Optimization of Production Flow at Eco Supplies Solar AB

Michelle Maria Jose

Department of Production Engineering

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Supervisor: Ove Bayard
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Abstract

In this competitive world with rapid growth of markets, the main goal of any company is to attain an edge over its competitors. In order to achieve this goal a company has to continually improve its process and eliminate the wastes in the process while not compromising on the quality of the product and customer satisfaction. Though Eco Supplies Solar AB is one of the largest producers of Photovoltaic solar modules in Scandinavia, the need for improvement is vital to match with growing requirements and to maintain its position in the market.

This master thesis was done for Eco Supplies Solar AB, so as to help them identify the waste along their value stream process. The project was divided into three phases. The first phase of the project was to map and analyze the plant layout as well as analyze the worker movement. This helped to understand the various movements through the entire process of production and the associated distances and time.

The second phase of the thesis was the execution of the Value Stream Mapping. For this purpose the entire production process was walked through and through several interviews the data was collected. The current state value stream map gave a one page static picture of the key areas of waste within the process and to suggest necessary changes so as to improve the efficiency. The suggested changes are implemented and the future state map is drawn. The results from the current state and future state map are calculated theoretically and analyzed.

The third phase is the use of Simulation to understand the behavioral effects of each the processes and to determine the overall change in productivity if the changes are implemented. It is difficult to implement changes in a production plant that works continuously for 24 hours. That would interrupt production and also lead to large costs. The easier and most optimal solution to implement changes, understand the behavior of each process before and after the changes and to analyze the changes is to run a simulation model of the current and future state. The simulation is done using Extend Sim software and the results are analyzed further.

The main aim of the thesis was to analyze the current plant layout and the product process and develop a methodology to identify visualize and measure the wastes in the production process of Photovoltaic solar modules.

Keywords: Plant layout, People flow analysis, Value Stream Mapping, Lean, Lean Production, Photovoltaic solar module, Simulation, Waste
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### Abbreviations

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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>CT</td>
<td>Cycle time</td>
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<tr>
<td>CO</td>
<td>Changeover time</td>
</tr>
<tr>
<td>EVA</td>
<td>Ethylene Vinyl Acetate</td>
</tr>
<tr>
<td>EL</td>
<td>Electro Luminescence</td>
</tr>
<tr>
<td>LT</td>
<td>Lead time</td>
</tr>
<tr>
<td>NVA</td>
<td>Non Value Added</td>
</tr>
<tr>
<td>VSM</td>
<td>Value stream Mapping</td>
</tr>
<tr>
<td>VA</td>
<td>Value added</td>
</tr>
<tr>
<td>WIP</td>
<td>Work in progress</td>
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1.1 Background
Eco Supplies Solar AB has been facing problems related to overall work efficiency and throughput since its expansion in 2005. As part of their continuous improvement process they wanted to identify key areas of improvement within the production process and to find an optimal solution for implementing the change. For this purpose a case study of the current process was carried out and using different lean manufacturing tools and simulation tool the results have been analyzed. By solving these problems Eco Supplies Solar AB would be able to achieve competitive advantage by marketing themselves as a company with successful lean production and also increase the efficiency and quality of work.

1.2 Research objective
The main aim of the thesis is to suggest the key areas of improvement in the current production process for the optimization of production flow. This means reduction of overall production lead time and increasing productivity.

1.3 Company Presentation
Eco Supplies Solar AB is one of the leading manufacturers of solar panels in the Scandinavian market. Solar Energy is the largest business area for Eco Supplies. Eco Supplies Solar AB produces and markets PhotoVoltaic Solar Power Modules. The company operates in the European solar energy market. Eco Supplies Europe AB is a stock-listed company on the Open Market of Frankfurt’s Stock Exchange with a yearly turnover of €20.43 million. The company is one of the largest, Scandinavian producers of high quality Solar Power Modules for the solar industry. The company has a production facility in Gällivare (Swedish Lapland) with a highly automated production plant and current capacity of ca. 45 MW per year.

1.4 Company products
Eco Supplies Solar AB produces different kinds of solar modules and depending on the size, every module consists of 36 to 72 multicrystalline or monocrystalline cells. The main products
that are manufactured are ST1, ST2 and ST120. The difference in the products lie in the size of the cells used in the product and the number of cells used to make the product. ST1 products contain 72 cells of 5’ size, ST2 products use 60 cells of 6’ size and ST120 has 36 cells of 6’ size. Depending on customer requirements the products can be customized. The product that is taken into consideration for this project is ST120 Polycrystalline modules.

1.5 Production process:

Raw materials required for the production of the Solar modules:

1. Glass panel
2. Solar Cells(5’ or 6’ depending on the product type)
3. Ethylene Vinyl Acetate
4. Tedlar
5. Copper ribbon
6. Aluminium frames
7. Junction box and silicon

**Glass panels** – High transmission, low iron tempered glass panels are used in the production of the solar modules. The size of the glass panel depends on the type of product that is produced. It is the glass panel that forms the base of the solar module.

**Solar Cells**– Depending on the type of product the cell is chosen. Product ST1 uses 5’ solar cells whereas Product ST2 and Product ST120 make use of 6’ solar cells. They serve as the backbone for the solar module as they are responsible for the production of electricity.

**Ethylene Vinyl Acetate**– EVA, a co polymer of ethylene and vinyl acetate, is used as an adhesive in the solar module production. It also helps in protecting the module from environmental exposure damage, provide mechanical support, optical coupling and electrical isolation.

**Tedlar**– Tedlar or PolyVinyl Fluoride is used as a backsheet in the production of the Solar module. The backsheet serves as an excellent UV resistor, electrical resistor and helps in protecting the Solar module from environmental and moisture damage.

**Copper ribbon**– The copper ribbons are used in soldering the cells together and making the strings. These copper ribbons are flat wires and facilitate the purpose of carrying the current that is produced in the solar cells.

**Junction box and silicon**– A junction box is a box used for concealing the electrical connection and to prevent them from wear and tear. A plastic junction box is fitted at the backside of the solar module with the help of silicon.
Aluminium frames- Aluminium frames are used for better reliability, strength and durability. The frames are glued to the laminates with the help of silicon.

The steps involved in the production process of the Solar module is described briefly:

**Step 1:** The glass panels are transferred from the storage to the station for cleaning and drying. This is done by a “cleaning robot”.

**Step 2:** After the glasses are washed and dried a layer of EVA is placed on each of the glass panel manually and is fed into a feeder.

**Step 3:** The feeder is driven manually to the KOMAX machine and is fed into the KOMAX/Reis setup

**Step 4:** The cells are loaded into the KOMAX machine which automatically tests the cells for any defects and rejects the defective cells

**Step 5:** The cells are then soldered together with the copper ribbons along their bus bars to form strings of 9-12 cells each.

**Step 6:** The strings are picked, aligned and placed on the Glass/EVA by the Reis robot.

**Step 7:** The next step includes soldering the copper wires and attaching the diodes to the module setup. If any defective solder in the string is found it is sent to the re work station

**Step 8:** After soldering another layer of EVA and one layer of Tedlar is placed and a visual inspection is done to check for any defects in the cells or strings.

**Step 9:** The whole module goes into the laminating machine and after lamination each laminate that emerges is divided into different classes based on their performance

**Step 10:** The laminates are then trimmed to cut out the excess Tedlar and EVA surrounding the laminates

**Step 11:** After trimming the junction boxes are fit on the backside of the laminates and fixed firmly onto it with the help of silicon.

**Step 12:** The next step is the framing of the solar modules. Aluminum frames are fitted onto the solar modules with the help of silicon

**Step 13:** After framing the solar modules are cleaned thoroughly for removing any extra silicon that might be present on the surface of the glass
**Step 14:** After all of the processes the solar module is finally tested for its power by using a sun simulator and measuring the performance and the graph of the IV curve. Based on the readings the rating of the solar modules are classified and printed.

**Step 15:** This is the final step after the power test. Packaging is done depending on customer requirements, into different cartons.

The diagram below clearly illustrates the various processes and the steps in which the solar modules are produced starting from the raw material to the final end product.

![Process flow diagram](image-url)

*Figure 1. Process flow diagram*
Chapter II: Theoretical reference frame

This chapter covers the key topics of history of Lean manufacturing and the theories related to Lean as well as Value Stream Mapping and the core methodologies used in Value Stream Mapping.

2.1 History of Lean production

The concept of Lean was first delivered to the world through the book “The machine that changed the world”. This served as a benchmark among craft production, mass production and lean production (Womack, Jones and Roos 1990).

During the post World War II period Japanese manufacturers faced problems related to financial matters, deficiency of materials and human resources (Askin and Goldberg 2002). Many of their industries required re-building and they turned to the Western world to gain ideas and inspiration on how to build their industries. In the Western world the mass production system introduced by Henry Ford was in practice to satisfy the huge demand. However, in the Japanese market with smaller production volumes per part and limited resources they had to devise a manufacturing system that was flexible and utilized lesser resources (Metall 2002). This gave birth to Lean production and the father of Lean is believed to be the production genius Taiichi Ohno at Toyota (Sohal and Egglestone 1994).

In the 1980’s the Western automotive industry began to realize that the Japanese companies achieved higher productivity and quality using fewer resources (Metall 2002). This triggered an interest in the Western companies and an investigation was initiated by Womack, Jones and Roos at Massachusetts Institute of Technology. The results of the research showed a huge gap between the productivity and quality of the Western vehicle industry and the Japanese vehicle industry. This Japanese philosophy of production was termed as Lean production (Sohal and Egglestone 1994).

According to the book “The machine that changed the world”, lean thinking originated from Toyota’s shop floor which gave rise to several tools like just-in-time (JIT), Kaizen, pull production, one piece flow, visual control, cellular manufacturing, inventory management, Poka Yoke, standardized work, workplace organization and scrap reduction (Seth and Gupta 2005).

Lean philosophy is a technique that consists of a group of activities that identify and eliminate muda (Japanese word for waste), which is non value added activities, that do not increase efficiency nor satisfy customer requirements (Womack and Jones, 1996). Waste can be defined as any activity that does not add any value but consumes resources.
2.2 Principles of Lean

The five principles of lean thinking (Womack and Jones, 1996) are:

1. Specify value from customer’s angle
2. Map the value stream
3. Establish flow
4. Establish pull system from customer
5. Work towards perfection

Value is determined by an organization from customer’s perspective and the product has to satisfy the customer requirements and desire at a price and delivery (Haque and Moore, 2004). A marketing strategy that does not include the customer will not work for an organization.

The second principle of value stream mapping relates to all the activities and processes that the materials have to pass through to be the final product for the customer (Haque and Moore, 2004). All the steps—value added as well as non value added—are mapped. Value added activities are those that add value to the raw materials, components and information and transform them into sellable products. Whereas non value added activities are those that consume resource but do not add any value to the product and they should be eliminated from the process. There are necessary non value added activities which cannot be eliminated from the process (Seth and Gupta, 2005).

The third principle is to focus on establishing a continuous flow through the production or supply chain instead of moving it as large batches i.e. the aim is to move from batch mode of production to continuous flow in design and production so as to produce a good quality product.

The fourth principle is to establish a pull system which can be achieved if the above three principles are followed correctly. The aim is that the upstream processes do not do anything until the downstream customer demands for it and gives a signal. A common pull system is a Kanban system.

The last principle is work towards perfection which means elimination of non value added activities as part of continuous improvement and so as to add value to the customer products.

To succeed in Lean implementation requires commitment from the management as well as the operators; the ability to understand the demands of the customers, develop the proper current state and also the proper communication between departments from the top to bottom (Tapping, 2002).

These principles have been divided into six steps for the implementation of the lean thinking by Hines and Taylor, 2000. The six steps are: understanding waste, setting direction, understanding
the big picture, detailed mapping, getting suppliers and customer involvement. The last few concepts lead towards the Value stream mapping concepts which is called as “big map” in the Toyota Company.

2.3 Objective of Lean Production

Elimination of all the waste while producing exactly what the customer wants (Liker, 2004; Dolcemascolo, 2006) is the main objective of all lean production systems. Waste is defined as any activity that consumes resources but does not add any value to the raw material or product. Taiichi Ohno, Toyota Production Engineer and architect of the Toyota Production System, described seven sources of waste that are commonly found in the industry (Askin and Goldbergs, 2002). The sources of waste are:

1. Overproduction
2. Defects
3. Unnecessary Inventory
4. Unnecessary processing
5. Unnecessary transportation between work sites
6. Waiting
7. Unnecessary motion in the workplace

These seven sources are discussed in detail below along with the tools to detect them and ways to reduce each of these wastes.

2.3.1 Wastes due to Overproduction

The most important and significant of all the wastes is waste due to over production. Over production means producing more, sooner than what is required by the next process. Overproduction leads to excess inventory and causes lots of investment to be tied up with the inventory. It also results in shortage of items because the wrong items are being made. Traditionally the job of supervisors was judged by the amount of production they did. The idea behind this was maximum utilization of resources which leads to overproduction waste. Overproduction also happens due to production based on forecast rather than on customer demands. Therefore, production should be done according to customer demands. According to Lean philosophy, machine and humans should be busy only when there is useful task to accomplish (Askin and Goldbergs, 2002). But the customers demand for delivery is generally much lesser than the production lead time. Hence forecasting becomes an inevitable factor and so the customer order point has to be pushed towards the upstream of production flow.

2.3.2 Wastes from defects

Deficiency of quality is the second source of waste. When a product or part is found to be defective, there is a necessity for it to be re built. This means using the resources, larger costs
and also a negative impact on the customer mind. It is essential to determine the root cause of the quality problem and rectify the problem from its source.

When there is a batch production, it gets difficult and takes more time to find the source of defect. This can also lead to scarping of the entire batch of products. In one piece flow, the defect detection is easier and the operator associated with the process can get instant feedback from the downstream customers.

2.3.3 Waste due to Unnecessary Inventory

Two types of inventory exists: Work in Process(WIP) and parts storage. WIP are the parts that are stored and wait between the processes whereas parts storage is the raw materials that is brought from the main warehouse to the production floor to be processed. Reduction of inventory can be done by reducing the buffer inventory levels by eliminating unwanted variations or by reducing the batch size. The advantages of reducing inventory are: lesser lead time, reduction in capital tied up with inventory, smooth production flow, lesser risk of obsolescence, decreasing the time needed to detect the defect in quality, lesser space rent.

2.3.4 Waste due to unnecessary processing

A production process that is not correctly designed can also be a source of waste. Activities in any industry can be categorized into three different process: value added activities, non value added activities, activities that are non value added but are necessary for the process. Changing the design of parts, limiting functionally unnecessary tolerances and rethinking process plans can often eliminate and simplify processes in the manufacturing activities (Askin and Goldbergs, 2002).

2.3.5 Waste due to unnecessary transportation between work sites

Unnecessary transportation and movement within a factory is mainly due to the inappropriate layout of a factory. Transportation wastes are all the unwanted transportation and movements of material, work in process and components which do not add any value to the product. A tool that is used to analyze the transportation waste is spaghetti diagram (LEIS, 1999). A spaghetti map gives a picture of the physical flow of material, products and humans. Basically, all the movements within the entire factory are drawn on a current layout map in order to show the unnecessary movements.

2.3.6 Wastes due to waiting

Waiting could be due to the following reasons: waiting for right information, products waiting for processing, machines waiting for their operators, machines waiting for the materials to arrive and also materials waiting in inventories which are the materials that spend most of their time in warehouses. (LEIS 1999)
Value stream Mapping is a tool used to analyze the product flow through the production process and factory. Process time, setup times, inventory levels etc. are mapped using standardized symbols.

2.3.7 Wastes due to unnecessary motion in the workplace

Any motion results in consumption of energy and time. Any motion that does not add value to such as stretching for tools, moving materials within a station, should be eliminated. This should be kept in mind when designing workplaces, procedures, operations etc.

2.4 Lean Tools

The most important Lean tools that are applicable to any industry to reduce and eliminate the wastes are described below.

2.4.1 5S tool

5S is a lean tool used to optimize the workplace and achieve a cleaner, safer and more efficient work place (Peterson, 1998). The tools are divided into 5 categories (Bicheno, 2004):

Seiri(sorting which means throwing unnecessary tools, parts and information), Seiton(setting in order which means giving a right place for each part and they should be clearly labeled for ease of locating when needed), Seiso(systematic cleaning which means cleaning or sweeping the environment and machine after each operation so as to maintain tidiness), Seiketsu(standardizing which means that for the same kind of operation the workers at all work stations should work identically), Shitsuke(sustaining the discipline which means the reviewing of standards so as to prevent the gradual decline to the older ways).

These tools helps in reducing cycle time, lead times, floor space, improves worker safety, improves worker efficiency, better team performance and inventory management(Hirano,1995).

2.4.2 Standard work

Standardized work is defined as a set of specific instructions that help in the most efficient way of producing. By implementing Standardized working methods employees will increase efficiency and production, improve quality and enjoy a safer working environment (Tapping, 2002).

2.4.3 Total Productive Maintenance (TPM)

TPM is a tool that is used and applied to cut down the equipment downtime which result in breakdowns, inadequate lubrication as well as improve the quality of goods (Tapping,2002). It is a kind of maintenance that is carried out in machines and equipments in a proactive manner.
integrated into the process so as to ensure that the machines keep running. TPM also benefits by helping improve quality, availability and performance (Bicheno, 2004).

2.4.4 Visual Management

Visual management is a tool that is integrated with 5S lean tool implementation and work standardization. It is a method of giving control to the workers over the production floor. The visual management system helps in seeing activities of standard work, maintenance related activities and also problem solving processes (Bicheno, 2004).

2.4.5 Change over time reduction

This tool aims at reducing the time associated with changing tools and fixtures which constitute a major part of reduction in the uptime of the equipments (Shingo, 1985). This can be achieved by identifying and switching internal activities to external activities. Quicker changeover also increases product variety by using cell layout (Tapping, 2002).

2.4.6 Just in Time (JIT)

JIT is the first step towards continuous flow which provides or produces a part just-in-time for the succeeding operation. It is a management thinking that focuses on eliminating waste by producing only the right product in the right place at the right time and the right quantity and quality (Chase, Jacobs and Aquilano, 2006).

2.4.7 Kanban System

Kanban system allows the product to be pulled from one state to the next by using a card that indicates the quantity that needs to be produced. This system forms a part of JIT.

There are 3 types of Kanban as pointed out by Tapping (2002):

1. Production Kanban: indicates number of products or parts that are required to be made
2. Withdrawal Kanban: indicates number of parts or products that can be removed from a supermarket
3. Signal Kanban: indicates the number of products that need to be produced in a batch

2.4.8 Six Sigma

Six sigma can be defined as a quality measure that utilizes product data and statistical analysis for measuring and improving the operational performances, practices and systems. Six sigma aims at reducing defects in processes and products.

2.4.9 Mistake Proofing (“Poke Yoke”)

Poka Yoke is used to ensure that products are made correctly the first time. It is a mechanism wherein the operator avoids mistakes by prevention, correction or drawing attention to the
operator. This tool is inexpensive but very helpful in reducing defects, waste and the cost (Bicheno, 2004).

2.4.10 Kaizen

Kaizen is a continuous improvement tool in the organization (Chase, Jacobs and Aquilano, 2006). It aims at involving everyone in the organization to take part in solution finding and suggest improvements on the problem or constraints within the business, without investing money.

2.5 Value Stream Management

Value stream management is defined an organizational method of planning, managing, implementing, sustaining and linking together the lean initiatives to the activities of the organization by collecting data and analyzing them (Tapping, 2002). Value stream management aims at “treating employees as human fixed assets” (Tapping, 2002).

Furthermore Value stream management can also be defined as a tool to help workers recognize waste and the sources of waste and build up a future state implementing the right procedures so as to reduce it, as pointed by Özkan, Birgün, Kılıçoğulları, and Akman (2005).

There are eight steps that constitute Value stream management (Tapping, 2002):

1. Commitment to lean
2. Choosing value stream
3. Learning about lean
4. Mapping the current state
5. Determining Lean metrics
6. Mapping the future state
7. Creating Kaizen plans
8. Implementing Kaizen

2.6 Value Stream Mapping

Value Stream Mapping is a tool that helps to understand the material as well as information flow that link the lean initiatives, as product or service moves through the value stream (Lovelle, 2001). It can also be defined as a lean manufacturing tool that is used to give a one page picture of the activities in the production floor and use those data to analyze and create a flow of materials and information. Value added activities and non value added activities form the crux of the value stream and looks at improving the material and information flow.
It is a lean tool that is helpful in working towards reducing cycle time and to get an understanding of the decision making flow and the process flow. The basic step is to first map the process and then map the information flow above it.

The main aim of VSM is to move from batch production with push systems to continuous production flow with pull system (Lovelle, 2001; Rother, 2004; and Womack, 2006). Tapping (2002) also pointed that VSM aims at identification of the production process, communication between departments, determining bottlenecks and all types of waste. VSM can be a starting stone for managers, engineers, production associates and suppliers to identify wastes and find the causes. Consequently, VSM not only serves as a strategic planning tool but also a change management tool.

Value stream Mapping is divided into four stages primarily (Corner, 2001 and Womack and Jones, 2003):

1. Identifying the product family
2. Drawing the current state map
3. Developing the future state map
4. Developing the work plan

2.6.1 Product Family

The initial stage of VSM is to identify the product family (Womack, 2006). Each company could make many products with different dimensions and qualities. However, some of these products fall into the same product family due to similarity in the stages of production of these products. (Lovelle, 2001). Utmost care has to be taken when identifying product family as a bad selection could dismiss the concept of VSM tool (Womack, 2006).

2.6.2 Current State Map

The next step of VSM after identifying the product family is to draw the current state map using standardized symbols to depict workstation, operators, cycle time, inventory levels,(Seth and Gupta,2005). There are 3 categories of symbols: Material flow, Information flow and general symbols. These symbols make up the big picture. The symbols are explained in Appendix A.

Material flow symbols represent machines, suppliers, customers, inventory levels, shipments, operators and the collected data is registered in a process/data box.

Information flow is depicted through lines which could be manual, electronic, kanbans and heijunka leveling. There are two types of information flow, the first one that constitutes the production and the other one that consists of regulation of the flow of the product (Womack, 2006). The lines generally have boxes to describe the information flow.
The main aim of developing the map is to identify the value added activities (creating value for the customer from their perspective), capability (good quality product is made), availability (percentage that the equipments can work), adequacy (capacity of responding to customer orders) and flexibility (ability to incorporate changes in the process) (Womack, 2006). Before mapping, it is essential for everyone in the organization to understand the principles of lean manufacturing (Seth and Gupta, 2005).

The next stage is determining the current state both from the customer’s perspective and the organization’s perspective (Womack, 2006). For example, maybe the customer would want cheaper products or the company would like to increase its utilities.

There are two types of mapping, internal and external which help in developing the final big map (Lovelle, 2001). The internal map is drawn with the data collected from the shop floor whereas for drawing the external map data is collected from the office.

The external map gives an idea of the customer demand and the information passing related to customer and supplier. The external mapping drawing starts with placing the customer icon on the top right corner of the drawing and the customer demand is put in the box. The supplier box icon is placed on the top left corner of the drawing and then the data is collected from the purchasing department. Information flow is collected from the sales department, engineering department, production department and purchasing department and recorded in the map with the help of information flow icons. As each organization might have many suppliers it is not feasible to show all the suppliers on the map; however the most important supplier has to be shown on the map (Lovelle, 2001).

The internal mapping focuses on identifying the production. Information collection and recording is done starting from the shipment area and going back into the processes so as to understand the flow. All the related important data is noted at this stage (Lovelle, 2001). After understanding the flow it is necessary to walk the entire shop floor a second time to collect and identify the lean metrics from the process such as inventories, days of inventories, work in process (WIP), cycle time, value added, non value added, availability, lead time, uptime, change overtime and so on (Tapping, 2002). All these data are identified and recorded in a process box in the map.

Once all of the data are recorded in the map, the customer and the supplier are connected by the frequency of the shipments. Also the production system is connected with information flow by communication arrows. The next step is to identify the push system, pull system or FIFO (First in First Out) in the production line or if there exists a combination of them (Seth and Gupta, 2005).

The last step is to draw the time line and the travel line beneath each of the operation under the inventory and the process box. Tapping (2002) suggests the calculation of the total work in process, total inventory in days, total cycle time, total lead time and uptime. By understanding these lean metrics it is possible to find the lean assessment and implement in the future state.
Some of these lean tools include 5S, teamwork, Kaizen events, Total Productive Maintenance (TPM), Standardize tools, Visual control, Six Sigma, Total Quality Management (TQM).

### 2.6.3 Future State Map

Future state map is a tool to visualize how the value stream ought to be (Brunt, 2000). It is the most important stage for improving operation and to attain lean implementation. The future state map should provide answers to the following questions (Womack and Jones, 2003):

1. What is the takt time for the chosen product family?
2. Will production follow continuous flow until shipping or be finished goods supermarket?
3. Can customer demand be met?
4. Where can continuous flow be implemented?
5. Where in production should pull system supermarket be implemented?
6. What single point in the production chain (pacemaker process) should the production be scheduled?

The first step is the calculation of takt time which is the number of parts required to be produced per unit of time. Takt time is based on bottleneck capacity.

\[
\text{Takt time} = \frac{\text{Operating time}}{\text{Customer Demand}}
\]

The second step is to identify and list all improvements that would help in achieving continuous flow such as replacement of old equipments, new equipments, standardizing processes and change in plant layout. Lovelle (2001) suggests Visual control and TPM are the key lean tools that help in reduction of waste and improve continuous flow. After this, the level of production has to be leveled using a pacemaker so that every upstream and downstream processes operate in a level.

### 2.6.4 Challenges and Difficulties

Tapping (2002) points out the main challenges and difficulties in implementing VSM:

- VSM does not identify wastes related to energy, water, air etc.
- Data gathered is subjective and is under assumptions sometimes, which could change during the course of the current state. Ultimately, the future map may fail to match with the real state that a company would be. The assumptions have to be rectified by communication with operators and managers.
- If there is no proper understanding of the process, it will be very difficult to find sources of waste or to suggest for improvements and opportunities could be overlooked.
- There is lack of management and operators commitment towards lean implementation.
o If guidelines are not properly followed, there could be mistakes in the future state map.

o There is always difficulty involved in matching the company culture with the lean manufacturing concept.

o If information flow is not present in the map, future state will be wrong.

o A coherent strategy to attack the wastes within the production process can be difficult to choose (Garnett and Jones, 1998).

o Mistakes occur when the team rushes with the current state and wants to focus only on the future state.
Chapter III: Methodology

Continuous improvement process is an ongoing process aimed at improving process, product and services. Though Eco Supplies Solar AB is one of the largest producers of Solar panels in Scandinavia there is always a necessity for improvement in the process so as to maintain a cutting edge over the competitors and stay ahead in the market.

Eco Supplies Solar AB had expanded its production unit in 2005 so as to increase the capacity of production. But there were problems in the form of lead production time, overall production as well as product flow associated with this. This led to an increase in cost of production along with a slump in the market due to increased production lead time. The objective of this thesis is to carry out a case study of the current production process and make a detailed analysis so as to identify the key areas of improvement and to eliminate the wasteful activities. The main idea is to give a clear view of the benefits by implementing lean manufacturing techniques and developing a lean culture within the production plant. Developing a lean culture in Eco Supplies Solar AB is vital so reduce the Non value added activities through the entire Supply Chain which accounts for the majority of the production lead time.

The structure of the project can be summarized as below:

- To walk the process and understand the entire production process
- To carry out a detailed analysis of the current product flow and plant layout
- To document the process flow and to identify the key areas of improvement in the production flow
- To use Lean manufacturing tools and analyze the current scenario and to suggest changes
- To implement the changes using lean manufacturing tools and to analyze the improvement
- To analyze and compare the results before and after implementation of Lean manufacturing technique
- To develop a simulation model of the current and proposed model and to analyze the behavior of the production flow and productivity. Simulation helps to give a clear picture and helps in understanding how the present system operates and what happens when there is a change in the process.
3.1 Plant layout and People Flow analysis:

Plant layout is one major factor for determining throughput times and overall productivity. Complex plant layouts can lead to high throughput times, large inventories and work in progress which in turn increases the total cost and decreases the profitability. Plant layout analysis has to be carried out to plan a change in the layout to help attain an optimal flow system so as to increase the productivity by decreasing throughput times, decreasing inventories and improving quality. This section gives a detailed description of the material flow analysis at Eco Supplies Solar AB.

3.1.1 Spaghetti diagram:

Spaghetti diagram is a lean manufacturing tool that helps identify redundancies and to monitor the personnel flow movement within the production plant. It helps to establish the optimal layout plan for the plant based on the distance travelled by the worker. The spaghetti diagrams have been drawn using AutoCAD 2007 to show the material flow and the worker movements within the production floor. The material and worker movement around the plant is shown in red.

3.1.1.1 Present Flow

![Spaghetti diagram of the present flow](image-url)
The above drawing gives a clear picture of the plant layout and the arrangement of machines in the production floor. From the diagram we can see that there are many movements within the plant which lead to an increase in the lead time hence reducing efficiency. The aim of the project is to propose different ways for better lean implementation and to find out the best optimal solution for plant layout, reduce waste and reduce production lead time. This not only increases the efficiency but also improves the quality of work and the efficiency of the work as the movements are reduced and thus fatigue is reduced.

Analyzing the people flow within the plant it is observed that there are many unnecessary movements of the workers. This is mainly due to the plant layout i.e. the machines are far from each other and the worker has to move around these stations to transport the material. This leads to fatigue and the worker gets tired after sometime. So the worker tends to take more time to do a work than the normal time as well as take more number of breaks. All these account for muda or wasteful activities and leads to increase in the overall production time. From the above drawing an approximation of the total distance travelled (both worker and material) has been calculated to be nearly 240 m. This means that the total distance from the fetching of the glass panel to the storage of the finished solar module is approximately 240 m in the present scenario.

The main machines/processes involved are:

- Cleaning robot- responsible for cleaning the glass panels
- KOMAX/Reis- responsible for cell tabbing, soldering and stringing
- ACR/GTI- same function as KOMAX/Reis
- Manual handling stations- manual soldering, rework and fixing diodes and visual inspection
- Laminator- responsible for making the glass laminates
- Silicon curing- fixing of the junction box
- Framing- fixing the aluminium frames to the Solar module
- Sun simulator- responsible for power rating of the Solar modules

Advantages of the present setup and flow:

- Production in the individual departments take place in a straight line so there is better worker mobility

Disadvantages/Problems of the present setup:

- Unnecessary movements which increase lead time and decrease efficiency
- Increase in queuing time and waiting time
- Increase in the floor inventory
- No communication between the departments
- More distance between the machines
- Limited storage space with no area for expansion
In order to overcome the problems and shortcomings of the present flow and to increase the plant efficiency, a few proposals to rearrange the plant layout have been suggested below. These proposals are suggested considering the different possibilities of plant layout. Finally the most optimal solution is chosen by taking cost and feasibility into account.

### 3.1.1.2 Proposal 1

The first proposal is suggested with the following changes:

- Removal of the laminator in production line 3 which is damaged
- Replacement of the ACR/GTI machine with KOMAX/Reis machine
- Replacement of the vertical power testing machine with a horizontal power testing machine
- Changing the position of the KOMAX/Reis machine and the Laminator machine
- Shifting the storage racks to the framing area and shifting the framing department to the storage area. This would enable a “T flow” production.
- Shifting the position of the stringer
- Removal of the quality machine and utilizing the room for buffer stock of glass panel, EVA and Tedlar required for each day
- Removal of the wall in storage area between the racks G and A
- Shifting the cleaning robot to a position wherein feeding the glass panel/EVA into the KOMAX becomes easier and consumes lesser time
- Opening a door towards the end of the production line 3 so as to facilitate easier transportation of the laminates to the framing section
- The distance that the material flows from the start to end of production is calculated to be 188 m (approximately).

**Advantages:**

- By rearranging the machines a “T” shape production flow is possible. This facilitates in improved material flow as well as worker flow with minimum number of unnecessary movements by bringing the machine closer
- Possibility for more racks in the storage area which means more storage
- Better communication and faster movement of products from one section to another section which in turn reduces the unnecessary inventory on the floor

**Disadvantages/limitations:**

- Difficulty in re locating the robot
- Difficulty involved in strengthening of the floor in the framing section so as to be able to hold the racks (when re arranging the two sections)
The second proposal is suggested with the following changes:

- Since there is a difficulty in relocating the cleaning robot, the position of the robot has not been moved and all other changes that have been suggested in proposal 1 has been implemented.
- An approximation of the distance travelled is calculated as 191m.

**Advantages:**

- Rearranging the machines helps in making a “T” shape production flow
- There is considerable decrease in the total amount of distance that the material travels through the floor
- There is possibility for more storage racks to be placed in the storage area
- More free floor space as there is better and faster movement of products from one department to the other

**Disadvantages/Limitations:**

- There is less floor space near the laminator and KOMAX machine in production line 2 which could affect the flow
- Stringer and laminator machine is pretty close to each other which could jeopardize worker safety
- More distance to be travelled from the manual handling station to the laminator in production line 3
3.1.1.4 Proposal 3

The third proposal is suggested with the following changes:

- Production line 1,2,3 to have the same setup as now
- Removal of the laminator in production line 3 which is damaged and replacement of the ACR/GTI machine with KOMAX/Reis machine
- Replacement of the vertical power testing machine with a horizontal power testing machine
- Shifting the storage racks to the framing area and shifting the framing department to the storage area.
- Removal of the quality machine and utilizing the room for buffer stock of glass panel, EVA and Tedlar required for each day
- Opening a door towards the end of the production line 3
- An approximation of the distance travelled is calculated as 230m.

Advantages:

- Since framing and power test machines are brought closer to the production line there is much lesser distance travelled

Disadvantages:

- In production line 1 significant time loss occurs when the strings are transferred from the individual KOMAX machine to the KOMAX/Reis setup
- There is more unnecessary travel involved in moving the laminates to the framing area
3.1.1.5 Proposal 4

The fourth proposal is suggested with the following changes:

- The changes proposed in the proposal 1 are implemented here with only one small change in the position of the laminators.
- The larger capacity laminators are arranged in the production line 2, 3 whereas the smaller laminator is shifted to the production line 1.
- The approximate distance travelled is calculated to be 195m

**Advantages:**

- The biggest advantage is the maximum utilization of the larger laminators. Since each of the larger laminators can laminate only 4 glass panels at a time, the remaining glass panels are placed on the other laminators. In this case lesser time is required in transporting the glass panels to the laminators and hence there is more machine utilization, reduced distance travelled and lesser time required to transport the panels.
- More storage racks and more storage space available

**Disadvantage/Limitation:**

- Cost involved in moving the robot is very high.
3.1.1.6 Proposal 5

The fifth proposal is suggested with the following changes:

- Retaining the production line 1 as is now and making changes in production line 2,3
- Removal of the laminator in production line 3 which is damaged
- Replacement of the ACR/GTI machine with KOMAX/Reis machine
- Changing the position of the KOMAX/Reis machine and laminators in production line 2,3
- Replacement of the vertical power testing machine with a horizontal power testing machine
- Shifting the storage racks to the framing area and shifting the framing department to the storage area.
- Removal of the quality machine and utilizing the room for buffer stock of glass panel, EVA and Tedlar required for each day
- Removal of the wall in storage area between the racks G and A
- Opening a door towards the end of the production line 3 so as to facilitate easier transportation of the laminates to the framing section
- An approximation of the distance travelled is calculated as 240m.

Advantages:

- In production line 2,3 there is a “T” shape flow
- More efficient use of the laminators in production line 2,3
Disadvantages:

- More distance travel in transporting products from production line 1 to framing section
- More distance travelled if both the larger laminators are to be used during production

The approximate distances that the material and worker moves within the floor in the present setup and in the suggested proposals is tabulated below:

<table>
<thead>
<tr>
<th>Setup</th>
<th>Present</th>
<th>Proposal1</th>
<th>Proposal2</th>
<th>Proposal3</th>
<th>Proposal4</th>
<th>Proposal5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (approx. in meters)</td>
<td>240</td>
<td>188</td>
<td>191</td>
<td>230</td>
<td>195</td>
<td>240</td>
</tr>
</tbody>
</table>

*Table 1. Table showing the approximate distances a material travels in the current process and in the proposals*

From the above tabular column we can summarize the following:

- The best optimal solution to increase efficiency is to rearrange the framing department and storage area so that production flow assumes a “T” shape.
- There is immense difficulty and a large cost involved in relocating the robot. Considering this limitation in order to increase the efficiency of flow as well as be cost efficient it is best to relocate the KOMAX/Reis setup and the laminator while keeping the robot in its current position. This allows for a smoother flow from the start to end of production.
- Keeping all points under consideration and from the above tabular column the most optimal solution would be Proposal 2

Limitations:

- The main limitation is that there is no proper quality check integrated along with the production process. This may lead to production of faulty products which in turn increases the overall cost.
- The wall between the production line 1 and 2 cannot be broken down which makes it difficult to move the machines and have a different plant layout.
- The cleaning robot has a foundation that is built on the ground surface. This makes it difficult and expensive to relocate the cleaning robot.
- Also the ceiling height of the production line 1 cannot be increased. So it is not possible to operate a forklift in this area.
3.2 Value Stream Mapping at Eco Supplies Solar AB:

This section gives a detailed description of the Value stream mapping at Eco Supplies Solar AB. The main aim of the thesis is to Optimize the Production flow by reduction of the throughput time and overall cost thereby increasing the overall efficiency at Eco Supplies Solar AB. The current production lead time is high which could lead to dropped markets and stunt plant growth. Improper plant layout, using old machines is the key contributors for this high lead time. The usage of Value Stream Map can help identify the key areas of waste and can help in suggesting improvements within the plant to reduce lead time and increase throughput. Information is gathered from the company’s MRP system and from visual observation on the shop floor. The information is used to map the Current state that shows the information flow and material flow for the production of Photovoltaic solar module. The data is analyzed to find out the areas that require the most improvement. These areas are further analyzed and lean manufacturing techniques are suggested to decrease the total lead time and increase the throughput. With these suggestions and improvements a Future state map is created and the results are analyzed and compared with the current state. Steps for creating the value stream map have been gathered from the book Value Stream Management (Tapping, Luyster & Shuker, 2002).

3.2.1 Subject Selection and Description:

The Solar module type that has been selected for the study is ST120. There are three types of Solar modules that is produced by Eco Supplies Solar AB namely: ST1, ST2 and ST 120. All three types have the same manufacturing process. The only difference lies in the setup and change over time of the machine.

The first step in the current production process is the order being received from the customer through electronic means (telephone or internet). Then the customer order is released to the production control. The production control reviews the customer order to check the bill of materials and order for the necessary materials required for the production. Production scheduling is planned between the production engineers and plant supervisors and the production orders are released to the shop floor. Orders are scheduled and planned based on delivery dates to the customer and the available materials.

The first step in the production of the solar module is cleaning. The glass panels are cleaned thoroughly with the help of a cleaning robot (Figure 2) and are placed on a manual work station. Here a layer of EVA is placed manually onto the clean glass and the glass with the EVA sheet is placed on a trolley (Figure 3). This operation is carried out in a batch mode and carried on to the next station. The main reason for the operation to be carried out in batch mode is because there is some distance between the robot and the next station and so the trolley is filled with 11 glass panels and is transported to the next station.
The trolley is driven manually to the KOMAX/Reis setup and fed into the machine setup. In the setup each of the glass panel with the EVA sheet moves on a rolling conveyor and is placed onto a bed where it is held for some time. In the meantime the solar cells that are loaded into the KOMAX machine are soldered together and a cell string of 9 cells is fabricated. Each of these strings are then picked by the Reis robot and placed with proper alignment on the glass panel that is lying on the bed (Figure 4). When the programmed number of strings is placed on the glass panel the glass panel with the strings moves on another conveyor belt and is placed onto an empty slot of another free trolley placed on the other side of the setup. When the trolley is filled it is driven out of the setup manually to the next work station.

In the next work station each of these glass panels are manually worked upon. In the Manual handling station (Figure 5) the ends of the solar cells are soldered properly and the electrical conductivity is checked. The solar strings that are damaged during stringing are sent for rework. When one glass panel is being worked upon the other glass panels are waiting in queue. After soldering another layer of EVA and a layer of Tedlar is placed on the glass panel. Tedlar acts as
an adhesive and helps to glue the solar cell strings to the glass panels firmly. After this a visual quality check is done and the glass panel is placed on the bed of the Laminator (Figure 6). The laminator has a capacity of laminating 4 glass panels at a time. So a batch of four is kept for lamination. The laminates after lamination are classified to different classes based on the errors found in the laminates. These laminates are then allowed to stand on a palette. Large amounts of WIP accumulate around the laminator (Figure 7).

Figure 6. Laminator

Figure 7. WIP near laminator

The laminates are transported to the next station only when one palette is filled. These laminates are transported manually to the next station which is at a relatively longer distance from the laminator. The next station is the trimming station where the extra pieces of Tedlar around the laminates are cut off. The trimmed laminate is then passed through a Silicon Curing test (Figure 8) where the junction box is placed on the back of the laminate. The junction box is the electrical conductor of the solar module. The junction box is glued to the back of the laminate with the help of silicon. This process is done in a batch of three.

Figure 8. Silicon Curing test

Figure 9. Framing
The next station is where the individual solar modules are taken for framing (Figure 9). Here at this stage there is WIP which occupies floor space. It is done by two workers and the frames are glued on to the laminates with silicon which hold the frames firmly. After framing the top surface of the glass panel is cleaned thoroughly to clean the residual silicon on the glass surface. The cleaned solar module is rolled on to the next station by a conveyor.

In the final station the solar module is tested for power rating by using sun simulator (Figure 10). The sun simulator is calibrated every 3 hours with a standard solar module. Depending on the shape of the I-V curve the power rating of the solar module is found and is printed and stuck on the back of the solar module. Finally the solar modules are packed (Figure 11) according to the needs of the customer and transported to the storage area (Figure 12) ready for delivery.

![Figure 10. Sun Simulator](image1)
![Figure 11. Packaging](image2)
![Figure 12. Storage](image3)

3.2.2 Data collection and data collection procedures:

Data is collected from the company’s ERP system as well as through visual observation by walking from the start of production to the end of production. The solar module type that is considered for this project is ST120. After collecting the data the next step is to map the Current state value stream. Information gathered from ERP system and visual observation are the machine setup time, machine change over time, machine cycle time, transportation distance, transportation time, inventory levels, WIP. Only the details collected for the above mentioned model is mapped and not the exceptions. The gathered information is then used to map the current state (Section 3.2.3) to show material and information flow. The collected data is tabulated and shown in Table 2. The next step is to analyze the data that is mapped and to determine from the current state the key areas of improvement and to suggest possible ways for implementation of lean techniques in these areas to improve production and reduce the throughput time.
Table 2. Current state solar panel production process and processing time for 1 solar panel

<table>
<thead>
<tr>
<th>Name of the process</th>
<th>Average processing time in seconds</th>
<th>Name of the process</th>
<th>Average processing time in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Cleaning</td>
<td>90</td>
<td>Framing</td>
<td>80</td>
</tr>
<tr>
<td>Stringing</td>
<td>257</td>
<td>Module Cleaning</td>
<td>80</td>
</tr>
<tr>
<td>Manual station</td>
<td>120</td>
<td>Power Test</td>
<td>90</td>
</tr>
<tr>
<td>Laminator</td>
<td>900</td>
<td>Packaging</td>
<td>60</td>
</tr>
<tr>
<td>Silicon curing test</td>
<td>90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.3 Data analysis and Current state map:

Table 2 shows the different processes in the production and the average processing time for each process. This section analyzes the data that has been collected and a current state value stream map is created using the collected data for the production of Photovoltaic solar modules (Appendix B). As shown in the current state map customer orders are received every month electronically and entered into the ERP. This data is then sent to the Production control that is responsible for preparing MPS. The MPS is prepared in coordination with the production engineer and the plant supervisor. Job direction and information flow happens manually to the work shift-in-charge who gives further work instructions to the individual people in each station. The information flow from the customer to the Production control and from the production control to the individuals is depicted in the drawing with the help of arrows. The work order is printed and handed to the work shift in charge who directs the individual work.

The first work order and worker will travel to the cleaning robot station to clean the glass panels. This operation is done in a batch mode of 11 glass panels. Each glass panel would take nearly 90s to be cleaned and to place the EVA sheet on it manually. This time is noted on the map as cycle time of the station. Here two operators work on this station. Once the trolley is filled with the glass panels the robot is switched off and the trolley is manually driven to the Komax/Reis setup.
In the meantime when the glass panels are being cleaned the solar cells are fed into the Komax machine. The Komax machine has an average changeover time of 2-3 hours depending on the model type and the type of cell that is used in the model. ST120 model has thirty six 6” solar cells, four strings of nine 6” solar cells are soldered together. The Komax machine first checks for broken cells and rejects broken ones. The cells are then soldered together to form a string of nine cells together. One string takes 61 seconds approximately. On each glass panel 4 strings are placed with proper alignment by the Reis robot. The total cycle time for this operation is 257s approximately (for one glass panel). After this operation the glass panel moves through another rolling belt conveyor and is filled onto an empty trolley. This operation is also done in a batch mode of 11 glass panels. So the total cycle time of this operation amounts to 47 minutes approximately. There is significant amount of Non Value added time in this process as the worker in the next station has to wait each time for the trolley to be filled so that they can be manually removed and the glass panel can be worked on. Moreover the current setup of the two Komax machines and the Reis robot also adds to a significant amount of Non value added time. The Reis robot has nearly 1.5 times more the capacity of the Komax machines which means that Reis robot can function normally only with strings being produced from two Komax machine else the Reis robot will not be utilized fully. In the current setup one of the Komax machine and the Reis robot are kept together whereas the other Komax machine is kept at a distance. This adds to the Non Value Added time because the strings that are made in the second Komax machine have to be fed into the Komax/Reis setup. So the total Non Value Added time in this station can be calculated as 90s (for feeding the strings from second Komax machine to Komax/Reis setup) plus 60s (time taken to re load the machine with solar cells) which gives a total of 150 s.

The glass panel is then taken out and is placed on the manual station. This takes another 30s which adds to the Non value added time. The total cycle time of this station is 120s and two operators work on this station on each panel. When one panel is worked on the other panels are waiting in a queue to be worked on.

The glass panel after visual inspection is placed on the bed of the Laminator. The capacity of the laminator is 4 glass panels at a time. The cycle time of the lamination process is 900s. During the lamination process the next set of four glass panels are worked on in the manual handling station. After lamination these laminates are then placed on movable pallets till the pallets are filled. The pallets can hold up to 80 laminates (ST120 models).

The pallets are transported to the next station only when the pallets are filled. The waiting time is nearly 5 hours for one pallet to get filled. Transportation of the laminates to the next station takes approximately 10 minutes. The plant layout is such that these machines are at a relatively larger distance from each other which takes a long time to travel and the travel distance is relatively longer. The movable pallet with the laminates then waits in the trimming area. One operator works in this station. This station also operates in batch mode with a batch of 3 laminates at a time. The cycle time of this station is 90s which is recorded in the value stream map.
The trimmed laminates are then taken one by one and are worked on in the next station by two operators. The cycle time of this operation is 80s. After the framing there are chances of some residual silicon on the surface of the solar module glass. This has to be thoroughly cleaned and the cleaning process has a cycle time of 80s.

After the cleaning process, the clean solar module is moved on to the next station on the conveyor. The final station is the Power testing station by the sun simulator. This station is worked on by one operator who checks the power of the solar module and the power rating is found. This operation has a cycle time of 90s. Finally, the power rated solar module is packed according to the customer requirements and specifications which has a cycle time of 60s.

The current state map contains all the necessary information and the key steps involved in the production of the Photovoltaic solar module. Each process is recorded on the map and all the key data regarding the present layout of the machines, their cycle times, number of operators, changeover time is specified in the data box of the value stream map. The travel distance of the material through the production floor is shown and the value added time and the non-value added time is also recorded on the timeline of the map. From the current state map we can see that large amount of inventory waiting in front of the bottleneck process ready to be transported to the next process.

3.2.3.1 Analysis of the current state map:

The current state map was created to give a one page picture of the production process of the Solar module. It shows clearly the information and product flow, the amount of WIP at each stage of the production process, the distance travelled by the materials through the entire process and the amount of value added and non-value added time involved in each process. The current state map also gives a clear picture of the areas of improvement within the entire process and serves as a base for creating the future state map.

The timeline in the current state map shows the value added time and non-value added time involved in the various production processes. By analyzing the time line it is identified that only 21% of the total time accounts for the value addition of the product whereas the remaining 79% accounts for non-value added time which in turn increases the overall production lead time. This is mainly due to batch production in the upstream processes and poor product flow. A detailed analysis of each section is given below.

- Analyzing the first process of laying the solar cells on the glass panels in the KOMAX/Reis setup, it is found that for one trolley of 11 glasses to be output from the process it takes approximately 47 minutes. In the next stage the glass panels are manually worked on individually with a cycle time of 2 minutes and after that they are placed as batch of four panels on the bed of the laminator for lamination. The lamination process takes approximately 15 minutes and in the meantime the two workers in the manual
station work on the remaining 7 glass panels. Once the lamination process is completed the workers place the next set of four glass panels for lamination. After this the processed laminates are categorized into various classes by visual inspection. It must be noted that there is no quality check involved during these processes except for visual inspection.

- When the second set of glass panels are placed in the laminator for the lamination process the workers remain idle as there are no glass panels to be worked on. This time also attributes to non value added time as waiting time of the worker. This time difference also makes the worker lazy and hence the work that can be done in 2 minutes is extended to 3-4 minutes so as to not remain idle during waiting. Once the laminates are finished they are not transported to the framing section but are placed on a palette and transported to the framing section only after the pallet is filled.

- The laminates are moved to the downstream processes as a batch of 80. This creates WIP in front of the laminate as well the pallet occupies floor space. Moreover 2 extra workers are responsible for transporting the pallets to the framing section as the distance between the framing section and the laminate section is quite large and the transportation would take nearly 5-10 minutes. This ultimately increases the production lead time as the downstream processes have to wait for the laminates to be worked on. Batch production also creates large amounts of WIP in the laminator process as well as occupies floor space.

- The batch production further carries on even in the next process of Silicon Curing where the laminates are fitted worked on as a batch of three laminates. After this process each laminate is fitted with aluminium frames by two workers. There is a queuing time that evolves in this process as each laminate is worked on individually at a time. Framing and cleaning is done by the same people and it takes 160 seconds for each laminate. This creates queuing time and WIP in front of the framing process. And this leads to occupying floor space. This creates non value added time in front of the framing process in the form of queuing time and WIP. Table 3 summarizes the VA/NVA analysis of the current state map.
### Table 3. Current state VA/NVA time analysis

<table>
<thead>
<tr>
<th>Name of the process</th>
<th>%VA</th>
<th>VA(seconds)</th>
<th>NVA(seconds)</th>
<th>Average processing time(seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning</td>
<td>94%</td>
<td>990</td>
<td>60</td>
<td>1050</td>
</tr>
<tr>
<td>Stringing</td>
<td>10%</td>
<td>257</td>
<td>2563</td>
<td>2713</td>
</tr>
<tr>
<td>Manual station</td>
<td>65%</td>
<td>120</td>
<td>60</td>
<td>180</td>
</tr>
<tr>
<td>Lamination</td>
<td>100%</td>
<td>900</td>
<td>0</td>
<td>900</td>
</tr>
<tr>
<td>Silicon curing</td>
<td>50%</td>
<td>270</td>
<td>60</td>
<td>330</td>
</tr>
<tr>
<td>Framing</td>
<td>35%</td>
<td>80</td>
<td>160</td>
<td>240</td>
</tr>
<tr>
<td>Cleaning</td>
<td>100%</td>
<td>80</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Power test</td>
<td>75%</td>
<td>90</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>Packaging</td>
<td>100%</td>
<td>60</td>
<td>0</td>
<td>60</td>
</tr>
</tbody>
</table>

### 3.2.3.2 Calculations and Results from the Current state map:

#### 1. Takt time calculation

Customer demand = 10000 pieces/month (or) 333 pieces/day

Shifts/day = 3

Working hours/shift = 8 hours (or) 480 minutes

Break time/shift = 15mins + 15 mins + 30 mins = 60 mins

Net working time/shift = 480-60 = 420 mins (or) 25200 secs

Net available time/day = 25200*3 = 75600 secs

Customer demand/day = 333 pieces

\[
\text{Takt time} = \frac{\text{Net available time/day}}{\text{Customer demand/day}} = \frac{75600}{333} = 227 \text{ sec/pieces}
\]
2. Percentage of value addition

Data collected from the current state map are:

Value Added time = 87 mins
Non Value Added time = 325 mins
Production Lead Time = 412 mins

Hence, % Value added = \(\frac{\text{Value Added time}}{\text{Production Lead time}} \times 100\) = \(\frac{87}{412} \times 100\) = 21%

This means that only 21% of the total time adds value to the product for which the customer will want to pay and the remaining is Non Value added time attributed mainly to the wasteful movements and other wastes in the form of queuing time and waiting time. As can be seen the production lead time is nearly 6.9 hours i.e. a single panel that could be made in 87 minutes takes 412 minutes to be produced due to Non value added activities. This leads to increased capital being tied up to materials and eventually will lead to losing customer satisfaction. In order to overcome these faults, the future state map with the suggested improvements are implemented and drawn and further analyzed which is discussed in the next section.

3.2.3.3 Suggestions to decrease production lead time:

- The first major change to be incorporated is the re arrangement of machines to obtain an optimal product flow through the plant. This has been discussed in Section 1 of this Chapter. Depending on various criterions the different proposals have been suggested and drawn. The most feasible as well as optimal proposal can be chosen to re arrange the machine so as to achieve a good product flow.

- The capacity of the Reis robot is twice the capacity of one KOMAX stringing machine. Hence in the current scenario the output of two KOMAX machines are fed into the feeder bed of the Reis robot in order to fully utilize the robot capacity. But as discussed above there is non value added time involved in shifting the feeder from the separate KOMAX machine to the bed of the Reis Robot. This can be avoided by a change in the current machine setup and making arrangements for the inclusion of the separate KOMAX machine inside the other setup and making the metal fencing around the new setup of the two KOMAX machines and Reis robot. This avoids the transportation time and the non value added time accompanied with it.

- There is non value added time that evolves due to the current KOMAX/Reis setup. The glass panels are fed as a batch of 11 and they come out as a batch of 11. This creates non value added time as there is waiting time in the next process that evolves. The machine
setup can be changed such that the glass panel can be output individually after the first process. This will reduce the waiting time and thereby decrease the non-value added time.

- Another major change to be made is regarding the production floor plan of the Storage section and the Framing section. In the current scenario, the laminates have to be transported from the laminator section to the framing section by crossing the storage section. This creates a lot of time for transportation and since the distance between the two sections is pretty large the laminates are transported as batches which creates WIP and occupies floor space. The product flow as well as production would be more efficient if the machines are rearranged in these two floors. This has been discussed in Chapter 1 and the most optimal and feasible proposal can be adopted.

- Another change that is suggested is in the Silicon curing test where the diodes are placed and glued in batches. In this process since it is carried out as batched there is WIP in front of framing and hence there is queuing time. Moreover since there is WIP it occupies floor space and the work place gets congested which jeopardizes worker safety.

- Another suggestion is to introduce kaizen mini projects which would improve the work quality for worker as well as increase the worker safety. Mini Kaizen projects related to inventory record accuracy can be carried out to improve inventory accuracy and to educate the importance of maintaining an accurate inventory. Training on 5S lean practices can be carried out and implemented at each work station as a step towards continuous improvement.

### 3.2.4 Future State Map:

A future state map by incorporating the suggested improvements is drawn and analyzed to show the improvement in results which is discussed in this section. The main problems in the current state can be summarized as:

1. Batch mode production
2. Poor product flow
3. Inefficient use of the workers
4. Poor machine arrangement
5. Poor quality check

The purpose of the thesis is to suggest proposals for reducing the lead time and increasing the productivity. The future state map is drawn with all the suggested improvements and incorporates various lean manufacturing techniques.
3.2.4.1 Analysis of the future state map:

- The plant layout has been changed and implemented as suggested in Proposal 2 as it is the most feasible and optimal solution for plant layout. Re-arrangement of machines and new plant layout brings the machines closer to each other. This facilitates smoother product flow as well as helps in replacing batch flow to single piece flow or smaller batch flow. The proposals for re arrangement have been discussed in section 1. Looking closely into this aspect when the machines are re arranged it can be observed that the laminator section and the framing section are brought closer to each other. This makes the machines much closer to each other, hence the time required to transport the products from the laminator to the framing section has been reduced drastically. Furthermore there is a pattern of flow of the products which is more organized. This structured flow reduces the Non value added activities significantly thereby reducing the Non value added time accompanied with it. Figure 13 shows a graphical description of the advantage of this improvement.

- The re arrangement of machines gives more space for the separate KOMAX machine in production line 1 to be clubbed and placed near the Reis robot. With this improvement another Non value added time can be reduced. The non value added time associated with this process in the current scenario is the need to transport the solar cell strings separately on a feeder and fed into the setup so that when there is no solar cell string available from the first machine the strings from the second machine are taken up to be laid on the glass panel. There is some time involved in transporting as the second KOMAX machine is situated at a distance from the Reis robot. The transportation is done manually by a worker each time the feeder in the second machine reaches the maximum capacity it can hold. There is another non value added time that evolves in this process. When there are no strings available to be laid from the first KOMAX machine and when the feeder from the second KOMAX machine is empty the Reis robot has to wait and it stops working until a new string is generated from the first KOMAX machine or till the feeder from the second KOMAX machine is filled. This is another loss of time and an addition to the non value added time. With the new arrangement there is no necessity for transportation of the strings and there is no lag or delay and waiting time.

- The change in the KOMAX/Reis setup also helps to significantly reduce the lead time. In the current scenario it takes approximately 47 mins for the entire batch of glass panels to come out of the first process. With the new setup it makes it easier and reduces the Non value added time, as waiting time, for the worker. When each glass panel comes out individually as soon as the laying of solar cells is done, the workers do not get lazy. Figure 14 graphically represents the advantage of implementing the change.
This can be explained further. In the current setup the glass panels are fed into the first station as a batch of 11 and come out as a batch of 11. It takes approximately 47 minutes to complete the entire set of 11 glass panels. In the meantime the workers are busy working at the second station where the cycle time is 2 mins. From this station each glass panel is placed onto the third station where the process is done as a batch of four. Now suppose one batch of four glass panels is placed in the laminator then there are remaining 7 glass panels to be worked on in the second station. These can be worked on in the time that the laminator takes to finish its current lamination process. In the meantime the process at the first station goes on. But once the first set of laminates are taken out and the second set of laminates are placed, there is another 20 mins remaining where the workers tend to do no work. This is another major area of Non value added time since in every one hour there is a 20 min wastage of time excluding the other breaks for the workers. In the new setup suggested this time lag can be reduced as each glass panel comes out as soon as the first process is complete. This makes the worker to work continuously without having to waste time in between. Both these improvements are shown graphically in figure 13 and figure 14.

- Another major change is in the batch mode of flow in Silicon curing. The laminates after being trimmed pass through the Silicon curing station in batches of three. This creates WIP as laminates have to wait in front of framing section. In order to eliminate this the batch mode is replaced by single piece flow Each laminate after being fixed with diode is passed on to the next station of framing This reduces the WIP and queuing time associated with the processes in the current setup.

- The introduction of 5S implementation and training is highly important in any industry as it not only improves work quality but also saves time in many cases. 5S is a very important step towards lean implementation though practicing this technique would be pretty difficult. It is very important to teach the worker about the importance of 5S.
techniques. It gets easier for them when they search for things when they are properly sorted, organized and labeled.

Similarly another important aspect is regarding inventory record accuracy. In the current scenario the inventory management system is not properly utilized. This leads to depletion of materials as well as over procurement as there is no proper inventory record maintained. Care has to be taken in training in the inventory manager on the need and implementation of the inventory management system.

3.2.4.2 Calculations and Results from the future state map:

1. **Takt time** remains the same as before of 227 secs/piece

2. **Percentage of value addition:**

In the current state map we had seen that the percentage of value addition to be 21 % of the total production lead time. The future state map was created with all the suggested changes and the VA/NVA Analysis of the future state map has been tabulated in the Table 4. The Non value added time also includes setup time, transportation time, queuing time, waiting time before process, waiting time after process. Summing up all these Non value added activities the production lead time has been calculated to be 55 minutes. This is mainly due to the significant reduction in the Non value added processes and comparing the two value maps it can be concluded that 304 mins reduction of Non value added activities has been achieved.

Total production lead time = 55 mins

Value added time = 45 mins

\[
\text{%Value added} = \frac{\text{Value Added time}}{\text{Production Lead time}} = \frac{45}{55} = 82 \%
\]

This implies that from a 21 % value addition process with the implementation of lean manufacturing techniques a value addition of 82 % can be achieved. This means that 45 mins i.e 82 % of 55mins of production lead time is value added activities compared to 10mins of non value added activities.
Table 4. Future state VA/NVA time analysis

<table>
<thead>
<tr>
<th>Name of the process</th>
<th>%VA</th>
<th>VA time (sec)</th>
<th>NVA time (sec)</th>
<th>Avg. processing time in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning</td>
<td>94%</td>
<td>990</td>
<td>60</td>
<td>1050</td>
</tr>
<tr>
<td>Stringing</td>
<td>81%</td>
<td>257</td>
<td>60</td>
<td>317</td>
</tr>
<tr>
<td>Manual station</td>
<td>80%</td>
<td>120</td>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>Laminator</td>
<td>100%</td>
<td>900</td>
<td>0</td>
<td>900</td>
</tr>
<tr>
<td>Silicon Curing</td>
<td>75%</td>
<td>90</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>Framing</td>
<td>100%</td>
<td>80</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Power Test</td>
<td>100%</td>
<td>90</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Packaging</td>
<td>100%</td>
<td>60</td>
<td>0</td>
<td>60</td>
</tr>
</tbody>
</table>

The table above shows the VA/NVA analysis of the future state map. From the table it is clear that with the implementation of the suggested changes there is reduction of the overall lead time of production and more value addition in each process. Many unnecessary steps are eliminated thereby saving time and cost.

3.2.5 Limitations in Value stream:

- In the current state value stream map the time for the production of only one solar module is considered.
3.3 Extend Sim Simulation Software:

To help in the decision process in today’s changing world, many companies rely on simulation software to simulate and analyze the possible future states. It is an easier way to analyze and see the result when there is a change in production or change in the process. It helps the companies to make prior decisions before implementing. It is a way of visually creating the entire production process and to see the result and is one of the most cost effective ways. In this project Extend Sim8 was used to model the production flow at Eco Supplies Solar AB.

3.3.1 Drawing the current production process flow

The entire production process is drawn using the Extend Sim software. Data such as cycle time, downtime, transportation time etc. was entered for each operation. The current production process as well as future production process is drawn with the data that is available from the value stream map. The simulation is drawn done as a discrete event simulation. The drawing is explained as parts in this section.

Model Section 1. Cleaning and Stringing

The above figure is the cleaning and stringing section in the simulation drawing. From the figure it is clear that the cleaning and stringing process happens simultaneously.
In the create block for cleaning the item quantity is given as 11 with an inter arrival time of 27 minutes. This is because the process is done as a batch of 11 glass panels which is then transported to the next station. The inter arrival time of 27 minutes is so that when the stringing process is completed the new batch of glass panels can be fed into the machine. However this is a manual process as the robot is switched on manually. Hence the inter arrival time is specified as a normal distribution with a mean of 27 and standard deviation of 1 with time units as minutes. After passing through the activity block of cleaning the panels are then held up to for a batch of 11. This is done by the batch block. Since batching combines all the items into one single item it is required to unbatch the item before the next operation takes place and so an unbatch block is used.

In the create block for cells the item quantity is given as 1 with an inter arrival time of 6.8 seconds. This is the time that the machine takes to generate the cell to be soldered and form the string. Here a decision block has been added because of the behavior of the Reis robot. The robot chooses the strings from the second KOMAX only when there is no input from the first KOMAX machine. This is depicted by the decision block and then a select input block is used to select which input to choose. The string is then combined with the glass panel by using a batch block. In the batch block 4 items from the stringing process and 1 item from the cleaning process is batched into one product.

**Model section 2: Manual Handling station and Laminator**

After the batching of the glass panels it requires to be unbatched into 11 separate items so as to be worked on in the manual station. So an unbatch block is used before the activity block. The activity block represents the manual handling station with a processing time of 2 minutes. Here only one glass panel is worked on at a time whereas the other glass panels wait in queue to be worked on. Once this process is done there is another batching of four items to be placed in the laminator. The processing time for lamination activity is specified in the block and after lamination the laminates are again batched so as to be transported. Batching is complete when 80 laminates are produced. This 80 laminates are then transported to the next station. The transport block is attached to the batch block and the time for transport is mentioned in the block.
Section 3: Silicon Curing, Framing and Power Test

The laminates that are batched into 1 item require to be unbatched as they are individually worked on in the next stations. So a unbatch block splits them into 80 different items. The next station is the Trimming and Silicon curing where a batch of 3 is worked upon. This is mentioned in the activity dialogue box. Once the process is done the item with the shortest processing time exits first and goes to the next station. The next station work is carried on by two workers who fit the frames and clean the glass. This activity is mentioned in the activity block and the processing time is mentioned in the block. The final activity is the power test which is done individually on each item. This activity block is connected to the previous activity block and the processing time is mentioned in the activity dialog box. The different shift timings for the two departments has also been included in the drawing using the shift block and the machines have been set to their respective shift timings with respect to the worker working on them.

3.3.2 Drawing the future production process

The future production process flow is drawn with the same blocks except for a few changes in the plant layout and the machine setup. The changes in the different sections of the model are shown below:

Change 1: Change in KOMAX machine setup
As seen above there is a change in the KOMAX/Reis setup as the second KOMAX machine is brought closer to the Reis robot and hence the transportation from the second KOMAX machine is eliminated. This is evident in the select block where the probability of the string being picked by the Reis robot is given as 0.5. So in this step the non value added time that was required for transporting the strings from the second KOMAX machine has been eliminated and so there is a decrease in the overall production time. After the strings are placed on the glass panel they move to the next station. The batching of the strings and the glass panel is done by the batch block.

Another important change that is shown in the KOMAX/Reis setup is in the output of the machine. In the current process the glass panels leave the machine as a batch of 11. This also adds to non value added time as waiting time. The new machine setup is in such a way that after each glass panel has finished its processing in the first station it goes out of the station to be worked on in the next station. Hence cycle time is reduced from 47 minutes to 4.2 minutes.

**Change 2: No WIP in front of laminator and laminates are transported sooner**

The laminator and the framing machines are brought closer to each other as discussed in the previous section 3.1 and section 3.2. Bringing the machines closer to each facilitates easier transportation from the laminator to the next station and there is no need for WIP or queuing time which added to a major part of the total production time. By this major change the production time have been reduced drastically thereby decreasing overall cost, decreasing WIP and increasing overall productivity and efficiency. The items that are batched together before being placed into the laminator station have to be unbatched as they are worked upon individually in the next station.

**Change 3: Changing batch mode of production to single piece flow in Silicon curing station so as to reduce the queuing length and queuing time**
The laminates after being trimmed and fixed with the diode are sent to the next station immediately. This reduces queuing time and WIP. The simulation is run for 1 month time and the results are tabulated and analyzed in the next section.

### 3.3.3 Assumptions:

- **Average downtime:**
  - For first KOMAX machine, TBF-96 hours, TTR-2 hours
  - For second KOMAX machine, TBF-120 hours, TTR-2 hours
  - For Laminator machine, TBF-144 hours, TTR-4 hours
- Rework is neglected as it is almost negligible
3.3.4 Simulation Results and Analysis

The simulation is run for 30 days for both current and future state production process. This is mentioned in the simulation setup tab and the global time units have been set to seconds. The table below gives a clear picture of the utilization, queuing time, waiting time associated with each process both in the current state and the future state as well as the overall production.

Table 5 shows the results from the current state and future state production flow.

<table>
<thead>
<tr>
<th></th>
<th>Current state</th>
<th>Future state</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KOMAX machine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilization of KOMAX 1</td>
<td>65%</td>
<td>50%</td>
</tr>
<tr>
<td>Utilization of KOMAX 2</td>
<td>35%</td>
<td>50%</td>
</tr>
<tr>
<td>Manual Handling Station</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue wait( in minutes)</td>
<td>4.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Utilization</td>
<td>91%</td>
<td>98%</td>
</tr>
<tr>
<td>Laminator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue wait(in minutes)</td>
<td>19</td>
<td>15.2</td>
</tr>
<tr>
<td>Silicon Curing test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue length</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td>Queue wait(in minutes)</td>
<td>96</td>
<td>35</td>
</tr>
<tr>
<td>Framing and Cleaning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue length</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Queue wait(in minutes)</td>
<td>102</td>
<td>54</td>
</tr>
<tr>
<td>Power Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue wait(in minutes)</td>
<td>2.35</td>
<td>1.8</td>
</tr>
<tr>
<td>Time that 1st product is</td>
<td>357</td>
<td>46</td>
</tr>
<tr>
<td>produced(in minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall production(in a month)</td>
<td>10240</td>
<td>11440</td>
</tr>
</tbody>
</table>

*Table 5. Table showing overall results from the simulation run of the current state future state*
The table above gives the overall results obtained from the simulation run of the current and future states. While the Value stream map gives a static picture of the process, the simulation was done to understand the behavioral characteristics of the process and the effects that each change would have to the individual processes. A detailed analysis of the simulation result is given below:

- It is seen that there is better utilization of both the KOMAX machines in the future state than the current state. This is mainly due to change in the machine setup and the need for transporting the strings from the separate KOMAX machine is eliminated here. Hence there is better utilization of both the KOMAX machines which in turn reduces the Non value added time as waiting time of Reis robot as well as the transportation time.

- The change in machine setup also reduces the queuing time of manual handling station. This means that earlier the glass panels had to wait for 4.2 mins (average) to be worked on but in the future state map it only has to wait in queue for 2.6 min (average). It can also be noted that the utilization of the station has increased.

- The change in the utilization of the manual handling station also reduces the queuing time of the glass panels in front of the laminator. The average queuing time has been reduced from 19 mins to 15.2 mins which also means more utilization of the laminator.

- Change in the plant layout brings the machines closer and the biggest change can be seen in the Trimming and framing stations. In the current layout, the laminates near trimming and Silicon curing station had an average queue length of 26 with an average queuing time of 96 mins. The change in layout helps to reduce this queuing time and queuing length significantly to an average queue length of 7 laminates with an average queuing time of 35 mins.

- Another significant change that is visible is in the queue length and queue time of framing and cleaning. Here in the current layout the average queue length is 24 with an average waiting time of 102 mins. This means that large WIP in the framing section and therefore large amounts of floor space was occupied due to the large WIP. With the change in the layout and few other changes this has caused good effects on the behavior of the processes and give better results. There is a reduction of the average queue length to 12 items with an average waiting time of 54 mins which means that there is lesser WIP and hence more space on the floor.

- In the final Power test station also the changes can be seen. The average queue wait time has reduced from 2.35 mins to 1.8 mins.

- The overall changes in the entire production process should be reflected also in the overall production. The overall monthly production has increased from 10240 to 11440 which is a 12% increase in overall production can be achieved.
3.4 Scope of the project:

- Only one type of model is considered during the project
- Only Production line 1 has been considered
- Changes in production schedule haven’t been considered
- Exceptions are ignored since the main goal of the value stream is to get a clear picture of the production processes and the flow.
Chapter IV: Summarization of results, Recommendations and Conclusion

This chapter gives a summary of the results found by the material flow analysis, Value stream map and the simulation. The results are further analyzed, explained and tabulated in this chapter. Furthermore, the recommendations/proposals are also mentioned which would help in better product flow and better production.

4.1 Summarization of results

The main objective of this project was to study and analyze the current process flow so as to visually describe a process and identify ways of improving the current process. The key areas of improvement are then suggested so as to change the current process flow and design. Before the actual implementation of the changes at the plant Eco Supplies Solar AB wanted to conduct a case study on the process flow and to see if the change would create an improvement in the overall productivity and reduce the throughput time. The project has been divided into three parts: Material flow and people flow analysis, Value stream mapping and Simulation using Extend Sim software.

**Phase I:** Material flow and people flow analysis was carried out to get an actual picture of the production process. This was done by walking through the entire production process from the start of production to the end of production. The material movement and worker movement associated with each process and station was clearly recorded. This led to the creation of the Spaghetti diagram. This diagram explained the plant layout and the worker movement through the plant. It helped to identify the key areas of improvement, the approximate distance travelled by the worker and the material and the faults in the current plant layout. From the diagram of the present production flow it can be seen that the worker makes many unnecessary movements and the material travels a large distance in the plant for production. This is mainly due to the plant layout which leads to large distance between the machines. Taking these into consideration a few proposals for rearranging the machines to obtain an optimal product flow has been drawn. Five different proposals have been suggested and a drawing of each of these has been done to show the movements in each of these proposals (Section 3.1 Chapter 3). The approximate distance travelled in the current process flow and the proposed production process flow is tabulated below.

<table>
<thead>
<tr>
<th>Setup</th>
<th>Present</th>
<th>Proposal 1</th>
<th>Proposal 2</th>
<th>Proposal 3</th>
<th>Proposal 4</th>
<th>Proposal 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance(approx.metres)</td>
<td>240</td>
<td>188</td>
<td>191</td>
<td>230</td>
<td>195</td>
<td>240</td>
</tr>
</tbody>
</table>
Considering the difficulty and cost involved in moving the cleaning robot and the limitation of breaking the wall between production line 1 and production line 2, the most optimal solution is Proposal 2.

**Phase II:** The second part of this project is the use of Lean manufacturing tools to determine the key areas of waste in the production process which leads to increased overall throughput time and overall cost. The lean manufacturing tool used in this project is Value Stream Mapping. For the purpose of drawing the current state map the different data related to each machine and process was collected and with the information and data collected the current state map was drawn. The current state map helped in understanding the main areas of wasteful movements and non value added activities in the production plant and a few suggestions were recommended to be implemented so as to overcome these shortcomings. The future state map was then drawn with all the suggested changes and the overall throughput time and efficiency was calculated theoretically. Both the results are then analyzed and the necessary improvements are suggested. The results are tabulated below and this data has been graphically represented in Figure 15.

<table>
<thead>
<tr>
<th></th>
<th>Current state map</th>
<th>Future state map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production lead time(mins)</td>
<td>412</td>
<td>55</td>
</tr>
<tr>
<td>% Value addition</td>
<td>21</td>
<td>80</td>
</tr>
<tr>
<td>Total distance travelled in meters</td>
<td>240</td>
<td>191</td>
</tr>
</tbody>
</table>

*Table 6: Table showing the current state and future state values before and after implementation of lean Manufacturing techniques*

![Graph showing the benefits of lean approach](image)

*Figure 15. Graph showing the benefits of lean approach*
Phase III: The Value stream Map gives a one page static picture of the current and the future state. The value stream map was drawn to identify the key areas of muda(waste) within the production process and to suggest for changes that could be implemented within the process. The future state map was drawn with the changes and the corresponding results were calculated and tabulated. The value stream map is just a visual picture of the production process. In order to find out the true results it requires practical implementation in the production process. However this would disrupt production and involve large expenses in the re arrangement and the training of workers. Hence an easier and more cost effective solution is to run a simulation model of the current production process and also the future production process with the changes implemented. The simulation is done in Extend Sim8 and the simulation is run for 30 months and the results are found. The results of the simulation and the improvements are graphically represented in Figure 16.

Figure 16. Graph shows the improvements observed in the future state simulation run
4.2 Recommendations/Proposals:

- A main problem that has to be addressed within the production process is related to the quality check. In the current production process there is no quality check integrated with the process except for the visual check at the Manual station before placing the glass panel on the bed of the laminator. The strings could be damaged due to overheating but the quality check is done only at the last station. The problem arises when only a single cell or few cells might be damaged which decreases the salability of the product and the defect is found at a stage where no re work is possible. Hence there is a requirement for a quality check at an earlier stage. The KOMAX Solar Company has developed viable and effective solutions for this problem by inventing and producing new string testers which can be chosen depending on the capacity of the plant. The table below shows the different testers available depending on the capacity of the plant. According to the table and the capacity requirements the Xinspect 3600ic would suit the requirements.

In addition to the backlight image processing approaches, electroluminescence testing surfaces normally invisible defects, such as micro cracks, dark area, and printing defects. Not all of them have the same electrical performance impact. Some might propagate to a more important defect later, others have a direct correlation to electrical performance, and others might even be ignored. Consequently, the additional verification of the electrical performance by a monochromatic I-V curve measurement facilitates a cost- and space-optimized solution. The monochromatic I-V curve also allows for a relative measurement
system to distinguish good and defective units by setting a previously determined acceptance threshold. In such a case, repeatability is more important than absolute values.

- As discussed in Chapter 3, the main reason behind the large production lead time is the plant layout. Immediate actions are to be taken regarding the re-arrangement of machines so as to attain an optimal plant layout and optimal flow within the plant.

- Training and knowledge to be given to the management regarding Value stream mapping and the importance of Value stream. A group consisting of the managers from the various departments to discuss on how to map the flow and to walk the process so as to identify the areas of waste and to suggest improvements. After understanding the entire process a brainstorming session should be conducted so that various proposals are suggested and different ideas are shared. After finalizing on the different implementations and changes to be made on the current production process, the changes are to be implemented and the results are to be closely analyzed.

- Inventory record accuracy should be improved. In the current scenario, there is no proper record of the inventory record which may lead to many problems such as stock outs and delivery delays, wasting of time looking for misplaced or missing items, overall cost associated with unwanted inventories, depletion of resources and also excessive purchase. In order to avoid these circumstances, the inventory record accuracy must be improved. Proper training of the Inventory management system should be given to the inventory manager and the use of the system should be encouraged.

- Another major change for the better production and better working of the system is the need for organized storage and inventory. This can be achieved by arranging rack layout to get optimal storage, creating rack location codes so that every rack has a unique identification number, using the proper color codes for the stock, assign unique part number and consolidate the parts so that same items are kept together. Another major change required is the use of bar code scanner. It is difficult when the bar codes are manually entered and there is a tendency to make mistakes. The use of bar code scanner makes the work easier and gives more accurate inventory of materials. Moreover the staff requires to be trained about how to use the inventory management system and the importance of maintaining the system.

- Another major change required is in the area of Housekeeping. In the current production process, it can be seen that lots of parts, tools and other unneeded items are crowded and stacked between workers. This not only jeopardizes worker safety but also leads to wastage of time in searching for the misplaced tools or parts. In order to overcome this 5S has to be introduced in the production process. It should be initiated from the top level
management and proper training must be given to the workers to implement 5S in their work. This not only improves worker condition and quality of work but also improves productivity.

○ The biggest change required is to develop a lean culture which is a continuous improvement process. For implementation of lean culture in the production plant, there should be proper Lean training for all the workers as well as the management. Lean implementation requires patience and the results might improve over the days. It is very important that everyone understands the importance of implementing a lean culture and all the workers have to be motivated to adopt lean culture in their working environment.

○ The final change is required in the order delivery system. A system is to be introduced where there is a guarantee for money. Since the production of a solar module involves large costs, when an order is cancelled or when the customer delays the payment, there arises a problem with the cash flow. Hence, it is suggested that some deposit or safety money be collected from the customer so as to cover for any losses that may occur.

4.3 Conclusion

The main aim of this thesis was to help Eco Supplies Solar AB in its continuous improvement process. As part of the continuous improvement process they wanted to identify the key areas of waste within the production process and to find ways of eliminating it. The main part of the thesis consisted of analyzing the current process and identifying the key areas of waste and key areas of improvement.

In order to accomplish this goal the lean manufacturing tool Value stream Mapping was used. The entire production process was mapped with the data and information collected from walking through the process and from the workers. The mapping exposed the entire production process and was helpful in identifying the waste within the process. This led to suggestions for improvements by implementation of lean techniques and a future state map was created.

The final phase of the thesis was the use of simulation software to develop a model where the behavioral effects on each process could be observed. The simulation for the current state as well as future state is drawn and the improvements are observed through the entire production process.

At the end of the thesis, I can conclude that Value stream mapping is a very important tool for Eco Supplies Solar AB to optimize the production flow and achieve higher productivity. The future state map that is created during this project could be used as a base for further improvement of the process.
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<www.ecosupplies.eu>

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## Appendix

### A. Value Stream Mapping Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Customer/Supplier Icon" /></td>
<td>Customer/Supplier Icon: represents the Supplier when in the upper left, customer when in the upper right, the usual end point for material</td>
</tr>
<tr>
<td><img src="image" alt="Process" /></td>
<td>Dedicated Process flow Icon: a process, operation, machine or department, through which material flows. It represents one department with a continuous, internal fixed flow.</td>
</tr>
<tr>
<td><img src="image" alt="Process" /></td>
<td>Shared Process Icon: a process, operation, department or workcenter that other value stream families share.</td>
</tr>
<tr>
<td><img src="image" alt="Data Box Icon" /></td>
<td>Data Box Icon: it goes under other icons that have significant information/data required for analyzing and observing the system.</td>
</tr>
<tr>
<td><img src="image" alt="Workcell Icon" /></td>
<td>Workcell Icon: indicates that multiple processes are integrated in a manufacturing workcell.</td>
</tr>
<tr>
<td><img src="image" alt="Inventory Icons" /></td>
<td>Inventory Icons: show inventory between two processes</td>
</tr>
<tr>
<td><img src="image" alt="Shipments Icon" /></td>
<td>Shipments Icon: represents movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customers</td>
</tr>
<tr>
<td><img src="image" alt="Push Arrow Icon" /></td>
<td>Push Arrow Icon: represents the “pushing” of material from one process to the next process.</td>
</tr>
<tr>
<td><img src="image" alt="Supermarket Icon" /></td>
<td>Supermarket Icon: an inventory “supermarket” (kanban stockpoint).</td>
</tr>
<tr>
<td><img src="image" alt="Material Pull Icon" /></td>
<td>Material Pull Icon: supermarkets connect to downstream processes with this “Pull” Icon that indicates physical removal.</td>
</tr>
<tr>
<td><img src="image" alt="FIFO Lane Icon" /></td>
<td>FIFO Lane Icon: First-In-First-Out inventory. Use this icon when processes are connected with a FIFO system that limits input.</td>
</tr>
<tr>
<td><img src="image" alt="Safety Stock Icon" /></td>
<td>Safety Stock Icon: represents an inventory “hedge” (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures.</td>
</tr>
<tr>
<td><img src="image" alt="External Shipment Icon" /></td>
<td>External Shipment Icon: shipments from suppliers or to customers using external transport</td>
</tr>
<tr>
<td>Icon</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td><img src="image" alt="Production Control Icon" /></td>
<td>Production Control Icon: This box represents a central production scheduling or control department, person or operation.</td>
</tr>
<tr>
<td><img src="image" alt="Manual Info Icon" /></td>
<td>Manual Info Icon: A straight, thin arrow shows general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant.</td>
</tr>
<tr>
<td><img src="image" alt="Electronic Info Icon" /></td>
<td>Electronic Info Icon: This wiggle arrow represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network). You may indicate the frequency of information/data interchange, the type of media used ex. fax, phone, etc. and the type of data exchanged.</td>
</tr>
<tr>
<td><img src="image" alt="Production Kanban Icon" /></td>
<td>Production Kanban Icon: This icon triggers production of a predefined number of parts. It signals a supplying process to provide parts to a downstream process.</td>
</tr>
<tr>
<td><img src="image" alt="Withdrawal Kanban Icon" /></td>
<td>Withdrawal Kanban Icon: This icon represents a card or device that instructs a material handler to transfer parts from a supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items.</td>
</tr>
<tr>
<td><img src="image" alt="Kaizen Burst Icon" /></td>
<td>Kaizen Burst Icon: used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream.</td>
</tr>
<tr>
<td><img src="image" alt="Operator Icon" /></td>
<td>Operator Icon: represents an operator. It shows the number of operators required to process the VSM family at a particular workstation.</td>
</tr>
<tr>
<td><img src="image" alt="Other Information Icon" /></td>
<td>Other Icon: other useful or potentially useful information.</td>
</tr>
<tr>
<td><img src="image" alt="Timeline Icon" /></td>
<td>Timeline Icon: shows value added times (Cycle Times) and non-value added (wait) times. Use this to calculate Lead Time and Total Cycle Time.</td>
</tr>
<tr>
<td><img src="image" alt="Go See Icon" /></td>
<td>Go See Icon: gathering of information through visual means.</td>
</tr>
<tr>
<td><img src="image" alt="Verbal Information Icon" /></td>
<td>Verbal Information Icon: represents verbal or personal information flow.</td>
</tr>
<tr>
<td><img src="image" alt="Signal Kanban Icon" /></td>
<td>Signal Kanban Icon: used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. It is also referred as “one-per-batch” kanban.</td>
</tr>
<tr>
<td><img src="image" alt="Kanban Post Icon" /></td>
<td>Kanban Post Icon: a location where kanban signals reside for pickup. Often used with two-card systems to exchange withdrawal and production kanban.</td>
</tr>
<tr>
<td><img src="image" alt="Sequenced Pull Icon" /></td>
<td>Sequenced Pull Icon: represents a pull system that gives instruction to subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket.</td>
</tr>
<tr>
<td><img src="image" alt="Load Leveling Icon" /></td>
<td>Load Leveling Icon: a tool to batch kanbans in order to level the production volume and mix over a period of time.</td>
</tr>
<tr>
<td><img src="image" alt="MRP/ERP Icon" /></td>
<td>MRP/ERP Icon: scheduling using MRP/ERP or other centralized systems.</td>
</tr>
</tbody>
</table>
D. Other pictures around the production plant

*Solar cell loaded into the KOMAX machine*

*Cell Load station*

*Glass module from the KOMAX machine with the strings*

*Rework station*

*Visual quality check before placing in laminator*
Stringer machine used for cutting EVA and Tedlar

Waste around the Manual Handling station

WIP in front of Framing section waiting for cleaning

Waste near Silicon Curing machine

Framing machine used for smaller Solar modules