Head & Base Production Optimization: Inventory Management Strategy

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Abstract

A new inventory management strategy was developed for Schlumberger to reduce waste in material handling and improve the warehouse receiving efficiency. The current warehouse receiving situation was analyzed; then the receiving procedure was summarized and the time spent for each step was measured. After that, the cause and effect analysis for the low efficient warehouse operation was analyzed and solutions are proposed.

The implementation of this model in the company has seen significant improvements in warehouse operation efficiency. The receiving time of specific machined parts has been reduced by 32% and the receiving of specific subassembled parts has been reduced by 53%. The improvement has led to a cost saving of US$ 422,148.

Keywords: Lean manufacturing, artificial lift, head & base, inventory management, warehouse

Thesis Supervisor: Kamal Youcef-Toumi
Title: Professor of Mechanical Engineering

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1. Introduction

1.1 Project Introduction

This research project was carried out at Schlumberger Limited (SLB) in Singapore. At Schlumberger, one of the most critical problems is that the current production rate for Head &Base (H&B), an essential component for all the final products, cannot meet the customer demands. This is caused by the long setup time in the machine shop. Another problem is that there is unnecessary material handling activities in the H&B production process. This project is focused on improving production rate as well as reducing waste activities in material handling during in H&B production.

This project is divided into two parts aiming at solving these two problems respectively: The first part aims to improve the setup time efficiency and the second part aims to design new inventory management strategy in order to reduce material handling waste. This thesis focuses on the second part of this project.

The main objective of the new inventory management strategy is to create new ways of storing the H&B parts to improve the receiving efficiency in warehouse. The approach to this project will follow the lean-six sigma roadmap with a focus on waste reduction.

1.2 Company background

Schlumberger Limited (SLB) is the world's leading oilfield services company supplying technology, information solutions and integrated project management that optimize reservoir performance for customers working in the oil and gas industry. Founded in 1926, today the company employs more than 87,000 people working in approximately 80 countries.

The company was founded by the two Schlumberger brothers who invented wireline logging as a technique for obtaining downhole data in oil and gas wells. Today, it continues to build on the industry's longest track record of providing leading edge

Exploration and Production (E&P) technology to develop new advancements-from reservoir to surface.

Singapore Integration center (SPE) is one of Schlumberger's largest research, development and manufacturing plants for electric submersible pumps (ESPs), downhole pressure/temperature gauges and gas lift mandrels (GLMs). It is a 550,000 square foot plant and has a full set of manufacturing operations, from foundry works producing castings for pumps, a large machine-shop to machine all the component parts, an assembly-shop and full Quality Control testing facilities.

The total workforce has more than 700 employees including more than 70 professionals (designers, engineers) in Engineering, Manufacturing, Sustaining who are focused on continuous improvements and new product development of SPE's products.

SPE adopts a make-to-order manufacturing model for its high-mix low-volume products. Most of the orders are then sold to internal customers such as Schlumberger's field services and other manufacturing centers.

1.3 The Product

The major products produced in SPE are electric submersible pumps (ESPs) which include a motor, a pump, a protector and a gas separator/intake. ESP systems have a wide range of applications and offer an efficient and economical lift method.

To ensure a competitive advantage over its competitors in the market**,** Schlumberger also provides monitoring systems, surface electrical equipment, engineering services, and optimization services to complement the ESP system. By integrating technology and service, Schlumberger successfully provides an optimum lift system for the well and optimize the pump and well performance while reducing operating costs for the clients.

The four major products are assembled into a fully functional ESP at customer's site, as illustrated in Figure 1-1.

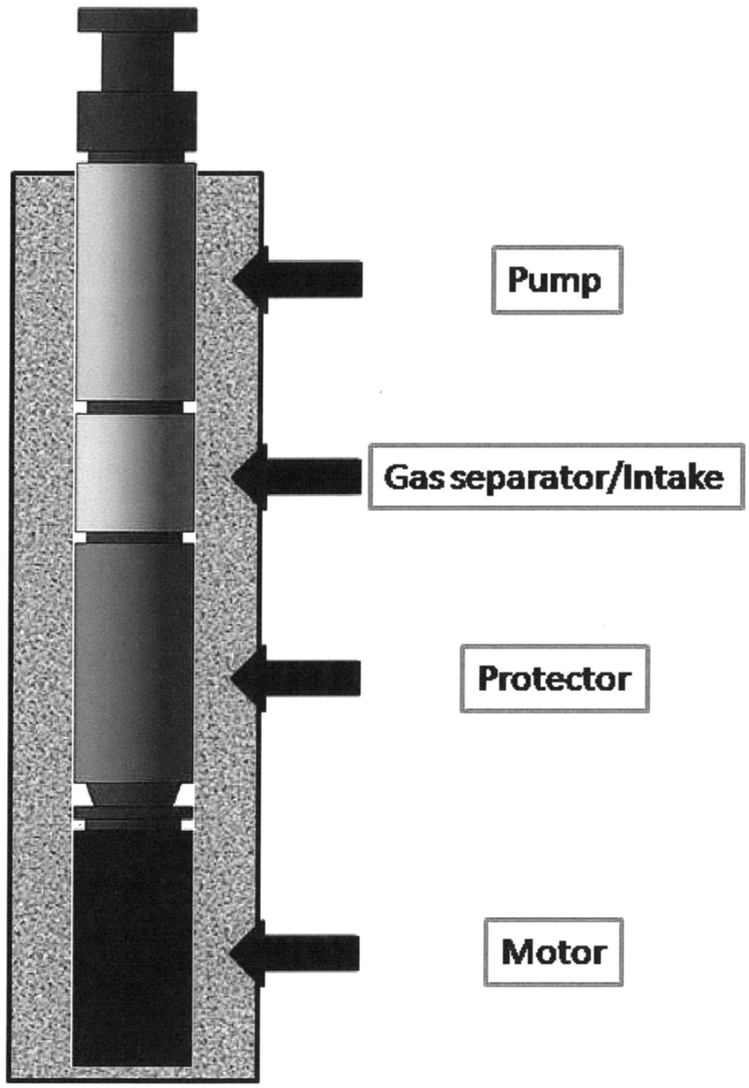

Figure 1-1: Final Assembled ESP

In the manufacturing process, basic components are first manufactured and then assembled into four major products. For reasons of economy and convenience, basic components are categorized into housing, shaft, head & base, thrust bearing, bar part, stage, and rotor. General steps regarding the manufacturing process for the four basic units include casting, machining and subassembly. Details are shown in Figure 1.2: Process Map of ESP Manufacturing.

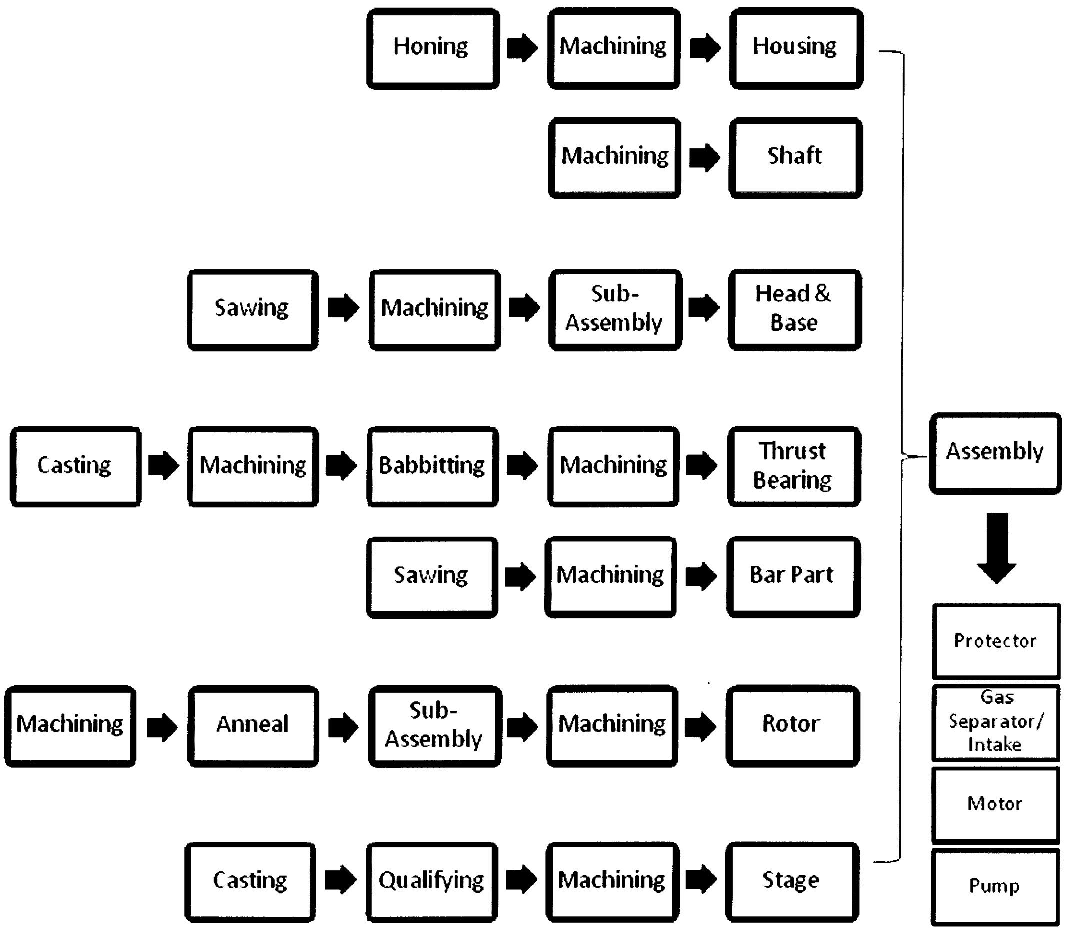

Figure 1-2: Process Map of ESP Manufacturing [1]

In this project, the main focus is in the manufacturing of Head and Base (H&B). H&B parts are one of the key components for all the final products. Each pump, motor, protector, and intake, will require at least one H&B part. The general steps for manufacturing H&B include sawing, CNC machining, subassembly. In total, there are more than 1000 different types of H&B parts.

2. Problem Statement

2.1 Introduction

This chapter first describes the current flow of H&B production. Then it discusses some problems the H&B department is facing, and analyzes the root cause of the problems. Lastly, the scope and objective of this thesis are defined.

2.2 H&B production process flow

There are three major steps in the H&B production process: sawing, machining, and subassembly. During the H&B production process, the parts go to warehouse twice for storage purpose. The process flow is illustrated in Figure 2-1

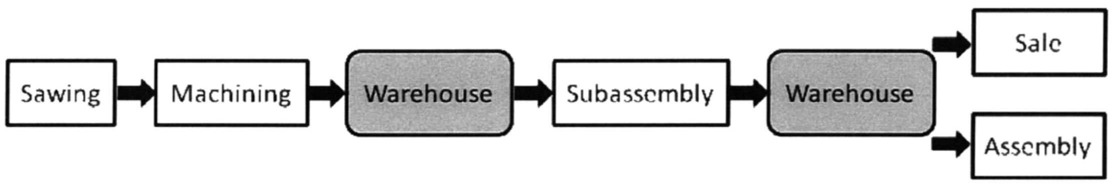

Figure 2-1 Head & Base Process Flow

At the sawing station, long bar shaped material is cut into short bar parts; then the bar parts are sent to the machining shop to be machined into detailed parts. After being checked by inspectors, the detailed parts are sent to the warehouse, waiting for subassembly process. The subassembly station assembles components and detailed parts together to make the H&B parts ready for equipment assembly. The subassembled parts are sent to the warehouse again. A few days later, some of the subassembled parts are sent to equipment assembly to be assembled into integrated products, while others are sent to the service center for direct part sale.

2.3 Limitations of current process flow

After examining the current process flow, two problems are identified. They are explained in detail below:

i. *The setup time in the machining shop takes approximately 12.5% of the machining time*

Setup is the process of changing the machine configuration from producing one part to another. The average setup time is about 3 hours, which includes the tool change time, tool calibration time, as well as extra rework and inspection time. The machine shop runs three shifts (each shift is 8 hours) per day and the average setup frequency is once per day; thus the setup time is about 12.5% of the total machining time.

The long setup time affects the machining capacity directly; thus the company has to outsource some work orders to contractors, which incurs much higher cost, increases the lead time and create difficulties for quality control.

The long setup time also affects the company's overall production strategy. Although the company tries to adopt a make-to-order strategy, the planner has to combine orders of the same part in order to reduce setup frequency and thus setup time. This practice then increases the work in process (WIP), which results in higher inventories holding cost. Moreover, it also increases the lead time.

ii. There is material handling and transportation waste in warehouse receiving process.

Figure 2-1 above shows that the H&B parts are sent to warehouse twice during the production. The first time is after machining, and the second time is after subassembly.

The receiving of H&B parts involves a lot of manual lifting and requires heavy usage of material handling equipment. The H&B parts sent to warehouse are temporarily stored in big wood bunks in the warehouse. Warehouse receiving operator consolidates the parts and transfers them to other bunks in order to put the same parts together and separate similar but not identical parts. If similar but not identical parts are stored together, there is a possibility that the issuing operator might pick up the wrong part. The consolidation process is inefficient because the operator needs to spend a lot of time to find appropriate empty bunks and transfer parts from one bunk to others. After consolidation, the bunks are placed onto high racks using forklift. The number of forklifts is limited; thus sometimes the bunks need to wait on the warehouse floor for a long time. There is only limited space in the warehouse for bunk storage and movement, but there are always a lot of bunks on the warehouse floor, which makes the receiving more difficult and creates the potential for an accident.

In addition to the inefficient receiving process, there is waste in material transportation of the subassembled H&B parts. The H&B subassembly station and equipment assembly station are adjacent to each other while the warehouse is located 100 meters away. However, the subassembled parts are not sent to equipment assembly directly. They are sent to warehouse, going through the tedious receiving process and then sent back to equipment assembly when needed.

2.3 Scope and objective

The objective of this project is to reduce unnecessary material handling and transportation in the warehouse receiving process.

The scope of this project will be limited to designing a new inventory management strategy for the H&B parts only. The project is divided into two parts. The first part is to improve the receiving process of H&B detailed parts, and the second part is to shift the inventory of H&B subassembled parts to subassembly area.

2.4 Summary

In sum, there are two major problems in the H&B production process, one is the long setup time and the other one is material handling waste. This project will focus on material handling waste reduction and will be limited to designing a new inventory management strategy for H&B parts.

3. Literature Review

3.1 Introduction

The company carries out many lean-six-sigma projects every year to continuously improve their production efficiency, which use tools from both lean and six-sigma. This head & base production optimization project is one of them. Lean manufacturing focus on speed and removal of waste, while traditional six-sigma focuses on quality. By combining the two, the result is better quality and faster process.

This project mainly focuses on removing waste in the warehouse receiving process; therefore improving warehouse receiving efficiency and reducing lead time. This chapter reviews the lean manufacturing concept and some tools used in lean manufacturing, which serves as the theoretical foundation for this project.

3.2 Lean manufacturing

Lean manufacturing or Lean production is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. In 1991, James P. Womack first defined Lean manufacturing is a generic process management philosophy derived mostly from the Toyota Production System (TPS) [2].The main focus of Lean is to optimize flow by increasing efficiency, decreasing waste and empirically digging out the problems. Lean principles come from the Japanese manufacturing industry. The term was first coined by John Krafcik in a Fall 1988 article, "Triumph of the Lean Production System," published in the Sloan Management Review and based on his master's thesis at MIT [3]

There are basically two approaches to Lean Manufacturing. One is to take Lean as a set of tools that assist in the identification and elimination of waste. The elimination of waste helps improve quality and reduce production time and cost. Examples of such tools are Value Stream Mapping, Five S, Kanban, and poka-yoke. The other approach focuses on improving the smoothness of work, thereby steadily eliminating unevenness through the process. Techniques to improve the smoothness include production leveling, Kanban and the Heijunka box.

In this research, we mainly follow choose the waste elimination approach in which the primary work is to distinguish the waste from normal manufacturing process.

Ohno defined three types of waste: muda (non-value-adding work), muri (overburden), and mura (unevenness). This ever finer clarification of waste is the key to establishing distinctions between value-adding activity, waste and non-value-adding work [4]. Taiichi Ohno further specified the waste into seven detailed categories [5]:

- Transportation (moving products that are not actually required to perform the processing)
- Inventory (all components, work-in-progress and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Waiting (waiting for the next production step)
- Overproduction (production ahead of demand)
- Over Processing (due to poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects)

This clear definition of waste is important and it made the success of TPS possible. It also provides us instructive guidance in identifying waste and therefore opportunity for improvement for the Schlumberger project. Most importantly, clear identification of where waste may also provide opportunity for breakthroughs in SMED, JIT and other process changing techniques.

3.3 Lean-six Sigma (LSS) project roadmap

LSS project roadmap [6] is the guideline for all the LSS projects carried out in Schlumberger, which is summarized based on previous successful LSS project experiences. It has five major steps: define, measure, analyze, improve and control.

The "define" step is to define the problem, understand the current process situation and show that this project is a business priority. Thus it is essential to communicate with all the relevant personnel, from top level managers, supervisors to bottom level operators. The top managers know the big picture and are able to articulate their vision and thinking clearly, while the operators understand the process better than anyone else. The operators can tell what should be improved to increase their productivity. After collecting enough information, the problem and project scope can be well defined and the process map can be drawn; moreover, it is easier to be approved by managers.

The "measure" step is to have the right measures for the project, establish the baseline measures of the current process, and set objectives in order to gauge improvement success. In this stage, quantitative data related to the process map should be collected. For this inventory management project, the current receiving time of H&B parts should be measured. These data are then used as baseline for future improvement.

The "analyze" step is to uncover the potential root causes of the problem and then prioritize them to find the ones that have the biggest impact on the problem. This step involves process map analysis, data analysis as well as cause and effect analysis.

The "improve" step is to generate solutions, and then prioritize, select, and implement the solutions. After that, the results are measured and compared with the baseline measures to examine the extent of improvement as well as whether the project objective has been accomplished.

The control step is to standardize the improved actions and sustain the results over time, then communicate and share the best practices with others and identify the future improvement needs for the area.

3.4 Summary

The lean manufacturing concept provides a solid theoretical foundation for this project; especially the tools that help reduce transportation and waiting. The LSS project roadmap provides an excellent outline for carrying out the project. This project will be carried out based on the lean manufacturing concept and will closely follow the LSS project roadmap.

4. Methodology

4.1 Introduction

This chapter describes the process of carrying out this project, following the lean six sigma project roadmap. Firstly, the current warehouse operation especially the receiving process of H&B parts is studied; then the time study for each step of the receiving is performed. Based on the current receiving process and time study, a cause effect analysis is performed, and several causes of the low efficient receiving process are identified.

4.2 Current situation analysis

Both the H&B detailed parts and H&B subassembled parts are stored in warehouse. Every part stored in warehouse has to go through a receiving and an issuing process. The current warehouse receiving and issuing processes are inefficient. An illustration of the warehouse receiving and issuing of H&B parts is shown in Figure 4.1 below:

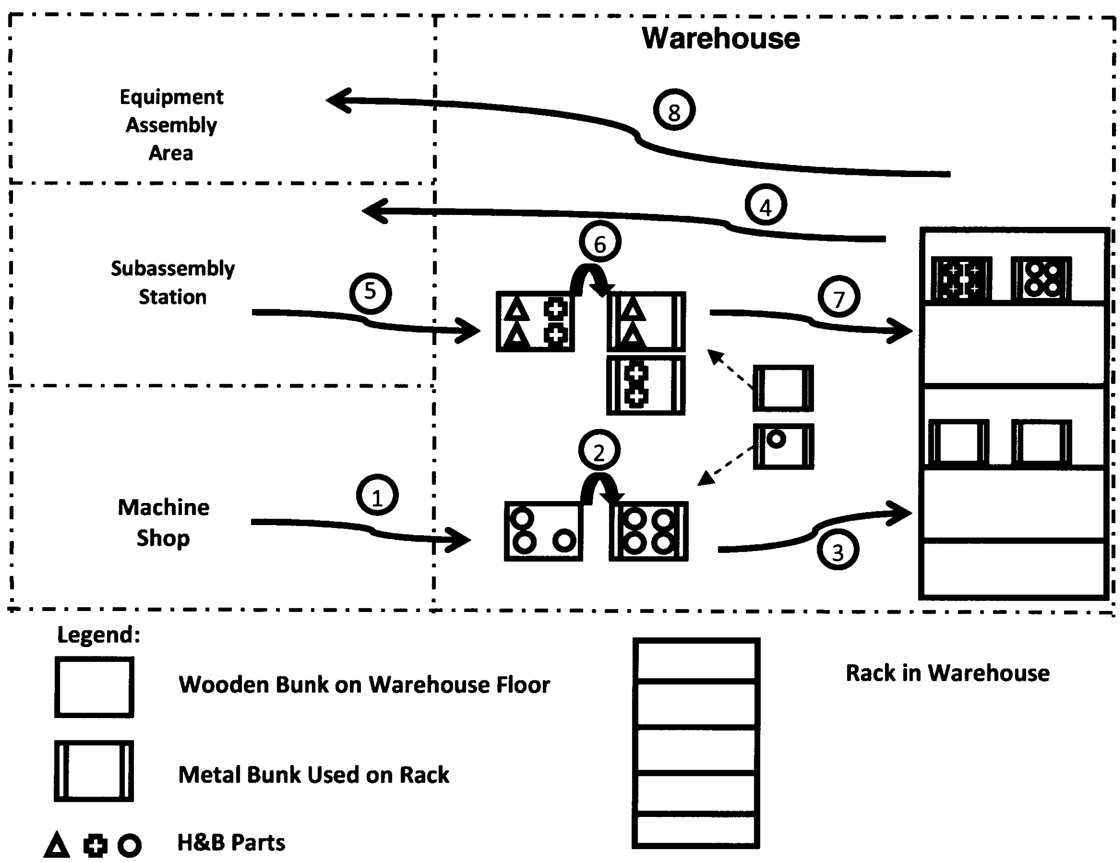

Figure 4-1: Warehouse receiving/issuing process of H&B parts

There are mainly 8 steps of work in the warehouse for the H&B parts, including receiving and issuing. The detailed explanation of these processes is stated below:

1. In process inspector delivers H&B detailed parts from machine shop to warehouse, and then transfers the parts from trolley to big wooden bunks on warehouse floor.

2. Warehouse receiving operator consolidates the parts into other bunks. The same parts are put together and similar parts are separated. If similar parts are put together, there is a possibility that the issuing operator might pick up the wrong part.

3. The consolidated bunks are placed onto the high rack using forklift.

4. When warehouse receives work order for subassembly, warehouse operator brings down the bunks from the rack, get the H&B detail parts, and then deliver the parts to subassembly station together with other accessories.

5. After the subassembly operation, the subassembly operator delivers the subassembled H&B parts back to warehouse and update the location of the parts in the system.

6. Warehouse receiving operator receives the subassembled H&B parts following the same procedure as receiving H&B detailed parts.

7. The consolidated bunks are placed onto the high rack using forklift.

8. When warehouse receives work order for equipment assembly, warehouse operators bring down the bunks from the rack, get the subassembled H&B parts, and then deliver the parts to equipment assembly area together with other accessories.

4.3 Data collection

After the general material flow and warehouse receiving procedure was understood, the detailed warehouse receiving process was studied and summarized. Then time study was carried out to examine how much time each step of the receiving process spends. The time spent on each step would help analyze the causes of low efficient receiving, and the total receiving time would be calculated and used as benchmark for future improvements.

The time study was divided into two parts, the first parts was for the H&B detailed parts receiving process, and the second part was for the H&B subassembled parts receiving process. The warehouse operator normally receives one bunk of parts after another. However, each bunk has different number of work orders and different number of parts. After the receiving process was studied, it's found that the major factor that affects the receiving process is the number of work orders. The time study result was the average receiving time for one bunk with 5 work orders.

H&B detailed parts

The time study result for H&B detailed parts receiving process is shown in Table 4.1 below:

Table 4-1: Time study result for warehouse receiving of H&B detailed parts

H&B detailed parts receiving					
NO.	WORK ELEMENT	Time Elements (min)			
		Auto	Manual	Wait	Walk
1	Check work order & find parts location		3		
2	Find bunks from rack and move bunks around			3	9
3	Transfer parts to other bunks		5		
4	Record location into work order & update bin card		10		
5	Update logbook		3		
6	Place bunk onto rack		3		
7	Send work order to clerk				1
Summary			**24**	**3**	**10**
Total Time		**37**			

The current receiving process has 7 steps. Firstly, the receiving operator check the work order from the system to see whether there are the same parts in warehouse, if there are parts in the warehouse already, the location is recorded down on the work order. This step needs 3 minutes for 5 work orders. Then the receiving operator checks the locations recorded on the work order, if there is enough space to put the parts, the receiving operator will transfer the parts to that bunk, while if the space in the location is not enough to put the parts, the receiving operator will find other bunks that have enough space and transfer the parts to that bunk. If there are no same parts in the warehouse, the parts will be transferred to any bunk that has enough space. The time spending on finding bunks is 12 minutes; 9 minutes spends on traveling between racks and moving bunks around and 3 minutes spends on waiting material handling equipments. After transferring one order of parts, the location of the parts will be recorded down on the work order sheet. For each order, it needs 1 minute to transfer parts and 2 minutes to record the location & update the bin card. After receiving the whole bunk of parts, the locations of parts will be recorded into a logbook, and then the work order sheets are send to warehouse clerks to update parts' location in the system and close the work order. The total time to receive one bunk of parts is about 37 minutes.

H&B subassembled parts

The time study result for H&B subassembled parts receiving process is shown in Table 4.2 below:

Table 4-2: Time study results for warehouse receiving of H&B subassembled parts

H&B subassembled parts receiving					
NO.	WORK ELEMENT	Time Elements			
		Auto	Manual	Wait	Walk
	Delivery (Subassembly Operator)				
1	Check part number		1		
2	Send bunks to warehouse				4
3	Update parts location		4		
4	Back to sub-assembly operation				3
	Summary		**5**		**7**
	Total Time (Subassembly Operator)	**12**			
	Receiving (Warehouse Operator)				
5	Check work order & find parts location		3		
6	Find bunks from rack and move bunks around			3	9
7	Transfer parts to other bunks		5		
8	Record location into work order & update bin card		10		
9	Update logbook		3		
10	Place bunk onto rack		3		
11	Send work orders to clerk				1
	Summary		**24**	**3**	**10**
	Total Time(Warehouse Operator)	**37**			
Total Time		**49**			

Two parties are involved in the current H&B assembled parts receiving process. Firstly the warehouse operator delivery the parts to the warehouse and then the warehouse operator receives the parts. During the delivery process, the subassembly operator first check the parts to ensure that all the parts are inspected and accepted by in process inspector, then he sends the parts to warehouse using stacker, after the parts are puts down the parts on the warehouse floor, the subassembly operator updates the parts location in the system. After that, the subassembly operator goes back to subassembly station and sends another bunk of parts to warehouse until all the subassembled parts are delivered to warehouse. On average, it takes 12 minutes to deliver on bunk of subassembled H&B parts to warehouse. The warehouse operator receives the subassembled H&B parts following the same procedure as receiving H&B detailed parts, and the time spending of receiving one bunk of subassembled parts is about the same as the time spending of receiving one bunk of detailed parts. So the total time spends on receiving one bunk of H&B subassembled parts is 49 minutes.

4.4 Cause Analysis

After the situation is understood and relevant data are collected. The cause and effect analysis is done using Ishikawa diagram. The result is shown in Figure 4.2 below:

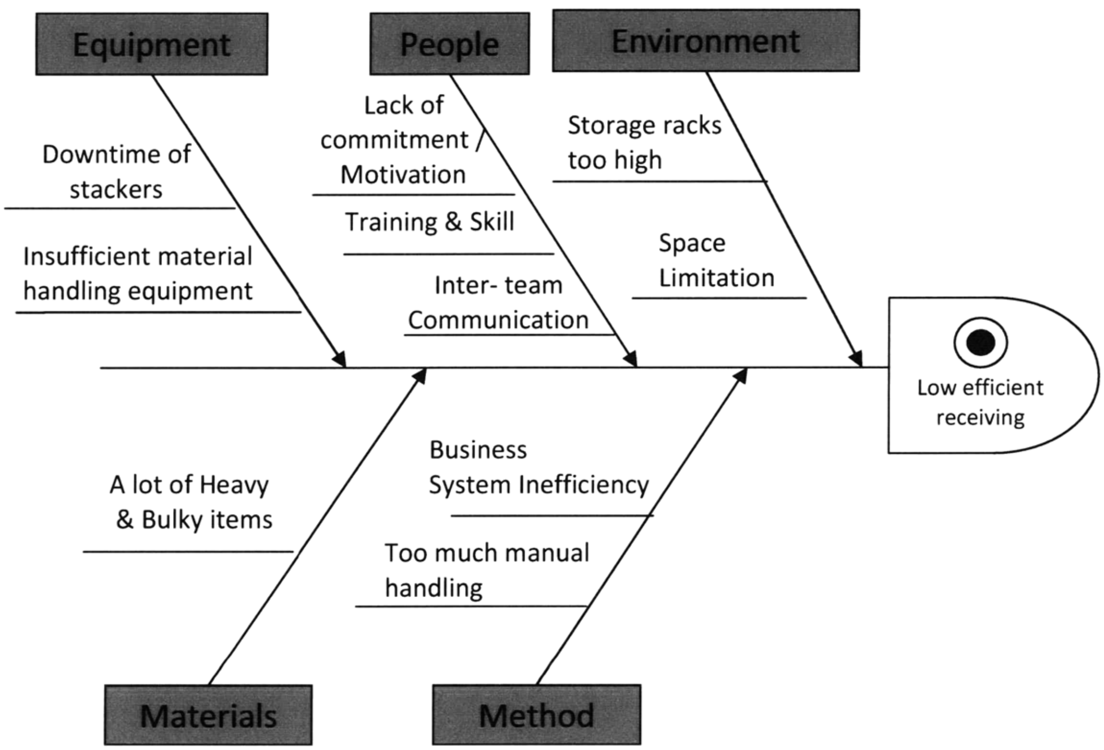

Figure 4-2: Cause and effect analysis

One major cause of the low efficient receiving/issuing is because of the business system inefficiency that the ERP system the company using is not compatible with the scanning technology, so the part location has to be manually recorded and entered into the system. The H&B parts change location many times in the whole flow and each location change involves a lot of manual work.

Secondly, there is too much manual handling of the materials during warehouse receiving processes. The parts are transported back and forth from one building to another and transferred from one bunk to another, which needs a lot of manual work. Moreover, there are a lot of heavy and bulky H&B parts, moving those parts from one bunk to another manually is fatiguing.

Thirdly, the transportation and handling of material depends heavily on material handling equipment (MHE), however, the number of MHEs in warehouse is not enough; thus sometimes people have to wait for the MHEs. The racks in warehouse are very high, thus forklift is an essential equipment to move bunks up to the racks. However, the number of forklifts is not enough, the receiving operators and issuing operators always wait for the forklifts to put parts onto the racks or get parts from the racks.

Human factors also affect the receiving/issuing process, such as lack of communication between receiving operators and issuing operators. Sometimes issuing operator needs the parts that are just been moved onto the rack, so he has to move the parts down from the rack again, which wastes a lot of time.

4.5 Approach

After the data collection and cause analysis, the warehouse receiving problem is divided into parts. The first part is the receiving of H&B detailed parts, the H&B parts that delivered from machine shop, and the second part is the receiving of subassembled parts, the H&B parts that delivered from subassembly station.

The reason to divide the problem into these two parts is that the subassembly operation is strictly make to order process that each subassembly work order corresponds to one customer order, while the machining operation is not strictly make to order that each machining work order usually combines several customer orders; so different inventory management strategies are designed for the H&B detailed parts and subassembled H&B parts, in order to improve the receiving process.

4.6 Part 1: H&B detailed parts

4.6.1 Proposal

The most time consuming step in the H&B detailed parts receiving process is finding bunks from rack, which needs 12 minutes. The second time consuming step is recording part location and updating the bin card, which needs 10 minutes. The part location update process is done manually because of the business system inefficiency that the ERP system the company using is not compatible with bar code scanning or RFID sensing systems. In order to solve this problem, the company has to change its whole ERP system, which is out of this project's scope. So this project focuses on removing the process of finding bunks. The proposal is to install a shuttle, which is able to bring down the trays inside automatically, which would avoids the process of traveling around the racks and bringing bunks up and down from the racks using forklifts.

An illustration of the proposal is shown in figure 4.3 below:

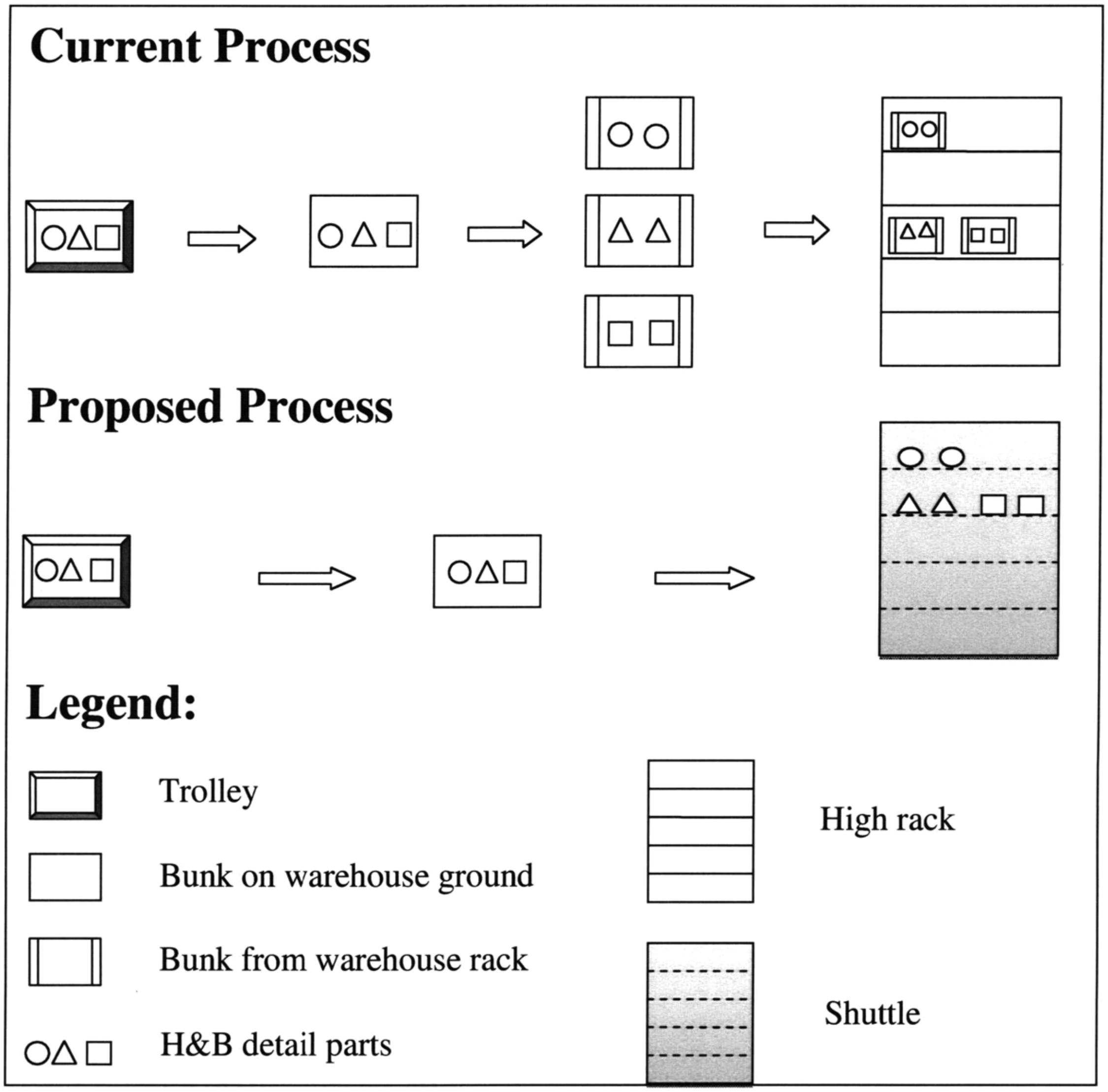

Figure 4-3: Comparison of current and proposed H&B detailed parts receiving process

It is found out that another Schlumberger production center has an unused shuttle that can be transferred here. The shuttle has 70 trays, and each tray is able to contain 450 kg weight. When the tray number is entered in the control board, the shuttle brings down the tray to the loading level automatically, and at the same time, the tray at the loading area is brought up. The whole process needs 55 seconds only, while the time needed to bring a bunk down from the rack and bring another up needs 4 minutes.

4.6.2 Implementation

In order to use the shuttle, floor layout and H&B parts delivery strategy are designed. The floor layout is shown in figure 4.4 below:

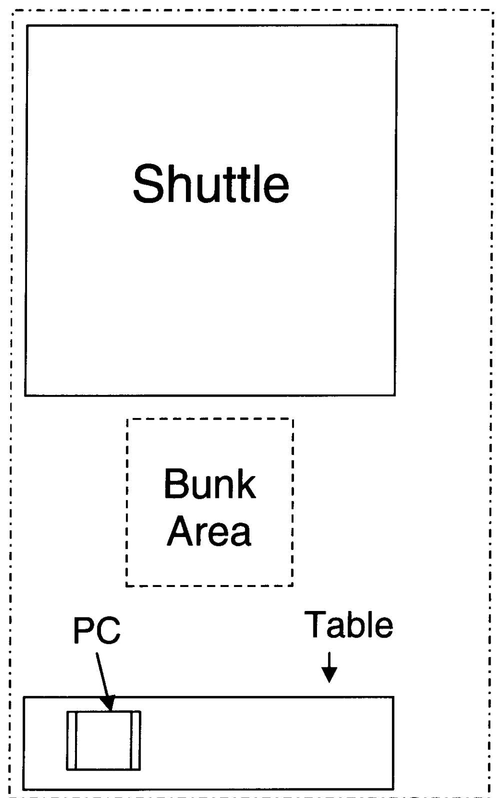

Figure 4-4: Shuttle layout

In this layout, there is a table in front of the shuttle to put stationary such as work order, pen etc., the PC on the table is used to check the work order and part location, and the bunk area is used to put bunks that delivered from machine shop.

The H&B parts delivery strategy is illustrated in figure 4.5 below:

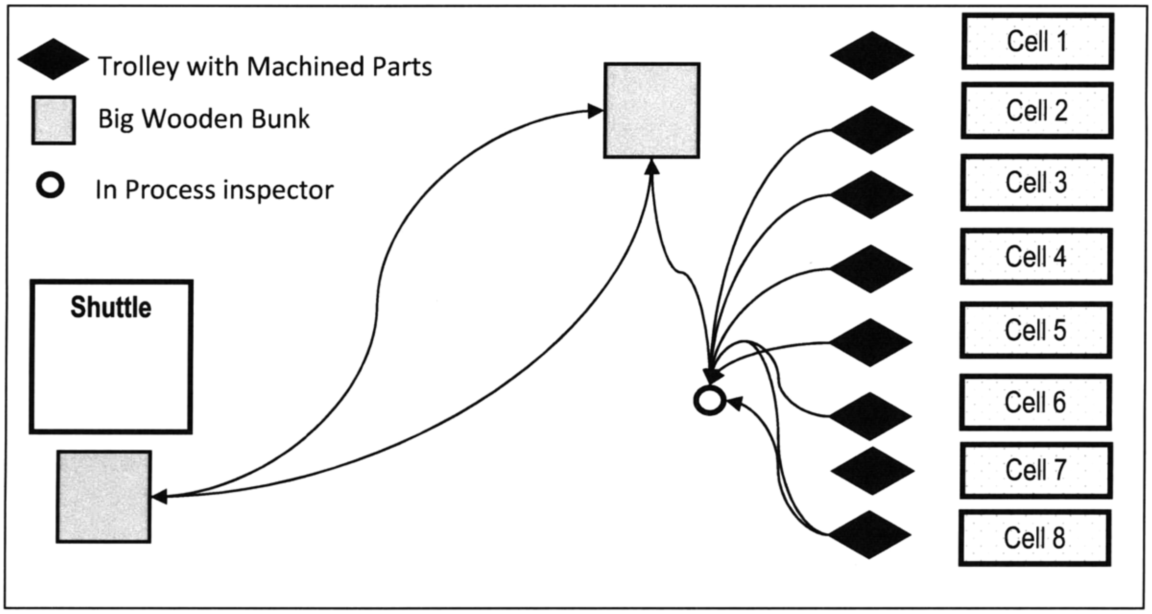

Figure 4-5: H&B detailed parts delivery strategy

In this strategy, after the in process inspector checked the machined parts, he transfer the parts from the trolleys besides each cell to the bunk on machine shop floor, after the bunk is full, he deliver the bunk to the shuttle bunk area using stacker. After that, the warehouse receiving operator receives the parts into the shuttle.

Each tray of the shuttle is able to support 450kg weight only, in order to effectively utilize the shuttle, only parts that below 10 kg are allowed to store inside the shuttle. This also reduces the risk of accidents. If several very heavy parts are placed in one side of the tray, there is a possibility that those parts will topple the tray over and break the shuttle down.

4.7 Part 2: Subassembled H&B parts

4.7.1 Proposal

The subassembly operation is strictly make to order process; about 55% of the work orders are for equipment assembly and the rest are for direct part sale. The subassembled parts for equipment assembly will eventually be delivered to equipment assembly station, while the parts for direct part sale have to go back to warehouse, then be packed and delivered to customers. So it's not necessary for the pars for equipment assembly go back to warehouse; they could be temporally stored at the subassembly area or equipment assembly area, which would then eliminate the inefficient warehouse receiving process. The new flow of subassembled H&B parts is illustrated in figure 4.6 below:

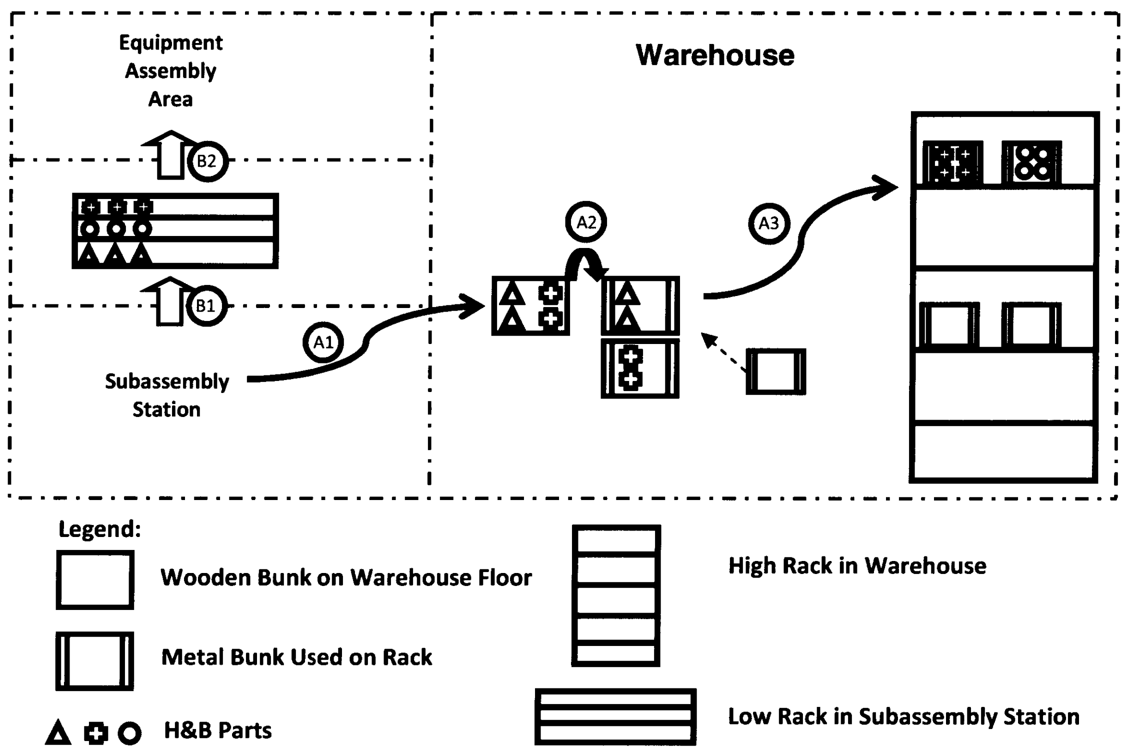

Figure 4-6: Proposed flow of subassembled H&B parts

In the new flow, the parts for direct part sale are still sent back to warehouse, while the parts for equipment assembly will be temporally stored at low racks near the subassembly station. Subassembly operator pushes the parts to the storage area using trolley and places the parts onto the rack directly from the trolley, without transferring to any bunks.

Currently, both the parts for direct part sale and for equipment assembly are sent back to warehouse, then the warehouse receives all the parts. When equipment assembly needs the parts, the parts are delivered to equipment assembly station from the warehouse. The process is shown in figure 4.7 below:

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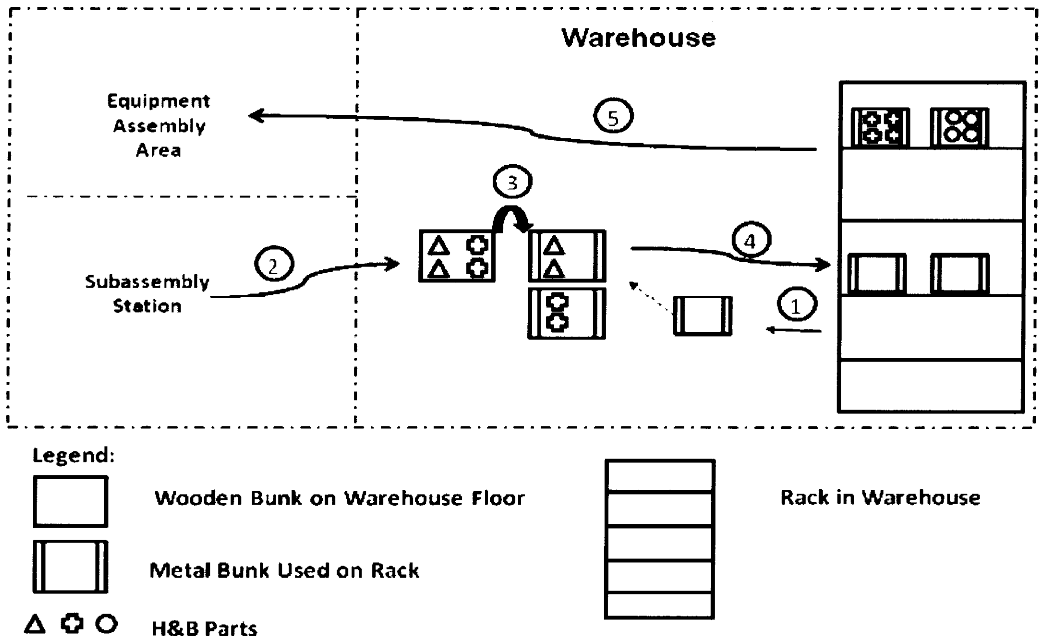

Figure 4-7: Current flow of subassembled H&B parts

4.7.2 Implementation

There is only limited space available in the subassembly area, so the required storage capacity need to be analyzed and then the new storage racks layout need to be designed according to the capacity demand.

Required storage capacity:

The required storage capacity is calculated from the equipment assembly capacity, which is shown in Table 4.3 below:

Table 4-3: H&B parts equipment assembly demand

	Assembly Capacity/Week	H&B parts per equipment				H&B parts demand /Week	H&B parts demand/Day
		Head	base	Body	Bag frame		
Motor	60	1	1			120	20
Pump	80	1	1			160	27
Protector	60	1	1	3	2	420	70
Gas Separator/intake	30	1	1			60	10
Total	230	4	4	3	2	2990	127

The major equipments the company producing are motor, pump, protector, gas separator and intake. The weekly assembly capacity for these products is 230, which needs 2990 H&B parts. The equipment assembly always runs on full capacity and works 6 days per week, thus the daily demand of H&B parts is about 127 parts.

According to the planning schedule, the parts need to stay at subassembly area for 4 days before sent to equipment assembly station, which means that the storage area has to be able to store 608 H&B parts. The average diameter of the H&B parts is 14 cm and the maximum height of the H&B parts is 34 cm. All the parts are going to be placed straight upward; thus the required storage capacity is: $14^2 \times 608 = 119{,}168\,\text{cm}^2$.

Rack layout design:

The available space in the subassembly area is 310 cm x 440 cm. New storage racks are designed based on the available space as well as required storage capacity. The racks have four levels and the spacing between each level is 40 cm, the width of the rack is wide enough to place 5 parts, and the length of the rack will fit to the available area. An illustration of the rack layout is shown in Figure 4.8 below:

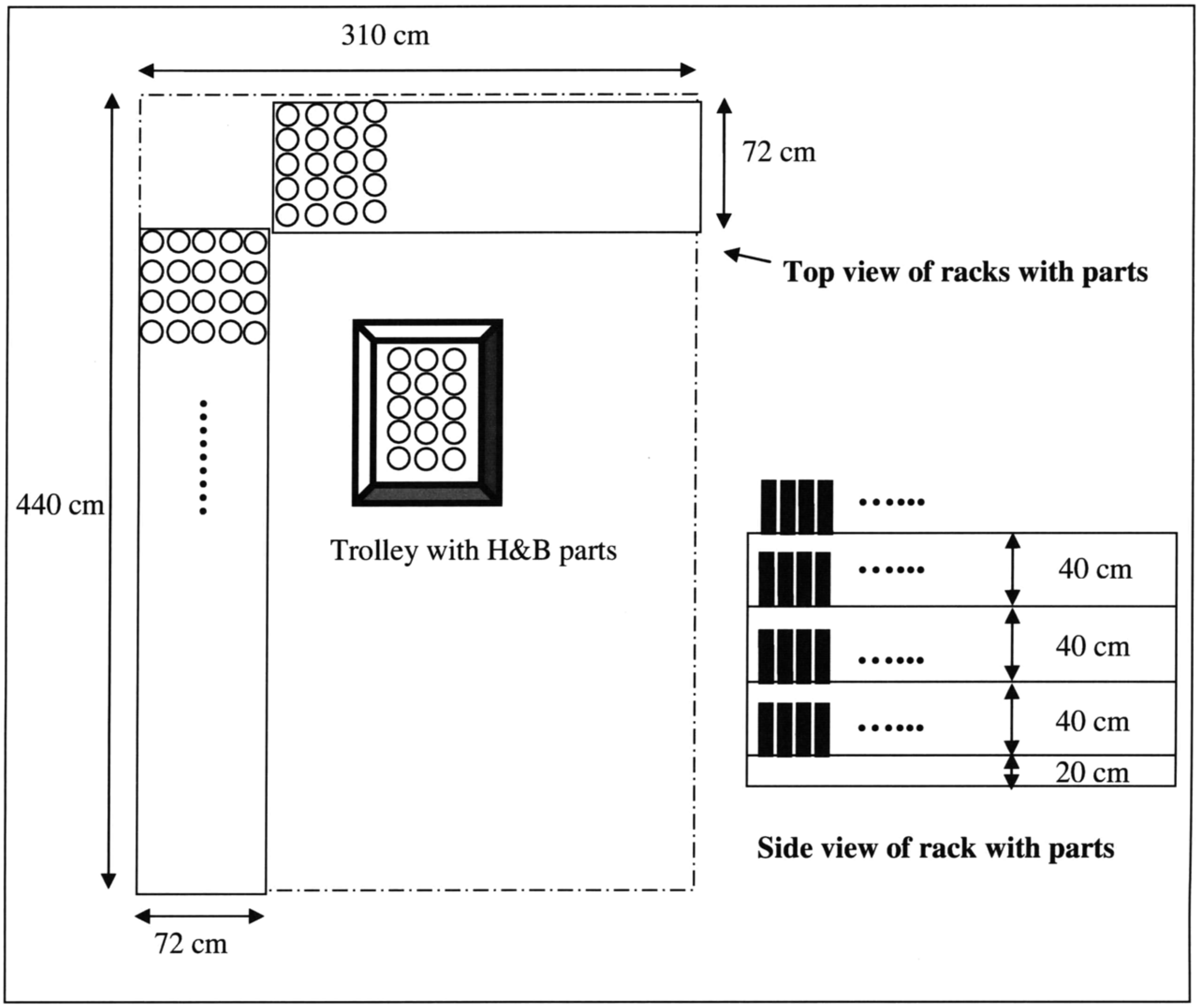

Figure 4-8: Illustration of new storage rack layout

The storage area of the designed rack is 169,680 cm^2, which is able to store 800 parts. So it's large enough to meet the storage capacity demand.

The arrangement of the two racks is like an "L" shape as illustrated in Figure 4.8 and the space in front of these two racks is for the trolley to stay and for the operator to walk around. When the subassembly operator receives the parts onto the rack, he pushes the trolley with H&B parts over and stops the trolley in front of the racks; then he transfers the parts to the racks one piece at a time and aligns them on the rack nicely. After all the parts are located onto the rack and all the paperwork are finished, he pushes the trolley back to the subassembly station and to do the normal subassembly work. When the issuing operator issues the parts, he pushes the trolley to the space in front of the racks; then he gets the parts from the rack and places them on the trolley.

Standard work procedure

After the rack layout was designed, detailed flow maps were designed for the H&B subassembly and equipment assembly operations, indicating the material flow as well as information flow. The flow maps are shown in Appendix 1 and Appendix 2.

In the proposed flow, the subassembled H&B parts for equipment assembly won't be sent back to the warehouse and the subassembly operators would be responsible for the receiving of the parts into the new storage area. Since the subassembly operators don't familiar with the warehouse receiving procedure, a standard work procedure is designed for the subassembly operators:

For assembly order:

i) Perform the subassembly operations as per work order

ii) Locate the finished parts into trolley and push it over to the Kanban area for inspection

iii) Ensure the inspection is done for every work order with green label tagged onto every 1st pieces of that work order.

iv) Push the trolley over to the A11000 rack and locate the parts onto rack

v) Update the yellow bin card on the rack and parts location in system immediately after locating parts.

vi) Send work order to warehouse for closure.

For sales order:

i) Perform the subassembly operation as per work order

ii) Locate the finished parts into bunk and push it over to the Kanban area for inspection

iii) Ensure the inspection is done for every work order with green label tagged onto every 1st pieces of that work order.

iv) Send the bunks and work orders to warehouse

The detailed standard work procedure is shown in Appendix 3.

4.8 Summary

After the current warehouse operation was studied, the data for current warehouse receiving was collected, and then the cause and effect for the low receiving efficiency was analyzed. Based on the differences between H&B machining operation and H&B subassembly operation, the warehouse receiving improvement problem was divided into two parts; the first part was to improve the receiving of machined H&B parts and the second part is to improve the receiving of subassembled H&B parts. Two proposals has been made and implemented for these two parts respectively. The next chapter will show the results of the improvement as well as discussion of the results.

5. Results and discussions

5.1 Introduction

This chapter shows the data collected after the proposals were implemented. The improvements are then calculated and discussed.

5.2 Part 1: Receiving of H&B detailed parts

5.2.1 Results

The time study for the receiving process is based on the same number of work orders and parts. The results for the new receiving process as well as the old receiving process are shown in table 5.1 below:

Table 5-1: Comparison of receiving time in new and old flow

H&B detailed parts Receiving (New)					
No.	WORK ELEMENT	Time Elements (min)			
		Auto	Manual	Wait	Walk
1	Check work order & find parts location		3		
2	Transfer parts into shuttle		5	3	
3	Record location into work order & update bin card		10		
4	Update record book		3		
5	Send work order for closure				1
Summary			**21**	**3**	**1**
Total Time		**25**			
H&B detailed parts Receiving (Old)					
NO.	WORK ELEMENT	Time Elements (min)			
		Auto	Manual	Wait	Walk
1	Check work order & find parts location		3		
2	Find empty bunks from rack and move bunks around			3	9
3	Transfer parts to other bunks		5		
4	Record location into work order & update bin card		10		
5	Update logbook		3		
6	Place bunk onto rack		3		
7	Send WO for closure				1
Summary			**24**	**3**	**10**
Total Time		**37**			

The time needed to receive a bunk of H&B parts into the shuttle is only 25 minutes only, compared to the time needed to receive a bunk of H&B parts onto the rack, which takes 37 minutes. A 32% reduction of receiving time has been achieved. A visual comparison of the receiving time is shown in Figure 5.1 below:

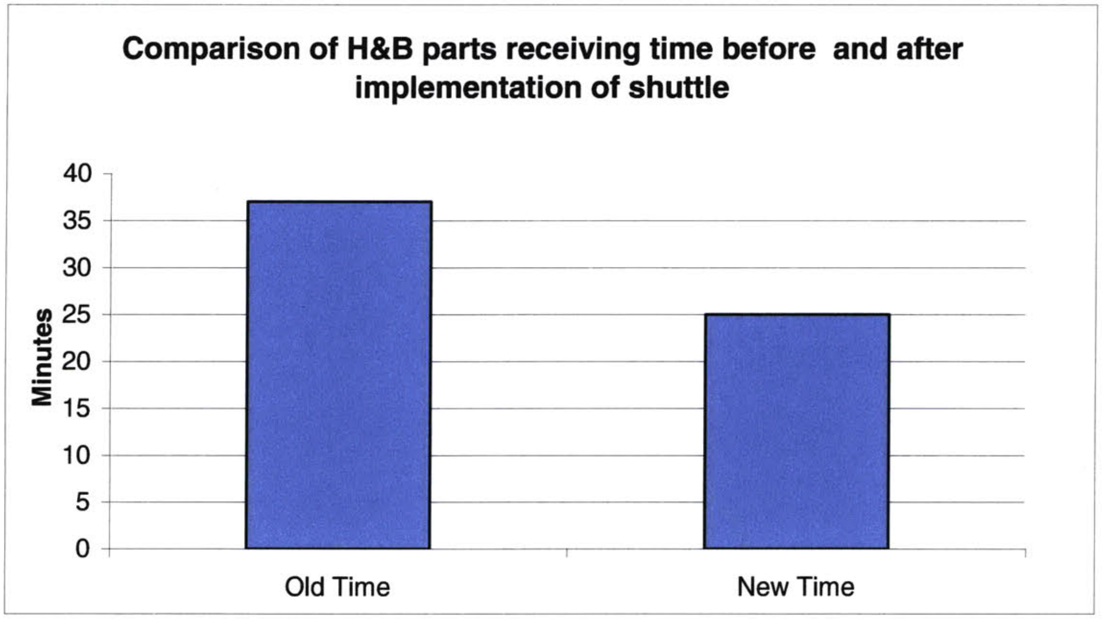

Figure 5-1: H&B parts receiving time before and after implementation of shuttle

Besides the receiving time reduction, the use of forklift is also eliminated, which reduces the cost for forklift purchase and maintenance. The annualized cost saving is calculated by the following formula:

$$\text{Total Cost saving} = \text{Labor cost saving} + \text{Equipment cost saving} + \text{Cost avoidance} - \text{Equipment Cost} - \text{Project Cost}$$

The total annualized cost saving for this project is US$ 221,105.

5.2.2 Discussion

Table 5.1 shows that two work elements are eliminated after using the shuttle, hence the receiving process becomes simpler. There are several reasons that the shuttle system helps to improve the receiving process.

Firstly, it eliminated the use of the forklift. The shuttle brings down the trays itself; thus no other material handling equipment is needed. It needs only 55 seconds to bring down one tray from the shuttle, while it needs 4 minutes to bring one bunk down from the rack using forklift. Moreover, if the forklift is not available, the warehouse operators need to wait for it, which is a waste of time. After the use forklift is eliminated, the receiving process becomes much smoother.

Secondly, the shuttle system eliminated a lot of unnecessary material handling activities. The parts do not need to be transferred from one bunk to another anymore, but are loaded into the shuttle directly instead. The process of finding the appropriate empty bunks is very time consuming. After the receiving operator checks the parts from the system, he knows whether the warehouse already has the same parts. If there are the same parts in warehouse, he needs to check whether that bunk has enough space to store the new parts. If the space is large enough, he either brings the bunk from the rack to the bunk containing the new parts or brings the bunk contains new parts to that location. Then he transfers the parts from the original bunk to the one from the rack. However, if the space is not enough to store the new parts, he has to find another bunk that has enough space to store those parts. After one type of part is received to the rack, he repeats the process for another part, until all the parts in that bunk are received to the rack. A lot of time is spent finding bunks and moving bunks around, so the receiving process is very inefficient. In the shuttle system, the receiving operator does not need to walk around or move the bunk around, what he needs to do is to just enter the tray number into the shuttle control panel, and the tray he wants to check will come down in 55 seconds. If there is not enough space in that tray, he simply enters another tray number. The bunk containing parts just stays in front of the shuttle and does not need to be moved around.

Moreover, the shuttle system reduces the risk of injury for warehouse operators. Before the implementation of the shuttle, the receiving operator had to transfer parts from one bunk to another which lay on the warehouse floor. He needed to bend down to transfer the parts, which could make him prone to back injuries. In the shuttle system, the loading level is 1.2meters high, and the bunk that contains the parts can be lifted up to the same height by stacker. Thus the warehouse operator is able to load the parts to the shuttle in standing posture. This improves the working efficiency and is better for the receiving operator's health.

5.3 Part 2: New flow of subassembled H&B parts

5.3.1 Results

This new flow has been implemented for pump H&B parts. The warehouse receiving times for the new flow as well as the old flow are shown in table 5.2 below:

Table 5-2: Comparison of H&B receiving time in new and old flow

H&B subassembled parts receiving (New Flow)					
NO.	WORK ELEMENT	Time Elements			
		Auto	Manual	Wait	Walk
	Receipt (Subassembly Operator)				
1	Check part number		1		
2	Push Trolley to new storage area				1.5
3	Transfer parts onto rack		5		
4	Record location into WO & update bin card		10		
5	Update parts location in system		4		
6	Back to sub-assembly operation				1.5
Summary			**20**		**3**
Total Time		**23**			

H&B subassembled parts receiving (Old Flow)					
NO.	WORK ELEMENT	Time Elements			
		Auto	Manual	Wait	Walk
	Delivery (Subassembly Operator)				
1	Check part number		1		
2	Send bunks to warehouse				4
3	Update parts location		4		
4	Back to sub-assembly operation				3
	Summary		**5**		**7**
	Total Time (Subassembly Operator)	**12**			
	Receiving (Warehouse Operator)				
5	Check work order & find parts location		3		
6	Find bunks from rack and move bunks around			3	9
7	Transfer parts to other bunks		5		
8	Record location into work order & update bin card		10		
9	Update logbook		3		
10	Place bunk onto rack		3		
11	Send work orders to clerk				1
	Summary		**24**	**3**	**10**
	Total Time (Warehosue Operator)	**37**			
Total Time		**49**			

In the new receiving process, the parts are temporarily stored at the subassembly area and do not need to be sent to the warehouse. Thus the parts transportation time is reduced and the complex warehouse receiving procedure is eliminated. So the total time to receive one bunk of parts is reduced from 49 minutes to 23 minutes.

The comparison of the total receiving time in the new flow and old flow is shown in table 5.3 and figure 5.2 below:

Table 5-3: Comparison of H&B subassembled parts receiving time

	Old Flow	New Flow
Subassembly Operator (min)	12	23
Warehouse Operator (min)	37	0
Total (min)	49	23
Saving (min)	26	
Improvement	53%	

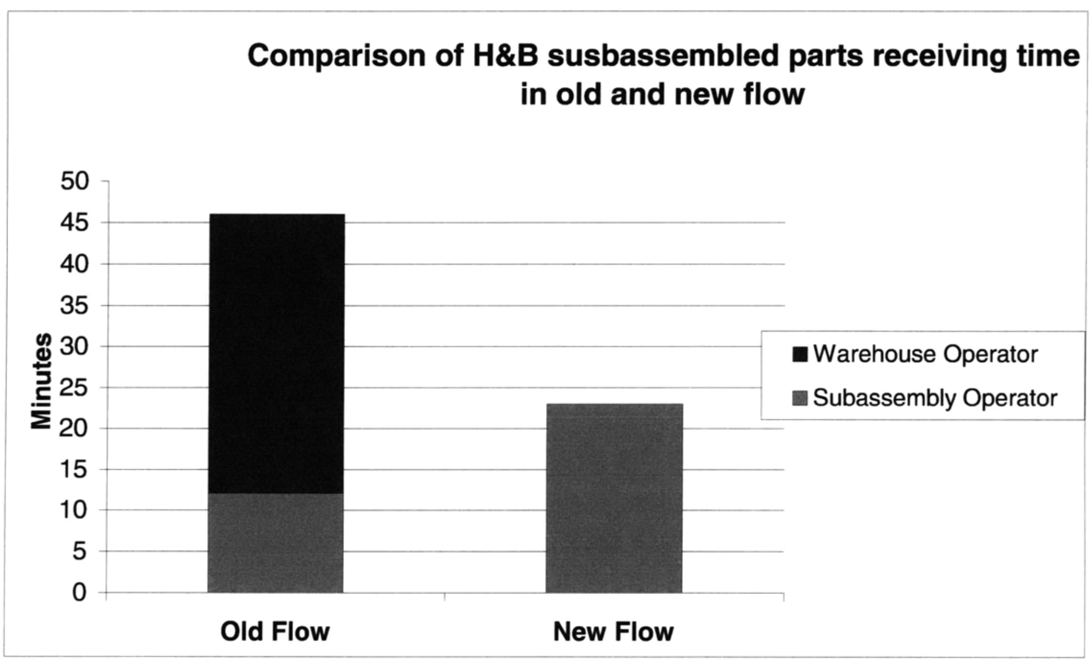

Figure 5-2: Comparison of H&B subassembled parts receiving time

The time needed to receive a bunk of H&B subassembled parts under the new flow is 23 minutes only, comparing to the time needed under the old flow, which is 49 minutes, an improvement of 53% receiving time reduction has been achieved.

The annualized cost saving is calculated by the same formula used in the first part of this project and the result is US$ 201,043.

5.3.2 Discussion

Table 5.2 shows that there are 11 work elements in the old H&B subassembled parts receiving process, while after the new flow is implemented, the work elements are reduced to 6 only. In order to show this more clearly, a comparison of the H&B subassembled parts receiving process under the old flow and new flow are illustrated in figure 5.3 below:

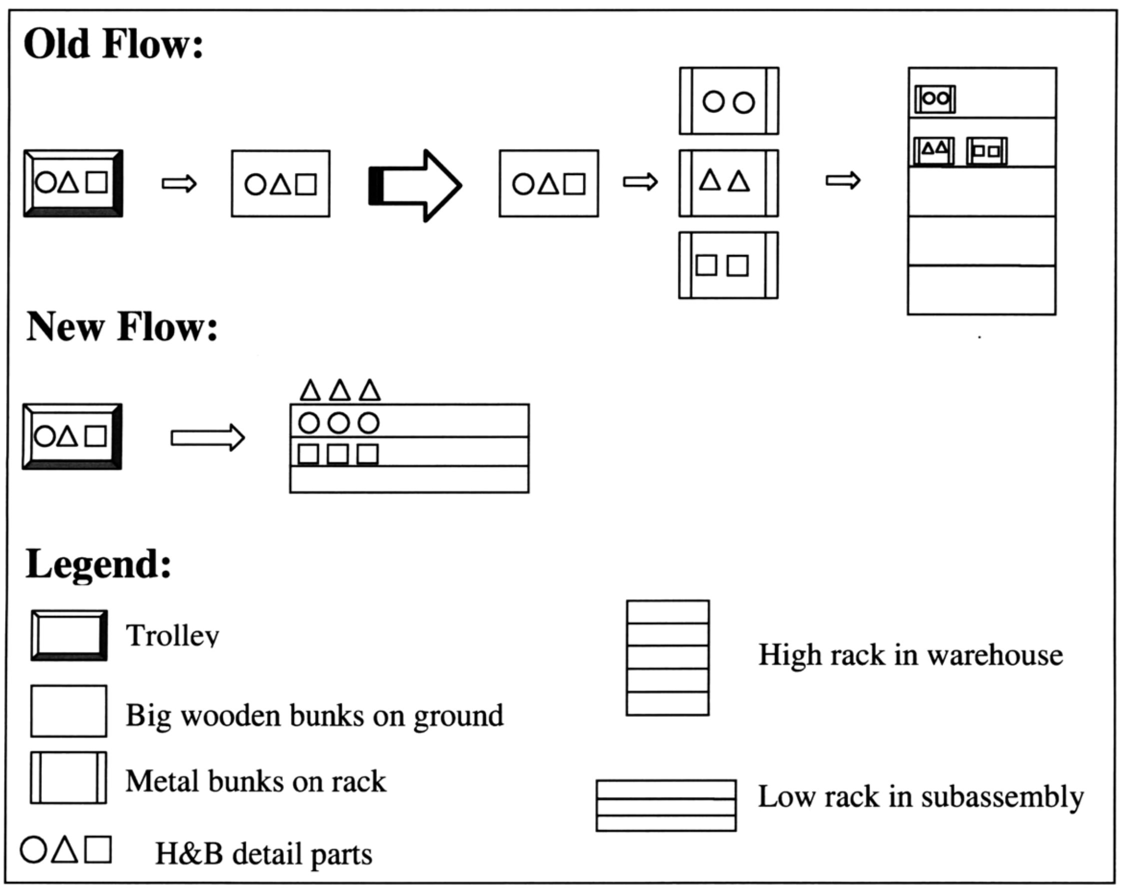

Figure 5-3: Comparison of subassembled H&B parts receiving in old and new flow

In the new flow, the H&B parts for equipment assembly does not need to be sent to the warehouse, thus the transportation waste is eliminated, moreover, the complex warehouse receiving process is eliminated. Instead, the parts are stored at low racks near subassembly area following a simpler receiving process. As a result, the receiving time is reduced by 53%.

After those parts for equipment assembly are stored at the subassembly area, the number of parts sent to warehouse is reduced. Before the new flow was implemented, there were always a lot of bunks containing H&B parts at warehouse receiving area. As all the bunks are moved around by stackers in the limited space where all the warehouse operators are working, such a cramped space increased the potential risk of accidents. After the number of parts sent to warehouse is reduced, the space is increased and the safety condition is improved, which complies with the company's spirit: safety first, quality second, production third.

This new flow also has impacts on future improvement of the H&B production process, which could reduce the lead time and make the process leaner. Because the original receiving and issuing process is very inefficient, there is a 4-day time interval between subassembly and equipment assembly. In these four days, the H&B assembled parts are always changed from equipment assembly use to direct part sale use or vice versa due to customer priority changes, which makes the issuing more complicated. After the H&B receiving processes are improved, this time interval could be reduced, which would reduce the production lead time and the frequency of order conversions.

Besides those advantages, there are also some concerns about the new flow. One of the greatest concerns is that the part might be lost. Part loss does not mean the parts are stolen by someone, but means that they cannot be found. This happens when a part's physical location is different from its location shown in the system. Since there are thousands of different parts, it is impossible to find parts by human inspection. The past experience shows that if the receiving and issuing are done by people from different departments, there will be more part losses. In order to solve this problem, a standard work procedure is designed for the subassembly operators and only the subassembly group leaders are authorized to receive the parts onto the storage racks. Another concern is that although the overall receiving time is reduced by 53%, the time that the subassembly operator spends is increased, which means a part of the warehouse operator's workload is transferred to the subassembly operator. However, the operator's performance is measured by the number of parts they assembled only and there is no incentive for them to do the receiving work. In order to solve this problem, the receiving work done by subassembly operator should be counted into their performance, or a material handler should be introduced to do the receiving work.

5.4 Summary

After the shuttle was implemented, the receiving time of one bunk of H&B detailed parts has been reduced from 37 minutes to 25 minutes, which is a 32% reduction. This reduction occurs mainly because the process of finding bunks and moving bunks around was eliminated. In the shuttle system, the bunk containing the H&B parts just stays in front of the shuttle. The shuttle is able to bring down any tray in 55 seconds time.

The new flow of H&B subassembled parts has been implemented on the parts used for pump assembly as a trial before implemented on all the H&B parts for equipment assembly use. In this new flow, the parts for equipment assembly use are temporarily stored at subassembly area, thus the original warehouse receiving process is eliminated. The receiving time of H&B subassembled parts has been reduced from 49 minutes to 23 minutes, which is a 53% reduction. There are several concerns in the new flow that need to be solved. The first one is to avoid part loss, which is due to the inconsistency between a part's physical location and system record. The second concern is that some of the warehouse workload is transferred to subassembly operator, but there is not enough incentive for the subassembly operators.

6. Recommendations

It is recommended that the company should use the shuttle to store the H&B detailed parts, which could help to reduce the receiving time by 32%. This has been implemented successfully.

The company should implement the new flow on all the H&B subassembled parts used for equipment assembly. Since the trial of the new flow for the pump H&B parts shows that the receiving time has been reduced by 53%, if all the H&B subassembled parts used for equipment assembly are stored in the new storage area, the receiving efficiency would be improved significantly.

The company should adopt a pull system and temporarily store the H&B parts at Kanban area between stations without sending them back to warehouse. Since the H&B parts are just work-in-process, they should flow smoothly from one process to the next, and minimum inventory should be kept.

7. Conclusion and future work

The problem that the company is facing is that there are material handling and transportation waste in the H&B parts receiving process. The objective of this project was to design a new inventory management strategy for H&B parts to improve the warehouse receiving efficiency.

This project was carried out following the lean manufacturing theory and the company's lean-six sigma project roadmap. Firstly the current warehouse operation was studied and necessary data were collected. Then the cause and effect was analyzed using a fishbone diagram, which identified the major causes of the low warehouse receiving efficiency.

A shuttle was installed in the warehouse for the H&B detailed parts storage, which reduced the H&B detailed parts receiving time by 32%. For the H&B subassembled parts, a new flow of the parts was designed and the parts for equipment assembly are stored at the subassembly area instead of in the warehouse. This new flow was implemented for the pump H&B base and a 53% receiving time saving was achieved.

The implementation of the shuttle and new part flow reduced the number of H&B containing bunks at the warehouse receiving area, which improved the safety condition in warehouse. Since there was more space for the material handling equipment to move around, the chance of accident was reduced.

In the future, the company should adopt a pull system and make the H&B parts flow between each stations to minimize inventory and thus material handling. The ideal flow of material is illustrated in figure 7.1 below:

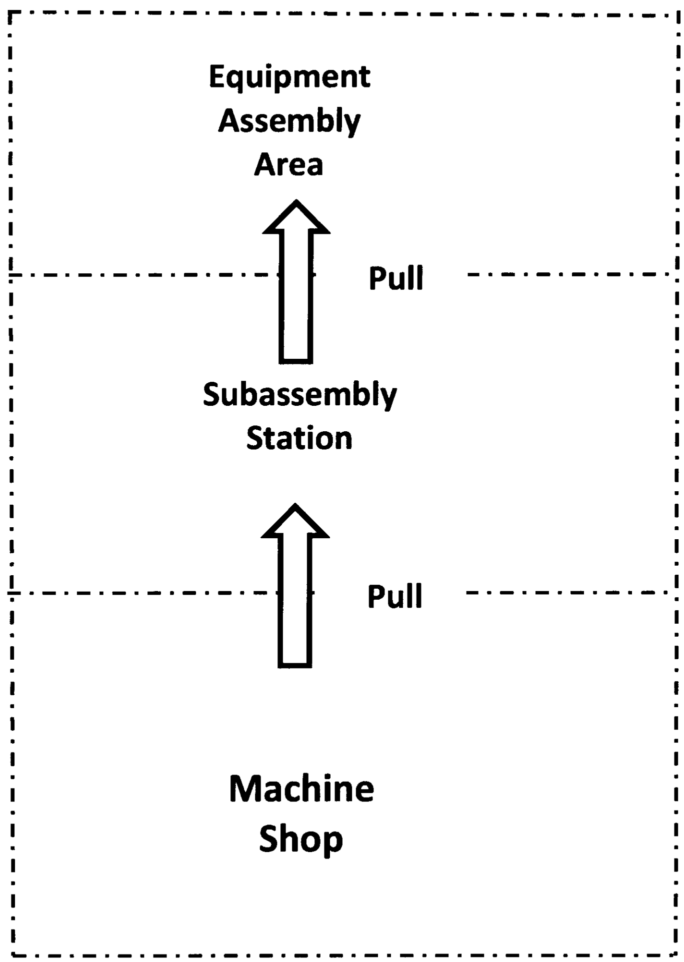

Figure 7-1: Ideal flow of H&B parts

In order to achieve a pull system and lean flow, a few issues need to be tackled in the future:

Firstly, the H&B machining process needs to be improved to become truly make-to-order. Only after the machining process becomes truly make-to-order, a pull system between the subassembly process and the machining process could then be realized. In the pull system, the machined parts are delivered to the subassembly station directly and would eliminate the receiving/issuing process in the warehouse. Currently, the inventory for H&B parts is more than one week's worth, which leads to high inventory holding cost. If pull system is adopted, the inventory could be reduced to one to two days' worth, which would reduce the inventory holding cost significantly. However, in order to achieve this, the set-up time must be reduced to a level that does not have significant impact on the production cost.

Secondly, the production leveling needs to be improved. Currently, the workload for H&B subassembly is planned on a weekly basis, which means they receive one week's order at one time and plan the actual daily production targets themselves. This makes the subassembly process less efficient and greatly increases the production lead time. If the schedule for subassembly is changed from weekly basis to daily basis, the subassembly efficiency could be improved and the lead time could be reduced significantly.

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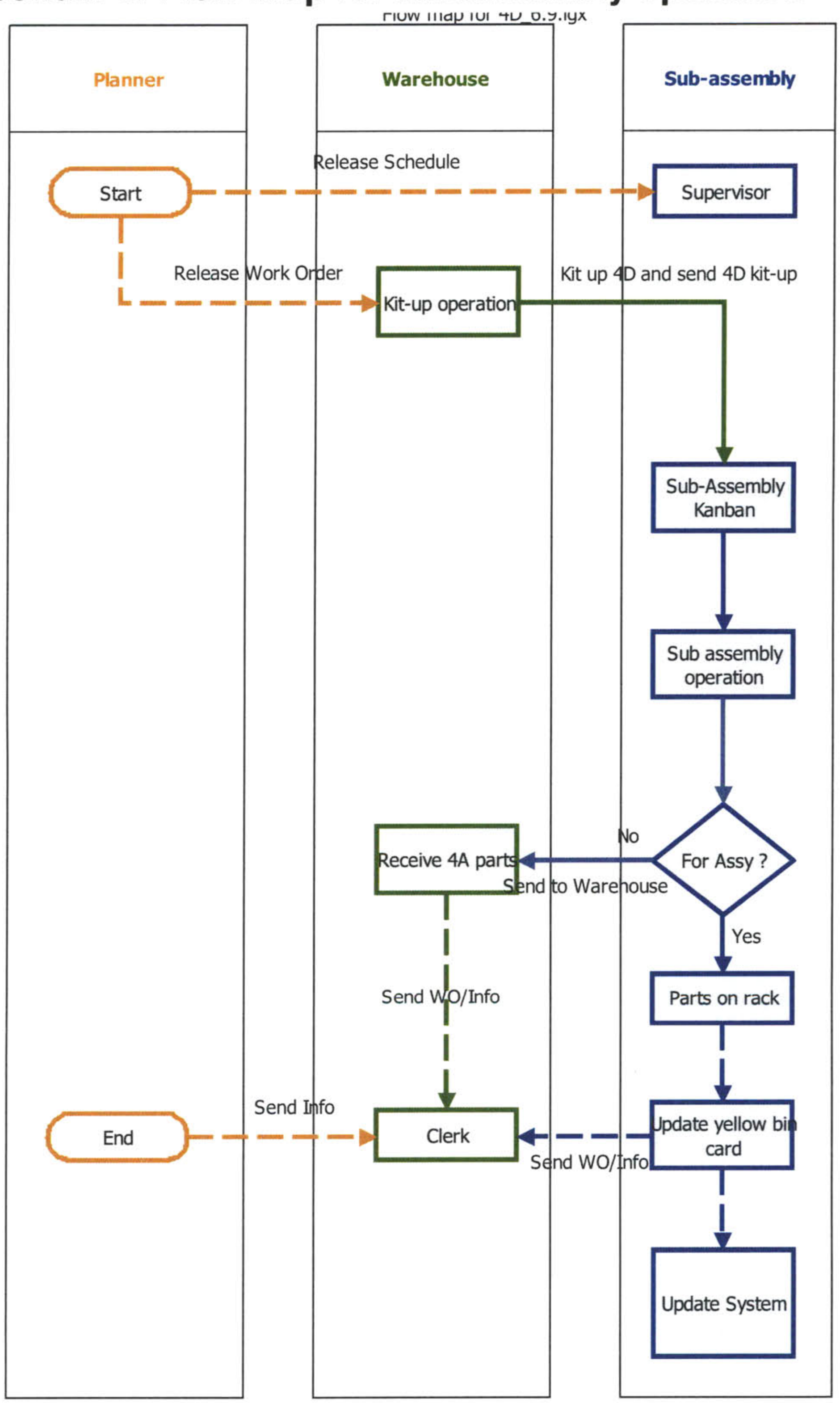
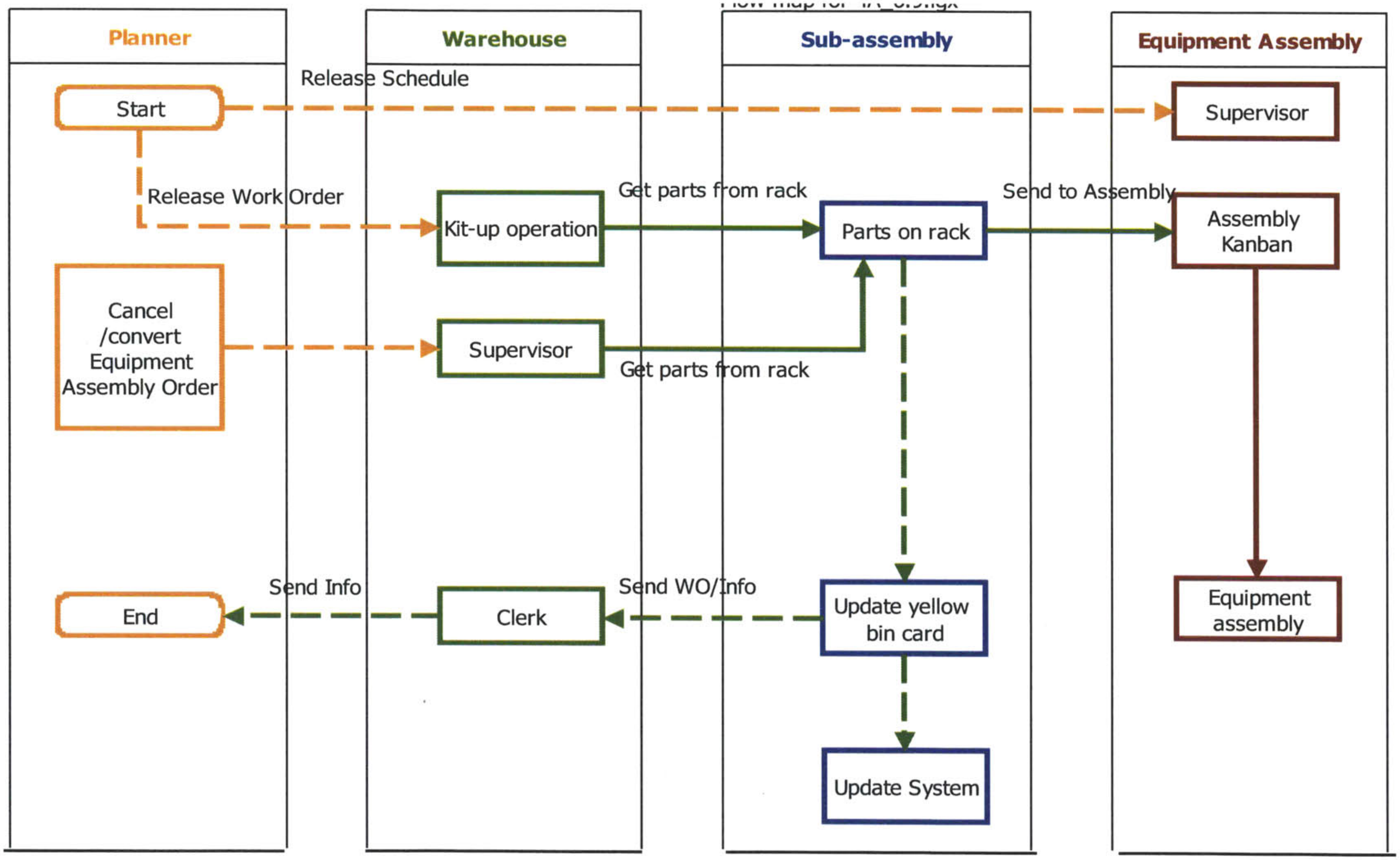
Appendix 1: Flow map for subassembly operation



Appendix 2: Flow map for equipment assembly operation



Appendix 3: Standard work procedure

Assembly Order (Order for equipment assembly)

1) Performed the sub-assembly operations as per work order

2) Locate the finished parts into Trolley and push it over to the Kanban area for IPI inspection

3) Ensure IPI inspection is done with GREEN label tagged onto every 1st pieces

4) Push the trolley over to the A11000 rack and locate the parts onto rack

(* Do not place similar parts in the same level of the rack)

5) Update the Yellow Bin card & System immediately after locating parts

(*Remember to Key in your Employee No under the "REMARK" Column)

6) Send work order to warehouse for closure.

Sales Order (Order for direct part sale)

1) Performed the sub-assembly operations as per work order
2) Locate the finished parts into Bunk and push it over to the Kanban area for IPI inspection
3) Ensure IPI inspection is done with GREEN label tagged onto every 1st pieces
4) Send the bunks and work order to warehouse for closure.