WORKLOAD ANALYSIS AND SCHEDULING POLICIES FOR A DOCUMENT PROCESSING CENTRE

by

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ABSTRACT

This thesis is the result of a six-month internship at the Steel Stock Department of Keppel FELS Singapore, a company which is involved in the design and construction of oil-rigs. The primary objective of this project is to reduce the tardiness of the delivery of steel materials and identify the reasons behind the delay. The initial stage of this attachment is devoted to understanding the process flow of the department. Analysis has been done to pinpoint to the exact causes of the delay, which is at the stages of document processing and dispatching to the storage areas.

The workload at each stage of document processing has been analyzed using a queuing model and it has been found that the stage that the issue vouchers have to be generated and printed out is the bottleneck in the entire process flow. Some recommendations have been proposed to alleviate the problem. The second part of this thesis focuses on the reasons why scheduling rules should be utilized when dispatching the issue vouchers to the storage areas. Three scheduling rules have been tested and their performances with regards to tardiness have been studied.

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Chapter 1 Introduction

1.1 Overview of the Company

Keppel FELS is a subsidiary of Keppel Offshore and Marine and is the world leader in the design and construction of jack-up drilling rigs and is a major global player in Floating Production Storage and Offloading (FPSO) and Floating Storage and Offloading (FSO) conversions. It has built the largest number of jack-ups on order in the last decade and built over 60% of all the jack-ups in the world in the last 5 years [1].

There are 2 major types of drilling rigs. The first type is classified as a bottom-supported unit that stands on its legs on the seabed during operation and is suitable for shallower water of up to 500 feet in depth. Examples would include jack-up drilling rig and submersible drilling rig. Another type is the floating unit, which is suitable for deeper depth of water of up to 10,000 feet and rough seas. Examples would include drill ships and semi-submersibles.

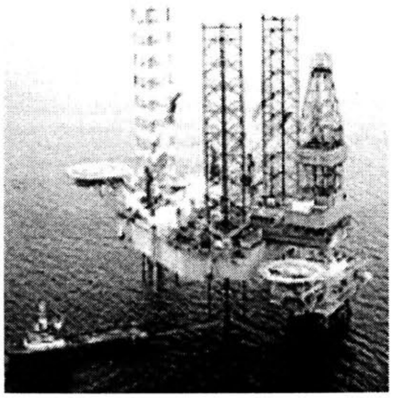
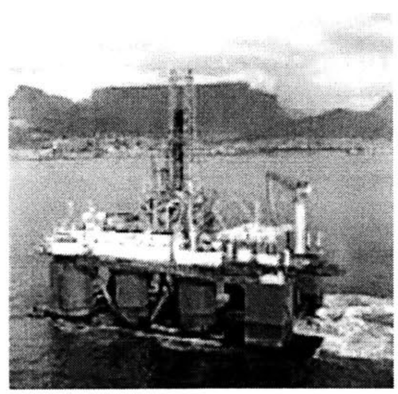

Figure 1-1: Jack-up drilling rigs (left) and semi-submersible drilling rigs [1]

In recent times, Keppel FELS undertook many new billon-dollar projects due to the rising oil prices. With the increase in the number of contracts, the loading of the yard is increasing. Projects run in parallel and hence resource management becomes important to ensure that limited resources are utilized in the most efficient way in the shipyard.

1.2 Workflow of Keppel FELS

The rig building process usually takes around 18 months per oil rig and the simplified business process flow is illustrated in Figure 1-2 as shown below.

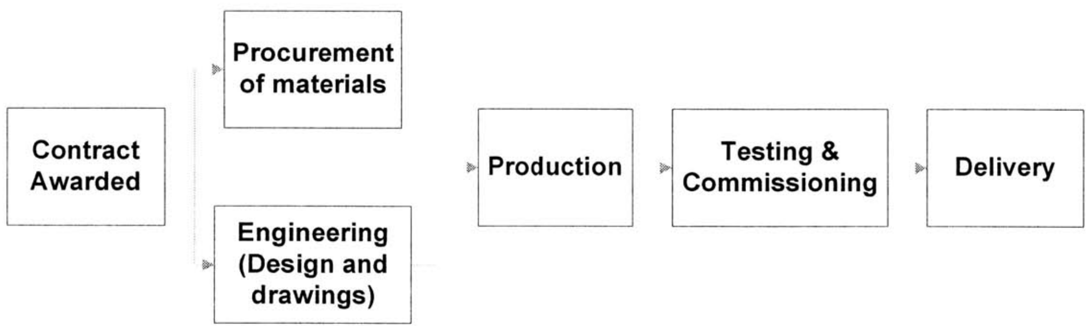

Figure 1-2: Typical workflow of building an oil rig

After the contract has been awarded to the company, procurement of steel materials and other equipment to be installed on the oil rig and the engineering design work will commence. This is followed by the production stage, which involves the fabrication and assembly of blocks. Before delivery, the rig must undergo rigorous testing before it is commissioned and sent to the customers.

1.3 Thesis Objectives

This thesis is the result of a six-month part-time internship at the Steel Stock Department of Keppel FELS. The details of the responsibility of the department will be given in the next chapter. The primary objective of this thesis is to:

- Identify the reasons behind the delay in the delivery of steel materials.
- Study and investigate any feasible improvement efforts to the current process flow of the department.

1.4 Organization of Thesis

Chapter 2 will provide a description of the process flow of the Steel Stock Department and the problem statement of this project. The process flow will be presented first as it gives readers a better understanding of the underlying problems. The following chapters will focus on the analysis and the solutions that can be applied to the problems. Chapter 3 will provide a review of some relevant technical literature and Chapter 4 will touch on the analysis of the workload of the Steel Stock Department, providing an insight to how much time is required to process each issue voucher. An issue voucher is a document that provides information on the type, dimensions and quantity of steel materials that have to be delivered to a specific user on a certain date; the issue voucher has to be presented to the user when the steel delivery is made.

Chapter 5 will address the solution on how the issue voucher can be dispatched according to different priority rules and the last chapter will conclude the thesis and provide some lessons learnt through this internship.

Chapter 2 Process Flow of Steel Stock Department

This chapter describes the process flow of the Steel Stock Department and the important role that it plays to ensure that the steel materials can be delivered on time. However, the materials are usually delivered late to the end users, who are the people in charge of the fabrication of the materials. This provides the motivation to study how to reduce the lateness of these deliveries, as steel is the fundamental raw material required for building an oil rig. Any delays in the delivery will propagate downstream and result in schedules not being met as planned.

2.1 Background on the Steel Stock Department

The Steel Stock Department can be considered as the first stage of the production process as it is responsible for the storage, blasting and transportation of the steel materials and it has to make sure that the right quantity and type of steel reaches the end users for the fabrication of the panels. This can prove to be a daunting task, as there are around 43 different grades of steel plates and the thickness of the plates can vary from 3 mm to 200 mm. There are also other types of steel materials that the department is responsible for, like angel bars, pipes, I-beams and bulb flats.

2.1.1 Storage

The first task that the department is responsible for is the storage of steel materials. It decides on where the materials are to be stored after they arrive at the port from overseas steel mills. The department also processes the accompanying documents, which are known as mill certificates that provide information on the location of the steel mill, the dimensions and the heat (treatment) number. The decision on the storage location depends on the storage capacity as well as the grade of the steel. There are currently 2 storage areas, namely Keppel FELS (abbreviated as KFELS) and Bluewater (abbreviated as BW), which is a subcontract company that provides extra storage space for the materials. The highest grade of steel, known as "Riverace", and common stock inventory are usually stored in KFELS, whereas the location for the rest of the materials will depend on how much spare storage capacity each company can provide.

2.1.2 Blasting and Transportation

The next task that the department is responsible for is the blasting process. The purpose is to prevent steel materials from corrosion during the long production cycle. There are 2 steps in the blasting process – abrasive blasting and priming. Abrasive blasting will remove all the rust on the surface of the material through the high impact of grids onto the steel surface. Priming involves coating the material with paint to prevent corrosion.

There are 4 plants that can carry out the blasting process. The decision on the blasting location is made by both KFELS and BW. There is a set of criteria that the Steel Stock Department in KFELS and BW will take into account when deciding which location to send the plates for blasting. For example, some plants cannot accept plates beyond certain dimensions, or of a certain project number. However, various plants have varying capacity per day as they blast plates from other companies too, in addition to KFELS.

Hence the decision is made on an ad-hoc basis, as calls are made to inquire about the capacity of the blasting plants before the materials are sent out.

After blasting, the steel material will be sent to the end users. The end users include the panel shop, which is a job shop responsible for the machining and welding of materials, the pipe shop in KFELS, and other subcontract fabrication shops. If the material is blasted at KFELS, KFELS will arrange for transportation to send it to the end users. If the material is blasted at other blasting plants, the transportation will be handled by the respective plants. Figure 2-1 gives a summary on the entire logistic network that the Steel Stock Department is responsible for.

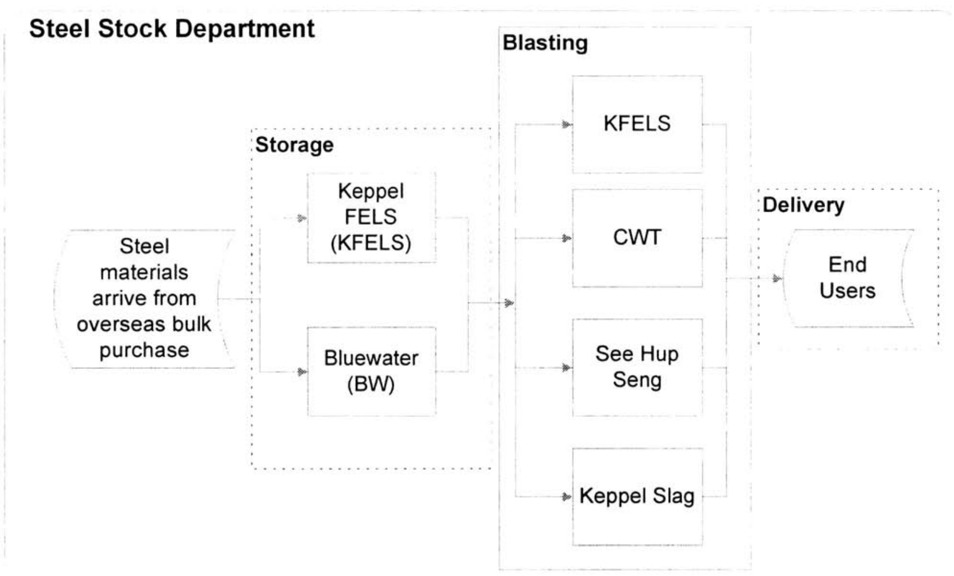

Figure 2-1: Schematics of the responsibilities of the Steel Stock Department

2.2 Process Flow

The entire workflow of the Steel Stock Department will be presented. The presentation is divided into smaller sub-sections to facilitate the explanation of the tasks being performed. Appendix A presents the flowchart of the processes described below.

2.2.1 MSS Generation

The Production Engineering & Planning (PE&P) Department is a separate entity from the Steel Stock Department. It is responsible for generating the shop drawings, cutting plans and the Material Summary Sheet (MSS) for other departments in KFELS. A MSS is equivalent to a Bill of Material (BOM) that lists the dimensions, grade and quantity of each material that is needed for a panel. Before generating the MSS, the PE&P department will check through a central database to ensure the materials are available before issuing the MSS. The production supervisors will write down the date that they require the materials on the MSS and the location to where the steel materials will have to be delivered according to the master schedule. Then they pass the MSS to the Steel Stock Department to process the request.

2.2.2 MSS Received

The production supervisors will record the MSS that they have submitted to the Steel Stock Department into a log book. When a sheet of MSS arrives at the Steel Stock Department, one of the staff will key in the requestor name, date required, MSS number and issue quantity into the Access database. The MSSs are usually keyed in after some consolidation on a daily basis. Depending on the workload, a MSS can be processed immediately after it has been sent in. After that, a check will be performed on the JDE system[1] to ensure that the material is present before the printing of the electronic issue voucher (abbreviated as EIV).

An EIV is a document that contains all the information on the MSS, as well as the picking and delivery locations and the required date. Many EIVs can be generated from one MSS, as the MSS can contain the material information for several pieces and types of steel. Each EIV will usually have the same type of material and the total weight of the material should not exceed one truckload (e.g. the total weight for the steel plates on one EIV should not be more than 25 tons). An EIV is an important document as it accompanies the materials through the picking, blasting and delivery processes before it is sent back to the department for archiving purposes.

If there is a shortage of materials, some measures can be performed. Materials of the same grade and dimensions can be "borrowed" from other projects and an EIV can be generated immediately as per normal. If such borrowing cannot be done, the PE&P department needs to be informed if they can substitute a higher grade material or use a larger piece of steel, or if local purchasing has to be done. Items that are bought from

[1] The JDE system is an ERP (Enterprise Resource Planning) software that is being utilized by the company for the inventory management of steel materials. This is a much recent system compared to the Access database.

local mills are known as "purchase items". Usage of a different material or local purchase material will lead to a revised issuance of MSS.

2.2.3 Generation of EIV

If everything goes well, the EIV will be generated by a staff in the department. The staff will input the picking location, the quantity of material issued, and the type of stock that the material belongs to (i.e. from common inventory or project stock). Appendix B shows the distribution of MSSs received and the number of EIVs generated on a daily basis. From the table, we see that a daily average of 20 MSSs received generates a daily average of 47 EIVs. After each EIV has been printed out, the material has to be deducted from the JDE system. This is to ensure that the material has been issued and the EIV number needs to be keyed into the JDE system. After that the EIV will be signed, placed and separated on one side for the workers from the respective picking locations to collect. The collection is usually performed on a daily basis, but can be more often for KFELS because of proximity to the steel stock office.

Figure 2-2 summarizes the steps involved for the EIV to be generated after the MSS is handed over to the Steel Stock Department. This process takes 1.9 days. After which, there is a period of waiting time as the EIVs have to be collected by the storage areas, before the materials are picked and ready to be transported to the blasting plants. This process takes an average of 6.7 days.

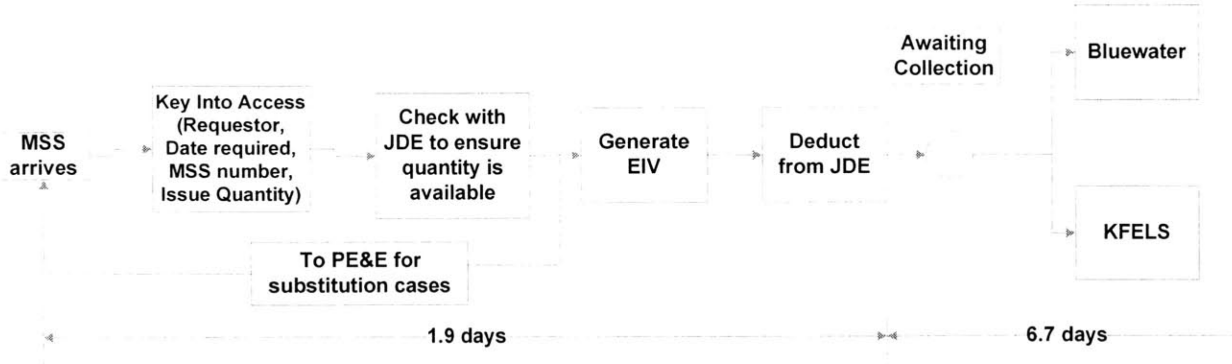

Figure 2-2: Flowchart of MSS arrival to EIV generation

2.3 Data Collection

I analyzed the department's Access database in order to obtain a clear picture of the amount of time each process takes, so that a comparison can be made between the stipulated planned time and the actual cycle time. Although entries from KFELS are dated from January 2005 onwards, entries for the first few months were sporadic as the department was trying to migrate from paper-based issue vouchers to the EIV system. Hence the analysis of the data is done for the period from 1st July 2005 till January 2006. Entries that belong to the below criteria are excluded from the analysis:

- Purchase Items
- Blanks in one or more of the fields, that are "Date Blasted", "Date Picked" and "Date Delivered"
- Erroneous dates between stages (e.g. blasting date is before picking date & delivery date is before blasting date)

Out of the 11,691 entries, only 4,607 entries are considered, which accounts for only 39.4% of the total number of entries. Purchase items are not considered because it will take a longer period of time for the steel material to arrive from a local mill and sent for blasting and delivery. Hence the amount of time spent on a purchase item is not indicative of the total time that an inventory item takes to be delivered to the end users. Table 2-1 gives a description of the fields that are present in the database.

Table 2-1: Terminology of terms in Access database

Field	Description
MSS Receive Date	The date that the Material Summary Sheet (MSS) is handed over to the Steel Stock Department and recorded in the database.
Required Date	The date that the material has to be delivered to the end user.
Issue EIV Date	The date that the Electronic Issue Voucher (EIV) is printed out.
Purchase Item	This field indicates whether the item is a purchase item. Materials are purchased if they cannot be found in the inventory and materials from other projects cannot be used.
Date Picked	The date that the material is located at the storage area and is loaded on trailers ready to be sent to blasting plants.
Date Blasted	The date that the material is blasted and is ready to be sent to its destination.
Date Delivered	The date that the material is delivered to the end user.
Issue Weight	The total weight (in tonnes) of the materials as indicated on an EIV in metric tones.
EIV Number	A unique document number given to each sheet of EIV generated.

2.4 Problem Identification

The dates from the Access database for the various stages are analyzed, and Figure 2-3 shows the duration it takes between different stages. The main problem statement is that there is a delay in the delivery of materials of 6.9 days.

It takes around 1.9 days between when the MSS is received and when the EIV is issued. After the EIV has been issued, it takes 6.7 days on average for the EIV to reach the storage facility and for the workers to locate and load the materials onto the trailers, ready to send out for blasting. It takes 2.5 days for the materials to be blasted after they have been picked and an additional 1.9 days for the materials to be delivered to the end users after blasting. Hence the entire process takes 13 days (1.9 + 6.7 + 2.5 + 1.9).

The numbers in parentheses in Figure 2-3 indicate the planned time that is allocated for each stage. That is, the department plans for it to take one day between the receipt of the MSS and when the EIV is issued, and two days between when the EIV is issued and when the steel material is picked and ready for blasting. In total, KELS plans for the entire process to take 7 days = 1 + 2 + 2 + 2.

In the current situation, the process actually takes 13 days on average. Hence the Steel Stock Department desires the receipt of the MSS at least 13 days before the required date. However the MSS is received only 6 days before the required date. This delay can be attributed to lack of materials. Before the MSS is generated, the PE&P department has to ensure that materials are present by checking through their database. Sometimes the materials cannot be found and the PE&P department has to perform local purchase which will account for the delay. Another reason is that the production supervisors might not hand the MSS over to the Steel Stock Department immediately upon receiving it.

There is an average tardiness of 7 days in the delivery of materials to end-users. Such a delay can cause deadlines to be missed and confusion in the production schedules as the end-users need to adhere to the timelines indicated on the master schedule. Given the constraint that the "MSS received" date cannot be moved earlier, one of the ways to reduce tardiness is to shorten the processing time between the stages from "MSS Received" to "Picked". The amount of time for the material to be blasted and delivered are already close to the stipulated time given for such tasks, hence we will focus our attention on the stages before that.

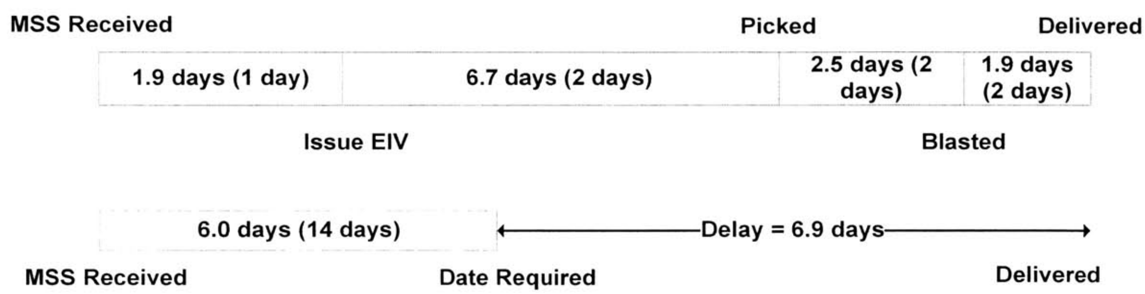

Figure 2-3: Actual processing and allocated planned time (in parentheses) for each stage

2.5 Solution Approach

2.5.1 Queuing Model for the Generation of EIV Stage

The data analysis shows that it takes almost twice as long for an EIV to be generated from a piece of MSS compared to the planned allocated time, namely 1.9 days versus 1 day. Handling and processing of documents is a straight-forward procedure and it should take a very short time theoretically. We will utilize a queuing model to understand the workload at each station, and whether the process can be effectively streamlined to achieve faster processing time.

2.5.2 Scheduling for the Dispatching of EIV at the Picking Stage

It takes 6.7 days from the stage when the EIV is issued to when the material is picked; this is more than thrice as long as the planned allocated time. The purpose of a scheduling strategy is to determine the best method of dispatching the EIVs to the storage areas. Currently all the EIVs are given out once they are processed, without any regard to the capacity loading of the storage and blasting plants as well as the urgency of the jobs. This leads to large variability in the weight of materials that the various plants have to handle. We investigate the scheduling for the dispatching of EIVs with regard to the limit on the capacity loading in Chapter 5 so as to take into account the processing time and the urgency of the jobs to minimize overall tardiness and to reduce variability in the weight of materials to be handled at each storage area.

Chapter 3 Literature Review

I conducted an extensive literature research through journal papers and textbooks to gain a better understanding of the theories and concepts that will be relevant to this project. In this chapter, I present a brief introduction to the two methodologies used in subsequent parts of the thesis, namely queuing theory and scheduling. By no means does this represent an exhaustive review of the literature.

3.1 Queuing Theory

Queuing theory is a branch of applied probability and its applications are wide-ranging, from telephone traffic engineering to hospital facility planning. The subject of queuing can be described as follows: consider a type of equipment (server) and a population of customers. A customer will request the use of the server and he will hold it for a length of time [3]. If a new incoming customer arrives and finds no available server, he can enter a waiting line and waits until the server becomes available, or he can go away. This process will have three basic characteristics, namely the input process, the service mechanism and the queue discipline.

The input process mainly describes the source of arrivals, the type of arrivals and the inter-arrival times [4]. The service mechanism describes the number of servers and the length of time the customers hold the servers [3]. The queue discipline describes the rule the server follows in taking the customers in service [4]. Examples of the rules include "first-in, first-out" or random selection.

The Kendall notation is used to characterize a queuing system. A queuing system is usually characterized in the form of *a/b/c/d*, where *a* specifies the inter-arrival process, *b* specifies the service time distribution, *c* is the number of servers and *d* denotes the maximum size of the waiting line (*d* will be omitted if there is no such constraint). For *a* and *b*, the following abbreviations are commonly used:

- M (Markovian), which denotes the exponential distribution and has the memory-less property.
- G (General), which denotes a general distribution with the mean and variance known.

There are other notations to describe the distribution of the inter-arrival and service times but are less often used. Examples would include D (Deterministic), which denotes a constant value for all the numbers and E_k (Erlang-k), which denotes the Erlangian distribution with k-phases, with k being a positive integer.

One purpose of analyzing a queuing system is to understand the steady-state behavior of such a system, which means that the system, after running for a long period, will settle down to a state that is independent of its initial state. Some of the characteristics that can be studied are the queue length (number of customers waiting at a given time), the waiting time (the time a new arrival has to wait till his service commences) and the length of the busy period (the length of time when the server will be continuously busy) [4].

3.2 Scheduling

Scheduling is a decision-making process that plays an important role in most manufacturing and service industries [5]. Meeting due dates and avoiding delay penalties are important goals of scheduling, which fits in with the objective of the Steel Stock Department, namely to deliver materials on time.

One aspect of scheduling is input control. Input control is defined as a procedure for smoothing production workload by delaying work during intervals of heavy load [6]. For example, input control can be done by holding the job in the form of paperwork and the job will be released according to some priority rules when there is available capacity to process the jobs. Such a control of paperwork is much easier than managing the actual materials on the factory floor. Input control can achieve a number of benefits. By limiting the load in the storage and blasting plants, it reduces in-process inventory levels and the confusion that accompanies lengthy queues and is useful in situations where many requests are running late [6]. Input control also helps to achieve more dependable throughput times and provide relief from the erratic fluctuations of capacity in those plants.

3.3 Dispatching Rules

In this thesis, dispatching rules are used for job sequencing. When a plant becomes available for processing, an operation in a job that can be processed by the plant can be assigned to it. If two or more operations are ready to be processed by the same plant at the same time, one of the operations has to be selected according to a dispatching rule that defines priorities or urgencies of the operations [7]. First-come, first-serve (FCFS) is generally used as a benchmark. Jobs are processed according to the sequence they enter the department.

There is a myriad of scheduling rules available for use. For the earliest due date (EDD) rule, jobs are sequenced in increasing order of their due dates. The job with the earliest due date is first, the job with the next earliest due date is second, and so on [8]. For the shortest processing time (SPT) rule, priority is given to the shortest job in the queue; this rule is effective in reducing average tardiness when due-dates are extremely tight [6]. There are also ratio-based rules. Critical ratio (CR) gives priority to the job with the smallest ratio of its slack time to the remaining processing time of the job. The Critical ratio is given by the following formula:

$$\mathrm{CR}(t) = \frac{d_j - t}{p_j} \quad \text{------------------------------------} \quad (1)$$

where d_j is the due date, t is the current time and p_j is the expected remaining processing time. Subscript j refers to job j.

However, the above-mentioned rules assume that all jobs have equal delay penalties, which rules out strategic differentiation of end-user demand. For instance, at Keppel, it is beneficial to differentiate orders that carry higher tonnage (i.e. materials that are heavier in weight due to better grade and/or bigger dimensions) and more quantity of materials. Hence more complex weighted-priority dispatching rules have been devised. Weighted shortest processing time (WSPT) rule is a variant of SPT; priority is given to the job with the highest ratio of weight (v_j) over the processing time, as shown in equation (2).

$$\text{WSPT} = \frac{v_j}{p_j} \text{ -------------------------------------- (2)}$$

Apparent Tardiness Cost (ATC) is a weighted composite dispatching rule that combines both WSPT and the minimum slack rule. The ATC rule schedules jobs one at a time; that is, each time the plant becomes free, a ranking index is computed for each remaining job [5].

$$\text{ATC}(t) = \frac{v_j}{p_j} \exp\left(-\frac{\max(d_j - p_j - t, 0)}{K\bar{p}} \right) \text{ ------------------- (3)}$$

where $\bar{p}$ is the average processing time of the remaining jobs and K is the look-ahead parameter that scales the slack according to the expected number of competing jobs.

Table 3-1 classifies the type of information needed by the different dispatching rules given above:

Table 3-1: Information needed by dispatching rules

Information required	**Rule**	**Rank**
Arrival times	First-come, first-serve (FCFS)	Min
Processing Times	Shortest processing time (SPT)	Min
	Weighted shortest processing time (WSPT)	Max
Due Date	Earliest due date (EDD)	Min
Combination (Processing times, due date and arrival date)	Critical ratio (CR)	Min
	Apparent tardiness cost (ATC)	Max

Chapter 4 Workload Analysis in the Processing of Documents

It takes around 2 days for an electronic issue voucher (EIV) to be generated before it is sent out to the storage areas to locate the materials. Generating the EIV is an important albeit simple and straight-forward step as it is the document that accompanies the materials through the storage and blasting stages.

This chapter traces the steps involved in the generation of the EIV. We will apply queuing theory to the document process to gain a better picture of the workload of the department. This will provide a good method for analyzing the amount of waiting time for the documents in the system. We will provide some recommendations on shortening the process time as well as streamlining the procedures.

4.1 Process Flow Mapping

Before any calculations are carried out, the detailed process flow from the arrival of MSS until the generation of EIV must be studied. We have already documented the process in Sections 2.2.2 and 2.2.3. We simplify the layout in Figure 4-1 on the next page. Each rectangular box represents a stage of processing the MSS and each stage has 1 server (1 worker).

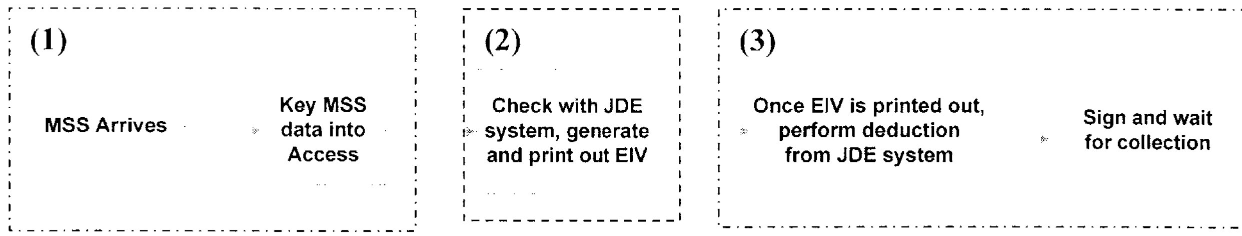

Figure 4-1: Simplified flow process of MSS to generation of EIV. Three queuing stages can be analyzed, as noted in parentheses.

In queuing theory, the Markovian, or memory-less assumption makes it easy to perform quantitative analysis on the queue's characteristics like waiting time and expected number in the system. However, the inter-arrival process violates the underlying assumption of an exponential distribution for the inter-arrival times; that is, the actual arrivals do not occur one at a time, completely at random, independent of the time of the last arrival. The service time also violates the memory-less assumption, as we will explain and discuss in the next 2 subsections. Hence we will model each stage in Figure 4-1 as a G/G/1 queue, where G stands for general distribution and both the inter-arrival and service distributions are general.

4.1.1 Variability of MSS Arrival

4.1.1.1 Scenario 1 – Light to Normal Workload

In times of light to normal workload of the Steel Stock Department, the MSS is processed right after it is handed over. However, the MSSs usually arrive in batches, as they are handed over by a supervisor in-charge of a particular project. Based on the MSS arrival data, which is recorded in a log book, there is an average of 5 projects (batches) of MSSs being sent daily to the department for processing. Hence there are 5 batches of MSSs that arrive each day. The mean number of MSSs received per day is 20 (refer to Appendix B). We assume a 6-hour workday as well as a constant number of MSSs received per project.

Let the number of batches received per day = 5.

Number of jobs in each batch = 4, and assume that the batch arrivals are evenly spaced out over the day. Hence the jobs are assumed to arrive each day from 8 AM to 2 PM. This process repeats exactly each day, whereby 8 AM of the current day is equivalent to 2 PM the day before.

Inter-arrival time per batch = $\frac{6}{5}$ = 1.2 hours

t_a = Mean time of arrival = $\frac{\text{Num. of work hours/day}}{\text{Avg num. of MSS jobs/day}} = \frac{6}{20} = 0.3$ hours

For the first job in each batch, the inter-arrival time is 1.2 hours, as that is the time since the last arrival. The inter-arrival time for the next 4 jobs in the batch is 0, as they arrive at the same time as the previous job.

σ^2_a = Variance of the inter-arrival time = $\left[\frac{5}{20}(1.2)^2 + \frac{15}{20}(0)^2\right] - t^2_a = \left(\frac{1}{4}\right)(1.2)^2 - 0.3^2$

$= 0.27$

Standard deviation of the inter-arrival time = $\sqrt{0.27} = 0.51$

The inter-arrival SCV is therefore $\left(\frac{0.51}{0.3}\right)^2 = 3$

4.1.1.2 Scenario 2 – Heavy Workload

If we were to consider an extreme example of high workload of the Steel Stock Department, the MSS is processed after some time after they have been handed over.

This means that the jobs arrive in 1 batch per day with no randomness; that is, the jobs all arrives at one fixed time each day.

σ^2_a = Variance of the inter-arrival time = $\left[\frac{1}{20}(6)^2 + \frac{19}{20}(0)^2\right] - t^2_a = 1.8 - 0.3^2 = 1.71$

Standard deviation of the inter-arrival time = $\sqrt{1.71}$ = 1.307

The inter-arrival SCV is therefore $\left(\frac{1.307}{0.3}\right)^2$ = 19

Therefore for queue (1), taking into consideration the different workloads of the department, we assume that the inter-arrival SCV is 11, which is the average of 19 and 3. An average of the two values is taken because it is hard to predict the amount of workload that the department will be facing daily.

4.1.2 Variability of Service Rates

The service time in the three queues does not follow the exponential distribution, which has the memory-less property. This memory-less property means that the amount of remaining time that a document remains in service is independent of the time already spent. However this is not valid for the Steel Stock Department. For example, when there are a lot of MSSs to process, the service rate is faster compared to periods when there is less workload. The author calculated the service rate by taking the timing of the MSS process with a stopwatch, over a period of 4 weeks. Table 4-1 shows the statistics of the processing times in each queue.

Table 4-1: Statistics on the processing time for each stage of the queue

Operating Steps (Time in Minutes)	Queue 1 Keying in MSS into Access	Queue 2 Checking JDE and Generating EIV	Queue 3 Deducting from JDE
Min	1.72	3.50	0.75
Max	8.56	25.00	13.00
Mean	6.14	12.00	3.38
Standard Deviation	2.37	4.10	3.69
Coefficient of Variance	0.39	0.34	1.09
SCV (Service)	0.15	0.12	1.19

4.2 Assumptions

1. The rework stage (i.e. the substitution stage in Figure 2-2) is ignored in this analysis and we assume that all the MSSs are converted into EIVs. Besides that, the MSS arrival cannot be split easily into a ratio for a G/G/1 queue.
2. A 6 hours workday is assumed for the entire queue. This is because the staff members in the department do not just handle MSSs and EIVs only. They are also in charge of other documentation work like dealing with delivery orders, mill certificates etc. Hence we estimate that they spend ¾ of their entire working day (8 hours) on MSSs and EIVs, which is a very conservative estimate. Sometimes they can only spare up to ½ of their work day on such tasks depending on their workload.
3. There should be consolidation of MSS after it is keyed into the Access database at the end of queue (1). However we ignore the consolidation process in this case and we assume it is a continuous process. Consolidation means that the MSSs are stacked together after the information is entered. There will be some waiting time before the MSSs are processed again to generate the EIVs.

4. The EIVs will be printed out at the end of queue (2) and they will be consolidated together. However we assume that it is a continuous process and the arrival of EIVs into queue (3) will be assumed to follow a normal distribution, hence a G/G/1 queue.
5. The arrival SCV for the EIVs (queue 3) is assumed to be the same as the departure SCV at the end of queue 2, even though these queues are dealing with different documents. Queue 2 is a "work processing" stage for the MSS, whereby EIVs will be generated and leave queue 2 to enter queue 3.

4.3 Results

We use the G/G/1 approximation to model the queue at each of the three stages as we have already examined the violation of the memory-less assumptions of the inter-arrival and service rates. The results for the calculation of the waiting time are shown in Table 4-2 and sample calculations are also shown.

Table 4-2: Parameters and results for individual queues

	Queue			
	(1)	**(2)**	**(3)**	
Type of document handled	MSS	MSS	EIV	
λ (Arrival rate for MSS)	3.33	3.33	7.83	MSS/hour
μ (Service rate)	9.76	5	17.74	MSS/hour
ρ (Utilization rate)	0.34	0.67	0.44	
SCV (Arrival)	11	9.74	5.46	
SCV (Service)	0.15	0.12	1.20	
D = Expected wait time in queue	0.30	3.94	0.15	hours
W = Expected wait time in system	0.40	4.14	0.20	hours
L = Expected num in system	1.33	13.80	1.60	
Q = Expected num in queue	0.99	13.14	1.16	
SCV (departure)	9.74	5.46	--	

Sample Calculations for queue (1):

λ = Arrival rate for MSS = $\frac{20}{6 \text{ hrs}}$ = 3.33 MSS/hr

Each MSS takes 6.14 minutes of processing time.

μ = Service rate for keying in MSS data in Access database = $\frac{60}{6.14}$ = 9.76 MSS/hr

ρ = Utilization rate = $\frac{\lambda}{\mu} = \frac{3.33}{9.76}$ = 0.34

D = Expected waiting time in queue =

$$\left(\frac{\rho}{1-\rho}\right)*\left(\frac{1}{\mu}\right)*\left(\frac{SCV_a + SCV_s}{2}\right) = \left(\frac{0.34}{1-0.34}\right)*\left(\frac{1}{9.76}\right)*\left(\frac{11+0.15}{2}\right) = 0.30 \text{ hours}$$

Q = Expected number in system = λ D = 3.33 * 0.30 = 0.99

W = Expected waiting time in system = D + $\frac{1}{\mu}$ = 0.30 + $\frac{1}{9.76}$ = 0.40 hours

L = Expected number in system = λ W = 3.33 * 0.40 = 1.33

SCV_d = SCV for the departure stream

$= (1-\rho^2)SCV_a + (\rho^2)SCV_s = (1 - 0.34^2) * (11) + (0.34^2) * (0.15) = 9.74$

Based on the feedback obtained from the staff in the department, the MSS has a waiting time in the department for around half a day, which translates to roughly 4 hours, based on an 8-hours workday. This translates to a percentage difference of around 3.4 %, compared to the amount of waiting time *D* in queue (2). The discrepancy can be explained due to the fact that the waiting time is estimated, and the queuing model only provides a gross understanding of the waiting time in the system.

However, if we were to sum up the total amount of waiting time in the queuing system, it is much smaller than the calculated cycle time of 1.9 days (noted in Section 2.4) as there is consolidation of documents at the end of each queue in the present situation. For example, the MSSs will be stacked together after the information has been keyed into Access database at the end of queue (1). All the consolidation stages will add significantly to the waiting time and the situation is more apparent when the servers (staff) have a lot of other tasks to perform, or when there are simply too many MSSs to handle.

4.4 Discussions

We can observe that there is a bottleneck in queue (2) with a very long waiting time of around 3.9 hours in the system, as the utilization rate is close to one. This agrees with the actual situation in the Steel Stock Department. Sometimes the department receives a very large number of MSSs on a single day, and it is difficult for the staff to generate the EIVs on time to meet the required date. They may take an additional 1 – 2 days to process the batch of MSSs received on that particular day. Coupled with the lack of priority of processing the MSSs, the more urgent cases do not receive immediate attention.

In addition to the waiting time in the three queuing stages in Figure 4.1, there is additional waiting time in the document flow at the final point of the process, namely when the EIVs have been generated and signed and are to be released to BW and KFELS. This waiting time for the personnel at KFELS to obtain the EIVs to pick the material is relatively short due to proximity; however, for the EIVs destined to go to BW, there is no fixed time that the BW staff will come to get the EIVs. They may come, for example, in the morning for the first day, and in the late afternoon on the second day. Hence there can easily be a delay of more than 24 hours for the EIVs waiting for BW to be obtained. A logical solution is to have a more consistent timing for BW to come to pick up the EIVs, so that the staff at KFELS can process them beforehand, and leave themselves with sufficient time to perform other tasks after that.

4.5 Recommendations

4.5.1 Additional Staff

An additional person from the department can be in charge of the generation of the EIV in queue (2). The calculations in Table 4-3 show that the expected waiting time is significantly reduced if there are 2 servers in the queue, hence a G/G/2 analysis. Even though everyone in the Steel Stock Department is trained to generate EIVs and perform deduction in the JDE database, most of them are not familiar with the exact procedures and seldom perform the tasks. Therefore, such tasks are performed by one person in the current situation. An obvious solution is to train another person to help when a lot of MSSs are received. However, such a proposal may not be feasible due to manpower shortage in the department.

Table 4-3: Improvement in the waiting time for Queue (2) by adding an additional server

Utilization rate ρ	0.33	
SCV (Arrival)	9.74	
SCV (service)	0.12	
π_0 (for k =2)	0.33	
D = Expected wait time in queue	0.017	hours
D = (convert to G/G/2) queue	0.082	hours

where $D = \left(\frac{\rho}{1-\rho}\right)\left(\frac{1}{\mu}\right)\left(\frac{(k\rho)^{k-1}}{(1-\rho)k!}\right)\pi_o$ for a M/M/k queue, $\pi_o = \frac{1}{\frac{(k\rho)^k}{(1-\rho)k!}+\sum_{i=0}^{k-1}\frac{(k\rho)^i}{i!}}$ and k represents the number of servers in that queue

4.5.2 Change of Job Scope

Another solution is to change the job scope of the staff in charge of processing the documents. In the original queue (Figure 4-1), there are 3 personnel in charge of the entire process. If there is a change in the job scope of the staff, there is a need for only 2 servers. One staff will be in charge of keying in the MSS data into the Access database, and he will proceed on with the checking of JDE to ensure that the material is present before the generation of EIV. Another staff will key in the relevant information for the EIV and print it out. The deduction of materials from the JDE system will take place after this.

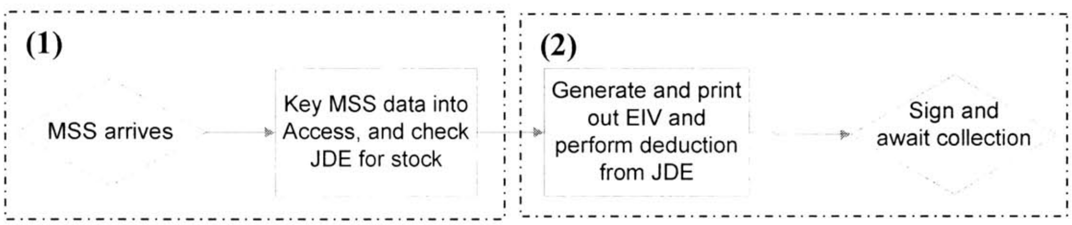

Figure 4-2: Change in the job scope results in 2 queuing stages and 1 server each

This method is more beneficial as the amount of workload will be more evenly spread out among the 2 servers, and the amount of waiting time in the queue is around 3 hours instead of 4. Figure 4-2 shows the improved process flow with 2 queues (with 2 servers in total) and a new analysis can be carried out with the following assumptions:

- 1 server per queue
- Markovian inter-arrival and service distributions are violated, hence a G/G/1 analysis for each queue
- No rework stage is considered, and all MSSs will be generated into EIVs

- 6-hours workday
- Queue (2) is a "work-in-process" stage. The type of document arriving into the queue is MSS but they will be processed to become EIV.
- Normally distributed and independent service times such that:

  E(Service Time for Queue 1) = E(Time to key MSS data into Access) + E(Time to check JDE database for stock); and
  Var(Service Time for Queue 1) = Var(Time to key MSS data into Access) + Var(Time to check JDE database for stock)

  where E represents expectation and Var represents variance of the distribution of the service times required to perform the stated task.

The timings for keying in MSS into Access and performing deduction of JDE is obtained from Table 4-1. However, another set of timings has to be obtained for the other two stages (checking JDE and generating EIV). This is because in the current situation, both tasks are performed together, and not in isolation, by 1 server and it is hard to estimate the exact amount of time spent on each separate task. Nevertheless, the author took the timing for each of the two stages using the stopwatch by paying special attention to the step when the staff switches from the JDE system to the Access Database (as EIV is generated using the Access database) and obtained the statistics on the processing time. Table 4-4 shows the statistics on the processing time for each stage of the queue.

Besides that, the amount of time required to perform JDE deduction in queue (2) is given per EIV. However, the type of document entering into queue (2) is MSS, hence a factor of $^{47}\!/_{20} \approx 2$ is multiplied with the expectation of the service time to perform JDE deduction per MSS. This is because for every 20 MSSs entering the queue, an average of 47 EIVs will be generated. Hence the equation can be written as:

E(Service Time for Queue 2) = *E*(Time to generate EIV) + *E*(Time to perform deduction from JDE *per MSS*); and
Var(Service Time for Queue 2) = *Var*(Time to generate EIV) + *Var*(Time to perform deduction from JDE *per MSS*)

E(Service Time for Queue 2) = 5.38 + 2 * (3.38) = 12.14 min
Var(Service Time for Queue 2) = $(4.92)^2 + (2)^2 * (3.69)^2 = 78.67$
Standard Deviation (Service Time for Queue 2) = $\sqrt{78.67} = 8.86$

Table 4-4: Statistics on the processing time for each stage of the queue

Operating Steps (Time in Minutes)	**Queue 1**		**Queue 2**	
	Keying in MSS into Access	**Checking JDE**	**Generating EIV**	**Perform deduction from JDE**
Document Handled	MSS	MSS	MSS	EIV
Min	1.72	1.32	1.82	0.75
Max	8.56	11.90	11.00	13.00
Mean	6.14	5.50	5.38	3.38
Standard Deviation	2.37	2.30	4.92	3.69
Coefficient of Variance	0.39	0.17	0.91	1.09

Table 4-5: Parameters and results for individual queues

	Queue		
	(1)	**(2)**	
Type of document handled	MSS	MSS	
Expectation of Service Time	11.64	13.32	
Standard Deviation of Service Time	3.30	8.86	
λ (Arrival rate for MSS)	3.33	3.33	MSS/hour
μ (Service rate)	5.15	4.94	MSS/hour
ρ (Utilization rate)	0.65	0.67	
SCV (Arrival)	11.00	6.43	
SCV (Service)	0.08	0.44	
D = Expected wait time in queue	1.97	2.88	hours
W = Expected wait time in system	2.16	3.08	hours
L = Expected num in system	7.20	10.28	
Q = Expected num in queue	6.56	9.60	
SCV (departure)	6.43	---	

4.5.3 Printing of EIV at Storage Areas

An electronic copy of the EIV can be sent through an internet connection to the storage areas and can be printed there. This will take place after all the necessary information required for the EIV has been keyed in and the deduction is done from the JDE system. This means that the stages of printing out EIVs and signing can be eliminated and there will not be any waiting time for the EIVs to be picked up by the pickers. However, this is just a preliminary study and further work should be done to access the pros and cons of such a system.

Table 4-6: Costs and Benefits of Printing of EIV at Storage Areas

	Benefits	**Costs**
1.	Saves time and effort for the department in trying to churn out the EIV on time to dispatch to the storage areas.	Cost of installing additional printers, network linkage equipment to the storage areas from KFELS.
2.	EIV can be dispatched out immediately once they have been generated. Waiting time for the EIV to be collected by BW can be eliminated, which can take around 1.8 days[2], as shown in Figure 4-3.	Additional workload may not be welcomed by the staff at the storage areas
3.	Document handling is simplified and easier to keep track of electronic files sent out.	Type of Electronic format to be used has to be worked out.

[2] This data is obtained from the BW as it also maintains their own Excel database to record down the date that it received the EIV from KFELS. The two databases from KFELS and BW are linked together through the unique EIV number of each entry and the amount of time that BW takes to receive the EIV after it has been printed is thus calculated.

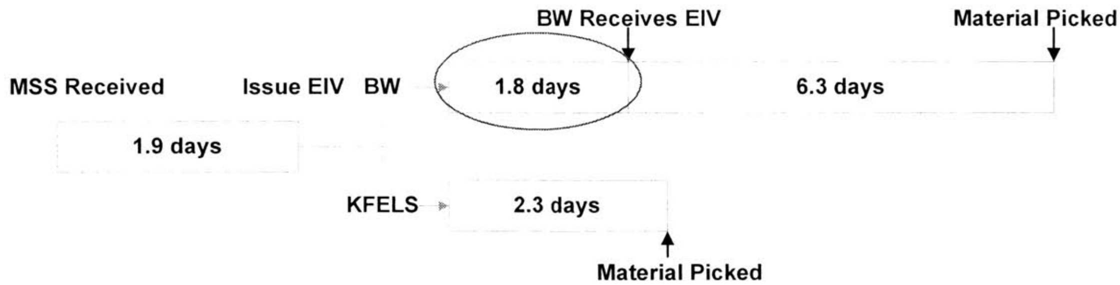

Figure 4-3: Amount of processing time required for different storage areas. An EIV will take an additional 1.8 days to reach BW after it is issued.

4.6 Summary

The workload at each stage of document processing has been analyzed using an approximate queuing model. We found that the stage that generates and prints the EIV is the bottleneck in the entire process flow. This is because it has the largest utilization rate and that particular stage required the longest service time compared to the rest of the stages. Some recommendations have been suggested, like adding an additional staff to help, but it may not be feasible given the manpower shortage in the department. Other measures that can alleviate the problem include changing the job scope of the staff handling the documents, such that only 2 workers are required instead of 3, and installing printers at the storage areas (outside of KFELS). The latter practice can be an attractive option as it can eliminate the waiting time of the EIVs before they are handed over to the storage areas, but more study has to be carried out to access the pros and cons.

Chapter 5 Scheduling for Dispatching of Documents

The purpose of the scheduling strategy is to determine the best method of dispatching the EIVs to the storage areas, with the objective of minimizing tardiness. This chapter seeks to explain the rationale of applying dispatching rules subject to a limit on the daily capacity loading. We test three scheduling rules. To gain a better understanding of the benefits of such rules, we use the company data to compare the tardiness performances of the current practice versus using the dispatching rules. We also provide some recommendations on improving the operations of the storage plants.

5.1 Current Situation & Rationale

In the current process flow, all the EIVs are released to picking once they are generated, with no consideration to the transportation capacity (in metric tonnes) of the storage plants as well as the urgency of the jobs. After picking the materials and loading onto a vehicle, each storage plant has a limited number of trailers to send the materials to the blasting plants. In Appendix C we report the average daily tonnage and the tonnage that each plant can handle.

During days when there are less EIVs to send to the storage plants, there is not much of a dispatching problem, as the urgent and non-urgent cases can be processed at that same time; the total load is under the maximum loading capacity of the trucks that the storage plants can handle.

However, during days when there is high workload, not all MSSs can be cleared within a day, and some will be carried over to the next day. Also, there is a possibility that the urgent cases will be processed even later, since the EIVs will be printed out later, and will be stacked together with other EIVs that have a later due date.

Although it is said that there is a practice that the staff at the storage and blasting plants will sort out the EIVs according to due-date priority, it seldom occurs. Besides that, there may be human errors when there is a large stack of EIVs generated and the higher priority ones are placed at the bottom of the stack. Although the staff members maintain that they will hold onto the EIVs that are required much later (around 2 weeks before the required date or more), it is hard to gauge how many EIVs are kept in the department before handing them over to the picking staff. There is no cut-off rule on how many days they are supposed to hold onto the EIV before the required date. It is also difficult for them to monitor and keep track of whether they have sent out the EIV.

5.2 Motivation

The purpose of the scheduling strategy is to determine the best method of dispatching the EIVs to the storage areas, with the objective of minimizing tardiness. Tardiness is defined as the positive lateness a job incurs if it is completed after its due date.

As noted by Hopp and Spearman, increasing variability always degrades the performance of a production system [9]. The quantity of weight of materials received by the storage plants has large variation and it has an impact on the capacity that they can handle. If BW receives a more consistent loading and a prioritized stack of EIVs daily, it will be beneficial to both BW and KFELS. There would be no need for BW to perform the sorting of more urgent cases. It would also make it easier for BW to plan the transportation loading, as the amount of materials to be sent to the blasting plants would more closely correspond to the available capacity at BW.

5.3 Data Analysis

I conducted a data analysis to simulate and compare various dispatching rule, using existing historical data from KFELS. This is because there is no priority rule applied to the jobs currently and I wish to find out the type of improvements that can be reaped should such a policy be utilized.

5.3.1 Type of Data Used

I used the same set of data for analyzing the tardiness problem in Chapter 2; that is, entries from 1st July 2005 till January 2006 are used for this section. The following data are excluded from the calculation of tardiness, but included in the computation of the total weight of materials issued per day, so as to give an accurate picture of the daily loading output of the storage areas:

- Purchase items
- Entries that have issue dates earlier than the MSS received dates (due to error in updating)

- Entries that have issue dates more than 14 days from the MSS received dates (entries may be purchase items, but are not indicated in the field)

Hence, the total number of remaining entries is only 8,391 entries, or 71.8% of all the entries. These will be used to determine the tardiness performance of different scheduling rules.

5.3.2 Processing Times

For each EIV entry, we set the expected processing time p_j depending on their storage and blasting locations. The timings are obtained by first filtering out the individual picking and blasting plant, followed by calculating the amount of time it takes for the material to be sent from one picking location to a specific blasting plant, and from the blasting plant to the end-user. The entries that are used to compute the processing times will only include entries that have the fields "Date Picked", "Date Blasted" and "Date Delivered" filled up. Purchase items are also excluded in the calculations. For example, if the materials are stored at BW, the entries where the picking location is entered as "BW" are obtained. After that, the entries are further differentiated according to the blasting plants where the materials are being sent to. Hence it takes an average of 8 days for the material to be picked at BW after the EIV has been issued and it takes an additional 3.9 days for the material to be blasted at the CWT plant after it has been picked from BW. Lastly, it takes an average of 1.7 days for the material to be delivered to the end-user from the CWT blasting plant.

Table 5-1: Processing time p_j for each stage

Issue EIV to picking		**Picking To Blasting**				**Blasting to Delivery**	
Storage area	Num. of days req.	From BW	Num. of days req.	From KFELS	Num. of days req.	Blasting Plant	Num. of days req.
BW	8	CWT	3.9	CWT	1.3	CWT	1.7
KFELS	2.3	KFELS	1.3	KFELS	1.3	KFELS	1.7
		KSLAG	2.6	KSLAG	1.3	KSLAG	1.6
		SHS	6.6	SHS	1.3	SHS	4.1

5.3.3 Determination of Maximum Daily Tonnage

From Appendix C, the average daily tonnage of materials issued by the EIV is 289 tonnes, with a high coefficient of variation of 0.977. It also shows that the scheduling of jobs according to the capacity of the individual storage area is not possible as the storage location is not entered in the database all the time. The last two columns in the appendix show the percentage difference between the total weight of the materials picked for the day, and the sum of the weight of materials reported by the two storage areas. The discrepancy is due to errors in reporting by the storage areas, and is much higher in the months of July and August. Therefore only the total tonnage for the issue day is considered to simplify the procedure.

We set the maximum daily tonnage to four possible levels – 350, 400, 450 and 500 tonnes, to test the sensitivity of the tardiness. The four levels are set based on the following figures obtained from BW and KFELS :

Number of trailers for BW = 2

Number of trips a trailer can make/day ≈ 5

Amount of weight each trailer can carry = 35 tonnes

Total tonnage for BW/day = 2 * 5 * 35 = 350 tonnes/day

Number of trailers for KFELS = 3

Number of trips a trailer can make/day ≈ 2

Amount of weight each trailer can carry = 25 tonnes

Total tonnage for KFELS/day = 3 * 2 * 25 = 150 tones/day

All the trailers in BW are used to transport materials to blasting plants but it is not necessarily the case for KFELS. Some of the materials stored in KFELS are blasted on-site, while others are sent to other blasting plants. The trailers in KFELS are therefore used for transportation of materials to the external blasting plants as well as to end-users. Hence, we will assume that only 1 trailer is used for transporting materials to other blasting plants, even though KFELS has 3 trailers. Hence the total weight of materials both plants can send out is approximately 400 tonnes/day. However this figure is subject to high variability as it depends on the weather, the speed of loading and unloading materials and traffic conditions. Thus, we will also test the dispatch rules using other capacity limits, namely 350, 450 and 500 tonnes.

5.4 Methodology

5.4.1 Assumptions

Before the dispatching rules are examined, it is necessary to make some assumptions for the department such that the analysis is valid:

- EIV "Issue Date" is equivalent to the date that the EIV is handed over to the storage areas. Currently, no data exists for the date which the EIV is handed over to the pickers in KFELS. BW does keep track of the date when it receives the EIV and we did obtain this data. However the number of data entries with that information is very limited (only 30% of all the 11,691 entries in KFELS database). Hence we will assume that the EIV "Issue Date" is equivalent to the date that the EIV is dispatched to the storage areas.
- We assume that all the MSSs received for the day can be processed and generated into EIVs before scheduling them for dispatching. This means that no additional MSSs will be handed over to the department after a certain time of the day.

5.4.2 Procedures for Simulation in Excel

1. All the entries in the Access database are exported to Excel spreadsheet format.
2. Entries for which the date of MSS received is between 1st July 2005 and 24th January 2006 are considered. The rest of the entries are dropped.
3. Purchase order entries, entries that have "Issue Dates" earlier than the "MSS Received Dates" and entries that have issue dates more than 14 days from the "MSS Received Dates" are dropped. Such entries will not be included in the calculation of tardiness.
4. Sort the entries according to "MSS Received Date" in ascending order followed by sorting the entries according to the fields required by each rule. The 3

subsections describe the steps involved for each individual rule and the methodology used if the weight limit is reached for the day.

5. Set up a new column to input a new "Issue Date". Since KFELS operate 24/7, Sunday is also considered a working day. However, Singapore public holidays are assumed to be non-working days. Appendix D shows the exact dates of public holidays.

The following three subsections explain the methodology used for different rules.

Let a_j = Arrival time = MSS receive date

r_j = Release time = EIV issue date

d_j = Due date = Date required

p_j = Expected processing time, which is computed from the averages of the time required for picking, blasting and delivery.

w_j = Weight of the material to be picked

n_j = Quantity of the material to be picked (e.g. number of steel plates or pipes)

T = Max daily tonnage set

(Note: Subscript j represents a job for a particular day in the database)

5.4.2.1 First-Come-First-Serve (FCFS) Rule

This dispatching rule is self-explanatory and the jobs are processed according to the sequence in which they enter the department. The jobs are assumed to have entered the Steel Stock Department in the sequence of the "EIV number", and they are scheduled in that order. If the weight limit is reached on any day, the "Issue Date" for the rest of the entries is shifted to the following day.

5.4.2.2 Critical Ratio (CR) Rule

Critical ratio is defined as the ratio of the remaining processing time to the slack time, to determine the priority of the jobs to be released first. (Slack time is defined as the difference between the time remaining until the desired due date and the remaining processing time) [10]. If the loading tonnage for the day is exceeded, the issue date is shifted to the next day, and a new set of CRs has to be calculated. The entries of the previous day and the current day are sorted out, with the smallest CR entry getting the highest priority. The heuristic is:

Set $r_j = a_j$, in ascending order of CR = $\frac{d_j - r_j}{p_j}$, subject to $\sum w_j \le T$

If $\sum w_j > T$, then transfer the lower priority jobs (those with largest CRs) to the next day, until the constraint is satisfied.

5.4.2.3 Weighted Shortest Processing Time (WSPT) Rule

The weighted shortest processing time (WSPT) rule gives priority to the highest ratio of weight (v_j) over the processing time p_j, and the jobs are ordered in decreasing order of $\frac{v_j}{p_j}$. This rule helps in reducing tardiness in congested lines by giving priority to short jobs. The weight v_j is computed as shown on the next page. The weight will be larger for more quantity and heavier tonnage of the material in a piece of EIV. If the loading tonnage is exceeded, the issue date is shifted to the next day. The entries of the previous day and the current day are sorted out, with the largest ratio getting the highest priority. The heuristic is:

Set $r_j = a_j$, in descending order of $\frac{v_j}{p_j}$, subject to $\sum w_j \le T$,

$$\text{where } v_j = \left(\frac{w_j}{\sum w_j}\right) \times \left(\frac{n_j}{\sum n_j}\right)$$

If $\sum w_j > T$, then transfer lower priority jobs (those with smallest WSPTs) to the next day, until the constraint is satisfied.

5.5 Results and Discussions

The results for the different dispatching rules are shown in Figure 5-1 with the loading capacity limit of 400 tonnes indicated in parentheses. The full table of values with different capacity limit is shown in Appendix E.

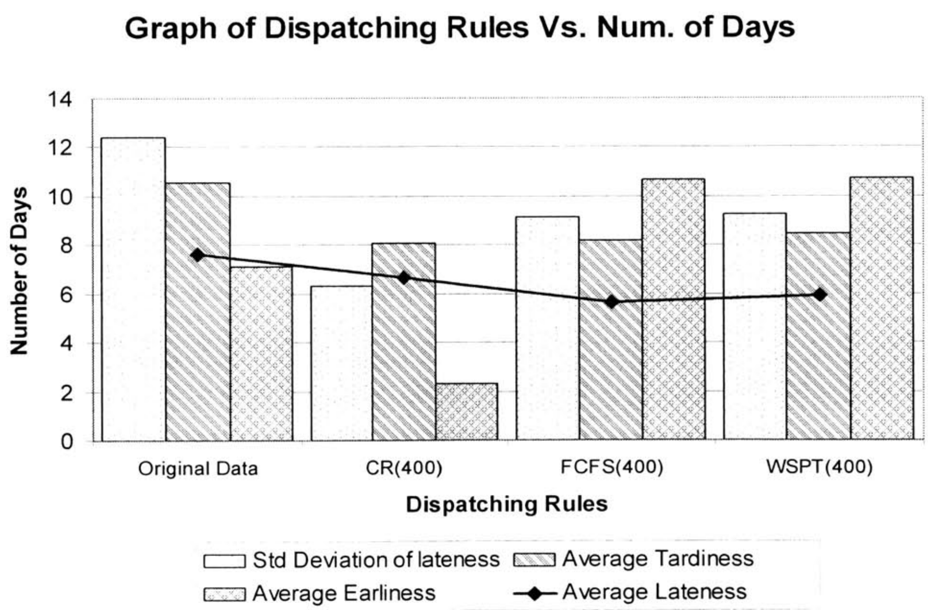

Figure 5-1: Performance of various dispatching rules

In terms of the average lateness, FCFS rule gives a slightly better performance. However if we were to look at the bar charts for the average tardiness, all the three rules give similar performance, but the CR rule has a much smaller average earliness. Hence, the smaller lateness value for FCFS is offset by a much greater value of earliness. This is because both FCFS and WSPT rules do not take into account the due date and hence, the jobs that are not required urgently are also processed first; whereas for CR, when jobs are due much later (i.e. CR > 1), the date that the EIVs are dispatched can be altered so that the CR is close to 1.

Another thing to note is that the WSPT yields the best results for the weighted average lateness as shown in Figure 5-2. This rule is the only rule tested that takes into account the tonnage and quantity of steel materials to be scheduled according to priority. Therefore the consensus is that there is no single rule that is the best under all possible conditions and the relative performances of the rules are affected by factors such as the capacity limit, due date tightness etc. [11] However for this case, the CR ratio rule performs better than other rules for the different levels of capacity loading limit.

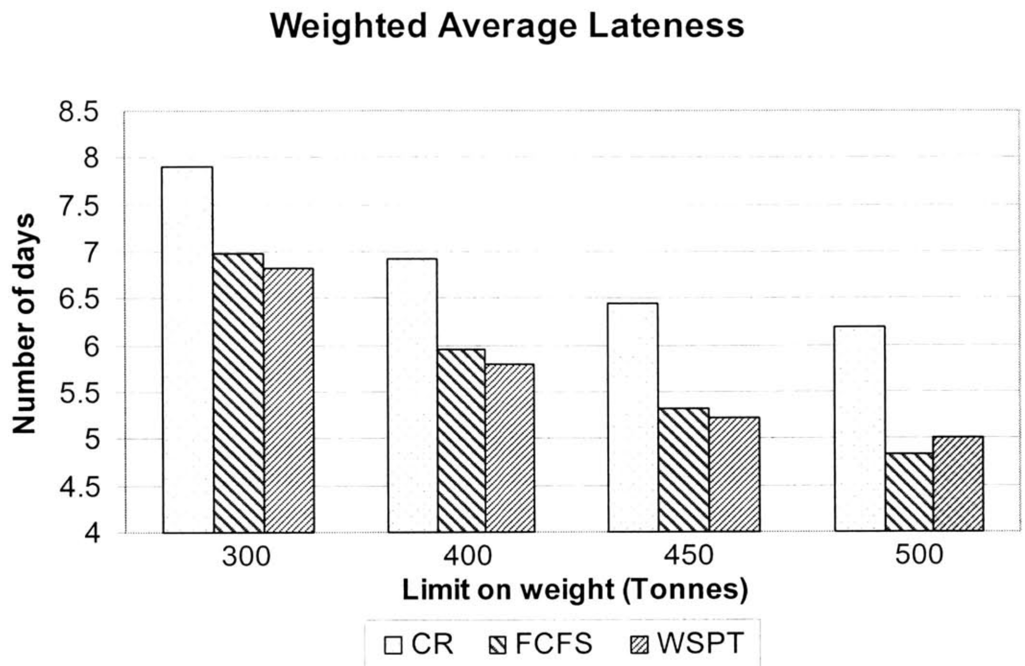

Figure 5-2: Performance of various dispatching rules on the weighted average lateness. WSPT rule gives the least weighted lateness for the different daily weight loading

Figure 5-3 shows the improvement in the variability of the weight of materials issued out daily. For the original data (line graph), the weight can range from close to zero to 1,500 tonnes. When the CR rule is applied subject to the daily limit of weight at 400 tonnes per day, the amount of variability is reduced by a significant amount, as shown by the area graph.

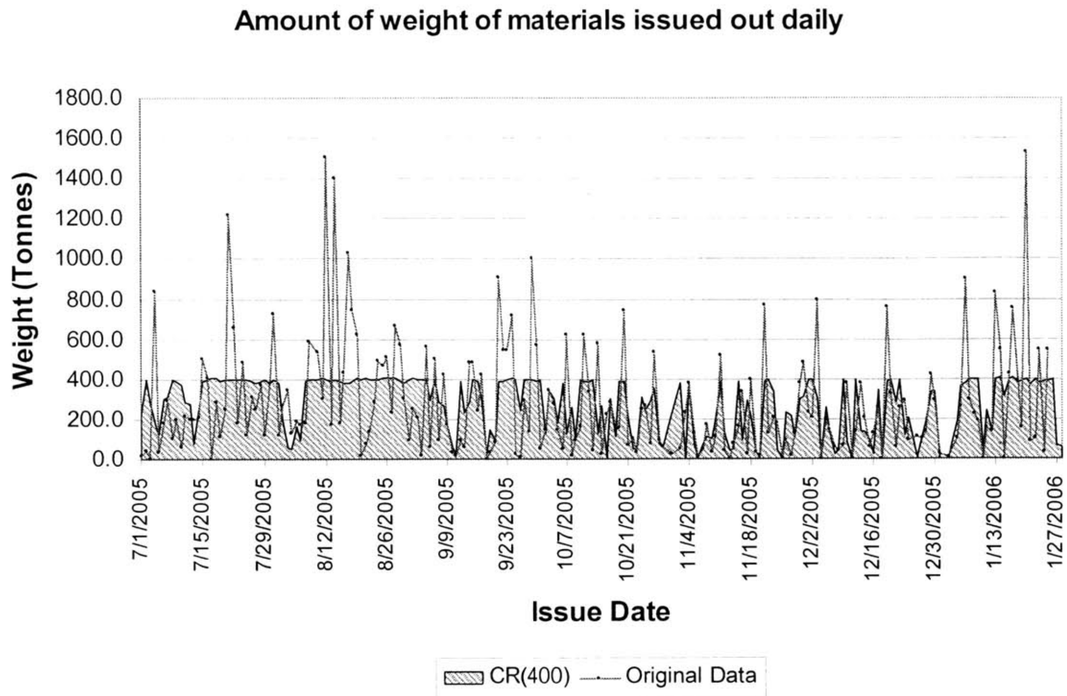

Figure 5-3: Weight of materials issued daily. The line graph shows the large variation in the weight for the original data, but the variation is reduced when the critical ratio rule is used. A daily limit of 400 tonnes is capped.

5.6 Recommendations

Besides advocating the use of critical ratio dispatching rule to prioritize the EIVs to be sent to the storage plants, it will be necessary to put in place some operational improvements to cut down on the waiting time that the documents spend waiting to be collected.

In Section 4.1.1, the author has already examined the variability in the MSS arrival times. It is difficult for the staff to keep on working on the documents throughout the entire workday as they have other responsibilities too. If all the MSSs can be handed over by the Production Department before a given cut-off time, then the workers can work on other tasks before processing the MSS. This is especially helpful in applying scheduling rules for dispatching the EIVs. All the MSS information will be known to the department and the urgent cases can be processed first. Once all the EIVs are generated and printed out, there is a fixed time to hand over the documents to the storage areas (most likely to be in the late afternoon). However such a practice will require coordination between different departments in the company to ensure its effectiveness.

5.7 Summary

The rationale for applying dispatching rules has been discussed in the beginning of the chapter, as the company does not exactly pay attention to urgency of the jobs as well as the capacity loading of trailers at the storage plants. If the storage plants receive a more consistent loading and a prioritized stack of EIVs daily, it will be easier for them to plan transportation loading, and it will be easier for KFELS to ensure the urgent cases are indeed processed first.

Three dispatching rules have been tested and the procedures for carrying out the simulation in Excel spreadsheet have been documented in Section 5.4. We found that the critical ratio rule gives the best performance with regards to tardiness and earliness performance as both have to be minimized.

Chapter 6 Conclusions

The primary objective of this project is to reduce the tardiness of the delivery of the steel materials and identify the reasons behind the delay. Analysis has been done to pinpoint the exact causes of the delay, which is at the stages of document processing and dispatching to the storage areas. The following summarizes the project tasks that were performed according to the objectives:

1. The workload for the processing of documents has been analyzed using a queuing model. The bottleneck occurs at the stage where the EIVs have to be generated and printed from the MSS information, as there is a long waiting time in the system. Some proposals have been suggested, like changing the job scope of the staff such that the amount of service time spent by each server is similar and shifting the task of printing the EIVs to the storage areas. However, the latter proposal has to be studied more in depth to access the feasibility of such a practice.
2. We have studied possible dispatching rules applied to the stage where the EIVs have to be sent out to the individual plants. These dispatching rules need to account for the maximum transportation capacity of each storage plant. We examined three dispatching rules and found the critical ratio (CR) rule to be an easy and effective one to use.

The result of the recommendations based on the above-mentioned studies will be the reduction of the cycle time from the receipt of the MSS to the delivery of materials. From Chapter 4, we have examined that the generation of EIVs takes only a few hours, if all the recommendations are followed. This means that the EIVs can be dispatched on the same day as the receipt of the MSSs and the new cycle time is much less than one day, which is a marked improvement from the present cycle time of 1.9 days. Chapter 5 then examines the tardiness performance of the dispatching rules by assuming that the EIVs can be generated and handed over to the storage plants on the same day as the receipt of the MSSs. By setting a limit on the daily capacity loading to 400 tonnes and using the CR rule, the cycle time from the receipt of EIVs by the storage plants to the stage that the materials are picked can be reduced by 20%. This may not seem very remarkable, but any reduction in the cycle time will definitely be beneficial to the end-users in meeting the deadlines for the production of the oil rig.

The author also offers the following points as the key lessons learned from this internship:

I. **Sharing of information is crucial** – A lot of problems can be alleviated through the sharing of information. In the case of the Steel Stock Department, if people are more proficient in the software and databases, they can provide additional help to lessen the workload of the people in charge of document processing. This sharing of information does not need to be restricted to within the department, but can be extended to other departments and external (storage and blasting) plants. If the due dates for materials can be shared more efficiently and made known earlier, probably through an electronic medium, then the department is able to send out the issue vouchers in advance, instead of waiting for the paper-based MSSs to be given to the department.

II. **Reducing variability is crucial too** – There is too much variability that the Steel Stock Department has to handle. This daily variability can occur in the form of the number of MSSs submitted to the department, the weight of materials that it has to handle, the type of steel materials to be sent to the end users and the varying capacity of the blasting plants. If the variability can be controlled right from the start (i.e. through the issuing of the documents), then it will be easier for the storage and blasting plants to allocate a given capacity to KFELS, since they also deal with other customers as well. Reducing variability also means that less time will be made on phone-calls and emails to keep on checking on the capacity of the storage and blasting plants.

III. **Communicating a vision takes effort** – Through this internship, the author realizes that it takes effort to communicate some of the ideas and solutions to help to improve the working procedures. Most of the time, the staff involved in the job are usually overwhelmed with their work and pay scant attention to such proposals. Hence, time and effort are spent in trying to communicate the advantages of the improvements. The vision and goals of the organization should not only be communicated through words, but through the actions of the leaders and it is heartening to know that the Steel Stock Department has a very supportive manager. He has initiated a meeting recently with the author and some of the key personnel in the department to discuss about the possible improvements and the feasibility of the proposals brought up in this report. They are generally very receptive to the ideas but it will take more than a presentation to change their current mindset.

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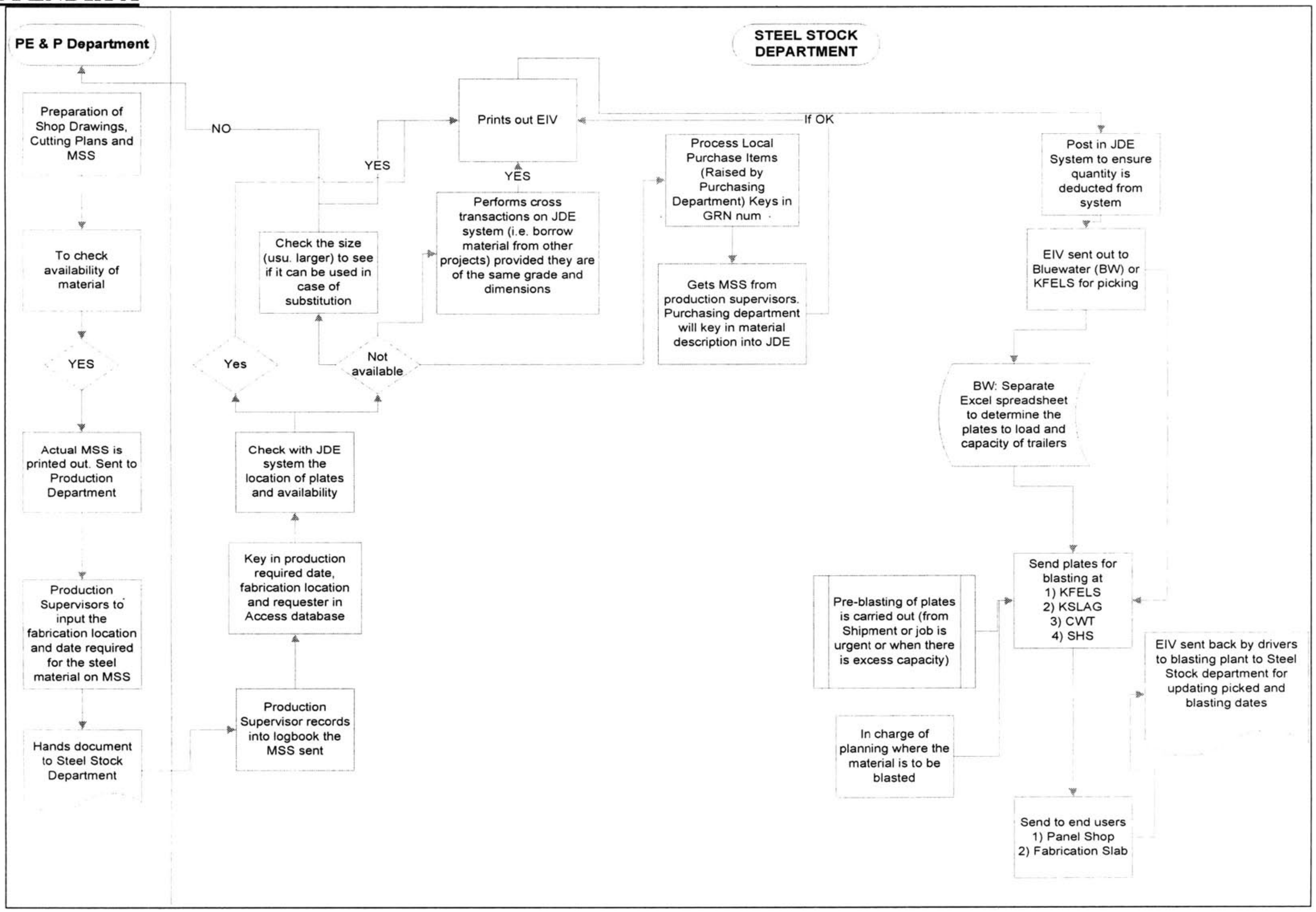
APPENDIX A



PE & P Department
STEEL STOCK DEPARTMENT
Preparation of Shop Drawings, Cutting Plans and MSS
To check availability of material
YES
Actual MSS is printed out. Sent to Production Department
Production Supervisors to input the fabrication location and date required for the steel material on MSS
Hands document to Steel Stock Department
NO
Production Supervisor records into logbook the MSS sent
Key in production required date, fabrication location and requester in Access database
Check with JDE system the location of plates and availability
Yes
Not available
Check the size (usu. larger) to see if it can be used in case of substitution
YES
Prints out EIV
YES
Performs cross transactions on JDE system (i.e. borrow material from other projects) provided they are of the same grade and dimensions
If OK
Process Local Purchase Items (Raised by Purchasing Department) Keys in GRN num
Gets MSS from production supervisors. Purchasing department will key in material description into JDE
Post in JDE System to ensure quantity is deducted from system
EIV sent out to Bluewater (BW) or KFELS for picking
BW: Separate Excel spreadsheet to determine the plates to load and capacity of trailers
Send plates for blasting at 1) KFELS 2) KSLAG 3) CWT 4) SHS
Pre-blasting of plates is carried out (from Shipment or job is urgent or when there is excess capacity)
In charge of planning where the material is to be blasted
EIV sent back by drivers to blasting plant to Steel Stock department for updating picked and blasting dates
Send to end users 1) Panel Shop 2) Fabrication Slab

APPENDIX B

Table B-1: Sum of MSS received and EIV generated per day

Date	Sum of MSS received/day	Sum of EIV issued/day
8-Feb-06	42	61
9-Feb-06	6	44
10-Feb-06	32	65
11-Feb-06	17	32
12-Feb-06	20	22
13-Feb-06	30	61
14-Feb-06	11	66
15-Feb-06	27	37
16-Feb-06	38	82
17-Feb-06	6	94
18-Feb-06	28	23
19-Feb-06	12	37
20-Feb-06	27	46
21-Feb-06	12	49
22-Feb-06	39	40
23-Feb-06	29	78
24-Feb-06	4	79
25-Feb-06	47	5
26-Feb-06	3	46
27-Feb-06	22	55
28-Feb-06	4	40
1-Mar-06	17	26
2-Mar-06	31	41
3-Mar-06	18	122
4-Mar-06	5	22
5-Mar-06	4	4
6-Mar-06	20	117
7-Mar-06	4	58
8-Mar-06	5	30
9-Mar-06	14	8
10-Mar-06	19	45
11-Mar-06	18	48
12-Mar-06	12	0
13-Mar-06	41	39
14-Mar-06	67	76
15-Mar-06	12	61
16-Mar-06	19	47
17-Mar-06	19	74
18-Mar-06	21	37
19-Mar-06	4	68
20-Mar-06	19	50
21-Mar-06	61	49

22-Mar-06	17	29
23-Mar-06	6	51
24-Mar-06	22	13
25-Mar-06	10	44
26-Mar-06	24	2
27-Mar-06	16	69
28-Mar-06	14	62
29-Mar-06	20	73
30-Mar-06	18	50
31-Mar-06	11	30
1-Apr-06	3	67
2-Apr-06	22	0
3-Apr-06	2	16
4-Apr-06	38	64
5-Apr-06	8	37
6-Apr-06	14	53
Average	**19.50**	**47.31**
Stdev	**14.03**	**26.25**
Coefficient of Variance (COV)	**0.719**	**0.554**

APPENDIX C

Table C-1: Weight of materials sent out daily from each storage areas

Issue_Date of EIV	BW (tonnes)	KFELS (tonnes)	Sum of BW and KFELS (tonnes)	Total Tonnage	% Difference
1-Jul-05	N.A.	N.A	N.A.	13.6	N.A.
2-Jul-05	30.9	N.A	30.9	44.6	30.7%
4-Jul-05	515.2	N.A	515.2	837.2	38.5%
5-Jul-05	0.6	N.A	0.6	31.2	98.1%
6-Jul-05	1.9	N.A	1.9	181.5	99.0%
7-Jul-05	53.5	N.A	53.5	295.2	81.9%
8-Jul-05	2.8	N.A	2.8	101.3	97.3%
9-Jul-05	13.7	N.A	13.7	198.8	93.1%
10-Jul-05	20.0	N.A	20.0	56.7	64.7%
11-Jul-05	46.1	N.A	46.1	214.9	78.5%
12-Jul-05	125.8	N.A	125.8	203.3	38.1%
13-Jul-05	41.3	2.1	43.4	200.5	78.3%
14-Jul-05	148.5	N.A	148.5	206.8	28.2%
15-Jul-05	458.1	N.A	458.1	497.8	8.0%
16-Jul-05	244.8	N.A	244.8	404.1	39.4%
17-Jul-05	N.A.	N.A	N.A	4.1	N.A.
18-Jul-05	256.2	N.A	256.2	289.4	11.5%
19-Jul-05	59.4	7.3	66.7	109.2	38.9%
20-Jul-05	103.5	45.7	149.3	251.5	40.6%
21-Jul-05	461.4	258.8	720.1	1220.6	41.0%
22-Jul-05	408.4	8.9	417.3	653.5	36.1%
23-Jul-05	69.3	13.3	82.6	181.2	54.4%
24-Jul-05	384.4	50.0	434.4	485.8	10.6%
25-Jul-05	107.8	N.A	107.8	123.1	12.4%
26-Jul-05	137.4	9.7	147.2	313.0	53.0%
27-Jul-05	129.6	N.A	129.6	248.5	47.8%
28-Jul-05	278.9	16.6	295.5	375.9	21.4%
29-Jul-05	8.9	N.A	8.9	125.4	92.9%
30-Jul-05	231.7	13.9	245.6	384.1	36.1%
31-Jul-05	555.7	14.3	570.1	726.7	21.6%
1-Aug-05	67.3	N.A	67.3	121.8	44.8%
2-Aug-05	196.8	4.0	200.9	266.3	24.6%
3-Aug-05	178.3	20.6	198.9	344.6	42.3%
4-Aug-05	49.3	8.9	58.2	133.5	56.4%
5-Aug-05	159.8	1.1	160.9	192.5	16.4%
6-Aug-05	128.5	N.A	128.5	174.8	26.5%
7-Aug-05	9.0	63.3	72.4	181.7	60.2%
8-Aug-05	483.7	54.2	537.9	589.4	8.7%
10-Aug-05	335.5	71.6	407.1	533.4	23.7%

11-Aug-05	226.5	6.8	233.3	306.4	23.9%
12-Aug-05	1396.3	59.9	1456.1	1509.8	3.6%
13-Aug-05	101.2	25.1	126.3	171.4	26.3%
14-Aug-05	1331.4	40.9	1372.3	1402.7	2.2%
15-Aug-05	123.3	12.5	135.8	179.7	24.4%
16-Aug-05	342.1	61.1	403.2	433.7	7.1%
17-Aug-05	958.0	30.1	988.1	1028.6	3.9%
18-Aug-05	491.4	108.0	599.4	745.6	19.6%
19-Aug-05	348.4	92.7	441.0	625.2	29.5%
20-Aug-05	N.A.	17.2	17.2	17.3	0.4%
21-Aug-05	17.4	27.2	44.7	79.0	43.5%
22-Aug-05	70.0	29.9	99.9	142.4	29.8%
23-Aug-05	57.0	65.3	122.3	283.9	56.9%
24-Aug-05	326.7	27.4	354.1	489.7	27.7%
25-Aug-05	335.2	31.2	366.4	470.7	22.2%
26-Aug-05	385.9	80.2	466.1	513.5	9.2%
27-Aug-05	204.1	17.8	221.9	229.6	3.4%
28-Aug-05	209.4	4.5	214.0	664.2	67.8%
29-Aug-05	533.4	12.0	545.3	573.0	4.8%
30-Aug-05	244.9	17.7	262.6	305.5	14.0%
31-Aug-05	24.9	56.2	81.1	97.4	16.8%
1-Sep-05	150.2	88.3	238.4	253.9	6.1%
2-Sep-05	136.9	20.1	157.0	208.7	24.8%
3-Sep-05	N.A.	6.1	6.1	13.5	54.6%
4-Sep-05	534.2	11.9	546.1	562.4	2.9%
5-Sep-05	17.3	41.0	58.3	60.9	4.2%
6-Sep-05	372.2	88.2	460.4	497.6	7.5%
7-Sep-05	13.9	66.4	80.3	99.1	18.9%
8-Sep-05	110.1	227.2	337.3	422.8	20.2%
9-Sep-05	34.1	105.8	139.9	172.8	19.0%
10-Sep-05	N.A.	33.1	33.1	33.1	0.0%
11-Sep-05	0.1	17.5	17.6	17.6	0.0%
12-Sep-05	N.A.	92.5	92.5	96.9	4.5%
13-Sep-05	34.0	23.7	57.7	61.0	5.4%
14-Sep-05	176.0	245.8	421.8	480.5	12.2%
15-Sep-05	294.0	182.6	476.6	486.5	2.0%
16-Sep-05	214.1	28.4	242.6	242.6	0.0%
17-Sep-05	286.1	106.6	392.7	425.6	7.7%
19-Sep-05	N.A.	33.7	33.7	33.7	0.0%
20-Sep-05	N.A.	83.2	83.2	83.2	0.0%
21-Sep-05	646.3	259.2	905.5	905.5	0.0%
22-Sep-05	351.5	197.8	549.3	549.5	0.0%
23-Sep-05	417.4	130.2	547.6	547.6	0.0%
24-Sep-05	602.2	117.8	720.0	720.0	0.0%
25-Sep-05	N.A.	26.1	26.1	26.1	0.0%

26-Sep-05	N.A.	11.7	11.7	11.7	0.0%
27-Sep-05	151.3	142.9	294.2	294.4	0.0%
28-Sep-05	N.A.	135.7	135.7	138.4	2.0%
29-Sep-05	838.5	156.4	994.9	1000.1	0.5%
30-Sep-05	476.9	82.6	559.5	573.8	2.5%
1-Oct-05	2.6	49.2	51.8	54.5	5.0%
2-Oct-05	63.3	76.7	140.0	145.5	3.8%
3-Oct-05	84.4	179.4	263.8	347.6	24.1%
4-Oct-05	220.1	59.9	280.0	280.7	0.2%
5-Oct-05	28.6	114.4	143.0	143.5	0.3%
6-Oct-05	19.6	32.3	51.9	51.9	0.0%
7-Oct-05	241.7	371.4	613.1	621.1	1.3%
8-Oct-05	11.1	2.1	13.2	13.2	0.0%
9-Oct-05	58.1	39.2	97.3	97.3	0.0%
10-Oct-05	9.2	153.0	162.2	162.2	0.0%
11-Oct-05	464.3	152.7	616.9	623.0	1.0%
12-Oct-05	216.9	118.6	335.5	336.4	0.3%
13-Oct-05	N.A.	41.6	41.6	41.6	0.0%
14-Oct-05	286.4	248.1	534.5	578.3	7.6%
15-Oct-05	6.1	16.2	22.3	29.6	24.8%
16-Oct-05	135.6	92.7	228.3	228.3	0.0%
17-Oct-05	166.1	100.5	266.6	283.8	6.0%
18-Oct-05	141.8	18.9	160.7	166.7	3.6%
19-Oct-05	74.5	51.6	126.2	153.8	17.9%
20-Oct-05	608.1	135.1	743.2	744.9	0.2%
21-Oct-05	17.6	48.7	66.3	66.3	0.0%
22-Oct-05	62.5	37.2	99.7	99.9	0.2%
23-Oct-05	16.2	7.5	23.8	37.9	37.4%
24-Oct-05	97.7	152.7	250.4	250.4	0.0%
25-Oct-05	146.2	121.1	267.3	271.7	1.6%
26-Oct-05	0.0	76.4	76.4	76.4	0.0%
27-Oct-05	365.3	170.7	536.0	537.6	0.3%
28-Oct-05	39.9	56.3	96.2	96.2	0.0%
29-Oct-05	12.7	51.6	64.4	64.4	0.0%
31-Oct-05	N.A.	25.9	25.9	25.9	0.0%
2-Nov-05	N.A.	48.0	48.0	48.0	0.0%
3-Nov-05	108.5	79.5	188.0	231.6	18.8%
4-Nov-05	284.6	98.6	383.2	383.2	0.0%
5-Nov-05	106.1	19.8	125.9	129.6	2.8%
6-Nov-05	N.A.	10.0	10.0	10.0	0.0%
7-Nov-05	4.4	44.8	49.3	53.0	7.0%
8-Nov-05	96.5	70.3	166.8	172.0	3.0%
9-Nov-05	4.5	24.4	28.9	34.1	15.3%
10-Nov-05	27.4	79.7	107.1	115.4	7.2%
11-Nov-05	426.7	90.1	516.8	518.9	0.4%

12-Nov-05	17.9	28.0	45.9	46.9	2.2%
14-Nov-05	8.9	64.3	73.2	74.1	1.3%
15-Nov-05	85.4	79.6	165.0	165.0	0.0%
16-Nov-05	234.2	105.0	339.2	339.2	0.0%
17-Nov-05	N.A.	29.5	29.5	30.1	1.9%
18-Nov-05	252.9	145.6	398.5	400.1	0.4%
19-Nov-05	2.5	30.0	32.5	33.0	1.5%
20-Nov-05	16.7	4.4	21.1	21.1	0.0%
21-Nov-05	435.7	108.9	544.7	767.5	29.0%
22-Nov-05	79.4	36.0	115.5	126.7	8.8%
23-Nov-05	124.3	83.2	207.4	211.4	1.9%
24-Nov-05	104.5	68.5	173.0	183.0	5.5%
25-Nov-05	N.A.	5.8	5.8	7.0	18.1%
26-Nov-05	44.0	46.2	90.2	93.7	3.8%
27-Nov-05	N.A.	14.0	14.0	14.0	0.0%
28-Nov-05	114.2	12.5	126.7	126.7	0.0%
29-Nov-05	246.3	111.3	357.6	384.6	7.0%
30-Nov-05	410.5	63.7	474.2	481.5	1.5%
1-Dec-05	135.9	71.3	207.2	232.3	10.8%
2-Dec-05	187.0	18.9	205.8	207.8	1.0%
3-Dec-05	697.9	79.1	777.0	797.2	2.5%
5-Dec-05	129.8	51.2	181.0	199.4	9.2%
6-Dec-05	54.5	71.0	125.4	144.5	13.2%
7-Dec-05	19.3	36.2	55.5	57.0	2.7%
8-Dec-05	30.2	13.5	43.7	43.7	0.0%
9-Dec-05	41.6	22.9	64.5	69.4	7.1%
10-Dec-05	209.3	162.0	371.3	380.4	2.4%
11-Dec-05	0.3	7.5	7.8	7.8	0.0%
12-Dec-05	64.9	71.7	136.5	139.8	2.4%
13-Dec-05	327.2	49.2	376.4	378.0	0.4%
14-Dec-05	60.1	128.2	188.4	209.4	10.1%
15-Dec-05	N.A.	53.4	53.4	64.6	17.4%
16-Dec-05	78.4	48.8	127.2	127.3	0.1%
17-Dec-05	209.2	40.6	249.9	262.5	4.8%
18-Dec-05	2.8	N.A	2.8	2.8	0.0%
19-Dec-05	673.5	63.6	737.1	764.0	3.5%
20-Dec-05	233.9	94.0	327.9	329.1	0.4%
21-Dec-05	10.2	46.3	56.5	57.6	2.0%
22-Dec-05	212.5	35.3	247.7	262.4	5.6%
23-Dec-05	244.6	43.3	287.9	291.8	1.3%
24-Dec-05	9.0	88.3	97.3	97.3	0.0%
25-Dec-05	113.3	N.A	113.3	113.3	0.0%
27-Dec-05	74.9	19.4	94.3	100.1	5.7%
28-Dec-05	135.9	4.5	140.4	141.1	0.5%
29-Dec-05	313.0	105.3	418.3	428.1	2.3%

30-Dec-05	219.9	33.6	253.6	293.0	13.5%
31-Dec-05	4.0	2.9	6.9	27.0	74.6%
1-Jan-06	N.A.	0.4	0.4	5.7	92.8%
3-Jan-06	12.7	37.1	49.8	50.3	1.0%
4-Jan-06	37.0	61.4	98.4	107.3	8.3%
5-Jan-06	139.1	124.3	263.3	263.7	0.1%
6-Jan-06	703.2	196.6	899.8	899.8	0.0%
7-Jan-06	197.3	85.5	282.8	292.4	3.3%
8-Jan-06	203.6	10.6	214.2	223.4	4.1%
9-Jan-06	138.8	52.9	191.8	191.8	0.0%
11-Jan-06	98.9	55.3	154.2	158.3	2.6%
12-Jan-06	84.2	42.1	126.3	136.0	7.1%
13-Jan-06	429.3	396.4	825.7	827.2	0.2%
14-Jan-06	246.2	284.7	531.0	547.8	3.1%
16-Jan-06	368.1	56.8	424.9	426.3	0.3%
17-Jan-06	619.5	131.5	751.0	753.6	0.3%
18-Jan-06	313.3	47.3	360.6	393.6	8.4%
19-Jan-06	83.6	69.9	153.5	155.6	1.3%
20-Jan-06	1481.9	33.6	1515.5	1532.3	1.1%
21-Jan-06	59.9	22.4	82.3	87.5	6.0%
22-Jan-06	88.6	13.2	101.7	101.7	0.0%
23-Jan-06	513.1	35.5	548.6	548.8	0.0%
24-Jan-06	13.1	18.2	31.3	31.6	1.1%
25-Jan-06	472.0	73.3	545.2	545.2	0.0%
AVERAGE	210.7	67.6	253.5	288.6	
Standard Deviation	245.3	66.7	266.2	282.0	

APPENDIX D

List of public holidays in Singapore from 1st July 2005 – 24th January 2006. A full list can be obtained from http://singaporeontheweb.net/publicholidays.htm

1. National Day – 9th August 2005
2. Deepavali – 1st November 2005
3. Hari Raya Puasa – 3rd November 2005
4. Christmas Day – 25th December 2005 (the following day is also a public holiday as Christmas Day falls on a Sunday)
5. New Year's Day – 1st January 2006
6. Hari Raya Haji – 10th January 2006

APPENDIX E

Table E-1: Results of the various dispatching rules

	Average Lateness	Weighted average lateness	Std Deviation of lateness	Average Tardiness	Average Earliness	Num. of Early Deliveries	Num. of Late Deliveries	On Time Deliveries
Original Data	7.63	8.74	12.44	10.54	7.12	1068	6795	528
CR (350)	7.56	7.9	6.78	8.85	2.53	358	7292	741
CR(400)	6.65	6.92	6.34	8.08	2.29	344	7061	986
CR(450)	6.24	6.45	6.24	7.76	2.38	379	6907	1105
CR(500)	6.01	6.19	6.2	7.6	2.3	401	6807	1183
FCFS(350)	6.58	6.98	9.41	8.89	11.61	759	7202	430
FCFS(400)	5.63	5.95	9.16	8.17	10.67	905	6970	516
FCFS(450)	5.07	5.33	9.15	7.76	10.36	994	6824	573
FCFS(500)	4.72	4.82	9.18	7.58	9.79	1133	6706	552
WSPT(350)	6.95	6.83	9.49	9.26	11.72	741	7240	410
WSPT(400)	5.91	5.79	9.27	8.48	10.72	893	6985	513
WSPT(450)	5.35	5.23	9.2	8.04	10.34	983	6853	555
WSPT(500)	5.09	5	9.18	7.85	9.98	1057	6798	536