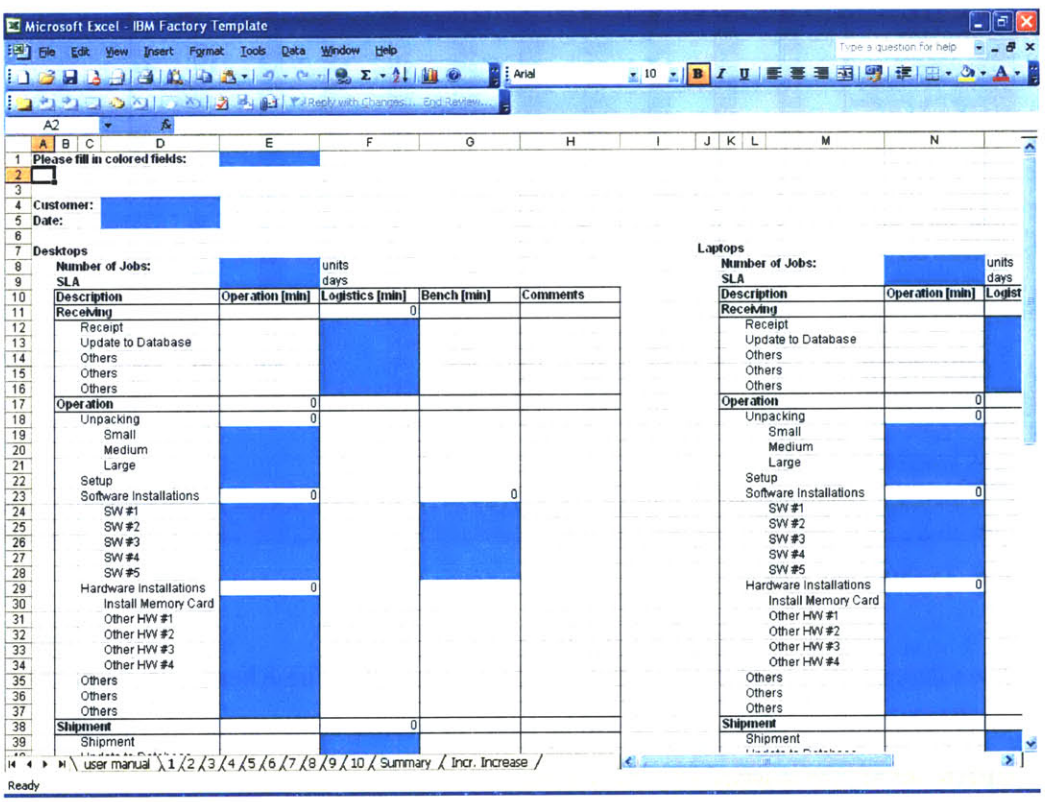
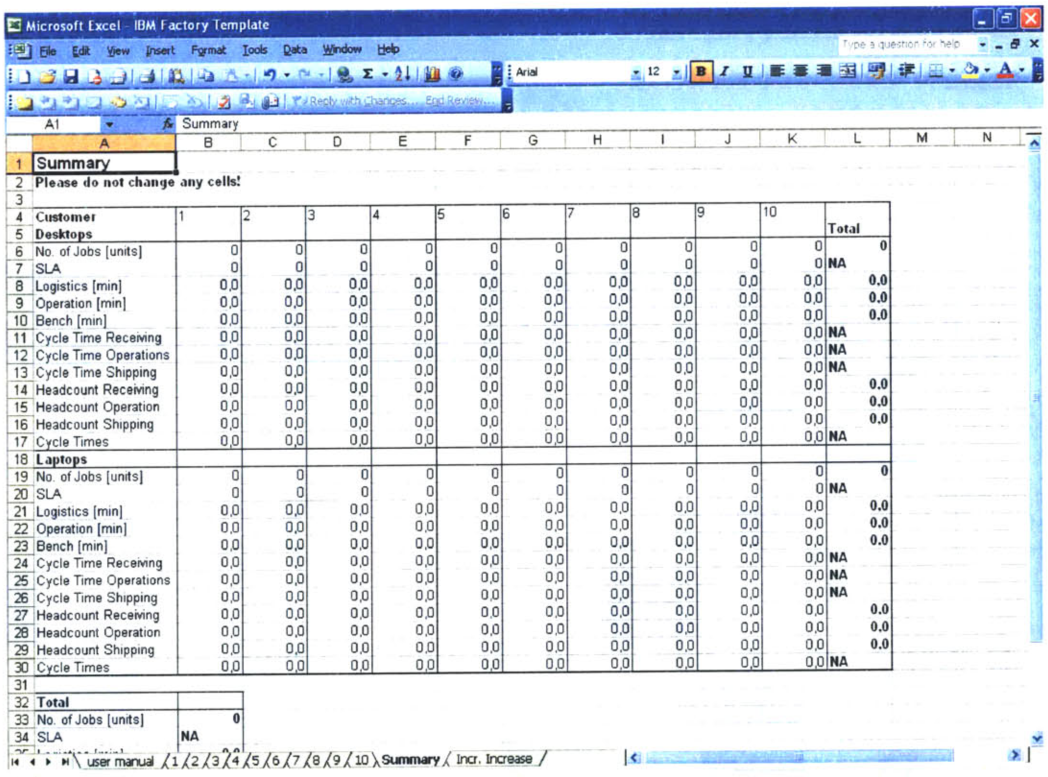


Fig. 22: Customer segment

Cells that require user input are colored.

4.4 Summary Sheet

The summary sheet lists all important values of the previous sheets and sums up the cycle times and headcounts needed for each customer segment and site respectively (Fig. 23).



	A	B	C	D	E	F	G	H	I	J	K	L
1	Summary											
2	**Please do not change any cells!**											
3												
4	**Customer**	1	2	3	4	5	6	7	8	9	10	**Total**
5	**Desktops**											
6	No. of Jobs [units]	0	0	0	0	0	0	0	0	0	0	**0**
7	SLA	0	0	0	0	0	0	0	0	0	0	**NA**
8	Logistics [min]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
9	Operation [min]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
10	Bench [min]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
11	Cycle Time Receiving	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
12	Cycle Time Operations	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
13	Cycle Time Shipping	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
14	Headcount Receiving	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
15	Headcount Operation	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
16	Headcount Shipping	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
17	Cycle Times	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
18	**Laptops**											
19	No. of Jobs [units]	0	0	0	0	0	0	0	0	0	0	**0**
20	SLA	0	0	0	0	0	0	0	0	0	0	**NA**
21	Logistics [min]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
22	Operation [min]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
23	Bench [min]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
24	Cycle Time Receiving	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
25	Cycle Time Operations	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
26	Cycle Time Shipping	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
27	Headcount Receiving	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
28	Headcount Operation	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
29	Headcount Shipping	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0.0**
30	Cycle Times	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**NA**
31												
32	**Total**											
33	No. of Jobs [units]	**0**										
34	SLA	**NA**										

Fig. 23: Summary Sheet

The total expected headcount at all three sites can be seen. These headcounts serve as a proposal and show whether there will be under or overcapacities at the sites for the current set of jobs inserted into the template.

4.5 Incremental Increase

The last sheet is optional and was created due to request by management. This sheet is called "Incremental Increase" and explains and calculates the additional time needed to complete work on one extra unit in a batch (Fig. 24).

The worksheet provides two columns to insert the batch size and the time needed to complete the entire batch. It will calculate the slope and the correlation factor. If the correlation factor is too small a warning will appear.

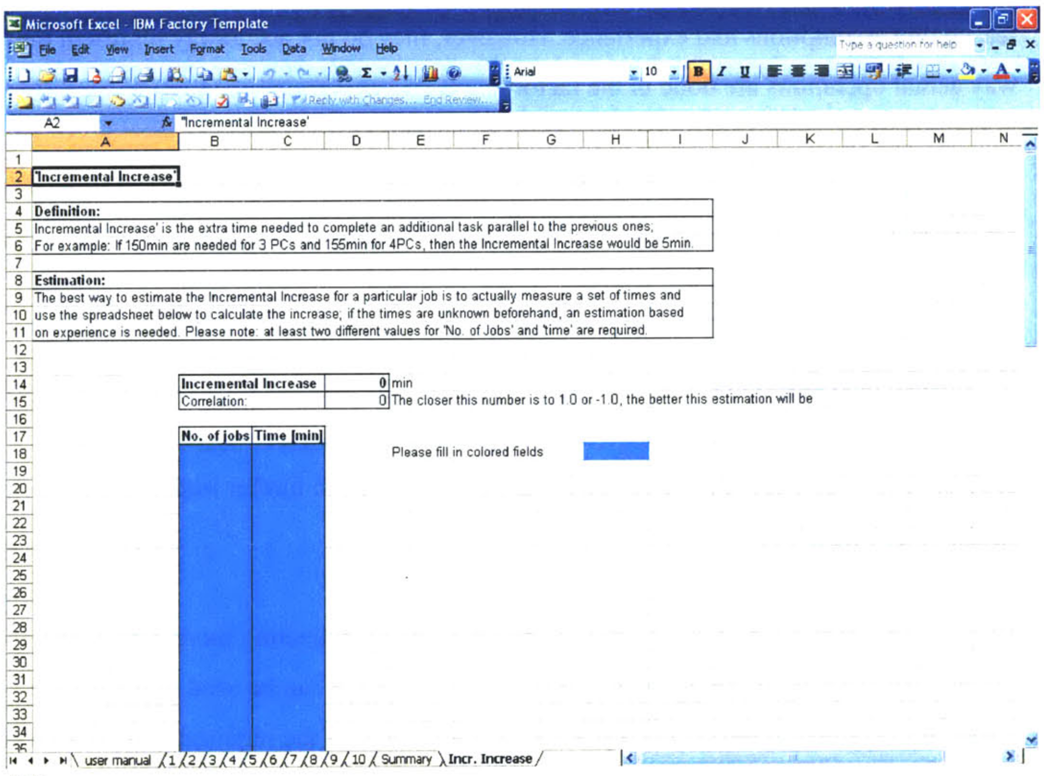


Fig. 24: Incremental Increase

If a set of times do not exist in advance, a rough estimation can also be used. After looking at the completion times of other units processed, an incremental increase of 5-10min can be considered a good estimation.

Chapter 5:
Conclusions

5.1 Summary

The internship project shows that through a relatively straightforward step by step analysis, a simple mathematical model can be developed to drastically improve an established process.

The whole qualification process of resource estimation and allocation was based on reasonable assumptions and experience. However, they do not accurately represent the way actual operations are done in the factory.

The new process is based on actual data collected at the factory. It has been verified on a small scale.

5.2 Future developments

A few areas of potential future research can be established to further improve the qualification template.

Probability distribution of cycle time can be analyzed by collecting more data. If the probability distribution for a larger sample size is known, it can be used to predict the necessary resources needed to complete a certain amount of the required units at a given probability.

Other resources can be analyzed. These include rack space or number of sockets. Optimal amounts of these resources can be determined this way.

The most important part is to verify the template on a large scale. Only if the template works accurately with a large set of data, additional features in the future will make sense.