Inventory Management of Steel Plates at an Oil Rig Construction Company

By

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

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Abstract
Keppel Fels produces make-to-order oil exploration rigs for the global market. Each rig requires close to 6000 metric tons of steel in the course of its production. Optimal management of this steel is very critical in this line of business. However, in recent years, demand for these rigs has been increasing at a tremendous rate and previous steel management policies are fast becoming unable to cope with this surge of demand.

The thesis first looks at characterizing the nature of the demand of steel plates in the company. This led to the identification of key factors of demand, resulting in a classification system of the steel plates according to their demand behavior. This system further led to the crafting of various policies to manage the risks involved in the procurement of the steel plates. We propose to use the newsboy model to minimize the inventory costs, subject to uncertain demand. The conclusion of the thesis presents the optimized steel plate procurement quantities for the company.

Thesis Advisor:
Professor Stephen C. Graves, Sloan School of Management

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Many thanks to Madame Lee who bothered to stop her work on the ever increasing pile MSS on her desk to answer my questions and to Mr Lim who didn't mind pushing aside all his cutting plans to hear me out.

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To Prof Siva who always took time to listen to me.

To Prof Rohit who didn't mind meeting me early in the mornings

To my family, your prayers and support through all these years have been worth so much more than anything the world could ever give.

And finally, to God who brought me into this program, this company and to this thesis, You truly are amazing.

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Chapter 1 Introduction and Overview

The business environment in which Keppel Fels operates is completely different today from the situation that it previously faced. Previously, the orders for the rigs that Keppel Fels produces arrived yearly, giving them more than sufficient time to construct a rig. In recent times, due to the increasing energy demands that the world is facing and the ending of the twenty year lifespan of oil rigs all around the world, Keppel Fels is facing a sudden upsurge in orders for its rigs. Adding further impetus to meet these demands and maintain its lead as the market leader, is the entrance of new companies seeking to get a share of this lucrative oil rig construction business. The success and survival of Keppel Fels as the market leader increasingly depends on its ability to deliver its products on time and at the lowest costs possible. The focus on being able to apply lean manufacturing into its operations has never been so great before and will only increase in the future.

1.1 Scope of the project

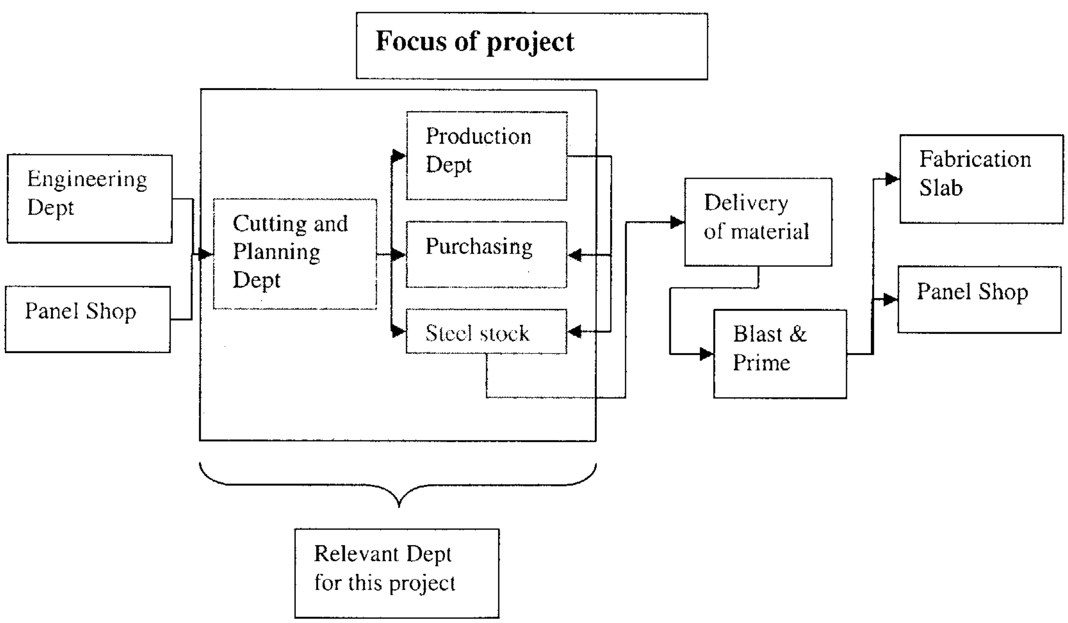

Figure 1 Departmental diagram for the scope of the project

The scope of the project starts from the procurement of steel plates until they arrive in the storage area. The work flow diagram gives an overview of the departments that are involved in my research project. The purchasing department handles the procurement of the steel plates, the cutting and planning department is in charge of initiating the purchases of steel plates and finally, the steel stock department is responsible for the storage of the steel plates when they arrive in Keppel Fels.

The goal of this thesis is to examine the possible areas in which operational research techniques might apply in the company. Specifically, it looks at what opportunities are there to implement inventory management policies to reduce the material costs of purchasing and maintaining steel plates in Keppel Fels. The result is to achieve lower costs and improved inventory performance in the company. This thesis focuses on the most popular rig that Keppel Fels produces- Jack-Ups- as this would be where the findings would have the most impact to the company.

Chapter one deals with the introduction into the company. It examines the oil industry in general and how it is related to what Keppel Fels is doing. The goal of this thesis is also covered in this chapter. Chapter two presents the motivation of the thesis. It will first cover the work flow of the relevant departments in Keppel, then moves on to the specific operational problems that Keppel Fels currently faces on the ground. Chapter three introduces the two tier ABC analysis that was performed on the steel plate inventory in the company. Chapter four presents the methodology by which we solved the inventory problem. It talks about the approach to the problem, the assumptions made. Chapter five presents the key findings, discussions and recommendations from the analysis that has been performed. Finally, in chapter six, we provide a summary of this thesis.

Note: Some figures and names in the thesis have been disguised as requested by Keppel Fels.

1.2 The rig building industry

The oil industry is something that most people in the developed world are very familiar with. It is the one of the main pillars upon which our economies thrive. In fact, almost everything that we see in our daily lives depends to some degree on the petroleum industry. From the gas that powers our cars to the plastics that we see in our bottles, many have components whose materials are based upon petroleum.

In recent years, the growth of large emerging economies like India and China has increased the demand for energy tremendously. This growth has fueled a greater demand for oil. As oil prices keep soaring, energy companies are now finding it economically viable to extract oil from poorer yield and more inaccessible places.

Aside from the Gulf States which have vast oil reserves underground, the most common place that oil is found is in the middle of the ocean. The primary means of extracting this oil is to use a well known piece of equipment called the oil rig. And Keppel Fels constructs most of these oil rigs.

1.3 Rig construction in Singapore

A common misconception is that the construction of oil rigs is very similar to the massive container ships that ply across the seas. The quote below highlights the differences very clearly:

"Basically, a vessel [ship] is like a warehouse, it is made up of the hull, empty cargo space and engine room; the oil rig is like a factory. This is how building a ship is different from building an oil rig"
MD/COO of Keppel O&M Tong Chong Heong[1]

Therein lies the one main difference between ships and oil rigs. A rig essentially is a floating factory that has to house all the necessary equipment to extract oil from the middle of the ocean. But unlike a normal factory on land, the rig has to be able to move, withstand and function in the harshest conditions that nature can throw at it.

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[1] Keppel Offshore Marine, July/August 2005

Another key characteristic in the rig building industry is the uniqueness of each rig that is being constructed. Each customer has different requirements for each rig that they have commissioned. Furthermore, companies that come from different regions around the world all must adhere to different regulatory requirements. This translates into a lot of re-engineering, and this is an area in which the large shipyards of South Korea, Japan and USA are not interested. Hence, the shipyards in Singapore have found a niche market in this industry that allows them to leverage on their key strengths of flexibility and adaptability. Other external factors that the company is able to take advantage of would be Singapore's strategic geographical location, excellent infrastructure, marine cluster support, pro- business policies of the government and the quality reputation of the local yards. [1]

With vast experience and strong engineering capabilities built up over the years, Singapore shipyards have emerged as leaders in the design, construction and repair of offshore oil rigs.

Chapter 2 The company: Keppel Fels

Keppel Fels is the leading designer and builder of sophisticated drilling rigs, having constructed 15 of the world's Jack-Ups in the last decade. This is by far its most popular product in the market. It also designs, builds, converts, upgrades and repairs the complete range of mobile offshore drilling units, floating production systems, production topsides and specialized vessels such as deepwater semi-submersibles, tension leg platforms and other highly sophisticated offshore vessels.

By capitalizing on the advantages that the shipyards in Singapore have, Keppel Fels has been able to remain as one of the most competitive and attractive rig building companies in the world. It is able to deliver its products at very competitive prices with very high quality standards.

In recent years, the demand for the rigs that Keppel Fels produces has increased tremendously. There are two main factors that contribute to this rise in demand. The first is that for the past few years, the main focus of the major oil companies of the world has been on mergers and consolidation. Now that this has settled down, their attention has once again turned back to their core business of drilling for oil. Secondly, if one were to look at the rig profiles throughout the world, currently half or more are more than 20 years old. The average operational lifespan of an oil rig is 30 years. The industry now requires new rigs to replace the existing ones. Hence, in recent years, demand for these rigs has been increasing at a tremendous rate and previous steel management policies are fast becoming unable to cope with this surge of demand. Keppel Fels currently faces key challenges in determining a suitable inventory management policy of the steel. These are the issues that this project seeks to address and solve.

2.1 Products at Keppel

There are 4 main rigs that Keppel Fels produces, segmented according to their means of submerging:

Depth of water	Name
Bottom Supported Units	Submersible
	Jack-Ups
Floating Units(deep water)	Drill Ships
	Semi- submersible

Table 1 Products at Keppel Fels

Bottom supported units

These two kinds of rigs operate in relatively shallow waters where it is possible to have a physical means of securing the main body of the rig to the sea bed to prevent drastic movement during operation.

Jack-Ups: The first and by far their most popular product is the Galaxy-class rig, or more commonly known as Jack-Ups. This name has come about due to the unique patented "jacking" system that raises and lowers the entire rig platform on its steel legs.[2] With their characteristic 3 "legs" that are around 560 feet long, these rigs are able to punch 10 feet down into the seabed anchoring the rig in waters of depths up to 400 feet, these rigs are the most popular rigs that Keppel Fels has produced so far. As a testament of the popularity in the market for Jack-Ups, the orders for these rigs span until the year 2010.

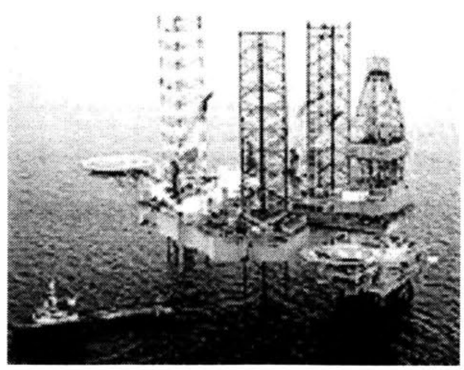

Figure 2 Picture of a Jack-Up

[2] Can do! The spirit of Keppel Fels, Colin Cheong

Submersibles: these rigs operate in shallow waters. They have ballasts which are flooded with sea water when the rig has reached the area where the oil well is located. The rig then submerges until its bottom base reaches the sea bed[3].

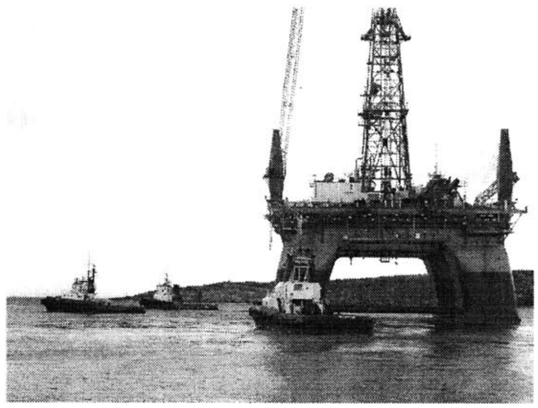

Figure 3 Picture of a submersible

Floating units

These units operate in much deeper waters than the 2 types of rigs stated above. In these regions of sea, it is physically impossible to have a physical means of anchoring the rigs to the sea bed; hence these units are designed to "float" while performing the drilling operation.

Drill ships[4]:

These ship are also know as FPSO(Floating, production, storage and offloading) are ships that transport oil from hard to reach regions to oil refineries. They are able to carry out a partial oil separation process as they transport the crude oil, making it unnecessary to finish this process on-board the rigs that they obtain the oil from.

[3] http://www.marad.dot.gov/education/adopt_a_ship/Images/semi%20submersible%20drilling%20rig.JPG, July 27, 2006, 02.33 am

[4] www.toolpusher.co.uk/images/bh1.jpg July 21, 2006, 02.43 am

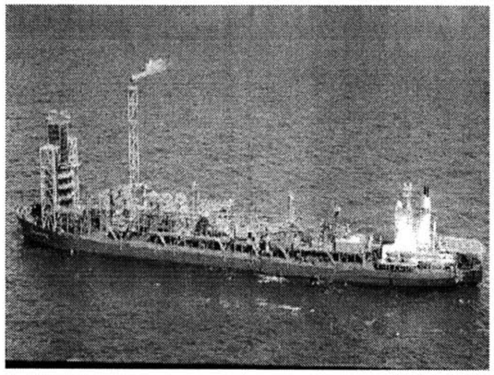

Figure 4 Picture of a drill ship

Semi submersibles: These rigs are designed to work in areas that are even deeper and sometimes more harsh than the Jack-Ups. Unlike the Jack-Ups, these rigs have a very different means of securing themselves. They do not have "legs" as they operate in waters where the seabed is too deep to reach. Aptly name semi-submersibles (or semis) because they are partially submerged when in operation, these are on a much larger scale than the Jack-Ups.

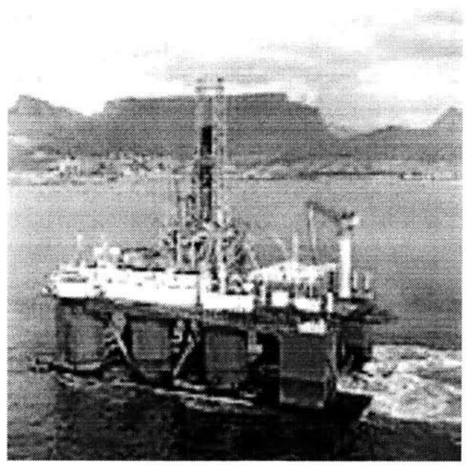

Figure 5 Picture of a semi submersible

2.2 Manufacturing at Keppel Fels

The superstructure of a rig is its most massive feature and this represents one of the major construction phases in the production of a rig. Huge amounts of manpower are channeled into the building of these steel giants. Yet for all their size, the construction process remains very simple. Like any child playing with Lego, Keppel Fels produces their rigs by starting from the most basic building blocks: steel plates.

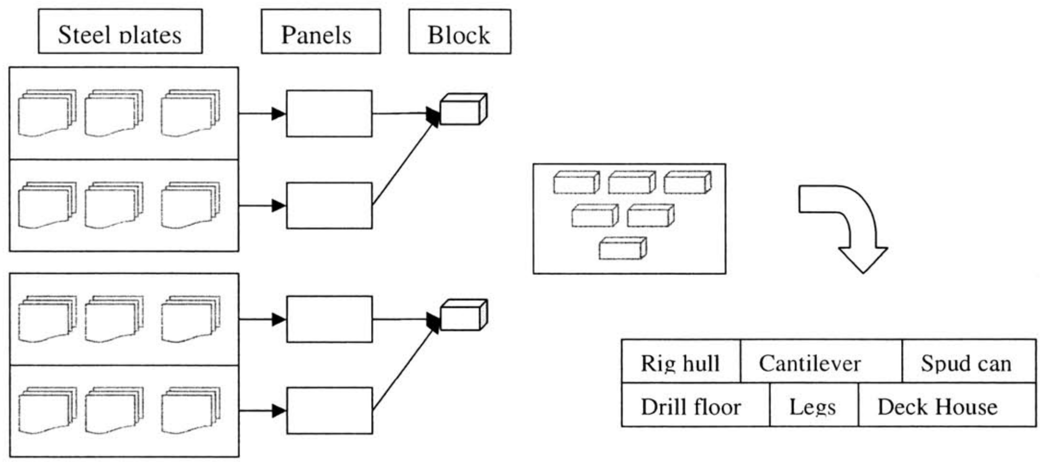

Figure 6 Steel plates: The building blocks of rigs

Multiple steel plates are cut into different shapes and welded together to give panels. These panels are then joined together to form blocks. Finally, these blocks are assembled to construct the main sections of the rig, shown in Figure 6.

2.2.1 Steel in oil-rig construction

Jack-Ups have to operate in very harsh conditions. Subzero temperatures and constant battering by towering waves are just part and parcel of what these rigs have to withstand each day of their operational lives. What makes it even more challenging is that rigs are essentially floating factories out in the sea, factories that have to be able to move to where the oil fields are. Their purpose is not just to "contain" the machinery that is inside of them, they have to be able to provide stable operating conditions for the machines to perform their tasks. But the very fact that they are floating factories also sets a limit to the total weight of each rig, so it is not as simple as constructing the strongest possible structure out of the heaviest material. Furthermore, the rigs also contain the quarters for the riggers who operate the rig. Any malfunctioning by the rig would endanger the lives of these riggers. When all these factors are combined, one can see that there are very stringent requirements that are imposed upon the entire Jack-Up. The structure is called upon to have extreme strength and yet to have the minimum possible weight. Steel, with its high tensile strength and relatively low weight, is the material that is best suited for this purpose.

2.2.2 Movement of steel in the yard

The raw form of steel that arrives in Keppel Fels is in the form of steel plates. Each plate can be differentiated by its specific grade, thickness and area. When these plates arrive at the company, they are first placed in the storage yard and lie there until they are to be used. Oxidation normally takes place when the plates sit in the yard, so prior to being used, the plates need to go through a blasting process that removes the rust from the surface. This takes place in the blasting hall. After blasting, the plates are transported to the NC cutting center where they are cut into the various shapes and sizes that are required of them. The panel line shop then takes over the numerous parts that have been cut and has the responsibility to assemble them into panels. When all the panels for a block have been completed, all the relevant panels are moved to the assembly area where they are joined to form blocks. Because the entire process of constructing these blocks takes around a few months, it is necessary to blast the block to remove any rust that might have formed. This is followed by an initial painting process. Finally, the blocks are transferred to the dry docks where they are joined with other blocks to form the main hull of the rig.

2.2.3 Complexity in design

The structure of each rig that Keppel Fels builds can easily weigh up to 6000 MTons. The Jack-Ups that are constructed are make-to-order products, highly customized to meet the specifications of each customer.

Because Jack-Ups are also considered sea vessels that are able to relocate to where the oil fields are, there are also weight constraints set upon each vessel. This implies that there are conflicting requirements of having the vessel to be as strong as possible and yet keeping its total weight at a minimum. Further complexity is added when a customer has more stringent requirements on certain parts of the rig. In such cases, when weight or operational requirements are more demanding, steel of a higher grade is used to ensure that the structural integrity of the rig is not compromised and the weight limit is not exceeded. Grade and thickness are the key characteristics that determine the structural capabilities of each kind of steel plate. This is the reason why Keppel Fels can use up to 300 different kinds of steel plates when constructing a single rig.

2.3 Steel procurement

The complexity of the highly customized orders presents a challenge to Keppel Fels when the time comes for it to procure steel plates for an oil rig. While purchasing steel, the team of highly skilled buyers has to consider numerous factors simultaneously in an effort to obtain the "best" buy for each oil rig.

2.3.1 Issues in steel procurement

There are two sources from which Keppel Fels obtains its steel plates. Foreign steel is purchased from vendors that are based outside of Singapore, some examples being Ukraine, Japan and China. Local steel is obtained from local vendors that are within Singapore itself. While it is much more economical to order foreign steel, the trade off is that the lead time for the foreign vendors is much longer than that for local vendors.

Keppel Fels operates in a low volume, make-to-order business. This is the reason why they procure steel on a project by project basis. Ideally, they would know exactly what they need at the time they have to make an order from foreign vendors. This would allow them to incur the minimum procurement costs. However, this is not possible due to the long lead time when ordering from foreign sources. Hence, they have to order based on a forecast.

Shortages in the forecast are topped up with steel obtained from local vendors, leading to higher procurement costs. However, the trade off of having too large a foreign steel purchase is that the excess steel is left in the yard which results in holding costs being incurred.

In addition, steel plates are also perishable items. Plates that are not used in 6 months are often rusted to the point of not being able to meet international rig construction requirements and have to be discarded.

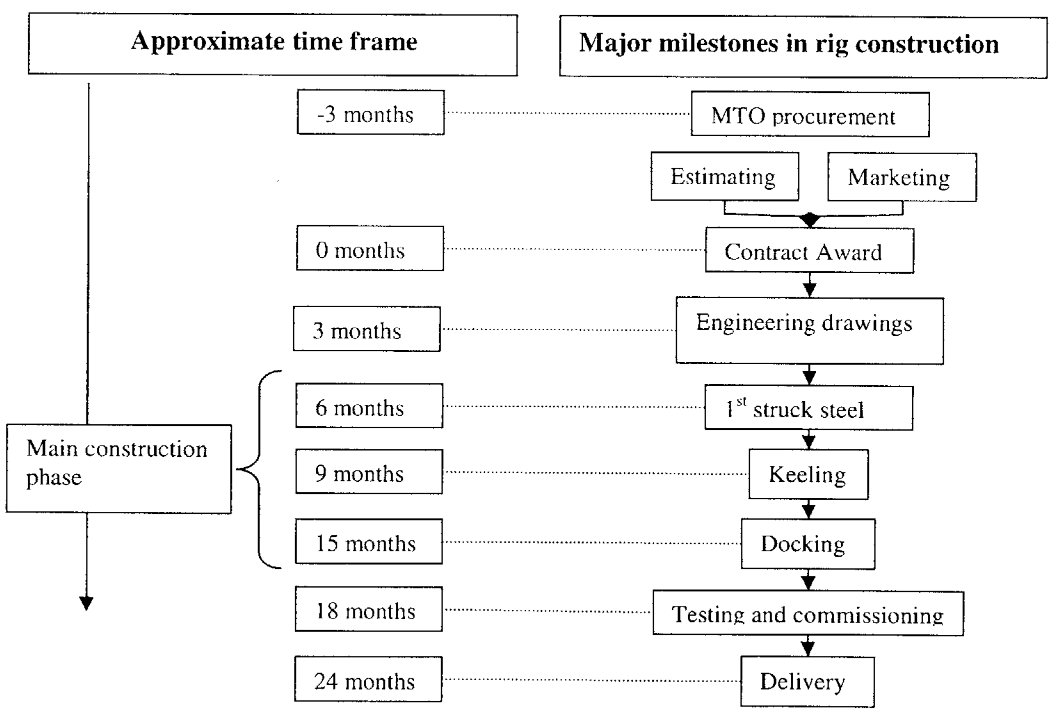

Figure 7 Time frame for rig construction

Definition: 1st struck steel is a company milestone whereby the first steel is used at the start of rig construction

In Figure 7 we show that from the time that a contract for a rig is signed till the first steel plates are used for construction is about 6 months. The lead time for foreign steel is around 9 months. The actual engineering drawings can only be obtained around 3 months before the start of first struck steel. Engineering drawings are able to give a much better estimate of steel requirements for the rig.

Should Keppel Fels want to capitalize on being able to make a bulk order and more economic steel prices from overseas, it has little choice but to order foreign steel with incomplete knowledge of the actual steel requirements.

The demand for steel plates is at its peak from the time of first struck steel till docking. This roughly works out to be 8 months out of the whole construction period of a rig, as shown in Figure 7. Combining this with the fact that the lead time for foreign steel is around 9 months, we see that the company effectively has only a single period to order steel from foreign vendors. Once that window is passed, the only other alternative for Keppel Fels to obtain steel is via local vendors.

The nature of the product is make-to-order and each rig is highly customized to the customers' specifications. This means that the demand for steel plates from one product to another is very variable.

In the contracts that Keppel Fels undertakes, customers sometimes also include the option to secure the construction of another similar rig by Keppel Fels. This largely depends on the level of satisfaction that the customers have with the quality of work and service provided by the company. In such cases, the designs and steel requirements are already known. The main issue would be that the customer requirement for the construction of the rig to begin almost immediately, leaving insufficient time to order the bulk of the materials. When constructions for these repeat orders begin, they cause shortages of steel plates to occur in the yard.

2.3.2 Current inventory management policy of steel plates

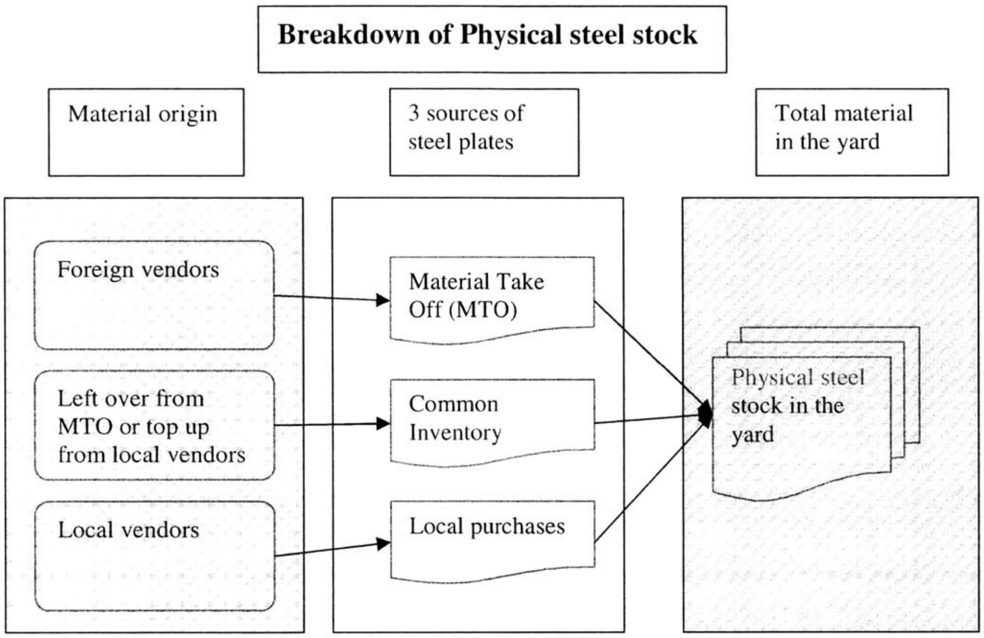

Figure 8 Breakdown of physical steel stock

Physically, there is only a single storage area for all the steel plates in Keppel Fels. Figure 8 shows the sources of these steel plates and their points of origin. Knowing where the steel plates come from and who supplies them allows a better understanding of the performance of the current inventory management policy of the company and how it can be improved.

2.3.2.1 Steel from MTO

MTO (Material Take Off): steel that is ordered from overseas vendors. Prior to the construction of each rig, Keppel makes a single bulk order that attempts to account for most of the steel that the rig might use. This bulk order is called the Material Take Off (MTO). There are a few reasons why Keppel performs this bulk order for each rig that it constructs:

1. As seen in Figure 7, exact engineering drawings are often available only 3 months before the construction of the rig (first struck steel). With a lead time of 9 months for steel from overseas, 3 months is insufficient time to place an order and receive foreign steel before construction starts.
2. The local suppliers do not have sufficient capacity to cope with the steel requirements for the construction of all the rigs at Keppel Fels, so ordering everything from local suppliers is not possible.
3. It is more economically viable as foreign steel costs approximately 1.5% less than locally purchased steel.
4. By purchasing steel from foreign vendors, a large proportion of all the steel requirements would arrive prior to the start of construction for each rig. This enables the panel shop to have greater flexibility in their scheduling policies. Production in the panel shop is highly fluid and production capacity is fully utilized at all times. In the event where downstream bottlenecks form, the panel shop will change its construction schedule by constructing the blocks for other rigs. However, this can only take place if there is sufficient material on hand to begin the block construction.

The main drawbacks of MTO that the company has to grapple with:

1. Long lead time (around 9 months).
2. Great variability in the lead time (possible delay of 2-3 months).
3. Bulk ordered steel is determined by preliminary drawings and is effectively only an estimate of what is needed for the construction of each rig. It is inevitable that there will be shortages in certain steel types that are used in the project; these shortages have to be topped up by the other two sources of steel.

2.3.2.2 Steel from common inventory

This is a stock of steel that the company maintains for the more commonly used steels. It can be bought overseas, locally or consist of leftovers from past rig's MTO. The reasons for the existence of the common inventory are:

1. Excess steel plates leftover from past MTOs. Because all MTOs are estimates, there will sometimes be excess steel that is leftover when construction for a rig is finished, and this is reclassified and stored in the common inventory
2. Keppel Fels has realized that there are some plates that are commonly used in all the rigs that it constructs. It tries to keep a certain amount of these common types of steel to act as a buffer in times of high demand

2.3.2.3 Steel from local purchases

These are steel plates that are purchased from local vendors in Singapore. This is only to take place if steel from the MTO bulk purchase and common inventory is insufficient to meet the fluctuations in demand. The trade off is the higher costs incurred from purchasing steel from local vendors.

2.3.3 Decision making process of steel procurement

Keppel Fels procures steel from two main sources: foreign and local vendors. Purchases from foreign vendors are initiated and performed by the purchasing department for the MTO. Local purchases of steel, however, are initiated by the materials allocation personal in the cutting and planning department, who informs the purchasing department of the details of the type of steel plates to obtain whenever there is a shortfall.

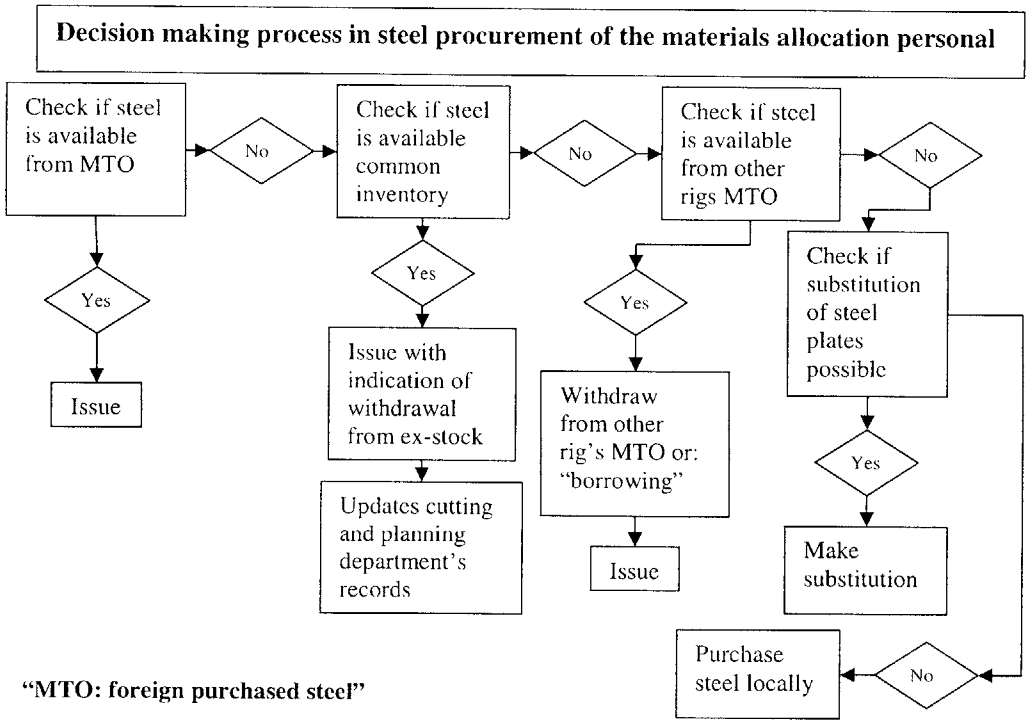

Figure 9 Decision making process in steel procurement

The materials allocation personal will attempt to meet demand in a project by using steel purchased by foreign vendors for the rig. She will only use material from the common stock if there is insufficient steel in the foreign purchased steel. The next alternative she would resort to would be to "borrow" foreign purchased steel from other rigs. Substitution of steel plates with another type is also possible but this has to be cleared with the draftsmen and the engineering department. Her last resort would be to make a local purchase of steel.

This convoluted sequence for using steel plates is the company's way of ensuring that all the steel that it purchases at a lower price is completely utilized and that steel is only bought if there are no more alternatives available. This is its current cost control measure.

However, the trade off is that this entire process is extremely time consuming. The materials allocation personal has to perform this decision making process for every MSS (Materials summery sheet: This is the document issued to authorize the withdrawal of steel plates when a cutting plan is approved. It contains a record of the details of the plates that are to be withdrawn. It also informs the purchasing department if there is insufficient material in inventory and the specifics of what should be bought) that passes through her hands. The most time consuming processes are the searches that have to be made from MTOs of other rigs and the substitution of alternative steel plate types.

2.3.4 Information flow of steel

Commonly used terminology and/or acronyms in the company
Cutting plan: A two dimensional drawing of the various parts that have to be cut from each steel plate
Engineering drawings: engineering drawings only tell the shape of the steel to be cut, the type, size and grade of steel plates to be used
JDE: An Integrated supply chain software that Keppel Fels uses

While Keppel Fels has used its JDE software for quite sometime, the employees have relied more on the initial databases that they had created in the past. The JDE system was used mainly to record purchasing of foreign steel, while smaller databases like Microsoft Excel and later on, Access were used to keep track of the movements of foreign and locally purchased steel. The goal was to shift all the data to JDE but due to the familiarity that the employees had with their old databases, this idea was never fully realized. Currently, there exist three databases in the purchasing and cutting and planning departments in Keppel: 1) JDE, 2) Microsoft Access for the overall inventory level and 3) Microsoft Access to keep track of the MSS that have been issued. Unless stated otherwise, the data used by the employees are from the Microsoft Access database

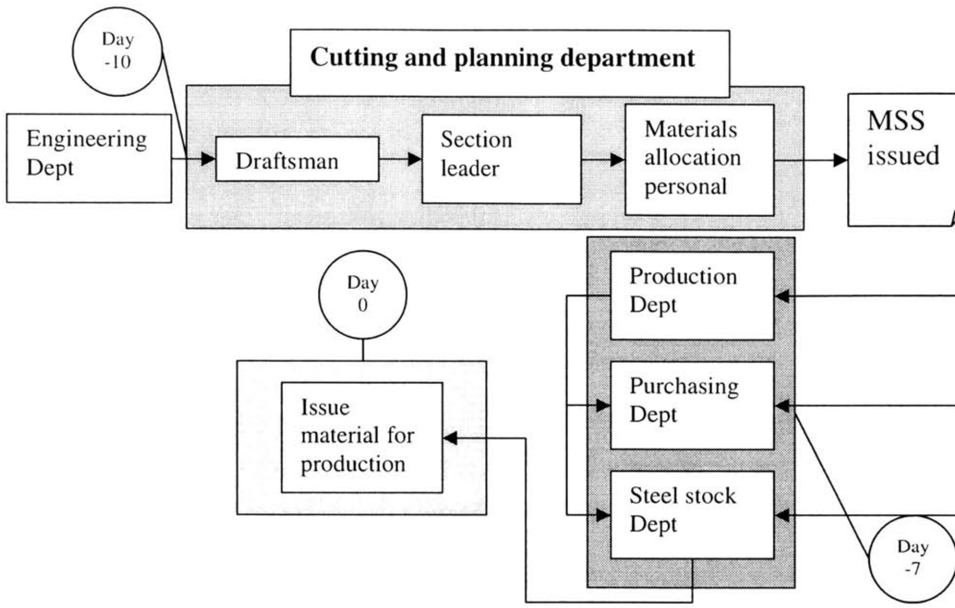

Figure 10 Time frame for the issuing of a Materials Summery Sheet (MSS)

Figure 10 shows the flow of information beginning from the engineering drawings that are created by the engineering department. These drawings then move to the cutting and planning department. The materials allocation personal then checks if there is sufficient material in inventory and issues the MSS. This MSS contains the authorization to withdraw material if there are sufficient steel plates in the yard and/or to inform the purchasing department of a need to buy materials locally. The MSS is sent to the three relevant departments because: the production department requires the MSS and cutting plan information for them to assign the adequate number of workers to cut the plate. The MSS may contain information on insufficient plates in the on-hand inventory which means that the purchasing department has to make an order from the local vendors. Finally, the steel stock department has to have a copy of this document as it is in charge of the picking and withdrawal of the plates.

Procurement, if needed, takes place locally because once the cutting plans are created, the parts that are to be cut for the construction process are often required with days, as shown in Figure 10.

2.4 Problem identification

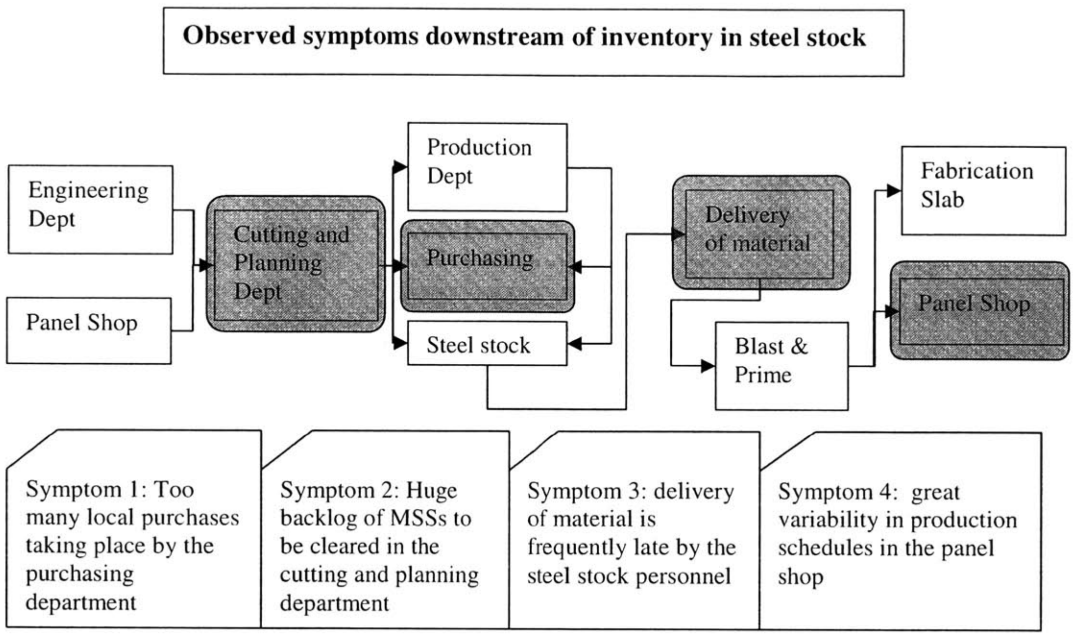

Figure 11 Diagram of observed symptoms downstream of inventory in steel stock

2.4.1 Key observations on the ground

This section describes key observations that were noted in four departments of the company. This was critical to the formulation of the problem statement.

Purchasing department: we noted that there were a large number of local purchases that were taking place each day.

Cutting and planning department: we observed that the materials allocation personnel have a huge backlog of MSSs to clear everyday. The cause of this backlog is that there always seems to be insufficient steel on hand, compelling her to go through the entire allocation process described in Figure 9, taking up much of her time. This mostly results in either massive amounts of "borrowing" from MTOs of other rigs or multiple local purchase orders being made.

Delivery of material: it was a common for the material to be delivered late to the panel shop. This is because a large proportion of the MSSs are issued late from the cutting and planning department and it is company policy that materials cannot be issued without an MSS.

Panel shop: this department frequently experiences great variability in the job (production of blocks) arrival to the panel shop. To begin a job, it is essential for the panel shop to have three items: 1) an MSS, 2) the cutting plan and 3) the correct steel plates. However, when the panel shop wants to begin a job, it is common that it does not have all three things on hand and production cannot proceed as planned. Because the panel shop is the department that is physically in charge of the block production, it feels the most urgency in adhering to the production schedule that has been set. Hence, it has adopted a very flexible production schedule to fully utilize its capacity at all times. The panel shop is seldom able to follow the actual production schedule, causing more problems downstream of its department.

2.4.2 Overall diagnosis

Problem statement: there is too much local purchasing of steel plates.

The issues of irregular job arrival, late delivery of material and large backlogs of MSSs are merely symptoms of a larger problem upstream. The key issue at hand is that there is insufficient material in the yard. There are frequent shortages for the fast moving steel plates. For slower moving plates, the company often has either too much of the wrong material or they simply do not have what is required. Either scenario leads to local purchases having to be made.

Steel plates in the yard come either from foreign or local vendors. When this fact is placed alongside the problem of too much local purchases of steel that is taking place on the ground, the key issue that plagues Keppel Fels becomes clearer: MTO quantity is not optimal.

This also leads to the company experiencing high purchasing costs as significant quantities of steel are sourced from local vendors. Because the company does not keep records of its steel plate inventory turnover ratio, MTO performance has never been quantified.

Prior to my study, the previous SMA student intern[5] had performed some preliminary analysis on the quantities of steel usage in rig construction; however, the analysis was limited as there was only complete data for three rigs. Nevertheless, his results helped Keppel Fels in identifying a particular rig that they felt to be of average size. The company has since then used the MTO that was bought for this "average" rig as the basis for all subsequent MTO purchases.

2.4.3 Motivation

The current means that the company employs to determine the quantity of MTO orders for steel plates has ample room for improvement. This thesis seeks to:

- To identify key issues that Keppel Fels faces in steel plate procurement.
- Where possible, to apply operational research methods to create a MTO ordering policy that minimizes inventory and purchasing costs for Jack-Ups.

[5] Improvement study on internal supply chain system in offshore industry, Hulman Soaloon, Singapore-MIT-Alliance Theme project 2004-2005

Chapter 3 Two-tier-ABC analysis

To identify key issues that Keppel Fels faces in MTO ordering, it was first necessary to characterize the nature of the demand of steel plates. The first step was to identify the key factors that would allow the plates to be categorized into relevant segments. In the course of discussions with the project supervisors and the employees from the various departments, I realized that classifying the steel plates with a conventional ABC analysis was insufficient, namely to only split them up according to high, medium and low quantity (value) plates. There are other factors that are important that govern the behavior of the demand of the plates. I have segmented these factors according to their order of importance, namely:

1. The total weight used for each type of steel plate (type is defined as a specific grade and thickness).
2. The frequency of demand (how often does a rig require any quantity of this particular type of steel plate).

Once we are able to segment the demand, we can craft different policies to manage the risks involved.

3.1 Segmenting the steel plates by value (weight)

There is a cost in implementing an inventory control system and there are trade offs between the cost of controlling the system and the potential benefits that accrue from that control. In multi-product inventory systems, not all products are equally profitable. Control costs may be justified in some cases and not in others[6].

The cost of steel plates is proportional to their weight. For this reason, weight was chosen as the primary factor as it allows Keppel Fels to gain an initial insight of the high and low valued segments of its inventory. It also allows the company to focus its efforts on where the greatest cost reduction might be achieved.

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[6] Pg 275, Production and operations analysis, 4th edition, Steven Nahmias, MacGraw-Hill Irwin

3.1.1 Method

The database in the company has fairly complete data for only 13 rigs. Data was lost due to the company migrating their data over 3 different generations of databases. Data for the rigs that were constructed prior to the usage of the databases was also unavailable as these paper records had been misplaced. In the course of this study, our analysis was conducted based on the data set for the 13 rigs. However, the possibility of incomplete data had to be factored in our calculations.

For each type of steel plate we computed the total weight by summing over the 13 rigs. We then sorted these total weights in decreasing order.

Total weight used for type A= $\sum$ weight of steel type A rig 1+ weight of steel type A rig 2..... weight of steel type A rig 13

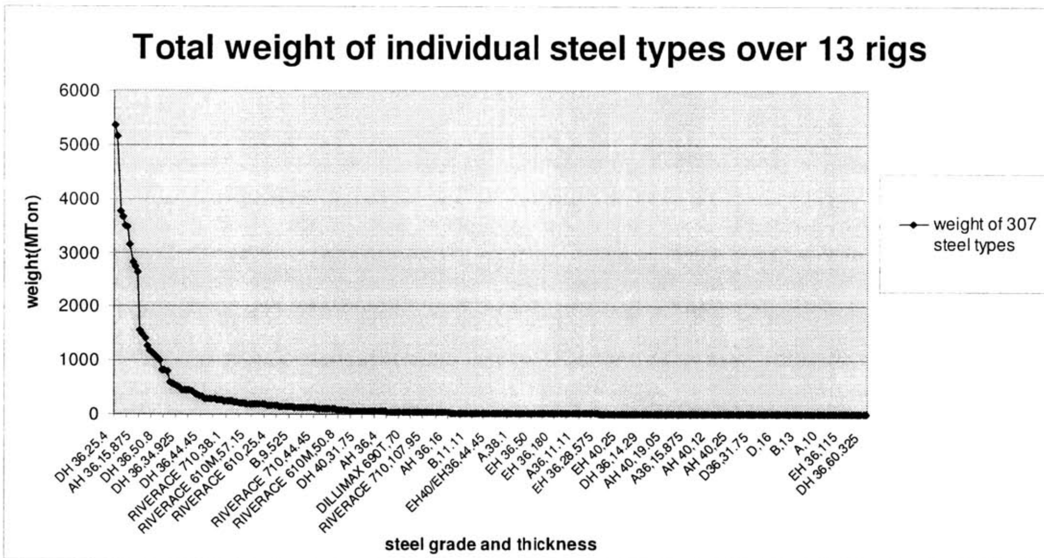

Figure 12 Total weights of individual steel types for 13 rigs

3.1.2 Observations for 2-tier ABC analysis

The *Pareto effect* holds true in the case of the inventory of steel plates. We can see from Figure 12 that a large portion of the total weight is accounted for by a small number of inventory items.

In particular, the top 19 types of steel account for 68% of the total weight and the top 59 types of steel account for 84.2% of total weight. There are a total of 307 types of steel with any demand.

This gives an insight as to the different valued steel segments at Keppel Fels.

3.2 Frequency of demand

Frequency of demand: the number of times that there was a demand for a particular type of steel out of the 13 rigs. E.g. Grade EH 36 steel plates of thickness 16mm have a demand which occurs in 3 out of the 13 rigs, Grade D steel plates of thickness 25.4mm have a demand which occurs in 8 out of 13 rigs.

This was chosen as the second factor because almost two thirds of the plates experienced infrequent (intermittent) demand in varying degrees. Inventory items with infrequent demand cannot be handled by the conventional newsboy model and a different set of assumptions had to be applied.

3.2.1 Obtaining frequency of demand

I assumed the frequency at which the plates are used in the 13 rigs to be a fair representation of the probability of usage. E.g. if a plate is used in 7 out of 13 rigs, I would say that the probability of it being used for the next rig is 7/ 13 or 54%. There were three possible segments for frequency of usage: high, medium and low. The average probability of usage for each category was found.

We note that the probability of usage is only the probability that the steel type would be used. It is not related to the quantity that is being used.

Figure 13 gives the histogram showing the frequency of usage for all the steel plates. For example, there are approximately 120 types of steel plates which are used only once in 13 rigs and approximately 5 types of steel plates which are used in 12 out of the 13 rigs.

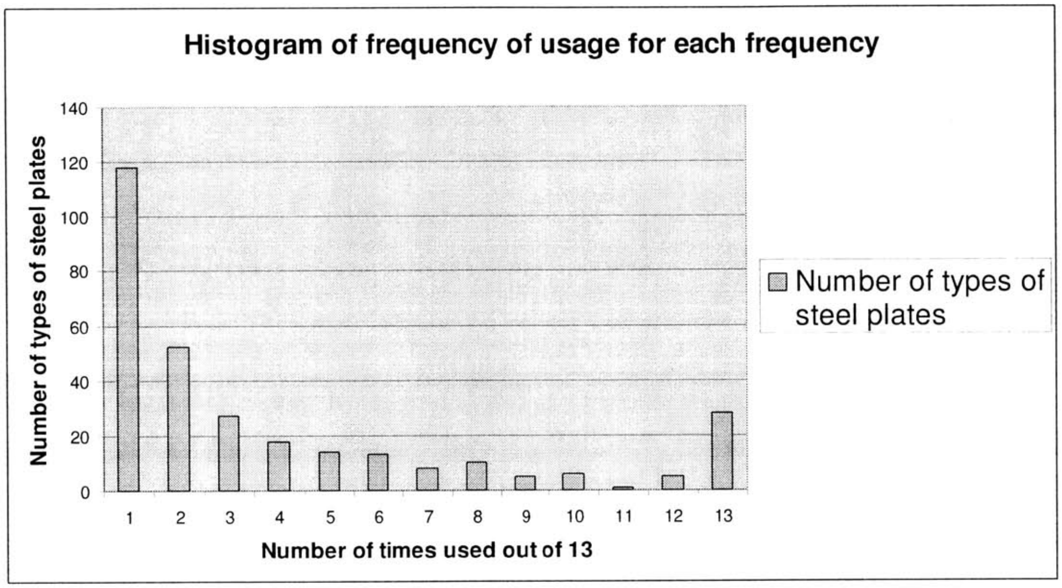

Figure 13 Histogram showing frequency of usage

3.2.2 Observations for frequency of demand

There were 2 main trends that were observed when frequency of demand was analyzed.

Trend	Quantity used per rig	Frequency of usage
1	Constant	Used in most of the rigs
2	Highly variable	Used intermittently among the rigs

Table 2 Demand patterns in frequency analysis

For certain steel plates like Grade A, of thickness 9.525mm, these are commonly used types that are used to build the main body (hull) of the rig. The "shape" of the hull does not change much across each rig. This explains why the weight for this particular steel type does not vary by huge amounts among the 13 rigs.

However, it is the other sections of the rig other than the hull that make each rig unique. These are the parts that are highly customized (with differing steel types used) and cause the total weight to vary by large amounts. This explains the large range in total weights.

3.3 Final result of the two-tier ABC analysis

We chose the final form of the segmentation in such a way that it would be relevant yet with as few classifications as possible. This would facilitate the implementation process at Keppel Fels.

The intent of the segmentation was to provide a key tool in formulating a set of reasonable procurement policies for each category of steel.

3.3.1 Categories and policies suggested

The steel plates were segmented into various categories based on the two critical factors that were previously identified. In all, there are three different categories (A, B and C). Only category B is further divided into 3 sub-categories so as to better differentiate the inventory policies.

3.3.1.1 Policy for Category A steel plates

Category A steel plates only make up 6.2% (19) of all types of steel plates but have been consistently used in all the rigs (probability of usage 100%). These plates account for 68% of the total weight

Comments

- Category A steel plates are the "cash cows" and require special attention from the company in inventory control. The requirements are set to be much stricter (high total weight and high frequency usage) than the other categories, allowing me to contain these steel plates into one category and come up with a single policy for them. Only 19 plates meet the requirements.

- The other benefit is that all the variability in frequency usage is channeled to the category B and C steel plates. This would be the category that would have to be segmented further and different policies would have to be implemented to manage them.

Solution approach: apply the newsboy model
The construction for each rig can be modeled as a single time period with a single purchase opportunity for foreign steel. Over ordering results in leftover plates, which will incur holding costs; under ordering results in the company purchasing the plates locally at a cost premium. The newsboy model was found to be the most appropriate approach for this category to balance these costs.

3.3.1.2 Category B steel plates: 3 types

Category B steel plates have been further sub-divided into 3 categories. This is because these are the steel plates which have total weights that are significant in the construction process yet exhibit a wide range of frequency of demand. Sub-division allows for the application of specific policies that better manage the risks in each category.

3.3.1.2.1 Policy for Category B1 steel plates

Category B1 steel plates make up 4.8% (15 types) of the types of steel plates. They have an average probability of usage of 96.15%, and account for 8.1% of total weight. While this is not as much as category A steel plates, a shortage on the ground would still have adverse effects on the production schedule.

Solution approach and assumptions: similar to category A

Since steel plates in this category have similar overage and underage costs to category A, a similar approach was chosen to find the optimal quantity to order.

3.3.1.2.2 Policy for Category B2 steel plates

Category B2 steel plates make up 8.1% (25 types) of the types of steel plates with an average probability of usage of 65%. They account for 8.3% of total weight.

Solution approach: newsboy model with longer holding time and hence a larger overage cost

The plates in this category are used less frequently than plates in the previous two categories. Shortages will have to be topped up by local purchases. However, any leftover plates are likely to wait for a much longer period of time (compared to category A) before being used; thus, we expect the holding time for any leftover plates to be longer. Overage and underage costs still exist but we use a larger overage cost due to the anticipated longer holding time.

3.3.1.2.3 Policy for Category B3 steel plates

Category B3 steel plates make up 14.3% (44 types) of the total number of steel plates with an average probability of usage of 31.8%. They account for 10.9% of total weight.

Comments

- These are the "problem" plates as their usage quantity cannot be said to be insignificant, yet their frequency of usage does not make implementing a standard ordering policy viable. That is, we think it would not be economic to order each of these steel types for each rig, due to their low usage frequency.

Solution approach:

1. To not implement any fixed buying policy at all and leave it to the buyer intuition to determine the quantities.

2. To implement a reserve capacity with the local vendors (this will be described and discussed more in Chapter 5).

3.3.1.3 Policy for Category C steel plates

Category C steel plates make up 66.4% of the total number of steel plate types, namely 204 types of steel. They have an average probability of usage of 14.14%, and account for 4.3% of the total weight.

Solution approach: purchase all of these kinds of plates from local vendor on an as needed basis. The quantity and frequency of usage is too low to order from the foreign vendors as part of the MTO.

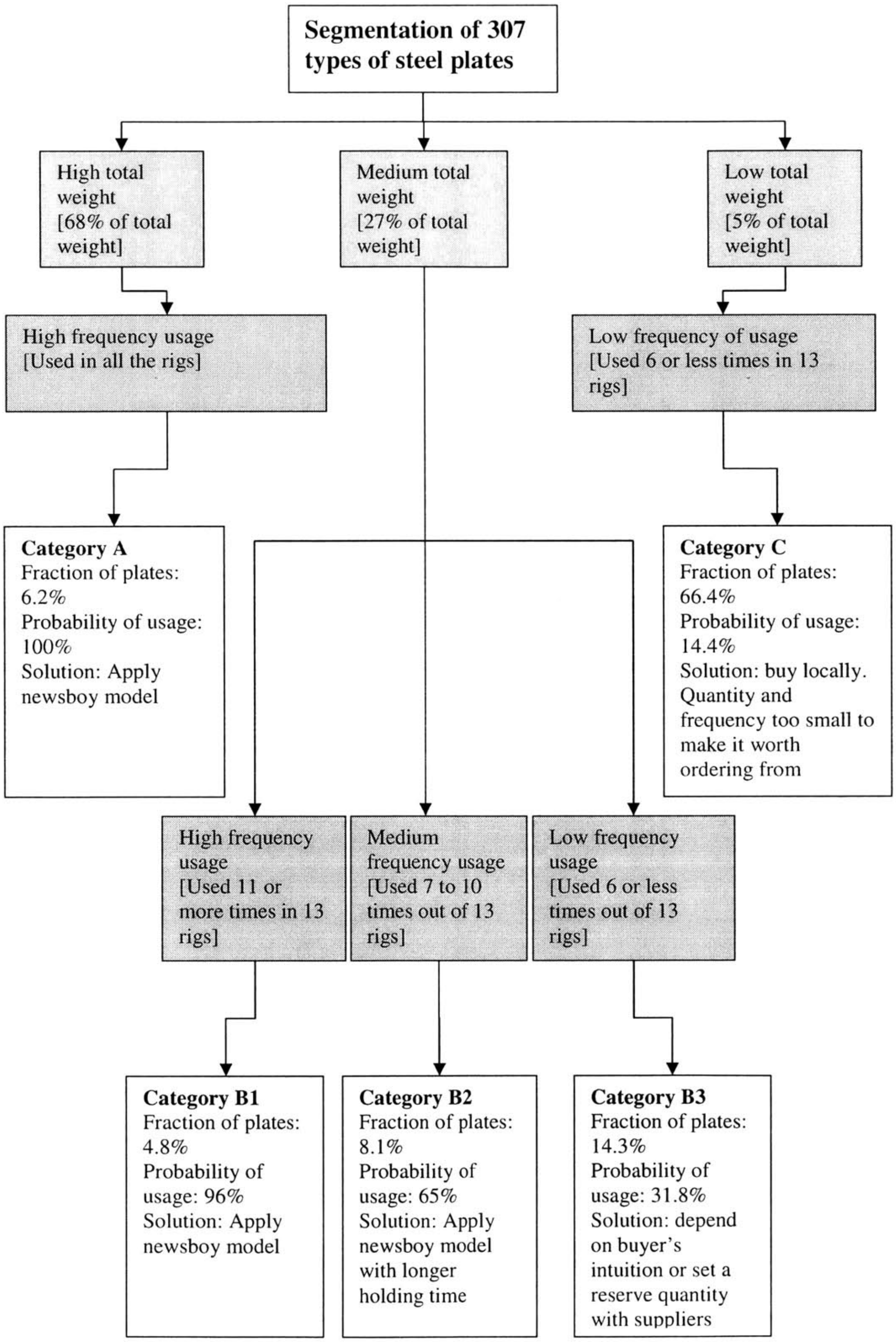

Figure 14 Diagram of the 2-tier ABC analysis

Chapter 4 Methodology

This chapter deals with the methodology that we chose to solve the problem in Keppel Fels. The primary approach is the newsboy model with varying overage costs. Section 4.1 talks about the methods used to improve data quality. Section 4.2 looks into the approach to the problem. Section 4.3 discusses the key assumptions that are made for the model.

4.1 Data aggregation

The maximum number of data points that were available for analysis of steel demand was 13 due to the limited database. We employed various approaches to explore how best to utilize this limited data.

4.1.1 Pooling of steel plates by sizes

The unit of measurement for the steel plate quantities is metric tons (MTon). The plates have been further categorized into grade and thickness only. The following reasons make it viable to pool the sizes of steel plates together:

1. In the construction of the rigs, steel grade and thickness are the most critical factors as they directly affect the structural integrity of the rig. The sizes of the steel plates only affect the draftsmen who are responsible for nesting all the various steel parts into each plate. They are able to perform their work well with all sizes of plates.
2. The company leaves it to the discretion of the purchasing department to determine the sizes of the steel plates to buy. What is monitored closely is the total weight that is bought as it has a direct impact on there being sufficient material for production and material costs.

Size of steel plates was deemed to be not a critical factor. By pooling together the sizes of the steel plates, it would serve to improve the accuracy of the estimates for each steel type. This would make the policies more robust.

4.2 Approach to problem

Inventory models subject to uncertainty are basically of two types: 1) periodic review and 2) continuous review. Periodic review means that we can review the inventory and place a replenishment order at discrete points in time only; continuous review means that we can review the inventory and place a replenishment order at all times. Periodic review models may be for one planning period or for multiple planning periods. For one period models, the objective is to balance the costs of overage (cost of ordering too much) and underage (cost of ordering too little)[7]. This model is more commonly known as the newsboy model and this is the approach that has been chosen for the situation at Keppel Fels.

4.2.1 Relationship of MTO order to Newsboy problem

There is a relatively short production season with a well defined beginning and end[8]
From an analysis of the data base, we found that within the first 8 months of construction, 84% of all the steel plates were used, which accounted for approximately 94% of the total weight.

This suggests that construction of the body of the rig is mostly completed within the first 8 months and that there is a fairly clear start and end of the construction phase.

An MTO order takes nine months to arrive at Keppel Fels, which means that the lead time for foreign purchased steel is much longer than the time of production of the rig. Once production starts, it is almost impossible for a second order of steel from foreign vendors to arrive before a large proportion of the construction ends.

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[7] Pg 245, Production and Operations Analysis, Steven Nahmias, Santa Clara University, McGraw-Hill Irwin

[8] Pg 384, Inventory management and production planning and scheduling, third edition, Edward A. Silver, David F. Pyke, Rein Peterson, John Wiley & Sons

There is insufficient quantity of steel plates and time to justify a second order from the foreign vendors. There is only one opportunity to order the MTO.

The producers have to commit themselves to a large extent, in terms of how much each stocking keeping unit to order prior to the start of the season[8]

Construction of the rig ramps up in the first eight months and the rate of usage of steel plates increases tremendously. Also, the huge demand for the rigs in the market makes it necessary to have multiple rig construction projects that overlap. The local vendors do not have sufficient capacity to supply all of the steel requirements of the entire shipyard. The company is compelled to find a means of securing most of its steel needs before the construction of each rig ramps up.

There may be one or more opportunities for replenishment after the initial order is placed due to changes in the forecast of demand[8]

The replenishment opportunity that is available to Keppel Fels is in the form of ordering steel from the local vendors in Singapore. The lead time for the local vendors is in days and the replenishment is able to take place when needed throughout the entire construction phase.

Forecasts prior to the season include considerable uncertainty stemming from the long period of inactivity from the time that the order is placed to the start of the season. During this inactive period, the economic conditions or style considerations may have changed appreciably[8]

The purchasing of the MTO takes place even before the details of the rig are clearly known. What Keppel Fels currently does is to make a purchase based on the quantities from an MTO of a previous rig that they deem to be of "standard" size. It is only 3 to 6 months after the deal is inked that the detailed engineering drawings are produced. Inaccuracies in the initial order of steel are a certainty.

Existence of underage costs

When the total demand during the construction phase exceeds the steel plates available from MTO, the company incurs underage costs in the form of the added costs of acquiring material from the local vendors.

Existence of overage costs

When the total demand during the construction phase is less than the stock available, excess steel plates that are left over are placed in common inventory. The holding costs that are incurred for the duration that the steel plates sit in the inventory are the overage costs that the company has to bear for ordering too much steel.

Hence, the main features of the MTO order are:

1. The duration of rig construction is taken to be 1 time period.
2. The company finds it necessary to make an initial bulk order of foreign steel.
3. Demand for steel is very difficult to predict accurately.
4. There is only one opportunity to order from the foreign vendors.
5. There are significant overage and underage costs.

These characteristics of the situation on the ground fit well with the features of the newsboy model; hence this is the approach that is taken to find the optimal quantity of steel to order.

4.3 Key assumptions

4.3.1 Fixed overage costs

We assume a fixed holding cost for each unit of excess steel plates. The company uses a holding cost rate of SGD$9.50 /ton/month for calculation. However, they do not keep regular records of how long excess steel plates normally stay in inventory, making it difficult to accurately define this variable. It was necessary to formulate some assumptions and fix the holding times that we would anticipate for each type of steel plate. Depending on the probability of usage for each type of steel plate, the holding time would vary accordingly.

We assume the holding time is 2 months for excess plates in category A and B1. The supporting evidence for 2 months being a reasonable estimate of holding time for the plates in category A and B1(high probability of usage) is as follows:

- Keppel Fels begins a new rig construction every 2-3 months. Each time a rig is built there will be a surge in the demand for steel plates. We thought that it was reasonable to assume that a FIFO picking system is used and leftover steel plates would be used first to fulfill any demand. This was because these plates are "older" and it would be logical to use them up first before they expired.
- A multi period analysis of the common inventory was performed by the previous student intern[5]. From his results, the time between re-orders was estimated to be approximately 20 days for these plates. Hence, 2 months is, in fact, a very conservative figure for fresh demand to begin.
- Keppel Fels has repeat orders for rigs. These represent unexpected demand which cannot be "buffered" by MTO and will have to be satisfied by local purchases or leftover steel from previous rig construction projects.

We assume the holding time is 6 months for excess plates in category B2. The supporting evidence of 6 months being a reasonable estimate of holding time for the plates in category B2 (medium probability of usage) is as follows:

- In the event that there are excess steel plates leftover after a project is completed, it is very unlikely that it would be used up as quickly as the fast moving steel plates. Since we know that Keppel begins a new rig construction every 2-3 months, approximately 2- 3 rigs would have begun construction in the course of 6 months i.e. there would be 2-3 fresh sources of demand for all steel types in this half year. With the medium moving plates having 65% probability of usage for each rig that is constructed, it is reasonable to expect that any excess plates is used in the course of these 2 -3 rigs being constructed. Furthermore, 6 months is the longest time that excess steel plates can stay in inventory before corrosion becomes too severe. So 6 months is the maximum time that can be allocated for holding time.

4.3.2 Underage costs

The average cost of foreign bought steel is SGD$1920 per MTon and the cost of locally purchased steel is SGD$1952 per MTon (the cost figures are from the previous student intern's thesis[5] and based upon 2004-2005 steel prices). Hence, the marginal cost (underage cost) to Keppel Fels when steel is bought locally is SGD$32 per MTon.

Summery of overage and underage costs

Steel plate Category	**Overage cost ($/ton) [$9.50/ton/month]**	**Underage cost ($/ ton)**	**Policy**
A	19	32	Newsboy model
B1	19	32	Newsboy model
B2	57	32	Newsboy model
B3	-	-	Reserve quantity
C	-	-	Buy from local vendors

Table 3 Overage and underage cost summery

4.3.3 100% service level

All demand is assumed to be met by either foreign purchases or local purchases. In the event that MTO has insufficient plates, Keppel Fels purchases steel from a variety of local vendors. For there to be a shortage in the company, it would require that all the local vendors experience a shortage of the material at the same time. This was felt to be highly unlikely.

4.3.4 Demand is normally distributed

We assume the demand for each steel type to be normally distributed.

Chapter 5 Results and discussion

This chapter covers the results that were obtained from the various policies that were suggested. A short discussion is given after each of the results. Section 5.1 looks at the possible sources of variability of data. Section 5.2 shows the various methods chosen to overcome this variability. Section 5.3 covers issues concerning the retrospective newsboy. Section 5.4 talks about the results obtained and what conclusions were drawn. Section 5.5 provides a quick verification of the results and finally section 5.6 provides the summary of the results and overall recommendation to be made to the company.

5.1 Uncertainty in the data

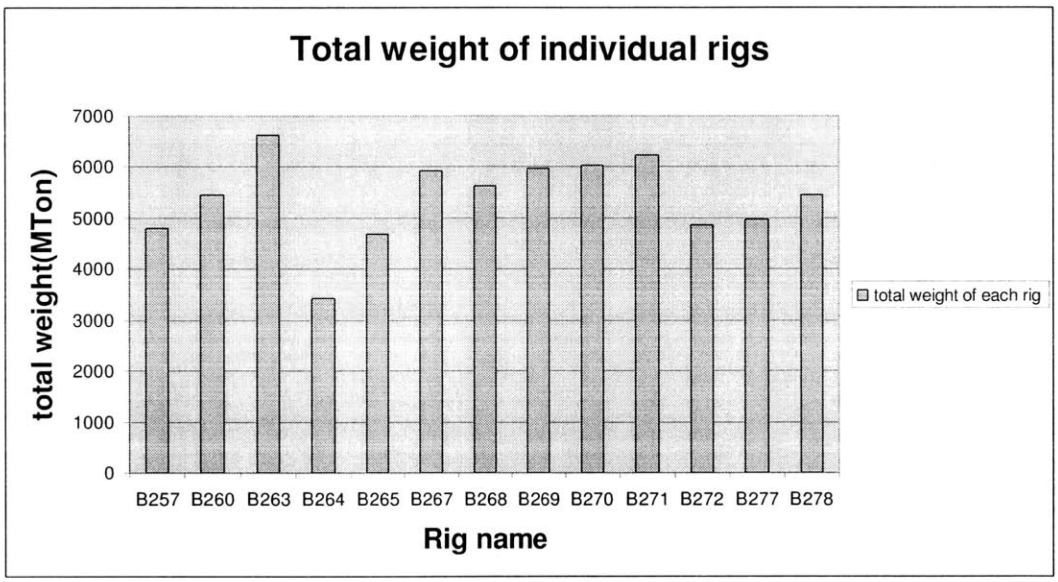

Figure 15 Total weight of the 13 rigs

The migration of data over 3 database platforms led to concerns regarding the accuracy of data that is currently available. Because the total weight for each rig is the only figure that the company could supply to verify the accuracy of the demand for steel plates, we assumed this to be synonymous with the quality of demand data collected. Figure 15 gives the total weight of the 13 rigs. It can be seen that the total weight of each rig varies between 4500 MTons to 6000 MTons, where MTons is metric tons. The observed variability could come from 2 sources:

1. missing data due to migration over 3 databases (but the impact of this was unknown)
2. inherent variability in the design of the rigs

Furthermore, the lack of more rigs makes it impossible to verify the source of this variability.

Consultation with the cutting planners (they are the ones who are involved with cutting the individual parts of the rigs from the raw metal plates) revealed that the best estimates regarding the weight of each rig was 5000 tons to 6000 tons, close to what was found. The project supervisors also felt that the difference in total weights was due more to the inherent variability of the designs in each rig rather than missing data. However, one observation noted was that while the differences in total weights were always ascribed to the variability in rig design, no one in the company could account for the effects of missing data in the system.

The conclusion that was drawn was that the data probably provides an almost complete picture of the actual demand for the 13 rigs, but there was still a possibility that there were inaccuracies in the data due to missing entries.

5.2 Approaches taken to overcome missing data

One approach that we took is to assign weights to each rig. That is, we give the rigs with more complete data (i.e. greater total weight was assumed to imply a more complete set of data) greater contribution to the calculation of the demand distribution. (See

Appendix 1 for formulas used in calculations). Below is an example of how the weights of the rig were calculated.

Rig name	Rig 1	Rig 2	Rig 3	Total weight for 3 rigs
Weight of rig in MTons	4790.6	5447.0	6580.0	16817.7
Weight assigned to each rig	0.284	0.323	0.391	

Table 4 Example for calculating the "weight" assigned to each rig

A second approach is to calculate steel requirements as a percentage of total rig weight. This was based on the assumption that the data:

- was fairly accurate but not complete
- had missing data that was distributed evenly across all the different types of steel

By shifting to percentages, it would still be possible to obtain accurate observations of demand.

Rig name	Rig 1	Rig 2	Rig 3
Demand for Grade AH 36 thickness 7.938mm(MTon)	46.81	62.91	99.69
Demand for Grade AH 36 thickness 7.938mm(% weight)	0.977	1.15	1.51
Weight of rig in MTons	4790.6	5447.0	6580.0

Table 5 Example of calculating demand in percentage weight

However, the shift to percentages and applying weights were still based on assumptions. Because the company had no other data available to help verify if percentages or weight in MTons would give a more accurate distribution, another means had to be found to test the accuracy of the demand distributions.

5.3 Testing with the retrospective newsboy

There are two main methods of defining the demand distribution of each steel plate, namely by percentage weight or by actual tonnage. However, the various distributions give results that are different from each other. As these 13 rigs are the only data that is available, I have chosen to work backwards with my newsboy model to verify which distribution would have provided the best results retrospectively; we will regard this to be the "best" demand distribution.

5.3.1 The logic of the conventional newsboy model

In the conventional newsboy, we assume an accurate demand distribution with accurate overage and underage costs, which would then give the optimal quantity with the least expected costs over the 13 rigs, as shown in Figure 16 .

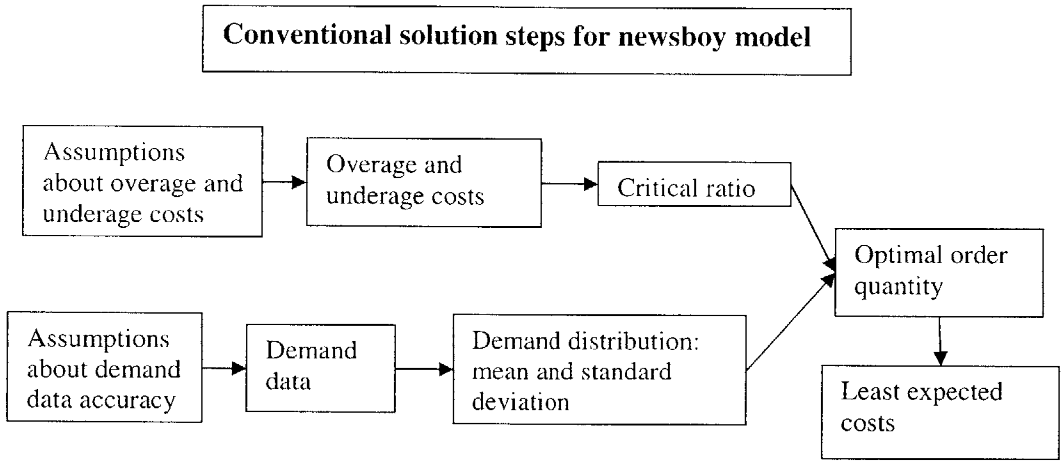

Figure 16 Logic of conventional newsboy model

5.3.2 The logic of the retrospective newsboy model

We have several different ways to choose a demand distribution for each type of steel, based on the data from the 13 rigs. We will compare these choices by doing a retrospective (or ex post) analysis with each distribution. That is, we will determine for each rig and each type of steel what the order quantity would be if we had used each distribution. We will then evaluate what the total overage and underage costs would have been if we had used these order quantities for all of the steel types. We can compare how each of the demand distributions would have performed, if we had used it for deciding the order quantities. We will argue to choose the demand distribution which performs best on this test.

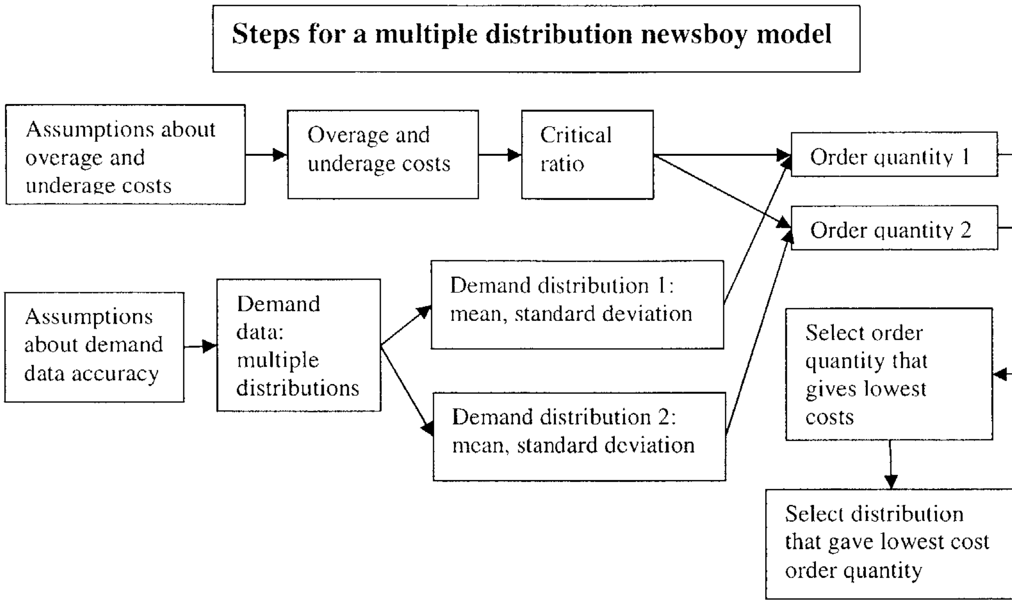

Figure 17 Logic of the test of the retrospective newsboy model

5.3.2.1 Method for the retrospective newsboy

Due to space constraints, Figure 17 only shows 2 distributions, but we actually did the analysis for six possible ways of setting the demand distributions for each of the 13 rigs. These order quantities were obtained from:

- 2 demand distributions in percentages (the demands for each steel type were converted as a percentage of total rig weight).
- 2 demand distributions using actual tonnage.
- Current MTO order that Keppel Fels uses
- 1 using solver

Type of demand distribution	Name of distribution method	Method of calculation
Type 1: Demand distribution in percentages	Percentage weight	All steel plate weights converted into percentage of rig weight Mean and variance found from 13 data points

	Weighted percentage weight	Weight of all steel plates converted into percentage of rig weight Each rig is assigned a weighted value Mean and variance calculated, factoring in weighted values of each rig
Type 2: Demand distribution in actual tonnage	Simple average	Using actual tonnage in demand data to work out mean and variance
	Weighted actual	Actual tonnage from demand data is used Each rig is assigned a weighted value Mean and variance calculated, factoring in weighted values of each rig
Current MTO order	Current forecast	-
Excel Solver	-	Uses Excel solver (linear programming) to find optimal solution

Table 6 Details of the 6 order quantities

(Refer to Appendix 2 for more details of calculation)

5.3.2.2 Purpose of each type of distribution

By having 2 main types of distributions (percentage weight and actual weight), between types testing can be performed. This compares the performance of distributions using percentage weight and actual tonnage and allows the assumption of evenly distributed missing data to be tested.

Within types testing allows us to access the impact of giving greater "weightage" to rigs with more (accurate) data.

The objective of including the current MTO order is to measure the performance of Keppel Fels current MTO order quantity and see how it compares to the newsboy order quantities.

The quantities generated by Excel solver provide us with a benchmark of the cost performance of each distribution method. If the data accurately depicts the demand distribution, then quantity and costs obtained by solver would tally with the values from the newsboy model. If the costs and quantities do not match, then the distribution cannot said to be accurate.

The retrospective newsboy method was applied to each of the applicable steel categories, i.e., category A, B1 and B2.

5.4 Results

5.4.1 Results for Category A steel plates

This is the category of steel plates that we expect the most cost savings. In this category, the "weighted actual tonnage" distribution give the greatest cost savings in addition to having total costs that were very close to the costs obtained by Solver. There was also no significant cost difference between the "weighted actual tonnage" and the simple average distribution.

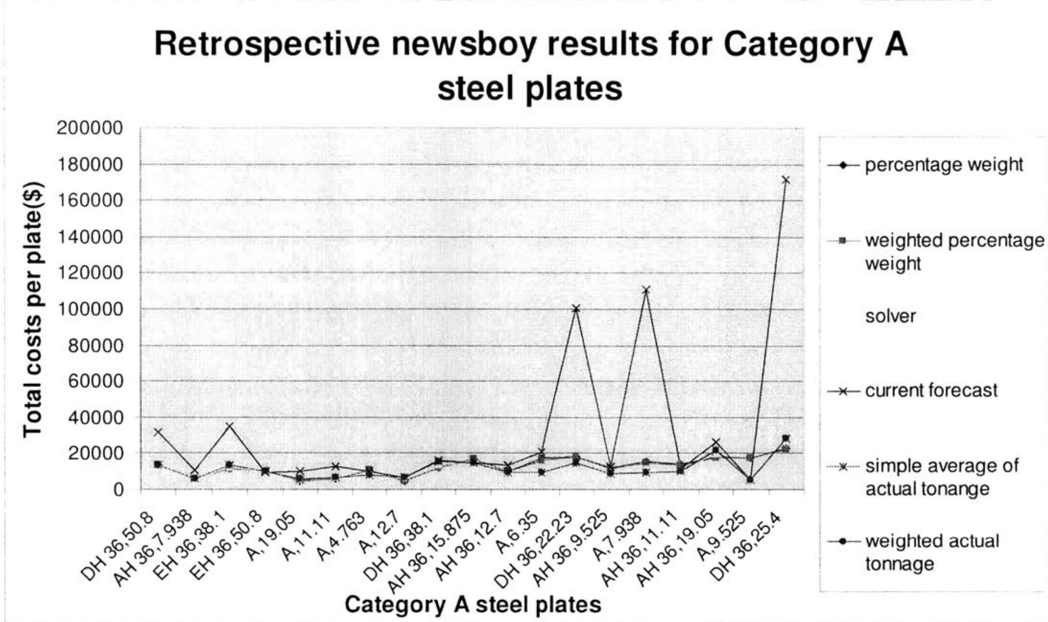

Figure 18 Retrospective newsboy graph for category A steel plates

Type of distribution	Name of demand distribution method	Total cost($)	Cost difference from solver (%)
Type1: demand distribution in percentages	percentage weight	242889.8	14
	weighted percentage weight	239319	12
Type 2: demand distribution in actual tonnage	simple average	219051	3
	weighted actual tonnage	218921.3	3
	current forecast	631603.3	197
	solver	212812.9	0
Average cost reduction per rig per plate type($)	1670		

Table 7 Results for category A steel plates

Sample calculation for average cost reduction per rig per plate type for category A steel plates (this same method has been applied to calculate all average cost reduction per rig per plate in categories B1 and B2):

= (total cost of current forecast – total costs from solver) / (total number of plates in category * total number of rigs)

= (631000 – 219000)/(19*13)

= $1670.8/ rig/ plate

5.4.1.1 Observations for category A steel plates

1. From Table 7, the current MTO procurement method at Keppel Fels would have resulted in overage and underage costs of $631,000. Implementation of the newsboy model with the "weighted actual tonnage" distribution would have resulted in overage and underage costs of $219,000. This provides a 65% ($413,000) reduction from current costs for this category of steel plates. The newsboy quantity has costs that are 2.9% more than the optimal costs found by solver.
2. Distributions using actual tonnage perform better than distributions using percentage weight.
3. Weighted distributions have slightly better cost performance than the un-weighted distributions.
4. "Weighted actual tonnage" distribution follows the solver results closely, as seen in Figure 18.
5. Average cost reduction per rig per plate type: $ 1670.8/rig/plate type (Table 7).

5.4.1.2 Discussion of category A results and recommendation

The assumption of using percentage weight to obtain better observations cannot be proved or disproved in this category as the high variability in the total weight of each rig skews all percentage weights unevenly, leading to inaccurate distributions.

The "weighted actual tonnage" distribution is able to provide costs that are close to the optimal quantities suggested by solver. These strongly suggest that the retrospective newsboy has found the best distribution.

Our recommendation is to implement the newsboy model quantities, using the demand distribution from the "weighted actual tonnage".

5.4.2 Results for category B1 steel plates

The six different distributions were again used to generate the various demand distributions for the steel plates in category B1. This section presents the results that were obtained from the analysis. While we thought that there was insufficient information to conclude why the "percentage weight" distribution gave better cost savings, implementation of either type of distribution (tonnage or percentage weight) would still give the company cost savings.

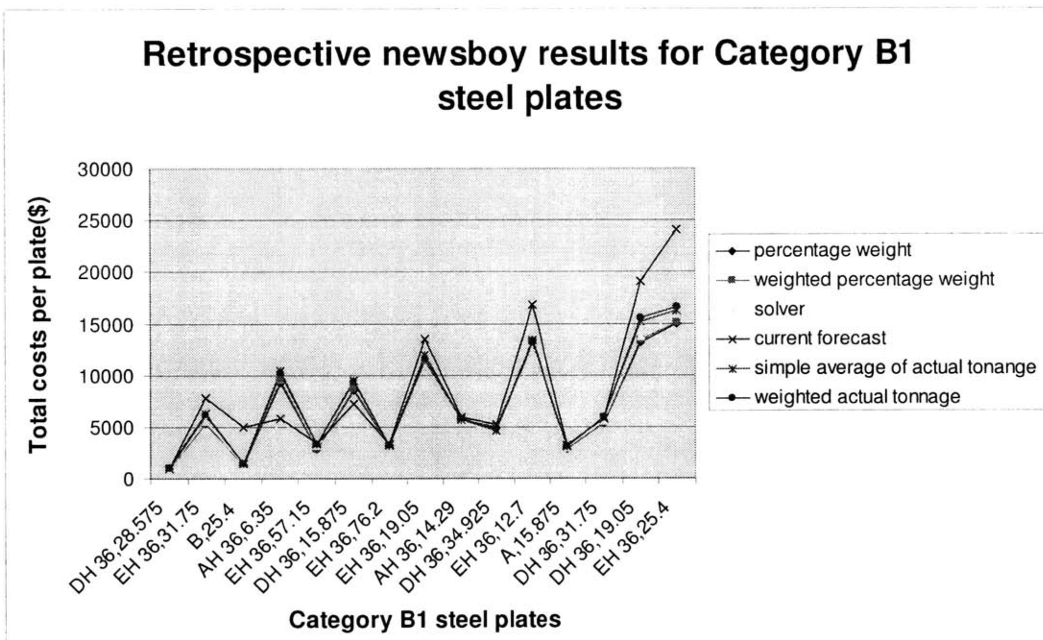

Figure 19 Retrospective newsboy graph for category B1 steel plates

Type of distribution	Name of demand distribution method	Total cost($)	Cost difference from solver (%)
Type1: demand distribution in percentages	percentage weight	103242.4	9

	weighted percentage weight	103638.1	9.2
Type 2: demand distribution in actual tonnage	simple average	111260.3	17
	weighted actual tonnage	111069.3	17
	current forecast	127388.3	34
	solver	94879.49	0
Average cost reduction per rig per plate type($)	123.8249		

Table 8 Results for category B1 steel plates

5.4.2.1 Observations for category B1 steel plates

1. From Table 8, the current MTO procurement method at Keppel Fels would have resulted in underage and overage costs of $127,000. Implementation of the newsboy model with the percentage weight distribution would have resulted in underage and overage costs of $103,000. This provides a 19% ($24,000) reduction in costs for this category of steel plates. This newsboy quantity has costs that are 8.8% more than the optimal costs found by solver.
2. Distributions using percentages perform better than distributions using actual tonnages.
3. There is no significant trend to show if weighted distributions perform better than un-weighted distributions.
4. Percentage weight distribution follows the solver results fairly closely.
5. Average cost reduction per rig per plate type: $ 123.8 rig/plate type (Table 8).

5.4.2.2 Discussion for results for category B1 and recommendation

"Percentage weight" distribution gives the least costs. This could be due to 2 reasons:

a) The assumption of evenly missing data holds true for this category of steel plates. This method of defining the demand distribution gives better observations because of its ability to "overlook" missing data or,

b) Demand for steel plates in this category are size (total weight) dependent i.e. larger and heavier rigs generally require more of this types of steel. "Percentage weight" is better able to predict the demand if usage depends on the total size of the rig.

Category A steel plates encompass 67% of the total weight of all the rigs and if the observation that the data in this category is accurately collected, it seems unlikely that there could be significant missing data in category B1 plates. A quick correlation test was performed to verify the second reason. The results do not suggest that there is a strong relationship between rig weight and quantity of each type of steel used which negates the second reason. Thus far, there does not seem to be a plausible reason for "percentage weight" performing better in category B1.

The reduction of costs, 19% for category B1 as compared to 65% in category A and the closeness to optimal solver costs in category B1 is 8.8%, as compared to 3% in category A suggest that the results are still reasonable as it is in line with the Pareto curve.

Our recommendation is to collect more data and perform further analysis to understand the behavior of demand in category B1 before implementation of the newsboy quantities. However, we note two points:

- 19% ($24,000) reduction in additional costs can be obtained for this category of steel plates and this does not involve excessive work.
- Usage of the newsboy quantities for all types of distribution gives an improvement over the company's current MTO procurement strategy.

The average cost reduction per rig per steel type is $123.8/rig/plate type as compared to the $1670.8/rig/plate type in category A. The company would need to decide if it is worthwhile to devote their resources to obtain this cost savings.

5.4.3 Results for category B2 steel plates

In this category, four different distributions were used to generate the various demand distributions for the steel plates in category B2. Unlike the previous two categories, the "weighted" distributions have not been included. This is because the frequency of usage was insufficient to generate a reasonable set of weights for each rig. The two methods for generating demand distributions are "percentage weight" and "simple average". This section presents the results that were obtained from the analysis. While the results suggest potential cost savings, we should collect more data due to the lack of data.

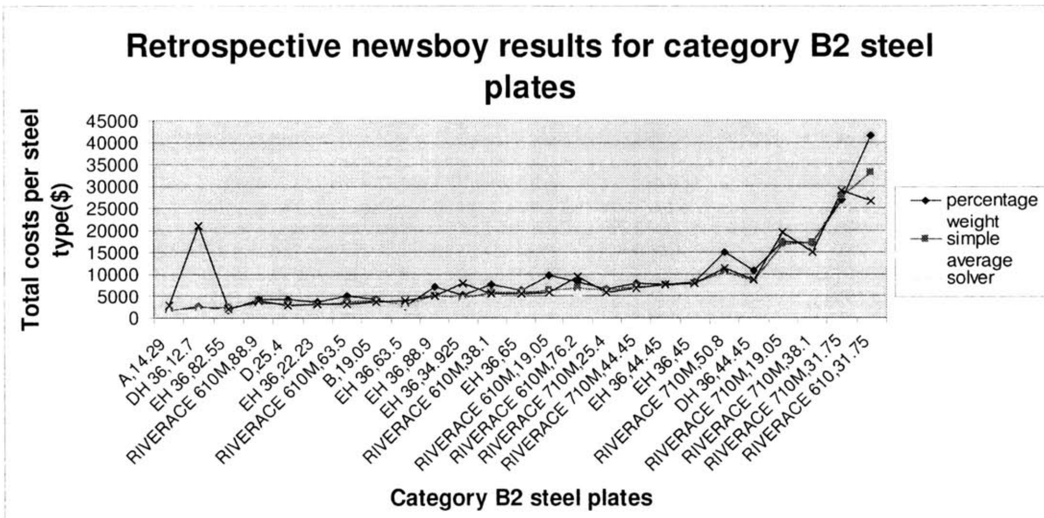

Figure 20 Retrospective newsboy graph of category B2 steel plates

Type of distribution	Name of demand distribution method	Total cost($)	Cost difference from solver (%)
Type1: demand distribution in percentages	percentage weight	231841.9	29.2
Type 2: demand distribution in actual tonnage	simple average	201790.1	12.5
	current forecast	223852.6	24.8
	solver	179354.9	0
Average cost reduction per rig per plate type($)	67.88459		

Table 9 Results for category B2 steel plates

5.4.3.1 Observations for category B2 steel plates

1. From Table 9, the current MTO procurement method at Keppel Fels would have resulted in underage and overage costs of $223000. Implementation of the newsboy model with the percentage weight distribution would have resulted in underage and overage costs of $202000. This provides a 9.8% ($22000) reduction in costs for this category of steel plates. These newsboy quantities have costs that are 24.8% more than the optimal costs found by solver.
2. The demand distribution using simple average gives the largest cost reduction.
3. Simple average distribution total costs are 12.5% higher than solver results.
4. Average cost reduction per rig per plate type: $ 67.9 rig/plate type (Table 9).

5.4.3.2 Discussion for results in category B2 and recommendation

The average cost reduction per rig per plate is fairly small at $67.9/rig/plate. There is less urgency to obtain an accurate inventory policy for this category of steel plates. Keppel Fels can afford to and should collect more data to further understand the variability and frequency of usage. There are also too few data points to say for certain if the values obtained are accurate.

5.4.4 Observations and recommendation for category B3 steel plates

These are the "problem" plates as their usage quantity cannot be said to be insignificant (10.9%), yet their relatively low probability of usage (31.8%) and small proportion of all the steel plates (14.3%) does not make implementing a constant ordering policy viable.

Our recommendation for Keppel Fels is to either:

- to not implement any fixed buying policy at all and leave it to buyer intuition or,
- to implement a reserve capacity with the local vendors

A simple illustration of the benefits of having a reserve capacity with local vendors using data from DH 36 steel plates with thickness 25mm:

Keppel Fels manages to secure a reserve quantity of 8 MTons with a local supplier. It pays the supplier $400 for this reserve quantity for each time period regardless of whether the reserve quantity is used. When a demand is experienced, the company will only pay an additional $1530 /MTon as long as demand is within 8 MTons. Any excess demand would have to be met by the spot market price.

This policy is compared to the worst case scenario where no reserve quantity has been obtained and the buyers have completely failed to anticipate an occurrence of demand for this type of steel. The company will incur the additional underage cost due to purchasing steel at the spot market price.

Description of price	**Price per MTon($/MTon)**
Spot market price	1952
Flexible reserve capacity price (for 8 MTons)	400
Flexible reserve capacity execution price	1530

Table 10 Price break down for reserve quantity

Total cost without reserve capacity and failure of buyers to anticipate demand: $76588
Total cost with reserve capacity: $69806
(Appendix 3 shows the cost calculations for the reserve capacity)

The benefits of having this reserve capacity are:

- A portion of demand can be met by the flexible reserve capacity price. This would enable the company to purchase steel plates at a price lower than the spot market when demand occurs.
- The simple example shows that lower procurement costs are possible if a reserve capacity with the right cost structure is implemented.
- The local vendor bears the risk of holding a perishable item.

The disadvantages of a reserve capacity:

- It would be challenging to decide the price of the reserve quantity as it depends largely on quantity reserved and the duration of reservation.

5.4.5 Observations and recommendation for category C steel plates

The characteristics of category C steel plates are that they have a probability of usage of 16%, the percentage of total weight that they contribute is 4.3% and they consist of 67% of all the steel plates.

Our recommendation is to purchase these kinds of plates from the local vendors. The quantity and frequency of usage is too low to make a constant ordering policy viable.

5.5 Checking the results

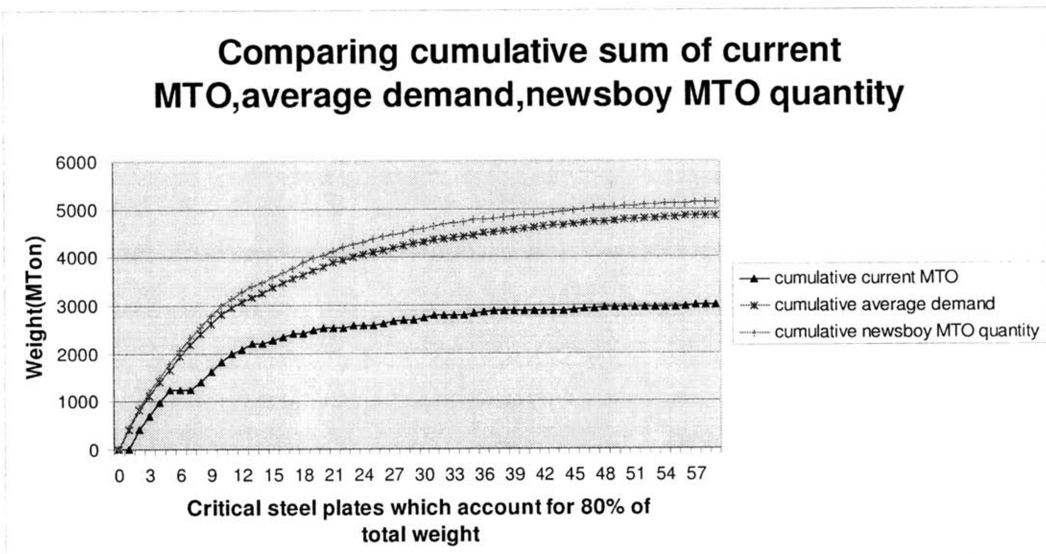

Figure 21 Cumulative sum of weights of critical steel plates of MTO vs newsboy order quantity

In Figure 21 we plot the cumulative demand forecast for the 59 steel plates from category A and B1 which represent 80% of total weight for a single rig. We also plot the cumulative order quantity for these critical plates from the current MTO and from the application of the newsboy model. We see that the current MTO is approximately 2000 MTons less than actual demand and that the total newsboy order quantity is more than the average demand. This confirms the observation that the current MTO quantity is insufficient (providing only 60% of average demand), resulting in too much local purchases. Since the overage costs are less than underage costs, the optimal quantity suggested by the newsboy model is greater than the average.

By increasing the order quantity of MTO to the newsboy quantities Keppel would gain 2 immediate benefits:

- A large proportion of the materials can be met from MTO, and the panel shop does not have to wait for steel to be purchased locally. Production in the panel shop can proceed more smoothly and according to schedule.
- Procurement costs can be reduced by having a larger proportion of demand being met from the less expensive foreign steel plates.

5.6 Summary of results and overall recommendation

We note that the number of plates can be taken to be a proxy for the "effort" that Keppel Fels has to expand to monitor and implement the inventory policies.

Figure 22 shows the cumulative cost reduction for each type of plate when the newsboy quantities and various policies are implemented in MTO. This allows us to understand the trade off between the number of plates over which the newsboy model has to be implemented and the possible cost reduction.

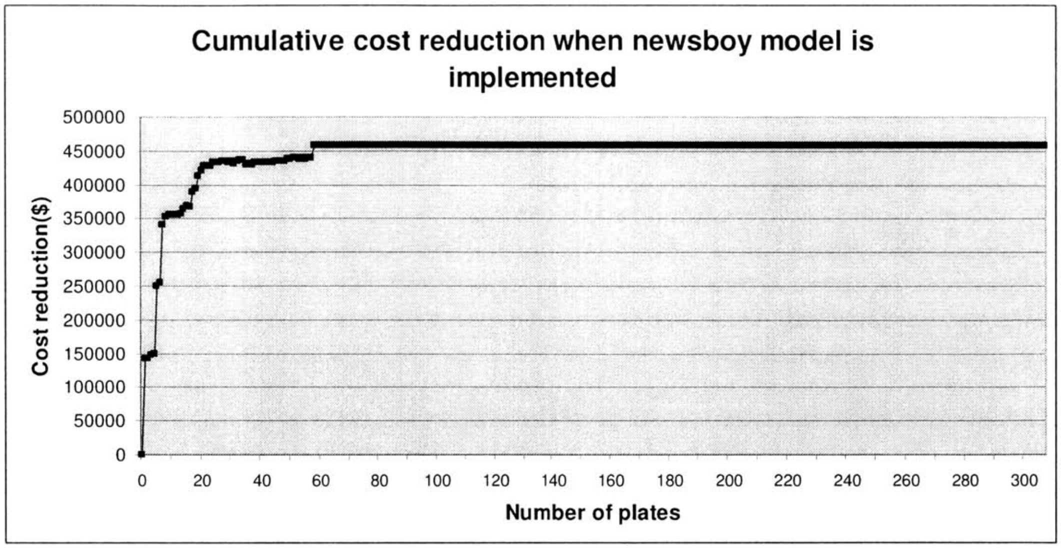

Figure 22 Cumulative cost reduction of newsboy model

Overall recommendation

1. Keppel should implement the newsboy model when planning for purchases of category A steel plates. The most significant cost reductions can be obtained and the demand distribution is relatively accurate for these plates. This category of plates has the potential to provide approximately 85% of total possible cost reduction, as seen from Figure 22.
2. Keppel should implement the newsboy model to plan the purchase quantities for category B1 and B2 steel plates only if the company has the time and resources to spare.
3. Keppel should rely on buyer intuition and expertise for category B3. The projected cost savings for category B3 plates do not warrant the time and effort to formulate and implement an inventory control policy.
4. Keppel should buy all category C steel plates from local vendors as their quantity and frequency does not make it viable for a constant ordering policy to be implemented.

Chapter 6 Conclusion

6.1 Summary of thesis

The goal of the thesis is to examine how Keppel might reduce its inventory costs for the steel plates for its Jack-Ups. The key problem that the company faces is that its MTO quantity is not optimal. Since the company had never done a study on the nature of the demand of steel plates, we had to identify the factors that were critical in defining the steel plate usage in the company. This led to a two-tier ABC analysis being performed to characterize the demand of these plates; based on this segmentation of the plates, we then formulated a set of procurement policies for each segment of steel plates. For plates with the greatest and most predictable demand, we recommended the newsboy model as the solution approach. We faced major challenges in deriving an accurate demand distribution due to insufficient data. We tried various methods to improve and verify the nature of the demand. Finally, we tested the newsboy models with various demand distributions and made a series of recommendations to optimize the MTO order quantity based on the newsboy model.

This thesis shows that implementation of the suggested procurement policies would result in Keppel Fels being able to reduce costs by about $40000 per rig and reduce the material shortages experienced on the ground. The bulk of the savings would come from the implementation of the newsboy quantities as the MTO order quantities for category A steel plates. This cost saving approaches should be put into place as soon as possible, in light of the multiple orders of Jack-Ups in the backlog.

6.2 Future work

More data should be collected and further analyses performed to verify the accuracy of the demand distributions for Jack-Ups.

This entire analysis should be applied to the other products that Keppel Fels produces so that similar cost reductions can be gained.

A quantitative means of defining holding costs of excess steel should be looked into. This could possibly lead to a more in depth study of a newsboy model with perishable items.

Future work might include an analysis which considers the impact of delay and shortages in foreign and local suppliers.

The concept of formulating a reserve quantity with the local suppliers is interesting and should be explored further as it is able to be developed into a generic framework for other industries.

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Appendix 1 "weightage" calculations
Example: finding the "weightage" of rig 1

"Weight" of rig 1 = W_1= (weight of rig 1)/ (weight of 13 rigs)

Appendix 2 formulas and steps used to calculate the different distributions

Calculations formulas for different distributions

1 Distribution of "percentage weight":

Individual percentage weights= $\left(\frac{actualdemand}{weight1rig}\right)\times 100 \Rightarrow \mu, \sigma$

Distribution of percentage weights obtained

2 Costs using actual forecasting (tons): to use the actual amount that Keppel is currently using in its forecasts. This would allow me to gauge their current performance.

3 Solver (find lowest cost using actual tonnage): solver was used to find the purchase quantity that would give the lowest costs over the 13 rigs. The decision variable was the order quantity while the total overage and underage costs over 13 rigs was minimized.

4 "Weighted" actual tonnage:

μ= W_1*(weight of steel plate for rig 1) + W_2*(weight of steel plate for rig 2)....+ W_13*(weight of steel plate for rig 13)

$\sigma = \sqrt{\text{var}(error)}$

Where

$\text{var}(error) = \sum W\_1(demandrig1 - \mu) + W\_2(demandrig2 - \mu)...$

Distribution of "Weighted" actual tonnage obtained

Newsboy model applied

5 Simple average of actual demand: the demand over the 13 rigs was simply averaged out. The error from the actual demand allow me to find the standard deviation of error from the mean. The newsboy model was also employed to find the order quantity.

$\mu = \sum \frac{weightrig1 + weightrig2 + ...}{13}$

$\sigma = \sqrt{\text{var}(error)}$

Where

$$\text{var}(error) = \sum (demandrig1 - \mu) + (demandrig2 - \mu)...$$

Distribution of Simple average of actual demand obtained

Newsboy model applied

6 "weighted percentage weight":

$$\mu = \sum W\_1(percentageweightrig1) + W\_2(percentageweightrigrig2)...$$

$$\sigma = \sqrt{\text{var}(error)}$$

$$\text{var}(error) = \sum W\_1(percentageweightrig1 - \mu) + W\_2(percentageweightrigrig2 - \mu)...$$

Appendix 3 Reserve capacity figures

Using data from DH 36 steel plates with thickness 25mm

	Rig 1	Rig 2	Rig 3	Rig 4	Rig 5	Rig 6	Rig 7
Demand for Grade DH 36, 25mm(MTons)		13.04	8.69		13.12		4.37
Cost without reserve quantity	0	25456.9	16971.27	0	25620	0	8540
Reserve quantity cost	400	400	400	400	400	400	400
Flexible excution cost		12240	12240		12240		6686
Spot market cost		9840.90	1355.27		10004		

Continue from table above

Rig 8	Rig 9	Rig 10	Rig 11	Rig 12	Rig 13	Total price
0	0	0	0	0	0	**76588.2**
400	400	400	400	400	400	5200
						43406.1
						21200.17
						69806.27

Appendix 4 Category A steel plates and newsboy order quantities

Grade	thickness	quantity(MTon)
DH 36	50.8	93.65618
AH 36	7.938	90.8771
EH 36	38.1	102.8132
EH 36	50.8	102.5909
A	19.05	100.3819
A	11.11	108.2149
A	4.763	117.3613

A	12.7	124.6035
DH 36	38.1	140.8822
AH 36	15.875	225.2283
AH 36	12.7	227.1112
A	6.35	232.1873
DH 36	22.23	263.937
AH 36	9.525	283.7452
A	7.938	281.435
AH 36	11.11	300.1212
AH 36	19.05	330.5833
A	9.525	404.6365
DH 36	25.4	458.149

Appendix 5 Category B1 steel plates and newsboy order quantities
[Percentage of total rig weight was found to give the optimal newsboy quantities]

Grade	thickness	quantity(% of total rig weight)
DH 36	28.575	0.116966
EH 36	31.75	0.568042
B	25.4	0.257295
AH 36	6.35	0.506062
EH 36	57.15	0.345467
DH 36	15.875	0.518609
EH 36	76.2	0.471718
EH 36	19.05	0.906028
AH 36	14.29	0.771566
DH 36	34.925	0.774187
EH 36	12.7	1.074405
A	15.875	0.862411
DH 36	31.75	0.972816
DH 36	19.05	1.091583
EH 36	25.4	1.443557

Appendix 6 Category B2 steel plates and newsboy order quantities

Grade	thickness	quantity(MTon)
A	14.29	4.848897
DH 36	12.7	4.082289
EH 36	82.55	8.500886
RIVERACE 610M	88.9	11.0635
D	25.4	9.750804
EH 36	22.23	7.179081
RIVERACE 610M	63.5	12.82586
B	19.05	6.32677

EH 36	63.5	10.83855
EH 36	88.9	16.51022
EH 36	34.925	11.61772
RIVERACE 610M	38.1	14.32798
EH 36	65	19.29116
RIVERACE 610M	19.05	14.23747
RIVERACE 610M	76.2	22.67611
RIVERACE 710M	25.4	20.55403
RIVERACE 710M	44.45	22.15288
EH 36	44.45	15.82003
EH 36	45	20.11507
RIVERACE 710M	50.8	25.66702
DH 36	44.45	22.68307
RIVERACE 710M	19.05	46.87392
RIVERACE 710M	38.1	43.23193
RIVERACE 710M	31.75	61.86928
RIVERACE 610	31.75	82.27752