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Lean Thinking in Small Size Assembly Company for Continuous Improvement

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ABBREVIATIONS

6S	Sort, Set, Shine, Standardize, Sustain (5S) + Safety
C/T	Cycle Time
JIT	Just-in-time
PDCA Cycle	Plan, Do, Check, Act Cycle
VCT	Value Creating Time
VSM	Value Stream Mapping
WIP	Work In Progress
ZQC	Zero Quality Control

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ABSTRACT:

There is a Chinese saying told "Save time means living longer, waste less means owns more." Lean should always be considered as a philosophy, rather than tools. Simply copy some Lean techniques might get significant results in a short time and the person who applied those techniques became the hero of the factory. However, if Lean philosophy is not properly understood, the dirty and bad organized factory will come back.

This thesis is concentrated on applying Lean as a philosophy by tailored techniques to small sized company, especially in assembly lines. Quanti-Quali research method is used to analyze the feasibility of expected results. In theoretical section, different Lean tools and strategies is introduced and studied based on the needs of small companies standpoint. In empirical part, a company based solution is proposed concerning short throughput time, optimized batch sizes, low WIP, zero inventories, just in time, zero quality control and so on. Quantitative data will be analyzed; root problems and bottlenecks will be defined.

To get a general view of the company operation process, value stream mapping is used to get a bird's eye view. With the help of VSM, a future state of operation in such a small company is studied and applied.

KEYWORDS: Lean philosophy, continuous improvement, one-piece flow, zero inventory.

1. INTRODUCTION

Toyota is the apotheosis of Lean Manufacturing. In such a giant car industry, Lean thinking has been carried through thoroughly. Many companies are learning Lean Manufacturing. However, what they learn is just picking some Lean tools from Toyota Production System. In most cases, some managers will copy some of good techniques after an impressed excursion. Nevertheless, few of them consider those tools as a philosophy. Very few of them could analyze and dig root problems. What Toyota did is “Be more like the tortoise than the hare”. In Toyota, they have surprisingly five hundred years strategy. It is not a matter of five hundred years or one hundred years. The point is that a company has to have a system, which supports their long term existence. This is what we call for continuous development.

When people talk about Lean Manufacturing, they always think that Lean fits for large industry. How does small companies learn such a big concept and apply on their own production is a field worth studying.

1.1. Research background

As a small size Assembly Company, XYZ has only been established for two years. They have their main focus on assemble parts to finished products. From the first beginning of limited engineering and R&D resources to manufacturing the entire products, the company has successfully delivered customized products to different customers. Of course, there are many aspects of the whole company operation system need to be developed to achieve the sustainable development, especially after they have received the long term and big order from one vital customer. The company decided to adopts Lean philosophy in production improvement to fulfill the biggest customer demand, furthermore, to achieve sustainable development.

1.2. Research purpose

This thesis is based on the XYZ company and use Lean tools to help the company to achieve the sustainable development in the production aspect. Problems and bottlenecks are needed to be defined and a feasible improvement program will be carried out to reduce the production lead time by half. Not only some company based lean tools will be analyzed and applied in the real life, but a lot of strategy oriented techniques will also be studied for the purpose of continuous development.

1.3. Research problems

The current problems in the production line is quite mess in workshop, long lead time and waste of resources. To solve these problems, different Lean tools consist of Value Stream Mapping, 6S, Andon system, Kanban, Zero Inventory, One-piece Flow, JIT and Poka-yoke will be analyzed and applied. The research problem is “how to decrease the lead time by applying customized Lean philosophy in continuous development standpoint?”

1.4. Research limitation

The research topic is studied in a small sized company which does final assemblies instead of machining components. In another word, human beings are thought of as production resources rather than machines in this thesis. Due to the difference between people and machine, a lot of factors are considered such as uptime, optimization of workloads, etc. For a limited research period and resources, the study is mostly in production department and part of sourcing department. However, many important issues like batch sizes, and so on should be analyzed through the whole supply chain. This could be the limitation of the research. If the possibility of further research is allowed, more researches and studies will be focused on supply chain management with a tight relation to production.

1.5. Research method

The main research methods used in this thesis are Qualitative and Quantitative methods. A change is made in production starting from some experienced mechanisms. How they like the job, timing of each operation and feedback from those people were collected. Personnel interview and discussion are the main source of gaining information of this study. Then the Quantitative methods were applied to analyze the results of amounts of data. Microsoft Excel and SPSS are two of the main software which contributes a lot to this research. After that, qualitative methods are used in workload balancing process with few proofing cases. The best workers in the factory first apply the development process and give feedback to the whole process, and then corresponding modifying is done in the process. Finally, all the other workers applied the new process for many times for the program ramp up. In a word, a Quanti-Quali research method is used in this thesis.

1.6. Thesis structure

The structure of the thesis consists of theoretical framework, introduction of production flow, expatiate and analyzing problems, analyze feasibilities and propose solutions.

In the theoretical section, relevant lean concepts will be presented. Lean tools will be introduced based on Toyota Lean Manufacturing System. Emphasis will be put on thinking of Lean as a philosophy rather than powerful tools. A few important Lean ideas will be carefully itemized.

In the empirical chapter, it includes the analysis of the XYZ Company's production line, the fish born diagram of lean thinking result for the company and value stream mapping for the current and future stage. All application of the lean tools will be shown.

In the conclusion chapter, the research results will be summarized, and future thinking of Lean manufacturing will be proposed.

2. LEAN PHILOSOPHY AND TOYOTA WAY

Many people might have learned or heard Lean, but rarely can they fully and deeply understand Lean. People who have learned Lean from some course and books might speak out lots of Lean principles and tools, but rarely people can think Lean as a philosophy. It might take time to fully understand and accept Lean as a philosophy.

This theoretical chapter will introduction Lean in top-to-down layers same as from Macro to Micro concept. First understand Lean as a philosophy, then applied Lean as a sustainable development strategy and last use Lean tools in practical. Relevance Lean tools will be presented.

2.1. Lean concept and developing footprints

Lean thinking means the requirement of thinking in the following three aspects. First, production is a flow without interruption (one-piece flow), and with only value-adding processes. Second, a “pull” system that passes back from customer demand and refill only according on how many has been taken away. Last, a company culture that everyone in the group contributes on continuous improvement. (Liker 2003: 7.)

The founder of Lean, Toyota, started its journey to lean in 1950s when they want to develop new operation principles facing the after war finance difficulties in Japan. During that time car market are quite small because of the low level of incomes. They needed to cut cost but avoid of cut employments. Some company might end at these difficulties, but Toyota developed a new more flexible production process which not so depend on long-term production runs. (Drew, McCallum & Roggenhofer 2004: 5.)

Toyota Production System, the new production system which Toyota developed allowed changeovers often and fast. They use multi-purpose tools and interchangeable machines. It

reduces the multi set-up fees and moving distance. The employees were trained to higher level also because they have to know how to use different tools and change machines and production line often. This investment on people was successful because the employees worked for the company for a long time even for a life time. The second benefit for this highly trained employees was that the company's continuously improvement. (Drew et al.2004: 5—6.)

Toyota's short-term run transfer to an advantage because it can react fast and change production by changing models. After many years, what Toyota did to react in the difficult time formed a new and independent operation system which is the key of Toyota today's success. (Drew et al.2004: 5—6.)

2.2. Fourteen Lean principles

In reality, company leaders always are able to see a short term view although they want to go further. Applying Lean or any kind of revolution, in a short term can bring efficiency and benefit for the company, but when leadership of the company change, company will going along to another personal way of the current leaders. The company cannot grow sustainably. In order for run into a long term win, Lean should be considered as a philosophy that substitutes any short term decision (Liker & Meier 2006: 8). So when the company change the leading group, the company can still go along in a sustainable development way.

Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.

Lean philosophy is not just on the surface. When the famous Toyota Production System was created by Taiichi Ohno, cost reduction has been the initial purpose and fervor, but that is not the only purpose make Toyota apply Lean. Toyota has a 500 years plan for their future development. Each executive of Toyota understand their position and purpose is deliver the company to the next level along the long term plan. Toyota provides a model of the future that many people are working aligned for a same purpose in many years. (Liker & Meier 2006: 8.)

Create a continuous process flow to bring problems to the surface.

Flow or one-piece flow means no one is waiting for other people working on products, which mean everyone, finish work at the same time and move to next process. Balanced work load and having flow normally shorten 90% of the previous time. Furthermore, Toyota also focuses on value-added flow which not only has material or information moving fast, but also connects people together with process. So when some problem accrues, it floats on the surface immediately. Flow is the initial element to achieve continuously development. (Liker & Meier 2006: 9.)

Use “pull ” systems to avoid overproduction.

Holding inventory to meet customer’s need, especially when the customer want the exactly products and amounts, and no failure of delivery is not a right way. In fact, holding inventory always cause out of the very products. Toyota invented a new way to avoid this: the “pull” system or as the Toyota’s *Kanban* system. The company hold small amount of each kind of parts and only refill them for the certain amount of parts. (Liker & Meier 2006: 9.)

Level out the workload (work like the tortoise, not the hare).

Heijunka means stability in the workload. It is the only way to having a continuous flow. When many companies think that uneven workload is the nature of unstable situation, Toyota is working hard on making the workload even by having the flexible workforces with contracting companies and suppliers. (Liker & Meier 2006: 9.)

Build a culture of stopping to fix problems, to get quality right the first time.

Toyota's founder Sakichi Toyoda invents the principle of stopping to fix problems. He got the inspiration from his grandmother who worked with loom. The problem with the loom was that all material is wasted after one single thread broke; the waste can only be stop until somebody sees that and change the thread. Toyoda invested the *Andon* system to alert the broken threads. Then the *Andon* system later is used in the Toyota Production System also for alert problems. In Toyota's production line, the whole production needs to stop once a problem happen, and problems need to be fixed right now. Seemingly it is waste of time, but productivity will be improved because problems found and solved out. (Liker & Meier 2006: 10.)

Standardized tasks and processes are the foundation for continuous improvement and employee empowerment.

If the process is not steady and repeatable, timing and output cannot be forecasted. Divisible process is the base of flow and pull. What Toyota do is to standardize the best practices today and learn from the practices, then to continuous develop up on the standardization. If not, single employee's ideas of improvement will be buried after this person move out. Only standardize can keep the ideas within the company. (Liker & Meier 2006: 10.)

Use visual control so no problems are hidden.

Toyota always thinks to support people first. People are visual creatures that they have direct and strong feelings of what they see. Having visual paper board and paper flip chart hanging on the wall can help people thinking more easily and focused. Although paperless office and factory is a big trend nowadays, Toyota still keep many visual paper charts and diagrams in factory. (Liker & Meier 2006: 10—11.)

Use only reliable, thoroughly tested technology that serves your people and process.

To avoid the previous failure of applying latest technology, Toyota has the principle of only use reliable, thoroughly tested and fully proven by tryouts technology. Toyota is very careful with choosing new technology unless there is a big need. They also encourage their employees to think new ideas, and once the idea is tested and proven, it will be applied very fast. (Liker & Meier 2006: 11.)

Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.

A manager in Toyota should fully understand the Toyota Way and make decision based on the Toyota principles. Almost every manager in Toyota is grown inside the company, except in some abroad branch where they have to hire some local managers. Still local managers need almost 10 years to study the Toyota Way and be grown. (Liker & Meier 2006: 11—12.)

Develop exceptional people and teams who follow your company's philosophy.

Toyota employees call themselves “team associates”. Toyota has the strong company culture that every employees belief it. This culture is always called their DNA. Toyota has excellent employees who understand the philosophy and work it in the system. The other companies who only copy the Toyota tools can achieve as excellent results as Toyota does. The people who use the tools matters. (Liker & Meier 2006: 12.)

Respect your extended network of partners and suppliers by challenging them and helping them improve.

Toyota respect partners and want to improve together with their partners. And they hope their partner can becoming better after they work with Toyota. So challenge is not only the core value of Toyota but also the right way to cooperate with business partners. (Liker & Meier 2006: 12—13.)

Go and see by yourself to thoroughly understand the situation.

There is a common thinking in Toyota that people always need to see the problems themselves than only read other people's reports and solve the problem base on theories. Responsible for a problem means checking the problem source, looking into problem and fully analyzing. In Toyota they are doing things in this way from the executives to the normal workers. It is not acceptable in Toyota culture that only collects the reports from subordinates to solve a problem. (Liker & Meier 2006: 10—13.)

Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.

Making decisions slowly to achieve totally agreement is a common way in Japanese management. Consensus makes the implementation go fast. But the deeply thinking is to dig the potential problems and solutions, so that they can get the best results. In Toyota Way, people ask five questions when people bring out a solution to a problem, they will be asked about how do they know what the real problems is, who have they spoken to, and are those people agree with the solution. Gathering the ideas of all the concerned people and get a consensus solution is a time-consuming process, but the solutions can get widely searched and fast implemented. (Liker & Meier 2006: 13.)

Become a learning organization through relentless reflection and continuous improvement.

Once the company has achieved stable process, they are starting to have continuous improvement. Toyota's "Five-Why Analysis" and the "Plan, Do, Check, Act" tool can help to find the root reason of slow and inefficient process. Slowness and problem can be found out easily when the process is stable. That's why Toyota people are continuous in learning. Learning helps Toyota going forward base on the past. (Liker & Meier 2006: 13—14.)

Self-reflecting is a key to Toyota's continuous successful. Toyota engineers always reflect on unsatisfied products and improve solutions, so that same problems will not happen again and better solution will be worked out. (Liker & Meier 2006: 14.)

2.3. Lean Manufacturing tools

Once the company has the purpose of implementing lean manufacturing and figure out the main factor of problems, lean manufacturing tools such as Value Stream Mapping, Kanban, 5S, Andon system, one-piece flow and Mistake Proofing can be applied to help the company achieve the continuous improvement.

2.3.1. Value Stream Mapping

A value stream means that all the value-added and non value-added actions required bringing raw material to customer and the design from concept to launch. Making Value Stream mapping can help to improving the whole. (Rother & Shook 2003: 3.)

A Extended Value Stream Mapping is a diagram that illustrates all of the actions from value-creating to wasteful that are need to make out a product from raw materials to the finish goods to customer. The actions to be drawn include two flows: the upstream of the customer orders to the sales department and the downstream of the products make out from raw materials to customers. Connect these two streams makes an closed cycle of demand and reaction. (Jones & Womack 2003: 1.)

Value Stream Mapping is the easy way of looking into the materials and information flows. Looking them in all, summarizing them notably and then planning an future state of improvement. Current state map illustrate current situation happening today and future state is the better state of current state. (Jones et al. 2003: 1.)

Production family should be chosen before drawing the Value Stream Mapping. Production family includes a sort of product variants going through similar processing steps and common equipments. The definition of the production family is complex and multi-choose, so it is better to use the same family and component in one mapping. (Jones et al. 2003: 1—3.)

The perfect Value Stream Mapping would be honestly show all which is start from the customer who is the end user of the product then to the entire path the value stream route. The benefits of using the Value Stream Mapping are presented in two ways. First is to define the problems of different functions, for example, production control, purchasing, operations, logistics and so on. The second benefit is that it can define the problems between companies. (Jones et al. 2003: 4—10.)

The principles for a Lean Extended Value Stream include:

- First, everyone in the entire value stream should be aware of the rate of customer consumption of the product at the end of the stream.
- A second feature of a truly lean extended value stream will be very little inventory.
- A third feature of an extended lean value stream is as few transport links as possible between steps in the production process.
- A fourth feature of a lean value stream is as little information processing as possible, with pure signal and no noise in the information flows that remain.
- A fifth feature of lean value stream will be the shortest possible lead time.

- A final principle of a lean value stream at the macro level is that changes introduced to smooth flow, eliminate inventories, and eliminate excess transport and lead time, should involve the least possible or even zero cost. (Jones et al. 2003: 44—48.)

The Value Stream Mapping is just a tool. The mapping is only worth when the future state is accomplished. But the VSM is the pictures of the whole company flow. It is difficult to implement all aspects in one time. So the VSM can be split into different steps. For example split future state VSM into different segments such as supplier loop, pacemaker loop and so on. (Rother et al. 2003: 86.)

After the future state VSM is split, a value stream plan should be made, which includes the time and actions to do, in what sequences, measurement of achievement and clear checkpoints and deadlines. The decision of the planning sequence is based on the following four principles. First, create a continuous flow based on TAKT time. Second, create a pull system to prevent overproduction. Third, level workload. Fourth, eliminate waste, reduce batch size, minimize inventory, and stretch the range of continuous flow. (Rother et al. 2003: 90.)

2.3.2. Just-in-Time and Kanban

Just-in-Time is one technique for implementing the “pull” system when thinking of eliminating the waste.

The meaning of Just-in-Time is only making “what is needed, when it is needed, and in the amount needed.” It can increase the productivity and eliminate the waste. It is a very useful tool in production line for large amount and especially when the product includes thousands of components. (Toyota Motor Corporation 2009.)

Kanban is considered as demand scheduling, it is the method of implementing Just-in-Time manufacturing. Kanban means “signboard” in Japanese language. It was developed by

Taiichi Onho in the late 1940s and early 1950s and it was famous in the 1970s during the global recession. At first, the purpose for Kanban system was developed to cut costs and control machine usage. Today, Toyota extends the usage of Kanban in defining obstacles of flow and chance for continuous improvement. (Gross & McInnis 2003: 1.)

Kanban can illustrate visually three kinds of information. First, Kanban shows how much the production line make, when they need to stop or change over. Second, Kanban also tells what to do when problems happening and who to look for certain kind of problems. Third, good Kanban system shows immediately production line status in scheduling. When using Kanban scheduling, products are made according to actual usage, which is show on Kanban, not forecast. (Gross 2003: 2—3.)

The two kinds of Kanban and the operation process are shown in Figure 1.

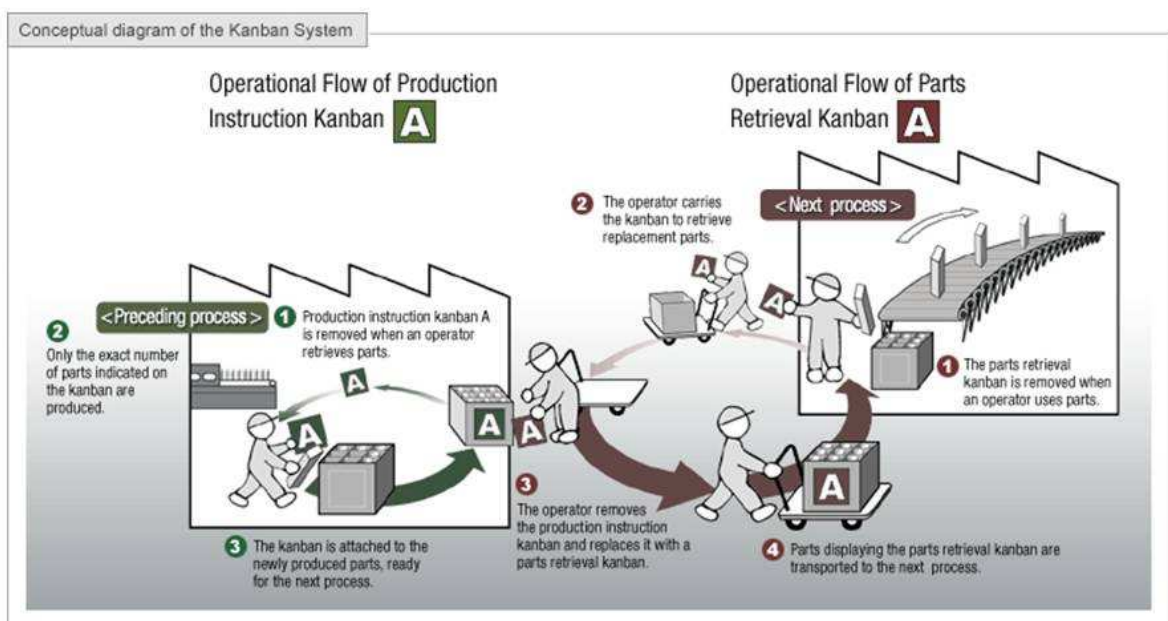


Figure 1. Conceptual diagram of the Kanban System (Toyota Motor Corporation 2009).

When starting to design Kanban system, a group of people should be gathered and sit down for discussion. The group includes cross-function members from production management, materials management, material handlers and production operators. The number of the group is between 5 and eight. Each member should have the power to response. And a project leader should be chosen out who is responsible for organizing team meeting, supervising and make sure things going on in plan. The project leader also should have the power for making final decision if other group members have conflicts and the project can't move on. (Gross 2003:19—23.)

After form the group, the next step is to gather and analyze the data for determine the Kanban size. The needed data are amount of parts operated in the production line, changeover time, downtime, and scrap levels. All data need to be document and analyzed after collecting. Review the data for making sure that all data is consistent, correct and realistic. (Gross 2003: 33—47.)

When determine the Kanban size, first we need to calculate the buffer. Buffers are considered by customer delivery requirements, internal lead times, supplier lead times and comfort level. Then the final size of Kanban container can be calculated. The equation is shown in Figure 2. (Gross 2003: 64.)

$$\text{Container Quantity} = \frac{(\text{Buffer Quantity} + \text{Replenishment Interval Quantity})}{\text{Container Quantity}}$$

Where:

$$\text{Buffer Quantity} + \text{Replenishment Interval Quantity} = (\text{Buffer} + \text{Replenishment Interval}) \times \text{Adjusted Production Requirement}$$

Figure 2. Equation for Calculating the Container Quantity(Gross 2003: 65).

The size of containers could be got with the sum of buffer quantity and replenishment interval quantity divided by container quantity. Where buffer quantity and replenishment interval quantity equals to buffer and replenishment interval multiple adjusted production requirements.

2.3.3. 5S

5S is originally Seiri, Seiton, Seiso, Seiketsu, and Shitsuke in Japanese language which means sort, set in order, shine, standardize and sustain. 5S is defined as a process to build a work place that help the company to combine the items of workplace organization, standardization, visual control, visual display and visual metrics. The meaning of each S is shown below:

- Sort means to find out required working tools, parts, working instructions and keep only the needed.
- Set in order means to put tools, parts in order for clearly and easily use.
- Shine means to clean the workplace for prevent impurities.

- Standardize means to maintain the workplace always in same condition.
- Sustain means to form the habit of applying the first 4 Ss. (Burton & Steven 2003: 112.)

The 5S process is extensively accepted as a basic step to achieve continuous improvement. It can help the workers understand the concept of waste and productivity. As long as the 5S process is applied, the target of continuous improvement is not far. The following figure shows the 5S steps and each step's result from applying. (Borris 2006: 156.)

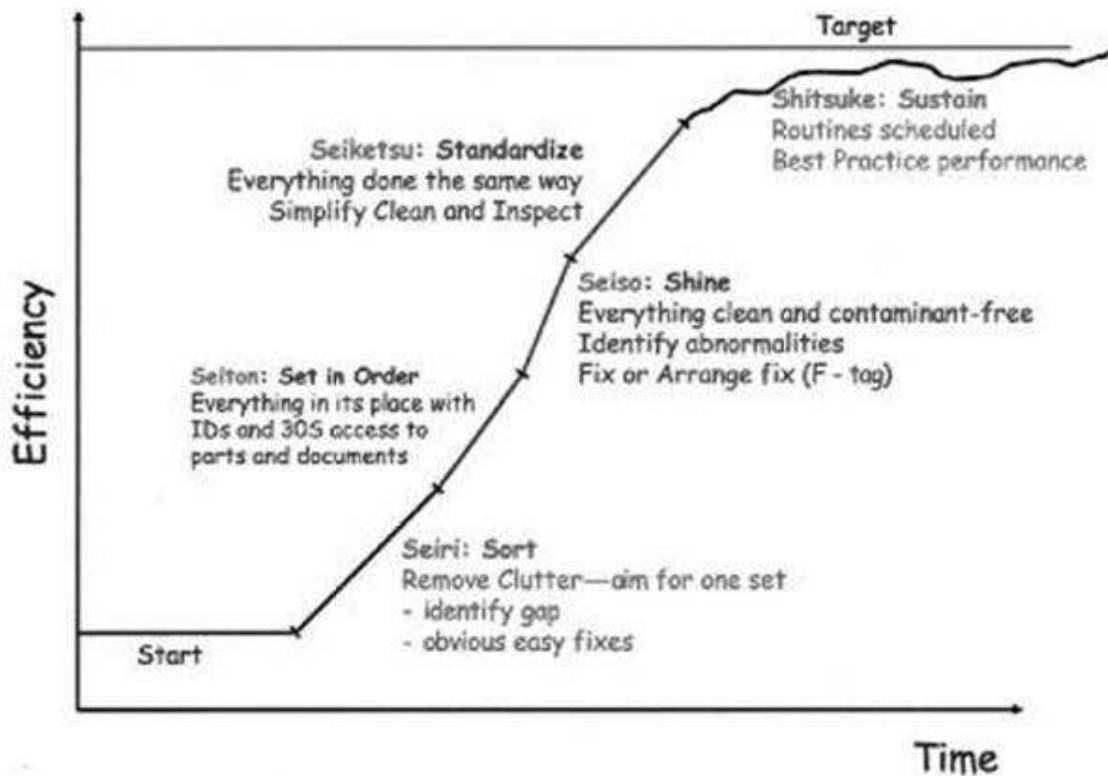


Figure 3. A schematic Illustration of 5S Processes (Borris 2006: 157).

2.3.4. Andon system

Andon System in Toyota Manufacturing System means the light signal system for help. Toyota calls the Andon system a “fixed-position line stop system” and it is assembled in every production line. When problems happens, operator in workstation push the Andon button, the yellow light turns on and the supervisor need to check the problem and decide if the problem can be fixed immediately or later. Then the supervisor pushes the button again to move the line again. Supervisor need to be trained well to know how to response to the Andon system. (Liker 2003: 131.)

2.3.5. One-piece flow

One-piece flow is also a tool of Lean Manufacturing. It is very easy to understand by the single word meaning. One piece means that in the production flow only one unfinished product is at one workstation, and the unfinished product is past by to the next workstation after the particular work that belongs to this work phase is done. In one-piece flow, each workstation has its own piece of unfinished product to work on and the product has no waiting time.

There are generally ten benefits of one-piece flow:

- Reduce safety problems. In one-piece flow the need of heavy parts lifting and forklift usage rate are reduced. So the injury caused by the overload of manpower and forklift accident is reduced.
- Bring better quality. In one-piece flow, quality problem of product and part can be found out at the first time and the fixing of the problem has to be done at the first time also.
- Give more Flexibility. One-piece flow gives the company more time to response to the change required by the customer. The company has longer time to re-plan the

production timetable and product because one-piece flow is faster than batch and queue.

- Easier on scalability. Equipment in one-piece flow can be smaller and the cost is also lower. Because the needs of high driving speed of production and large size of parts are no long existed.
- Smaller Inventory. In one-piece flow, Work-in-Process (WIP) is dropped down , so that the money used on keeping, transporting inventory can be used for some other purposes.
- Higher productivity. In one-piece flow, wastes on movement, transportation and waiting are decreased largely than the batch and queue production which means the productivity is higher.
- Easier on refilling material. Material is moving at the same takt time, so that the refilling of the material is easier.
- Smaller space. Because the Work-in-Process amount is reduced, so that there are more space on the work floor. Also because one-piece flow needs all work station connected closely, so the spacing is even smaller.
- Require better quality control. Because there is no buffer in one-piece flow, the quality must be ensures. This requires improvement of quality control in materials, machines.
- Encourage people. By apply one-piece flow, the big achievement and improvement can be seen, they are encourage to bring more energy and ideas. When everybody is involved in the entire process, the work place becomes fun. (Pereira 2008.)

2.3.6. Mistake-proofing and Zero Quality Control (ZQC)

Zero Quality Control (ZQC) is a quality control (QC) approach to achieving zero product defects. Zero defects is the goal of ZQC. The principle of ZQC is that is the work process is well controlled, then it cannot produce defects. Machine and people sometimes make

mistakes; ZQC is a method of proofing mistake and prevent error becoming defects. (The Productivity Press Development Team 1997: 14.)

There are many reasons for company focuses on zero defect products. One important reason is the customer satisfaction and loyalty. One defect product can bring totally bad image to the customer. Another reason is the cost. Defects also cost money, such as, waste of materials, reworking hours or repairing damage, these cost drag down your productivity and competitive ability. The key reason for focus on zero defects is that company does not need to keep inventory for buffer of products, because no defects products are produced. (The Productivity Press Development Team 1997: 15.)

Before achieve zero defects, causes of defects should be learnt. In any one of the below five situations, most of the defects could happen:

- Inappropriate procedures or standards.
- Excessive variability.
- Damaged or excessively variable materials.
- Worn machine parts.
- Human mistakes. (The Productivity Press Development Team 1997: 17.)

There are three kinds of approaches to product inspection and each kind of inspection leads out different results. Judgment Inspection means checking the product before delivery out the company to customer. It can only discover defects but it doesn't reduce the amount of defects. Information Inspection means only give feedback to the production line after defects problems happen. It only reduces defects but it does not prevent all the defects unless all kinds of problems would happen. Source Inspection, which is the main factor of ZQC, catch errors and give feedback before producing so that the errors will not turn into defects, which means, process is controlled and defects cannot be done. (The Productivity Press Development Team 1997: 26—30.)

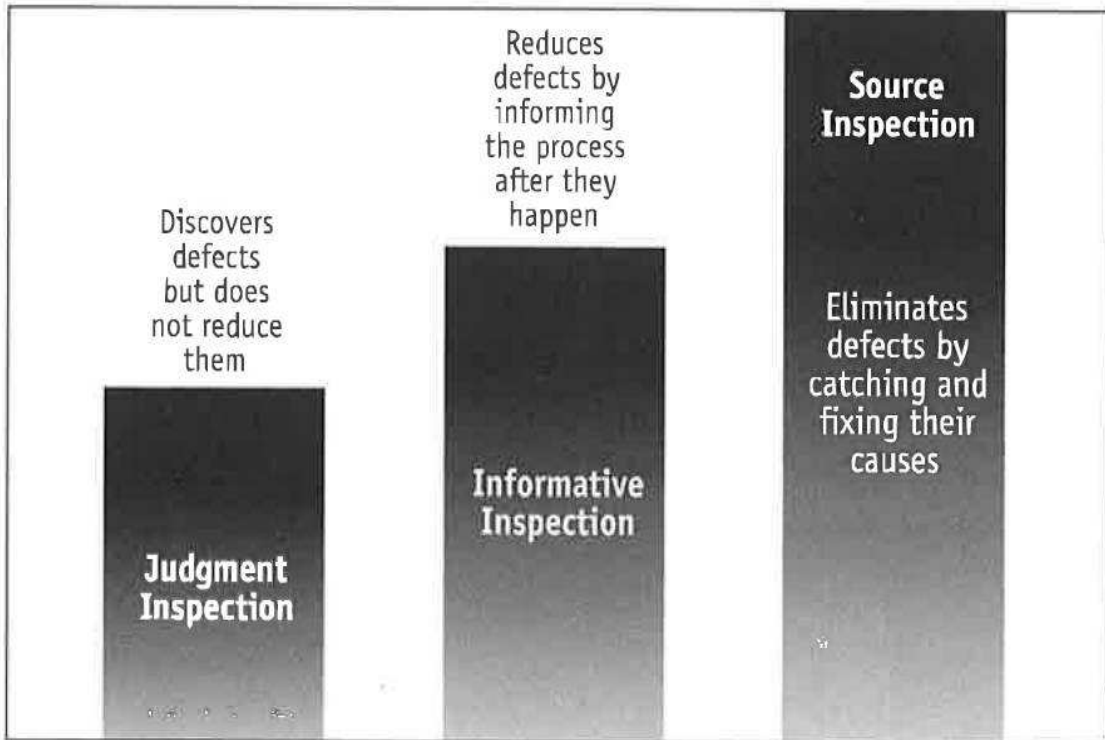


Figure 4. Three Approaches of Product Inspection.

Four elements of ZQC are source inspection, 100 percent inspection, immediate feedback and poka-yoke (mistake-proofing). In which, element source inspection is the key element to ZQC to prevent error turns into defects. 100 percent inspection does a source inspection on every single product. But it cannot ensure defects or a statistical number of defects will not happen. The third element, immediate feedback in ZQC inspection is done by a signal or alarm system to tell the workers about errors before the product turn into defects. (The Productivity Press Development Team 1997: 24, 31, 32.)

The fourth element in ZQC approach is mistake-proofing system also called poka-yoke. Poka-yoke device is installed in the machine to do 100 percent inspection of the source inspection. Electronic sensors or passive devices are used in Poka-yoke system. And the

best is to let the workers in each work station give the idea of the installation way. (The Productivity Press Development Team 1997: 33.)

2.3.7. Bird's-eye view drawing

A bird's-eye view diagram is the down look of the traces of the worker's movement. It includes work steps number and walking lines.

Drawing a bird's-eye view diagram can easily and visually show the worker's working time and walking time. The movements of the workers from one work step to other work steps are drawn as a line to connect each step.

After drawing the bird's-eye view diagram, observe the finished drawing, if it looks quite disordered, it means the production flow is bad and the worker station layout is not well organized.

2.3.8. Deming Theory

Plan, Do, Check, Act cycle (PDCA cycle) is also called the Deming Cycle was first introduced by W. Edwards Deming in the 1950's. It is kinds of closed loop which continuous process of giving feedback so that the problems and needed changes can be shown visually to the management. Plan means the plan for changes and improvement.

Do means to apply the plan and inspect the results. Check means to record the results and report to management. Act means choose the changes or improvements to apply in the

process. Then go back to Plan again for changes corresponding to the feedback. (Arveson 1998.)

3. MAIN RESEARCH PROBLEMS

In the year of 2008, the global companies suffered from the financial downtime. The Assembly Company XYZ had also been affected by the downtime. As a small and young company, it has survived by relying on the stable demand from one vital customer. But it didn't accomplish the demand by itself. The company had to sign out-sourcing contracts with several partners to help them assemble products. The benefit were divided and deducted.

The key reason for the company's problem is the long lead time. The main research problems become to define the main factors need to be improved and find out the bottleneck of the production line. And build up a continuous improving production line for a long-term run. The company would like to adopt Lean Manufacturing in their production line.

3.1. Production overview

There is one production line with twelve work phases in the whole production flow. Exclude the last two phases which are Testing and Final Inspection & Packing, Work Phase 1 to 10 are all assembly phases. Every phase has three people working on it at the same time.

The layout of the production flow is in a shape of "C". The production assembly starts from Work Phase 1 and continuously moves from one phase to the next. Crane is used whenever the production needed to move.

Each phase has its own work plate. Work plate is a quadrate estrade, includes shelves hanging tools and putting screw boxes, computer table with screen, main box, keyboard,

mouse and battery charger base for automatic screw drivers. There are common places for keep all kinds of screws, but it is far away at some corner in the factory.

All materials ordered from suppliers first come into a rented warehouse, workers in the warehouse put all kinds of materials in sets according to phases. Then all sets are transported to the factory. Materials for four products are sent to each phase in one time by one call.

3.2. Obstacles in production flow

Using the crane to move the products from phase to phase is quite unwieldy and slow. The layout of the production flow is not convenient for moving.

Bottleneck is one big reason for the long lead time. When problems such as broken material, wrong assembly work and lack of worker happens, this will cause this phase becomes a bottleneck. All the work phases are waiting for the bottleneck phase.

The finish products are keeping in the factory for delivery every week. All the sub-contract companies also send their assembled products to the factory for testing and final inspection and packing. All the products are waiting for test, finishing and delivery all standing in the factory.

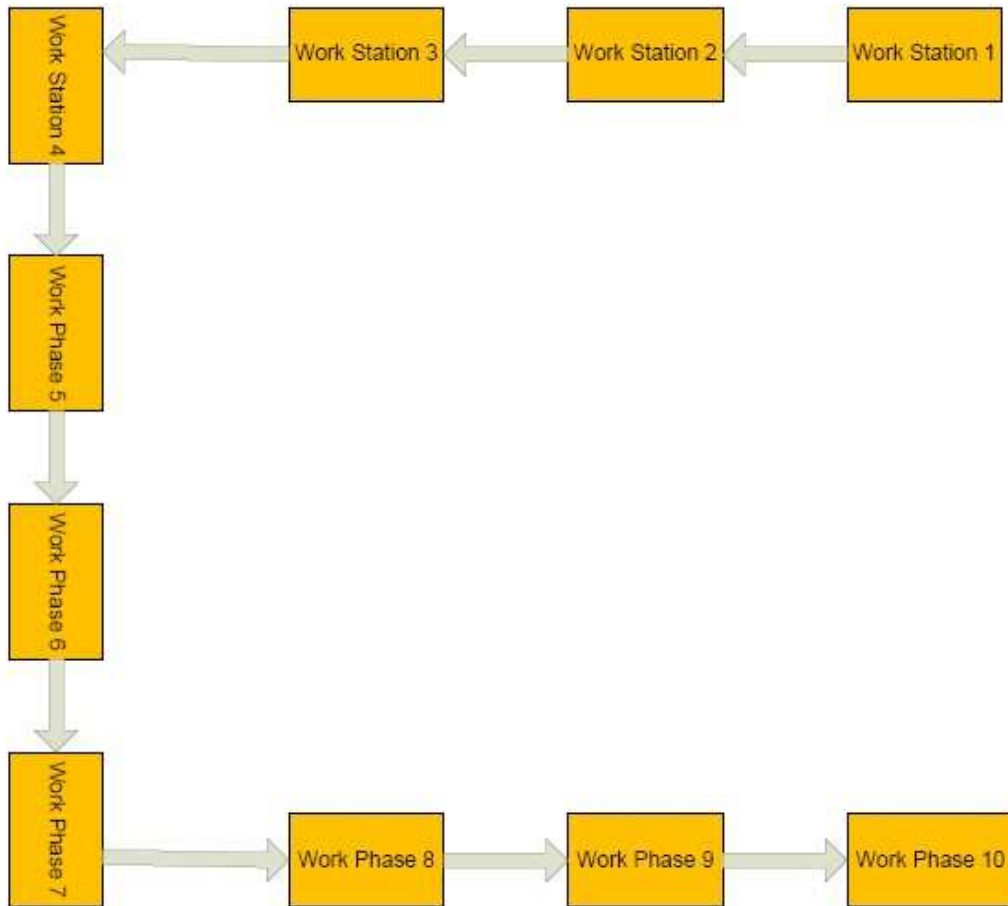


Figure 5. Current Layout of Work Floor.

3.3. Inconvenient workstations

The work estrade for each work phase take too much field and space. Front side faces the product. Both side with shelves and backside with half shelf and an entrance for people walking.

Tools no matter useful or useless are all hanging on the tool shelf. Every work phase has a set of standard tools, but every phase has its specific need of tools. Also when some work phase are missing some tools, people looking everywhere to borrow the tools but might forget to return.

Screw boxes take place of one whole shelf, each box contain one kinds of screw, no matter big or small, from diameter of 3mm to 12mm. The workers reload the boxes when they are empty. And the screw shelves for all kinds are in the corner far away. Some boxes take a month to finish where else some boxes need to reload twice for one product.

3.4. Indefinite job allocation

The workers don't have a common sense of lean concept. They have never learnt lean by themselves or been trained to understand lean philosophy and apply lean in the production process.

There is no clear work partition for each worker. Three workers in one work phase read assembly instruction from one computer. They do whatever they want to. Although three workers discuss who do what beforehand, but one worker is often on the way of other worker, so the other worker has to wait. It is waste of time.

Workers change work phase every week. When they get familiar with their work, they are moved away and start over from the next phase again. It is the waste of turned out proficiency.

The workers also walk around to get tools, materials, screws and anything else. If we use a bird-eye view diagram to visualize, it can be like this in Figure 1.

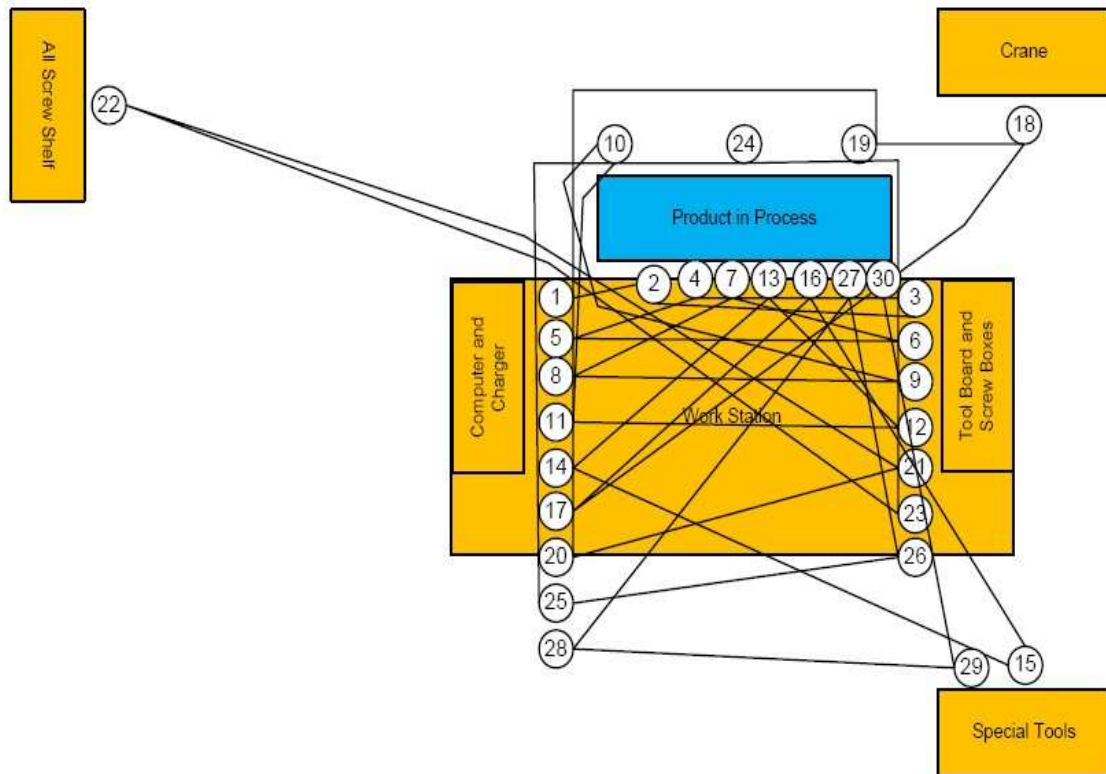


Figure 6. Current State Bird's-eye View.

3.5. Inappropriate batch sizes

The materials also take too much field and space. The warehouse fee and transportation fee are quite high.

The materials for 4 products are all waiting besides each work station. Some kinds of bulk materials are also stored in the factory. The in-inventory fee is expensive.

Workers open the package, throw the trash and recycle the pallet. Workers also make some sub-assembly works when the materials come. These are all non value-added action of the production.

Bulk materials are the parts ordered from suppliers and deliver directly to the factory not the rented warehouse. These parts are usually used in Work Phase 0. Some of them are coming in thousands of amount.

3.6. Quality problems

All materials coming into the factory have a defect rate of 10%. No sourcing inspections are doing in the factory. Wrong amount and bad quality materials are the main cause of defect rate. Quality problems are only reported and reflect when they are found out by workers.

Failure rate of products are 15%. The main reasons are defect materials and wrong assembly work process.

3.7. Value Stream Mapping in current state

To float the problems and understand the whole work process more clearly, a Value Stream Mapping for current state is drawn. See Figure 2.

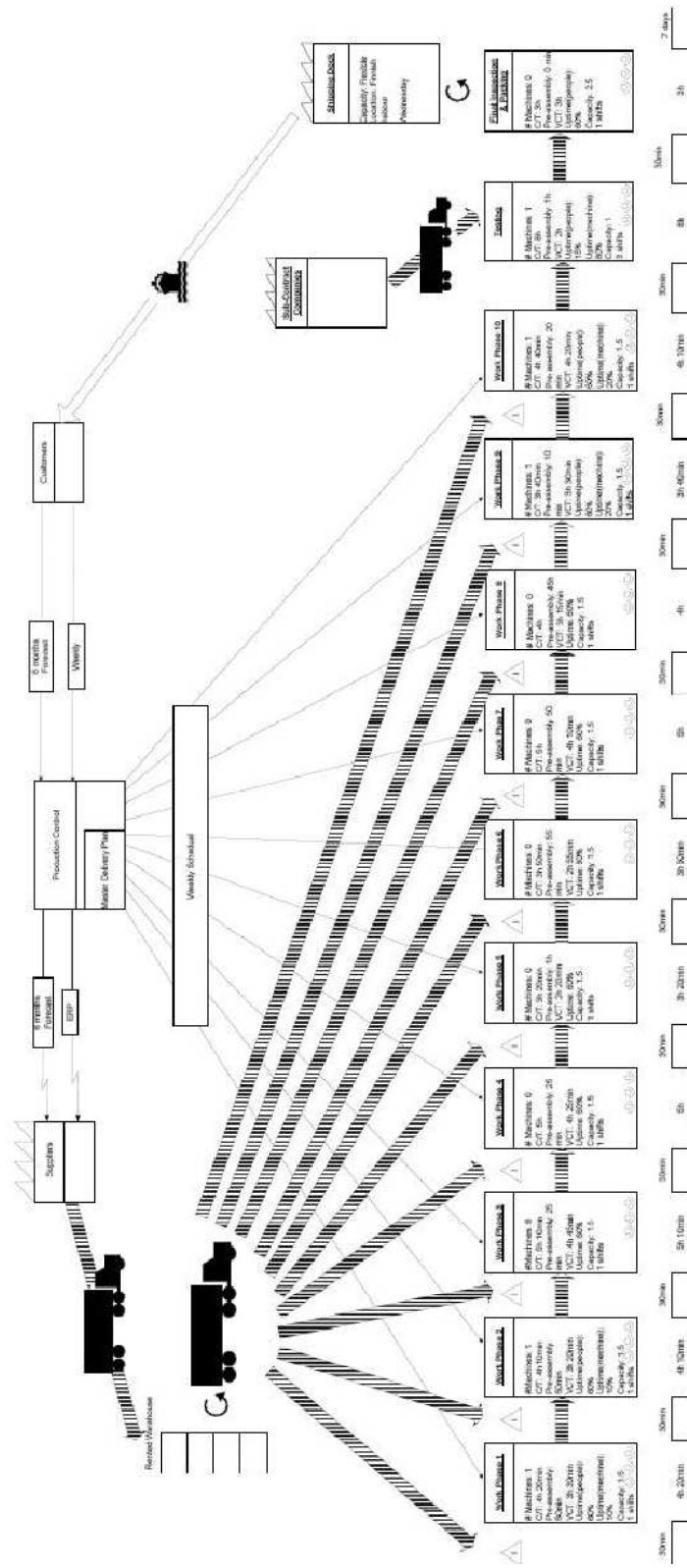


Figure 7. Current State of VSM.

Productin Lead Time and Production Processing Time is show in Table 1.

Table 1. Current Lead Time.

Current State C/T & Waiting Time		
	Cycle Time	Waiting Time
Work Phase 1	4h 20min	30min
Work Phase 2	4h 10min	30min
Work Phase 3	5h 10min	30min
Work Phase 4	5h 10min	30min
Work Phase 5	3h 20min	30min
Work Phase 6	3h 50min	30min
Work Phase 7	5h	30min
Work Phase 8	4h	30min
Work Phase 9	4h 40min	30min
Work Phase 10	4h 10min	30min
Testing	3h	30min
Final Inspection & Packing	3h	7days
Total	48h 40min	7day 6h

Waiting Time between each work phase is thirty minutes. The Processing Time also includes part of pre-assembly work, which are non value-added to the production.

4. RESEARCHES AND POPOSED COUNTMEASURES

Applying Lean in different company requires different countermeasure. Suitable modification and flexible executive are needed. Everyone in the company should fully understand Lean philosophy, use Lean as a strategy and apply Lean tools correctly, especially the leaders.

First thing in all development, a whole picture of the company developing system should come out. To achieve the continuous improvement for the company, a Fishbone diagram can be drawn to be observed, executed and followed. See Figure 4.

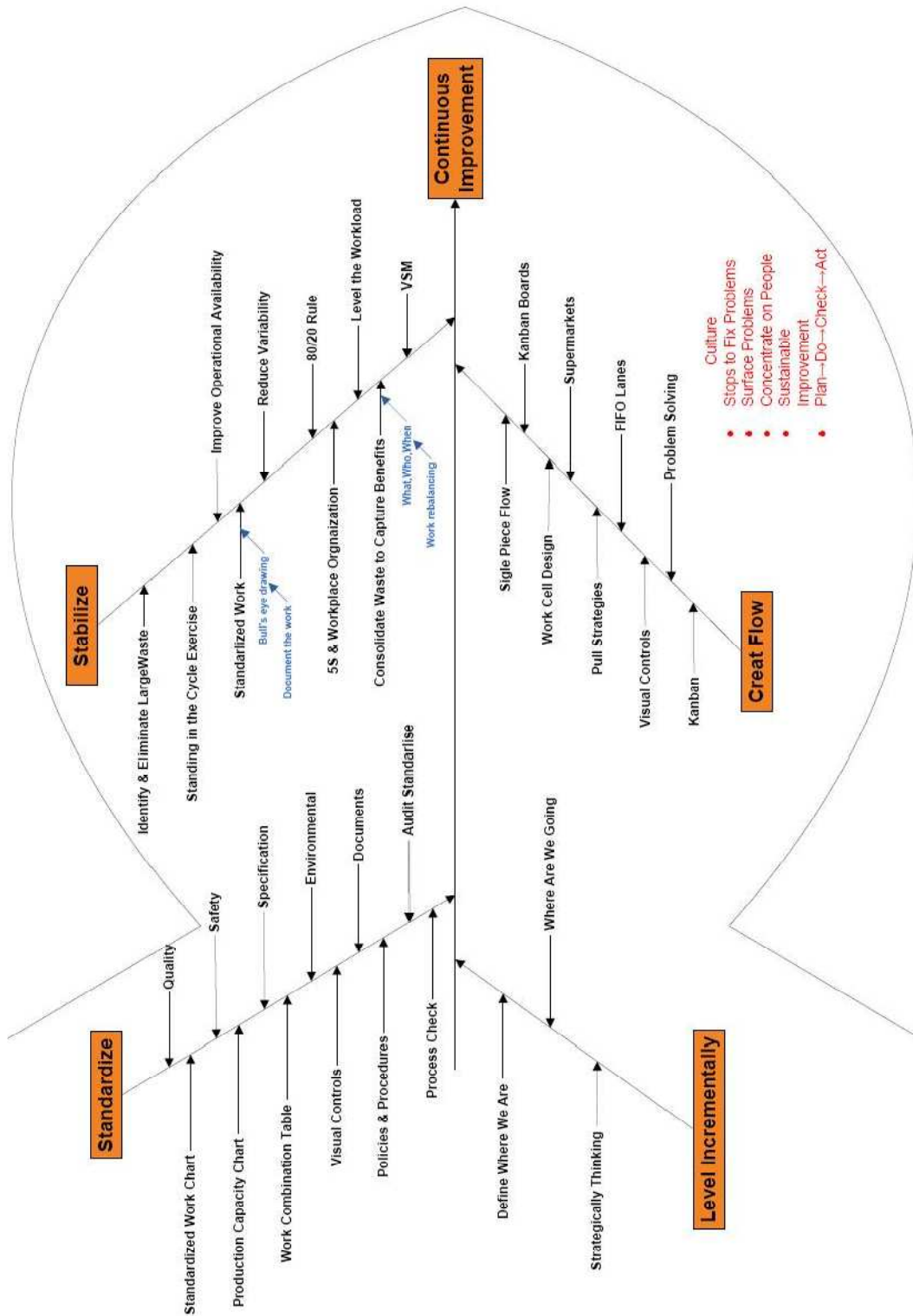


Figure 8. Fishbone Diagram of Continuous Development.

As the limitation length of this thesis, not all the actions regarding each branch will be presented. Only the solutions related to the branch of Stabilize and Create Flow will be introduced.

4.1. Problem shoot-outs in production flow

The work process in current state is quite uneven, and non value-added processes are included also. Work process and layout of the production line are redesigned. And a VSM for future state can be drawn.

4.1.1. Work processes

New production line is designed in two lines and each line includes 7 work phases. Each line starts from Work Phase 0 to Work Phase 6. Because the testing and finishing equipment has only one set, both outcome products will go to Testing and Final Inspection & Packing work phases.

Non value-added processes can be considered as pre-assembly works. All pre-assembly works are split out and rearrange to a new phase named Work Phase 0. Three workers will work at Work Phase 0. Work Phase accept all incoming materials and making pre-assembly works then send all screws and parts to different work phases by using convey. All non value-added works are done in Work Phase 0.

All the value-added work processes are rearranged and equally separated to Work Phase 1 to Work Phase 6.

The moving system is changed also. The old “7” shape production line is now put in two straight lines. 360 degree turning wheels will be added to the bottom of the basement of the

product. So that product is flexible to move from one work phase to the next. The waiting time of using the crane is eliminated.

All the Packed products will send to the shipping dock wait for full load and deliver to customer instead of standing in the factory, the waiting time of Final Inspection and Packing is eliminated.

The pre-assembly time and waiting time and the improved Value Creating Time is show in the following table.

Table 2. Current Pre-assembly and Value Creating Time.

Current State Pre-assembly Time & VCT		
	Pre-assembly Time	Value Creating Time
Work Phase 1	50min	3h 30min
Work Phase 2	50min	3h 20min
Work Phase 3	25min	4h 45min
Work Phase 4	25min	4h 25min
Work Phase 5	1h	2h 20min
Work Phase 6	55min	2h 55min
Work Phase 7	50min	4h 10min
Work Phase 8	45min	3h 15min
Work Phase 9	10min	3h 30min
Work Phase 10	20min	4h 20min
Testing	1h	2h
Final Inspection & Packing	0min	3h
Total	7h 30min	40h

4.1.2. Layouts

New layout design for the production line is shown in Figure 5.

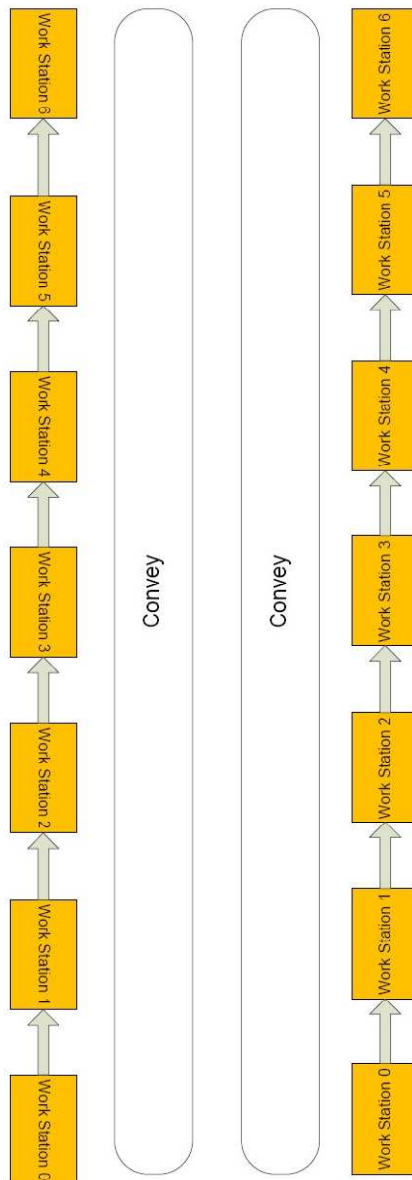


Figure 9. New Layout Design.

4.1.3. VSM for future state

The Value Stream Mapping for the future state is drawn in the Figure 6. All the non-value added behaviors are reduced, the process is going in one-piece flow, and JIT.

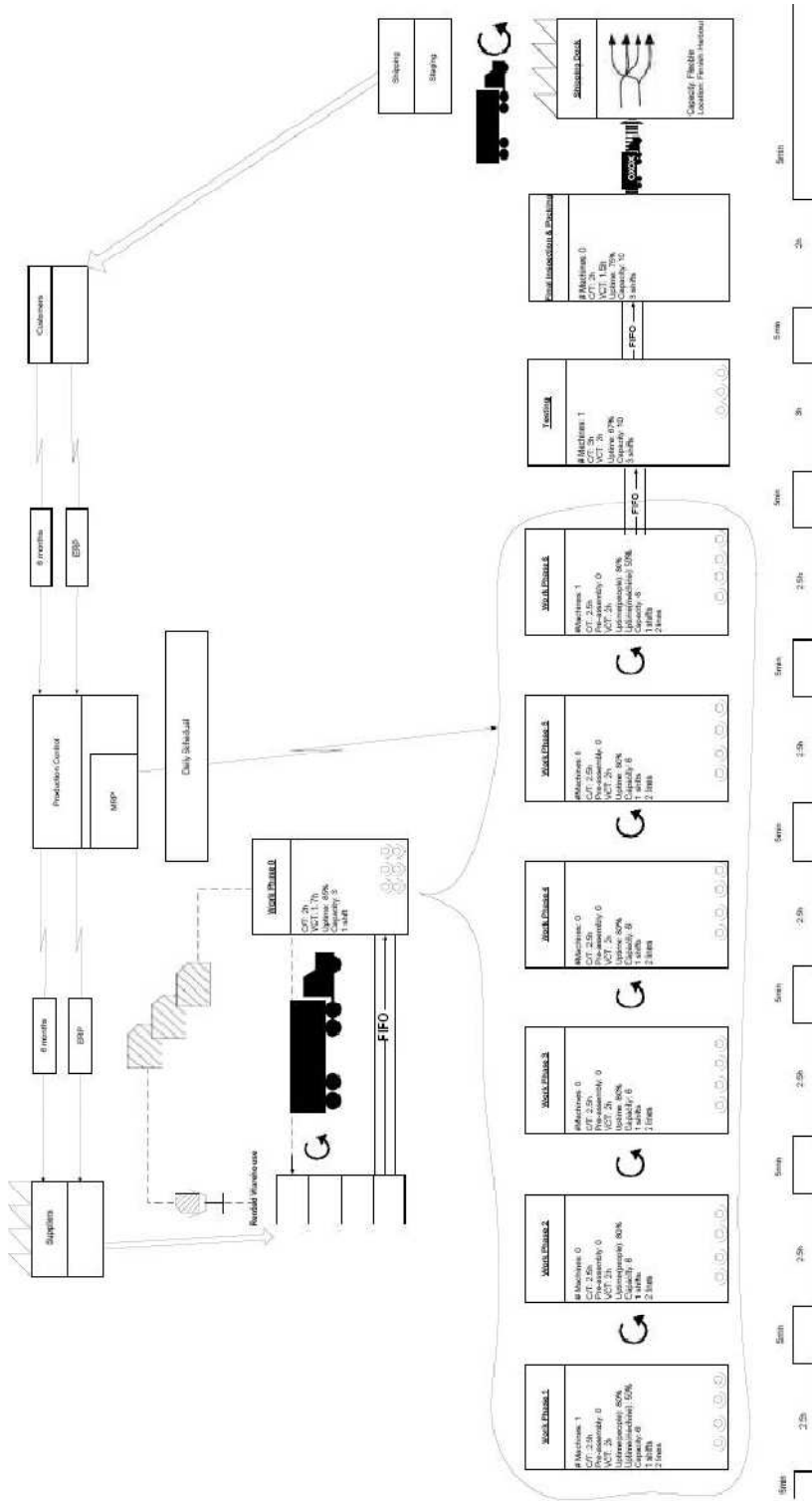


Figure 10. VSM for Future State.

Planned Cycle Time and Production Lead Time are shown in Table 3.

Table 3. Planned Cycle and Waiting Time

Planned C/T &Waiting Time		
	Cycle Time	Waiting Time
Work Phase 0	2.5h	5min
Work Phase 1	2.5h	5min
Work Phase 2	2.5h	5min
Work Phase 3	2.5h	5min
Work Phase 4	2.5h	5min
Work Phase 5	2.5h	5min
Work Phase 6	2.5h	5min
Testing	3h	5min
Final Inspection & Packing	2h	5min
Total	22.5h	45min

4.2. Workstation re-organization

The work estrades for each work phase will be removed. Instead, a movable two-side shelf will be located between two work phases. Computers which only have touch screens will be used. One side of the shelf contains computer, tools and trash bins those are the only things needed in each work phase.

Andon system is used in the new production line. The Andon Light Visual Control System with flashing capability and audio alarm is installed in every work phase so that once the workers need to call the manager or maintenance, report defect parts or tool problems or need of stopping production line; the Andon system can help them. The worker also needs

to input every case in Andon database for further studies of the engineering department or quality control department.

Tools will be recorded and documented on the Tool Board Layout Instruction. Only needed tools will be remained in each work phase, and a drawing of the tools' out shape will be drawn on the tool board so that workers can easily find the place to put the tools and the tools are not laying anywhere. Borrowing tools will be forbidden. There will be common tool board for those who need some special tools.

Screws will be sent by the Work Phase 1 workers, which are separated for different workers. The workers can find the screws according to the assembly working instructions. Also the screws will be put in sets, just like, one bolt is put together with washer and nut while they need to use at the same time.

4.3. Train people

Lean training course will be arranged by the company. It will face to everyone in the company. Also some Lean expert will be hired to train the workers in the practical working time. To help them understand, think and improve.

New assembly working processes are designed in this way: two workers are working at each work phase, all assembly works are split into two parts A and B, each worker following working instruction for either A or B, the new working instruction are designed in the purpose that each worker do one part of job on different place of the product, so that they are not on the other worker's way so that the worker's standing and waiting time are eliminated.

4.4. JIT and value added behaviors

The materials will come daily. Arranging work of the parts in each set will be rearranged. Sets number will be reduced. A material shelf will be build up besides the Work Phase 0 and the nearer side of the entrance.

Workers at the Work Phase 0 will do the work in a fix procedure. When the materials come in the morning, workers accept all the sets. Lift the sets for next products on the upper layers and put the sets need to be processed on the ground layer. They pick parts from sets, make pre-assembly work, arrange them in work phases, and add screws for the corresponding work phase. After they finish prepare for all work phases, they put all the materials on the rolling transport belt. Then roll the materials to each work phase.

Kanban is used in the bulk materials. Kanban sizes are determined by the delivery time and amount of use weekly. So that only a few amount but enough of parts are keeping in inventory.

4.5. Zero Quality Control

Sourcing inspection is crucial for the quality control, the earlier the better. Requirements for the suppliers to have the quality inspection before delivering the material will be obligatory. It is better to invite the suppliers to come and visit the factory. Let the suppliers understand the whole system will make them more clearly in the company's requirement and reduce the misunderstanding.

Improving of the work assembly instruction is needed. A scientific systemic way of build up instruction should be adopted.

Standard module of tools to prevent the mistake will be used. For example adding clear number tags to wires and color tags to materials for different work phases.

4.6. Expected results and feasibility analysis

Results coming from this improving plan are the cycle time cut by half but keeping the same workforce. One-piece flow will be achieved. Problems and bottlenecks will easily be found later on. And uptime of the people and machine all increase.

5. CONCLUSION

This thesis is a study of how to apply Lean thinking in a small size assembly company XYZ to help the company achieve the continuous improvement. The study is based on understanding the Lean philosophy and adopts Lean Manufacturing tools in the redesign of the production line.

The techniques used in the analyze and redesign of the production line are Value Stream Mapping, Just-in-time and Kanban, 5S, Andon system, one-piece flow, Mistake-proofing, and the Deming Cycle.

The 5 aspect of the production line are analyses: Production flow which also includes work process, production line layout, work station, workforce, material and quality control.

The Value Stream Mapping for current state is drawn. And the main problem of the company is the long lead time. Then the Value Stream Mapping for the future state is planned.

The solutions and suggestions given in this thesis can help the company solve out the problems and achieve the continuous improvement. But the study is limited and future research should be carried on. When the lead time is shorten, and production line achieve one-piece flow the bottleneck will represented again. The following study analyzes and improvement should continue.

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