Kaizen Events Implementation
for Cycle Time Reduction in Gauge Production Line

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Abstract

This thesis describes the implementation of three Kaizen events designed to improve efficiency on a gauge production line which consists of both semiconductor and mechanical equipment for manufacturing complex products with low volume and high configuration mix. A kitting process design reduced cycle time by 12 minutes in the mechanical assembly and by 3 minutes in the packing. A redesigned fixture improved loading and unloading time at the auto calibration. Use of this fixture decreased setup and dismantlement in one batch by 16 minutes. A newly designed jig made multiple loading available in batch of 8 at the vibration test, in which case, 17.5 minutes were reduced from the cycle time

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Chapter 1 Introduction

1.1 Company background

Company X is the world's leading oilfield services company supplying technology, information solutions and integrated project management for customers in the oil and gas industry to optimize reservoir performance. The company was founded in 1926, and today the company employs more than 79,000 people working in 80 countries. Company X supplies a wide range of products and services from formation evaluation, seismic acquisition and processing, well testing and directional drilling to well cementing and stimulation, artificial lift and well completions, and consulting, software, and information management.

Singapore Integration Center (SIC) is one of Company X's largest research, development and manufacturing factory. The Company X Singapore focuses on artificial lift products. The 550,000 square foot plant has a full suite of manufacturing operations, ranging from foundry works producing castings for pumps, a large machine-shop to machine some of the major component parts, to several assembly-shops and full quality control testing facilities. Most of the products are sold to internal customers such as Company X’s field services and other manufacturing centers.

1.2 Introduction to main products

Three main production lines of the Company X Singapore produce the electric submersible pumps (ESP), gas lift mandrels (GLM) and down-hole pressure/temperature gauges. The gauge shown as Figure 1-1 is the focus of this project.
Gas Lift (GL) and Electric Submersible Pumps (ESP) are two major types of Artificial Lift (AL), which is to use artificial method to lift the oil from a production well. ESPs are commonly used in deep wells where environmental conditions are complicated. To ensure good performance and safe operation of the ESPs, Company X also provides monitoring systems to complement the ESP product. The monitoring system includes the thermocouples, pressure sensors and vibration sensors, which together form the down-hole gauge. The gauge is built into the ESP products (Figure 1-1) and provides real-time feedback of the down-hole operating environment. The information obtained by gauge helps engineers to predict potential catastrophic conditions and to prevent ESP failure. By integrating technology and service, Company X successfully provides an optimum lift system for the well and optimizes the pump and well performance while reducing costs for the customers. Company X Singapore offers AL solutions for applications ranging from simple and economical to complex and high-temperature and high-pressure environments. Figure 1-2 and Figure 1-3 are schematics of ESP and GL products by
Company X Singapore. The figures show the components and complexity of the products.

Figure 1-2 Schematic of ESP product

Figure 1-3 Schematic of GL products
1.3 Gauge production overview

1.3.1 Gauge

The gauge consists of three major parts: the gauge electronics which include the pressure and vibration sensors as well as thermocouples, the choke which holds the gauge electronics and the housing which insulates and protects the electronics from outside environment and provides the connections between the gauge and other parts of the ESP.

There are several types of gauges produced in Company X Singapore. Although their functions are similar, their demands, sizes, weights, and prices are different. According to the current situation, A, B, C, and D are the most important four types of gauges. And the demands for each type in year 2008 and 2009 are tabulated as Table 1-1. Products A comprise the majority of the demand in both 2008 and 2009.

Table 1-1 Demands of main products in year 2008 and 2009

<table>
<thead>
<tr>
<th>Types</th>
<th>2008 Sales</th>
<th>Percentage</th>
<th>2009 Sales</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2,481</td>
<td>80.84%</td>
<td>1,291</td>
<td>57.48%</td>
</tr>
<tr>
<td>B</td>
<td>112</td>
<td>3.65%</td>
<td>336</td>
<td>14.96%</td>
</tr>
<tr>
<td>C</td>
<td>204</td>
<td>6.65%</td>
<td>253</td>
<td>11.26%</td>
</tr>
<tr>
<td>D</td>
<td>272</td>
<td>8.86%</td>
<td>366</td>
<td>16.30%</td>
</tr>
<tr>
<td>Total</td>
<td>3,069</td>
<td>100.00%</td>
<td>2,246</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

1.3.2 Production process

The gauges are produced in the monitoring lab; an 80-square meter enclosed clean room with controlled indoor environment. The temperature and relative humidity are controlled at 21°C and 50% respectively to protect electronic components. Figure 1-4 is a schematic of the layout of the gauge production cell.
There are two major processes in assembling a gauge: the electronics assembly/auto-calibration and the mechanical assembly/testing. These two activities are initiated by different work orders, but the mechanical assembly activity needs the calibrated electronics as the essential part supply. Figure 1-5 shows the process flow of gauge production.
In the electronics assembly step, the gauge electronics is assembled from transducers and the Printed Circuit Board (PCB) purchased from suppliers. The electronics then undergo a 16-hour process at the auto-calibration in batches of 16, which performs tests with a range of temperatures and pressures to check the sensitivities of the sensors. If the PCB passes the tests on temperature and pressure, each one of them is then placed in a box and stored on the rack called “electronics supermarket”. This supermarket is to buffer the mechanical assembly downstream.

In the mechanical assembly step, the calibrated electronics are firstly fixed into the choke, followed by the Megger test to check the functionality of the thermocouples. The choke-electronics subassembly is then fixed into the steel housing, before it undergoes the vibration test, where the gauge is placed on a shake table with various acceleration magnitude and frequency to check the sensitivity of the vibration sensors. The next step
is the leak test, where high-pressure water is pumped into the gauge housing to check integrity of the gauge in the high-pressure down-hole conditions. Finally the log test is performed to ensure that every functional unit is intact. If the gauge passes all the tests, it is engraved with company logo, packed with all test results in a disc and delivered to the customer. When a part of the gauge does not meet the specifications during a test, the failure is analyzed by a technician, who then decides whether the part will be reworked or reported and returned.

A report of non-conformance (RON) is generated for all parts which eventually fail the tests. These faulty parts are stored in the RON rack for a period of time and sent back to the suppliers if necessary.

1.3.3 Current production

The production line operates with a make-to-order policy, or a pull system. After receiving orders from customers, the production planner schedules the production according to current production volume and capacity and assigns the due dates for the orders. Then work orders are released to the warehouse and the production line. The warehouse will help to prepare the kits according to the bill of materials (BOM), and deliver the kits to the gauge production cell for assembly.

Currently, the lab runs 2 shifts per day, 5 days per week. And there are usually two to three operators working in each shift. In the 1st shift, operator A works on the electronics assembly and auto-calibration; operator B works on the mechanical assembly and Megger test; and operator C works on the housing, vibration test, leak test, final log test and packaging. In the 2nd shift, two operators work on mechanical assembly and housing
to packaging, respectively. Currently, the daily total output for this assembly line averages approximately 10 gauges.
Chapter 2 Problem Statement

The implementation of Kaizen events offers the possibility of improving production capacity. Figure 2-1 shows customer demands for products A-0 and A-1, A-d, B, C and D from year 2008 to year 2010 and the projected demand to 2013.

As illustrated in this bar chart, the customer demand is forecast to increase dramatically in next few years. As Figure 2-1 shows, the demand will nearly double from 3200 pieces in 2010 to 6200 pieces in 2011. Moreover, the forecast demand rockets to 13,000 pieces in 2013. In terms of daily demand, it is equal to 13 pieces per day in 2010, 26 pieces per day in 2011 and 58 pieces per day in 2013. However, currently, the production line can only build 10 gauges per day on average, which is too slow to fulfill the dramatically increasing demand.
Under this circumstance, the company plans to expand the current assembly cell; moving it to a new place whose size is twice as large as the current one. By redesigning the value stream of the assembly line and implementing Kaizen events, the throughput could be improved to meet the demand forecast. In order to achieve this goal, mixed model value stream mapping was employed to create both current and future state value stream maps, identify improvement opportunities, balance workload for operators and machines, and redesign the assembly flow. During this process, several Kaizen events were implemented to eliminate wastes to improve overall customer value. Finally, the floor layout plan for the new assembly line was put forward. This thesis focused on implementation of Kaizen events for cycle time reduction to eliminate waste, improve production rate, and approach the future state value stream map. Other research was performed by Xiaoling Lang[1] and Junying Liu[2] who explored mixed model value stream mapping and floor layout design respectively.
Chapter 3 Theoretical Background

In this chapter, an introduction of lean manufacturing concepts and tools is given at the beginning of section 3.1. Then, the theories of manufacturing systems are introduced in section 3.2. In this part, an introduction is given on batch production and single piece flow. Section 3.3 provides introduction of concepts which are related to kitting. And section 3.4 discusses two simple inventory models that are building blocks for kits inventory management in the following chapter.

3.1 Lean manufacturing

3.1.1 Lean manufacturing concepts

Lean manufacturing is a generic process management philosophy derived from Toyota Production System. The key goal of lean manufacturing is to continuously improve production to increase value added work by eliminating waste and reducing incidental work. There are seven deadly wastes[^3] listed in Table 3-1. Another significant concept in lean manufacturing is Kaizen. Kaizen means improvement in Japanese. In the view of lean manufacturing, no process is regarded as perfect; it always needs to be improved.
Table 3-1 Seven deadly wastes

<table>
<thead>
<tr>
<th>Type of wastes</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Movement of products that is not actually required to perform the processing</td>
</tr>
<tr>
<td>Inventory</td>
<td>All components, work in process (WIP) and finished products that are not being processed</td>
</tr>
<tr>
<td>Motion</td>
<td>Walk or movement that people or equipment take more than is required to perform processing</td>
</tr>
<tr>
<td>Waiting</td>
<td>Waiting for the next production step</td>
</tr>
<tr>
<td>Overproduction</td>
<td>Production ahead of demand</td>
</tr>
<tr>
<td>Over processing</td>
<td>Resulting from poor tool or product design creating activity</td>
</tr>
<tr>
<td>Defects</td>
<td>The effort involved in inspecting for and fixing defects</td>
</tr>
</tbody>
</table>

3.1.2 Lean manufacturing tools

There are many lean manufacturing tools which can help to solve manufacturing issues and improve production continuously.

**TAKT Time** is available work time per piece to fulfill customer’s orders. It equals to the available work minutes divided by required product quantity to determine minutes per piece or cycle time shown as the formula.

\[
\text{TAKT TIME} = \frac{\text{Available work minutes}}{\text{Customer demands}}
\]

**Value Stream Mapping** is a process mapping tool to help gain insight into the amount of wastes by mapping complete processes and then just the value-added steps. During creating current state value stream map and future state value stream map, Kaizen
opportunities are obtained when the issue that is how to move from current situation to future state is taken into deliberation.

**Poka Yoke** is a Japanese term for mistake proofing. It can be any mechanisms that prevent operators from making mistakes.

**Just In Time** is a tool to reduce in-process inventory level and decrease production costs correspondingly. The implementation of this strategy relies on visual signals such as Kanban to tell production when to make the next part.

### 3.2 Manufacturing Systems

In this section, an introduction is given on batch production and single piece flow. And then a comparison between these two manufacturing techniques is conducted to show which method fits gauge production line better.

**Batch production** is the manufacturing technique of producing parts at one work station group by group. It is widely used in the production of sports shoes, pharmaceutical ingredients (APIs), inks, paints and adhesives.

**Single Piece Flow** is the manufacturing technique of producing one part at a time, and flowing through manufacturing and supply chain as single unit, transferred as customer’s order.

A comparison of batch production and single piece flow describes the benefits of each. Batch production is able to reduce the setup or changeover time between each group of parts, especially efficient in minimizing cleanup and reconfiguring of machinery in color-run industry. The advantage of single piece flow is less in-process inventory and shorter...
lead time. In gauge production, the changeover time for different products is equal to setup time for each product. Hence, single piece flow is more beneficial for the gauge production in terms of lower WIP level and shorter lead time.

### 3.3 Kitting

Kitting is the process to group the components required for manufacturing, in the correct quantities, in specific containers. Ideally, the components are organized in the order in which they are needed. In this section, several types of kitting are introduced.

**External Kitting** is a grouping work done by an entity external to the company. It has two different types, which are kitting at manufacturer and kitting at a third party.

**Internal Kitting** is done either by the internal warehouse or as a production operation prior to assembly. Internal kitting is a good first step in kitting implementation if sufficient capacity exists in the warehouse or in production. Part locations should be organized to optimize the picking and kitting process.

**Theory of Bill of Material (BoM) structure** is to structure BoM to facilitate kitting and the releasing of Work Orders (WO). As illustrated in Figure 3-1, below, the Bill of Material should be structured as follows.

- **Work Order Top Level Part Number**
  - Manufacturing Kit
    - Production Kits
    - Small Parts Kits
  - Non-Kitted Components
    - Large Components
Non-Kitted Shop Supplies

Each kit should be organized based on the Assembly Procedures which provide the assembly sequence.

3.4 Inventory Basics

Supply chains comprise material and information flows. This section discusses two simple inventory models to manage one of the primary material flows; the movement of physical products between stages.

3.4.1 Continuous Review

In continuous review model, the inventory position which equals to on-hand and on inventory level is monitored continuously. When the inventory position drops to $R$ units
(the reorder point), order Q units (the order quantity). Because the inventory position is reviewed all the time, once the position hits the reorder point it will trigger replenishment of Q units immediately. L is the replenishment lead time. In this model, the reorder point R and the order quantity Q are constants but the order cycle r which is the time between orders is variable.

![Diagram](image)

**Figure 3-2 Continuous review model**

Shown as Figure 3-2, the length of order cycle #1 is different from that of order cycle #2 but the order quantity Q units is same. That is, in the continuous review model, the order cycle varies but the order quantity is fixed. In this case, the reorder point needs to be carefully determined to ensure that there is sufficient inventory available to cover the demand over the replenishment lead time L. Assuming that the demand is normally distributed, a common approach to set R is to cover the demand over the lead time with high probability. The formulas is \( R = L\mu + z\sigma\sqrt{L} \). \( \mu \) and \( \sigma \) are the mean and the standard deviation of daily demand respectively. \( Z \) value is a safety factor which is related to the probability the safety stock will cover. The typical choices of \( Z \) value are tabulated as
Table 3-2. This model is most appropriate for A items with high value and with fixed order sizes dictated by supplier.

Table 3-2 z value

<table>
<thead>
<tr>
<th>z value</th>
<th>Prob. of no stock-out</th>
<th>Expected Backorders per cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.645</td>
<td>0.95</td>
<td>0.021* $\sigma$*sqrt(L)</td>
</tr>
<tr>
<td>2</td>
<td>0.98</td>
<td>0.0085* $\sigma$*sqrt(L)</td>
</tr>
<tr>
<td>3</td>
<td>0.999</td>
<td>0.0004* $\sigma$*sqrt(L)</td>
</tr>
</tbody>
</table>

3.4.2 Periodic Review

In periodic review model, the inventory position is monitored at interval of a certain period of time $r$. The orders are placed right after each review. In this thesis, the base stock policies, a special case of periodic review policies, are used in inventory management. In base stock policies, the order quantity is set equal to the amount consumed during the interval of length $r$.

As shown in Figure 3-3, the order cycle #1 and order cycle #2 have the same length but the order quantity is different among each intervals. That is, the interval of time between
orders is fixed but the order amount varies in the periodic review model. The base stock level should be chosen so that the probability to stock out is small. For normally distributed demand, the base stock level is set

\[ B = (r + L)\mu + z\sigma r + L \]

where \( z \) value is the safety factor. It equals to the number of standard deviations of protection chosen. The \( z \) value can be found in Table 3-2.
Chapter 4 Methodology

In this chapter, two major methods are discussed; mixed model value stream mapping and Kaizen events. The first part of this chapter describes mixed model value stream mapping which is the tool to identify Kaizen events. More details about current state value stream map and future state value stream map are demonstrated in the thesis of another teammate, Xiaoling Lang[1]. The Kaizen events in the second part are the focus of this chapter. In this section, a kitting project and two fixture design projects are described.

4.1 Mixed model value stream mapping

In approaching the problem, a product family was chosen by using mixed model value stream mapping method. Value stream mapping is a tool to help gain insight of improvement opportunities. The first step to create mixed model value stream map was to identify the product family. There were three principles on which this identification should be based. First, the products within one product family must have 80% similarity of processes. Secondly, product knowledge, such as physical attributes of the products, should allow the family members to go through the same process by sharing the same workstation. Thirdly, the work contents of family members for each process should have less than 30% variation. Under these criteria, A (A-0 and A-1), B and C were grouped as family A. Product D was categorized into product family B.

After identifying the product family, time study and motion study were completed in order to collect data, such as cycle time, WIP inventory and so on, to create mixed model current state value stream map for product family A. The current state value stream map is shown in Figure 4-1.
Figure 4-1 Current state value stream map of product family A
Based on the current situation, 9 questions regarding production situation in 2011 listed as below were discussed among managers, engineers and operators. These questions led us through the process of constructing future state value stream map. There questions were.

- What is the Takt time with 2 shifts?
- What is the finished goods strategy?
- Where to implement continuous flow?
- Where to implement FIFO?
- Where to implement supermarket pull system?
- Where is the scheduling point (pace maker)?
- What is the interval?
- What is the pitch (management timeframe)?
- What are the necessary improvements?

By discussing these questions, the team created the process flow for the future state value stream map which is shown in Figure 4-2. Moreover, 29 Kaizen opportunities including FIFO sizing, fixture design, kitting design and so on and so forth, had been identified.
Figure 4-2 Future state value stream map of product family A
4.2 Kaizen events

As demand is increasing sharply, the Takt time for product family A, which consists of A, B and C, is decreasing to 64 minutes in 2010, 32 minutes in 2011 and 16 minutes in 2013. Currently, the total processing time is about 2 to 3 days including 2 days for room-temperature vulcanization (RTV) curing. In order to meet the Takt time, three Kaizen events are implemented for cycle time reduction in this section.

4.2.1 Kitting process design

4.2.1.1 Advantages of kitting

Kitting is to group one set of components which are needed to assemble one gauge. There were four main reasons why the production needed kitting. Firstly, kitting could reduce cycle time at the mechanical assembly step. When noting the result of cycle time study shown in Figure 4-3, it was easy to get to the conclusion that mechanical assembly was the bottleneck. While studying the video of this process, some preparation work such as soldering high voltage feedthrough and thermocouple feedthrough could be eliminated by moving to the external kitting, in which case these feedthroughs would be prepared by the supplier. According to the standardized worksheet cited in the appendix, the soldering and insulation work on feedthroughs cost 10.2 minutes on average. In so doing, 10.2 minutes of cycle time could be eliminated.
Secondly, kitting was a tool to facilitate single piece flow to reduce WIP and lead time. In the current situation, the gauge manufacturing system was operating in batch production which caused long lead time and high Work In Process (WIP) inventory level. On one hand, the total lead time was about 100 days from customer’s order to shipping, which meant that the customers had to wait for at least three months before receiving their orders. On the other hand, the WIP inventory level was around 224 pieces. It became one of the major factors that increased the production cost. In order to reduce lead time and WIP inventory level, the gauge department was eager to implement single piece flow to replace current batch production system. After analyzing current state value stream map and future state value stream map, it was agreed with managers and engineers that single
piece flow could be achieved from mechanical assembly station to package. And kitting was such a practical method to implement single piece flow.

Thirdly, when it comes to quality control issue, kitting was a visual management tool to easily check that all components were assembled. It was Poka Yoke which meant mistake proofing to help operator avoid mistakes.

Last but not least, kitting didn’t only group parts but also part numbers, in which case it reduced part numbers and work load on inventory management noticeably because there were fewer parts of which to keep track. Owing to these four advantages, a kit design was implemented and discussed as follow.

4.2.1.2 Bill of Material Structure Creation for Kitting

According to the theory of BoM structure, BoM was constructed after taking two issues into consideration. For one thing, the kit flow needed to be determined. Because it took 2 days in RTV curing process, the in-process inventory at curing was 28 pieces on average, which meant that if one kit went through processes completely, 28 parts and 28 kits would be stored there. In this case, a curing station required much more space than what the production room could provide. Owing to that, it was necessary to have two kits in the manufacturing system. One kit flow started at mechanical assembly station and ended at curing. The other kit flowed through all of downstream processes after curing. For another, it was necessary to categorize components to internal kitting and external kitting. The internal kit would be prepared by warehouse and the external kit would be purchased from suppliers. So the more parts the external kit contained, the less workload the production needed to take. After finalizing these two problems, the BoM for A-0 and A-1
were created as Figure 4-4 and Figure 4-5. Take A-0 as an example, the BoM structure is described here. Firstly, the shop supplies such as solder, jelly flux, solder wire and so on were not kitted. Secondly, the top-sub was not in the kit because of its heavy weight. It would be issued to the production with the mechanical assembly kit. Thirdly, the kit for A-0 mechanical assembly shown as Figure 4-6 contained one external kit box for small parts shown as Figure 4-8. All the other parts were internally kitted, including feedthrough assembly, chock plate, choke assembly, choke bracket, back-up ring, viton o-ring and aflas o-ring. Fourthly, the calibrated electronic assembly was not kitted because they were produced in batch of 16. Fifthly, the bottom-sub, desiccant bag and shock dampener were grouped as one kit for housing process. Sixthly, the kit for A-0 final packaging assembly shown as Figure 4-7 contained one external kit box for small parts shown as Figure 4-9 and one external kit bag. Other parts were internally kitted, including viton o-ring, aflas o-ring, transit cap, lock washers and lock screws.
Figure 4-4 BoM structure for A-0

Figure 4-5 BoM structure for A-1
4.2.1.3 Physical Kit Design

After constructing BoM, the next step was to design the physical kits, the characteristics were considered, such as weight, size, material, etc. Figure 4-6, Figure 4-7, Figure 4-8, and Figure 4-9 show the physical kit for experiment. In addition, another prototype for the spare kit shown in Figure 4-10 was designed for replacing defective parts. The spare kit would be always closed except when a component failure is detected.

Figure 4-6 Kit: A-0 mechanical assembly
Figure 4-7 Kit: A-0 package

Figure 4-8 Kit: small parts for A-0 mechanical assembly
Figure 4-9 Kit: small parts for A-0 package

Figure 4-10 Spare kit for A products
4.2.1.4 Feedback Survey for Kitting Improvement

After running trials on these prototypes, a feedback survey on kit design was conducted on operators who had used the kits. These feedback forms are cited in the appendix. According to the opinions given back from the operators, a few changes listed below on kit design had been made to refine the kit design.

- **Mechanical assembly kit**
  - The kit didn’t need to contain nut hex whose part number is P002-0056-408 because it would come with diode from electronic board.
  - The box for small parts needed a fixture to prevent it from falling down.
  - A trolley was needed to carry the kit because the work station didn’t have enough room to put.

- **Packing kit**
  - The kit needed two taper plugs whose part number is 100094889 instead of one.
  - It would be easier to pick the small parts in the box up by taking use of Allen key if they were arranged to stand rather than lay on the foam.
  - A trolley was needed to carry and transfer the kit between final log test work station and packing work station.
  - It was necessary to apply grease on the hollow transit cap and the housing lockers when kitting these parts.

- **Spare kit**
  - The kit needed to contain desiccant bags. When the failure of leak test happened, the operator needed to replace the housing. The operator dismantled the housing at first and then assembled another one with the gauge. Because the desiccant
bags could only be exposure in the open air for four minutes before invalidation, the operator usually replaced all the desiccant bags inside. In this case, the spare desiccant bags were in need.

4.2.1.5 Kit Delivery Plan and Inventory Level

This section discusses the delivery plan and inventory control of the kits. In current production, the kits can be delivered according to the production orders which are issued by planner. Basically, the kits are prepared by the warehouse and stored in raw material inventory where is near the production line. When the orders come to a workstation, the operator goes to the raw material inventory to collect the corresponding kits with the orders. At the same time, the kits inventory is controlled by the periodic review model. The warehouse comes to review the inventory position periodically and then replenishes the kits inventory to the maximum level. In future production, the kits will be delivered by Kanban system and be replenished by periodic review model. The production line will be pulled by customers. Once the finished goods are shipped to customer, the corresponding Kanban will be issued to the production. When Kanban for the production goes to one work station, the kits will be delivered to this workstation by a specific person with the same quantity of on-hand Kanban. Also, the warehouse will review the kits inventory position to replenish the inventory after each certain interval of time. Since the inventory level is related to the demands, before taking use of this model to control the kits inventory, two assumptions regarding demanding were discussed. At first, the demands were assumed as normal distribution on which the periodic review model is based. Secondly, the standard deviation of the demands in the second half year of 2010 was assumed the same as that in the first half of this year. Because the demands were
increasing sharply, the characteristics of demands in 2010 had changed a lot from those in previous years. In this situation, the historical data before 2010 regarding demands had little value to estimate the future demands in next six months. Also, it was appropriate to take use of most recent demands to forecast the demands in the future. When these two points were taken into consideration, the second assumption was regarded as reasonable.

The demands information is tabulated in Table 4-1. The standard deviation of daily demand is the standard deviation of monthly demand divided by \( \sqrt{20} \). 20 is the number of total business days within one month.

<table>
<thead>
<tr>
<th>Table 4-1 Demands of 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>January</td>
</tr>
<tr>
<td>February</td>
</tr>
<tr>
<td>March</td>
</tr>
<tr>
<td>April</td>
</tr>
<tr>
<td>May</td>
</tr>
<tr>
<td>June</td>
</tr>
<tr>
<td>Standard deviation of monthly demand</td>
</tr>
<tr>
<td>Standard deviation of daily demand</td>
</tr>
<tr>
<td>Mean of daily demand</td>
</tr>
</tbody>
</table>

Based on the discussion on the demands, the periodic review model was applied on the kits inventory control issue. If the warehouse would review the inventory position once per day, because the mean of daily demand in 2010 for A-1 was about 7 pieces the lead time of replenishment was \( L = 5 \frac{\text{minutes}}{\text{kit}} \times 7 \text{ kits} = 35 \text{ minutes} \). Thus, the lead time of replenishment was neglected when comparing with the review period. Assume the
probability of no stock out as 99.9%, the $z$ value was 3. Then, the base stock level for $A-I$ was

$$B = (r + L)\mu + z\sigma\sqrt{r + L} \approx 1 \text{ day} \times 6.95 \frac{\text{pieces}}{\text{day}} + 3 \times 7.523297 \frac{\text{pieces}}{\text{day}} \times \sqrt{1 \text{ day}}$$

$$\approx 30 \text{ pieces}$$

Similarly, the base stock level for $A-0$ was

$$B = (r + L)\mu + z\sigma\sqrt{r + L} \approx 1 \text{ day} \times 2.83333 \frac{\text{pieces}}{\text{day}} + 3 \times 9.450573 \frac{\text{pieces}}{\text{day}} \times \sqrt{1 \text{ day}}$$

$$\approx 31 \text{ pieces}$$

Hence, if the review period was one day, then the base stock level of kits would be set at 30 for $A-I$ and at 31 for $A-0$. The warehouse needed to replenish the kits to the base stock level once per day.

If the warehouse would review the inventory position twice per day, then the lead time of replenishment could also be neglected. Assume the probability of no stock out as 99.9%, the $z$ value was 3. Then, the base stock level for $A-I$ was

$$B = (r + L)\mu + z\sigma\sqrt{r + L} \approx 0.5 \text{ day} \times 6.95 \frac{\text{pieces}}{\text{day}} + 3 \times 7.523297 \frac{\text{pieces}}{\text{day}} \times \sqrt{0.5 \text{ day}}$$

$$\approx 20 \text{ pieces}$$

Similarly, the base stock level for $A-0$ was
\[ B = (r + L) \mu + z\sigma\sqrt{r + L} \]

\[ \approx 0.5 \text{ day} \times 2.8333 \frac{\text{pieces}}{\text{day}} + 3 \times 9.450573 \frac{\text{pieces}}{\text{day}} \times \sqrt{0.5}\text{day} \]

\[ \approx 22 \text{ pieces} \]

Hence, if the review period was half day, then the kit inventory level could be reduced to 20 for A-I and at 22 for A-0. The warehouse needed to replenish the kits to the base stock level twice per day.

4.2.2. Fixture redesign for setup and dismantlement time reduction at auto calibration

By watching the video of auto calibration, a Kaizen opportunity was identified to improve the process to mount and dismantle the PCB boards. When mounting the PCB board on a brass plate for auto calibration, the PCB board was assembled to the brass plate by 2 screws and nuts. Figure 4-11 shows how the PCB board was fixed on the brass plate.
After mounting one batch of 16 PCB boards on the brass plates, the brass plate with PCB boards would be put on a rack which should be carried into the oven of auto calibration machine. After calibration, the PCB boards were dismantled from the brass plates. According to the time study, it took about 32 minutes to mount and dismantle one batch of 16 PCB boards. Given that the motions to assemble and disassemble the brass plate from PCB board were non-value added and time consuming, a faster loading and unloading method was desirable to reduce the mount and the dismantlement time. According to the requirement of this setup, the PCB board was not required to be assembled with the brass plate very tightly. In this case, a clamp instead of screws and nuts was a possible way for fast loading and unloading, it was expected to save 16
minutes for one batch. Figure 4-12 shows the design for the brass plate. The 2D drawings of each part are shown in the appendix.

There are two key features pointed as the red arrows that guarantee fast loading and unloading. One feature of the design is the brass clamp shown as Figure 4-13.

**Figure 4-12 Fixture design for fast loading and unloading**

There are two key features pointed as the red arrows that guarantee fast loading and unloading. One feature of the design is the brass clamp shown as Figure 4-13.
This clamp is used to fast load and unload the diode pointed as the blue arrow in Figure 4-12. The exploded view in Figure 4-14 shows how all the parts are positioned in this subassembly clearly.
When the operator mounts the PCB board on the brass plate, the diode is assembled to the clamp at first by taking two simple steps shown as Figure 4-15. The first step is to put the diode to the slot. And the second step is to slide the diode into the clamp. Because it is an interference fit between the diode and the clamp, it is tight enough for the clamp to fix the diode on the brass plate. When dismantling the diode from the clamp, there are also only two steps to take in the opposite order as the mount; sliding the diode out of the clamp and then taking it away from the slot.
Figure 4-15 Two steps to fix diode

The other feature is a Delrin clamp shown as Figure 4-16. The partially exploded view of this subassembly in Figure 4-17 shows how the clamp and the PCB board are assembled together. The green object in the figure is the PCB board and the yellow one is the brass plate.

Figure 4-16 Delrin clamp
There are two reasons why Delrin was chosen. At first, melting point of Delrin is 347 Celsius degrees which is higher than the temperature in the oven. Secondly, Delrin has a constant elastic modulus which remains at 0.8 GPa\(^3\) at room temperature (73°F). So when the operator pushes the PCB board onto the Delrin clamp, the two pins can bend inwards and then come through the holes on the PCB board. Right after the pins on the Delrin clamp go through the holes on the PCB board both of the pins would come back to the original position and the ribs on the pins would fix the PCB board on the brass plate. After auto calibration, the operator just needs to squeeze the ribs on the two pins inwards and then the PCB board can be taken away from the brass plate.
4.2.3 Jig design for multiple loading at vibration test

Vibration test is to check functionality of the vibration sensor in the gauge by fixing the gauge on a shaker machine. The shaker machine can provide vibration in one direction. If the output of acceleration reading from the gauge falls within a confidence interval, then the gauge is able to pass this test. For example, if the input acceleration is 1 g and the output in this direction is within the range of [0.5, 1.5] g, then the gauge is considered as pass. The confidence interval is given by the customer. Currently, owing to the restriction of fixture, the vibration machine could only test one D gauge at one time. This project was to design a new fixture to hold 8 pieces of D gauges so that the vibration test was able to produce in batch of 8. After discussing with a manufacturing engineer in the company, the jig was designed in Solidworks. The assembly drawing is shown in Figure 4-18. The 2D drawings of each part are shown in the appendix.

![Assembly drawing of the jig](image)

Figure 4-18 Assembly drawing of the jig
Basically, the jig consists of three main parts; bottom plate, middle plate and top plate which are shown in Figure 4-20, Figure 4-21 and Figure 4-22 respectively. There are four triangular slots on the bottom and middle plates. Each slot constrains four degrees of freedom of the gauges which are movement along and rotation about Y and Z axes. The pins on the end of the slots fix two degrees of freedom; movement along and rotation about X axes. Because the diameter of the gauges has tolerance of 0.005 inches, a rubber plate is assembled under the middle plate and the top plate in order to offset the tolerance by strain of the rubber under pressure. The partially exploded view in Figure 4-19 shows the rubber plates clearly. After assembling the gauges and plates together, this jig will be mounted on another base jig in the way which is shown in Figure 4-23. The left picture in Figure 4-23 is the base jig on which the newly designed jig should be put. The right picture in Figure 4-23 shows how one jig is mounted on the base jig. Owing to the structure of the base jig, the ear plates on the bottom plate and top plate is positioned in order to fit the base jig.
Figure 4-19 Partially exploded review

Figure 4-20 Bottom plate
When designing the bottom plate and the middle plate, a pin-slot feature and a pin-hole feature were used to constrain the middle plate. The direction of the slot pointed in Figure 4-21 is along the z axes. These two features can fix three degrees of freedom of the middle plate; the movement along x and z axes and the rotation about y axes. The rubber plate under the middle plate can fix another three degrees of freedom of the middle plate; movement along y axes and the rotation about x and z axes.
Figure 4-22 Top plate

Figure 4-23 The base jig (Left); another jig is mounted on the base jig (Right)
Chapter 5 Results

This chapter describes a quantified result of each project on cycle time reduction. In section 5.1, the benefits of kitting project have been proved by the test run. In section 5.2, although the fixture and jig haven’t been tested, the expected results are discussed and agreed by the manufacturing engineers in the company.

5.1 kitting

By running a trial on kitting for three days, it has been shown that kitting can reduce cycle time by 10.2 minutes on average at the mechanical assembly and by 3 minutes on average at the packing. According to the standardized worksheet regarding mechanical assembly shown in the appendix, the second step which is to prepare wires and assemble them with high voltage feedthrough and thermocouple feedthrough by soldering and insulating takes 10.2 minutes on average. Since the external kitting purchases the feedthroughs that have been soldered and insulated per request from supplier, this step can be eliminated from mechanical assembly. In this case, 10.2 minutes can be reduced at mechanical assembly workstation. The cycle time for mechanical assembly is decreased to around 48 minutes. Also, the operator at packing needs to spend about 3 minutes on average in looking for parts. Since all the parts needed for packing have been grouped, the kit also reduces 3 minutes on average at packing.

5.2 Fixture design for fast loading and unloading at auto calibration

By taking use of this fast loading and unloading fixture, one minute is expected to be reduced for each electronic board at setup and dismantlement. Thus, 16 minutes can be reduced at setup and dismantlement for one batch.
5.3 Jig design for multiple loading at vibration

The use of the newly designed jig makes batch production of 8 gauges available at vibration test. Because the vibration test takes 20 minutes for one run, the time of testing one gauge is reduced to

\[
\frac{20 \text{ minutes}}{8} = 2.5 \text{ minutes}
\]

as expected. Thus, 17.5 minutes can be saved from processing one gauge at vibration test.
Chapter 6 Discussion

6.1 Discussion on costs generated by kitting

The benefits of kitting have been discussed a lot. However, kitting also generates costs at the same time. Firstly, it costs more to purchase an external kit for small parts shown as Figure 4-9 and Figure 4-10 than to buy the parts separately. The parts are produced by different suppliers. The supplier of the external kit needs to purchase all the parts at first and then group these parts into kits. This process would generate inventory cost and consume time for the supplier so the price of the kit is expected to be higher than the parts themselves. Because the supplier of kits has not been determined at this point of time, it is still unclear that how much one kit of parts is. Secondly, the external soldering and insulation of one set of feedthroughs also costs 60 US dollars more than the price to purchase just the materials. The price of original materials for one set of the feedthroughs is 110 US dollars but the price of one set of the feedthroughs that have been soldered and insulated becomes 170 US dollars. What the company gain by buying the additional 60 US dollars is 10.2 minutes reduction at mechanical assembly. Currently, the total processing time to produce one gauge is about 170 minutes and the profit of one gauge is about 3000 US dollars. Thus, the benefit of 10.2 minutes equals to

\[
\frac{3000}{170} \times 10.2 = 180
\]

US dollars which is triple as the cost. So the manager has decided to implement the kitting.
6.2 Kits inventory control issue

When taking use of the periodic review model to calculate the inventory level of kits, the demands are assumed as normal distribution. In this section, the reliability of this assumption is discussed. The normality of the demands data in the first six months of 2010 is test in Minitab. The probability plots of demands of A-1 and A-0 are shown in Figure 6-1 and 6-2 respectively.

![Probability Plot of A-1](image)

**Figure 6-1 Probability plot of demands of A-1**
The points in the Figure 6-1 are plotted well along the straight line which indicates a good normality. However, the \( p \) value is 0.277 which means 27.7% chance of rejecting the normality. Thus, the demands of A-1 in the first half year of 2010 don’t fit normal distribution very well. In the Figure 6-2, the points fall aside the straight line and \( p \) value is only 0.035, so the demands of A-0 in the first half year of 2010 fit normal distribution very well.
Chapter 7 Recommendation

7.1 Cycle time reduction on Mechanical Assembly Workstation

This section discusses two possible solutions to reduce cycle time at mechanical assembly workstation to meet Takt time in 2011. After reducing 10.2 minutes by taking use of kitting, the cycle time study of production line is shown as Figure 7-1. It illustrates that the mechanical assembly workstation still doesn’t meet the future Takt time for year 2011. In order to meet the demands forecast, two recommendations are proposed here to reduce cycle time at mechanical assembly workstation and improve the throughput of production line. One recommendation is to add another mechanical assembly workstation which is exactly the same with the current one. The other recommendation is to break down the work content at this workstation.
If the company adopts the first recommendation, the cost is the salary for one more operator plus the whole mechanical assembly workstation including the tools and fixtures. The profit is to reduce the cycle time at this workstation to a half. The cycle time study is shown in Figure 7-2.
If the company adopts the second recommendation, then the workstation right after soldering choke wires on PCB board will be separated. According to the standardized worksheet shown in the appendix, it takes 23.5 minutes from the beginning of mechanical assembly to finishing soldering choke wires with PCB board. And the downstream work content takes 25.2 minutes. The cost of taking this proposal is the salary for one more operator plus one fixture, several tools that can’t be shared such as solder and heater gun and a FIFO lane rack or a trolley to carry the WIP. The profit is to reduce the cycle time to meet the future Takt time. The cycle time study is shown in Figure 7-3.
The common point of these two recommendations is to recruit one more operator at mechanical assembly work station. This point happens to have the same view with the operator balancing study in the thesis of the teammate, Xiaoling\cite{1}. According to her research, the mechanical assembly work station will need two operators so as to fulfill the demands. However, because the idea to break down the mechanical assembly into two work stations requires additional space for FIFO lane to store WIP, the first recommendation is more space saving and then more desirable when the high cost of cleaning room is taken into consideration.
Chapter 8 Conclusion

This thesis describes three Kaizen events to improve the production line to meet the increasing demand. The kit design project helps eliminate 10.2 minutes at mechanical assembly and 3 minutes at packing. Also, the redesigned fixture for fast loading and unloading is able to reduce 16 minutes for setting up and dismantling one batch of electronic boards at the auto calibration. In addition, a newly designed jig speeds up the production rate of vibration test by 8 times.
Chapter 9 Future Work

Kaizen is a continuous effort to improve the production line by eliminating wastes, reducing cycle time as well as expediting the production rate. Firstly, the fixtures described in this thesis will be fabricated and then test in short future. After modifying the design by trial on, both of the fixtures will be able to reduce corresponding cycle time which was consecutively expected. Secondly, since 29 Kaizen events have been identified by creating current state value stream map and future state value stream map, there are still several Kaizen opportunities that need implementation, such as a fixture design for combining two separate setups into a two-in-one setup at manual leak test and final log test workstation. Thirdly, since the manager has determined to expand the capacity of mechanical assembly workstation, two possible ways which are described in Chapter 7 to design another specific workstation for mechanical assembly is on the way and will be implemented in next few months.
Reference

[1] Xiaoling Lang; Operational improvement and mixed model value stream development for gauge production line.

[2] Junying Liu.; Assembly line layout and Kanban system design for an oilfield services company


Appendix

1. Original kits of small parts for mechanical assembly and packing
2. Feedback survey on operators

Feedback Survey on Gauge Assembly Kit Design

This is a feedback survey about gauge assembly kit design. Your opinions are very valuable for us to make improvement. For questions 1-8, you can grade each statement from 1 to 5: 5=strongly agree, 4=agree, 3=neutral, 2=disagree, and 1=strongly disagree. For question 9, please describe your ideas as clear as possible. We would really appreciate your time and opinions. Thank you very much.

Name  Lok Chen Sing  Date 8/7/2010

1. The kit contains and only contains one set of all components needed for assembling one gauge.  4
2. All of the parts have clear labels.  5
3. The small parts in the box follow the assembly flow.  5
4. The kitting reduces walk distance and time to find components.  5
5. The kitting reduces time on preparing HV& TM feedthrus.  4
6. All of the parts are easy to pick from the kit.  4
7. The kit is not heavy to carry.  4
8. The size of kit fits the work station well.  2
9. What other improvements do you think am necessary for kitting?

- The kit might increase cost
- A fixture for the box might be necessary to prevent it from falling.
- It might be better to separate choke and choke bracket.
Feedback Survey on Packing Kit Design

This is a feedback survey about packing kit design. Your opinions are very valuable for us to make improvement. For questions 1-7, you can grade each statement from 1 to 5: 5-strongly agree, 4-agree, 3-neutral, 2-disagree, and 1-strongly disagree. For question 8, please describe your ideas as clear as possible. We would really appreciate your time and opinions. Thank you very much.

Name: Avaimis Lewis
Date: 09/21/10

1. The kit contains and only contains one set of components needed for packing one gauge. 4
2. All of the parts have clear labels. 4
3. The small parts in the box follow the packing flow. 4
4. The kitting reduces walk distance and time to find components. 5
5. All of the parts are easy to pick from the kit. 4
6. The kit is not heavy to carry. 5
7. The size of kit fits the work station well. 3
8. What other improvements do you think are necessary for kitting?
   (a) All the components must be placed vertically for easy inserary 
   (b) The components must be placed by row in the box with near placement 
   (c) Kit part number also can be included in the box so that list must be shown on the box.
Feedback Survey on Packing Kit Design

This is a feedback survey about packing kit design. Your opinions are very valuable for us to make improvement. For questions 1-7, you can grade each statement from 1 to 5: 5-strongly agree, 4-agree, 3-neutral, 2-disagree, and 1-strongly disagree. For question 8, please describe your ideas as clear as possible. We would really appreciate your time and opinions. Thank you very much.

1. The kit contains and only contains one set of components needed for packing one gauge.
   5

2. All of the parts have clear labels.
   4

3. The small parts in the box follow the packing flow.
   4

4. The kitting reduces walk distance and time to find components.
   4

5. All of the parts are easy to pick from the kit.
   5

6. The kit is not heavy to carry.
   4

7. The size of kit fits the work station well.
   4

8. What other improvements do you think are necessary for kitting?
   
   I think, instead of putting at the boxes, can we design the toolkit with putting the kit in the toolkit and don't need any boxes.
3. Standardized worksheet for mechanical assembly workstation

<table>
<thead>
<tr>
<th>WORK ELEMENT</th>
<th>Icon</th>
<th>KEY POINT</th>
<th>Time Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>collect parts and rings, clean choke bracket and top sub</td>
<td>5 6.5 cutting</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Collect wires and prepare assemble the HV and thermosyphon feedthrough, soldering and insulating</td>
<td>8.5 11.05 kitting</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>install b-rings and backup-rings</td>
<td>0.9 0.85</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>assemble choke bracket onto top sub (moved to the housing table, used housing fixture to facilitate)</td>
<td>2 2.6 eliminate walking and avoid sharing the fixture with housing—design a fixture for the assembly</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>install all feedthroughs into top sub, apply torque</td>
<td>1.5 1.95</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>install choke into choke bracket</td>
<td>3 3.9</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>put on fixture, pick Calibrated Electronics from supermarket, mark part number</td>
<td>1.1 1.43 implement barcoding, so we can do scanning instead of marking</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>cut out choke, cut wires on PCB, clair the board using solder sucker, PCB wire insulating, solder choke wires on PCB, clean with alcohol and compressed air</td>
<td>6.5 8.45</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>install PCB into choke bracket, fix diode, soldering feedthrough wires with PCB wires, then insulate the wires, fix the transducer on the top sub (torque), fix the wires and transducer by tapes</td>
<td>10 13 soldering requires techniques to perform fast, right torque to the transducers, make sure the transducers are firmly fixed</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Megger Test, Tm Test = RTV and Cover, data key in &gt; 10G and record the result</td>
<td>11 14.3</td>
</tr>
</tbody>
</table>

Key:

- Safety/Ergonomics
- In-process Stock
- Quality Check

Totals: 98.2 0

4. 2D drawings of the fixture design for fast loading and unloading at auto calibration
5. 2D drawings of the jig design for multi loading at vibration test