Design and Implementation of a Continuous Improvement Framework for an Organic Photovoltaic Panels Manufacturer

by

Gregorio Colaci

M.S. in Mechanical Engineering, University of Rome “La Sapienza”, 2010

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of Master of Engineering in Manufacturing at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2011

© 2011 Gregorio Colaci
All rights reserved

The author hereby grants MIT permission to reproduce and distribute publicly paper and electronic copies of this thesis document in whole or in part.

Author ................................................... Gregorio Colaci
Department of Mechanical Engineering
August 6, 2011

Certified by .................

David E. Hardt
Ralph E. and Eloise F. Cross Professor of Mechanical Engineering
Thesis Supervisor

Accepted by ................

David E. Hardt
Ralph E. and Eloise F. Cross Professor of Mechanical Engineering
Chairman, Committee on Graduate Students
Design and Implementation of a Continuous Improvement Framework for an Organic Photovoltaic Panels Manufacturer

by

Gregorio Colaci

M.S. in Mechanical Engineering, University of Rome "La Sapienza", 2010

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of Master of Engineering in Manufacturing

Abstract

The MIT MEng Team worked at Konarka Technologies, the world leader organic photovoltaic panels (OPV) manufacturer, on several improvement projects. The concentration was on operations improvement as well as production information tracking and analysis. This thesis report, however, focuses primarily on the implementation of a continuous improvement culture. Tools to implement the 5S methodology, such as 5S Audit, Kaizen board and Kanban board, were provided, and operators were trained. A layout improvement solution was developed, and a plan for implementation recommended. The new layout was designed to increase visual control of the processes and to reduce movement of material by 85%. Each phase of the project went through review and discussion to encourage operator involvement in order to develop a continuous improvement culture.

Keywords: 5S, Lean manufacturing, Kaizen, Kanban, layout design improvement optimization, tracking system, inventory reduction, material movement reduction, waste reduction.

Thesis Supervisor: David E. Hardt
Title: Ralph E. and Eloise F. Cross Professor of Mechanical Engineering
Acknowledgements

First of all, I would like to thank my family and SunMin for supporting me through the difficult times during this year, the most valuable period of my life. Without your love and support, I would not be able to successfully finish my master degree and start my exciting career.

I would like to thank Professor David E. Hardt for his professional comments on the subject of this thesis and dedicated supervision throughout the project. I am impressed by Hardt's meticulous attitudes towards academic research and the way he enjoys life. He has been my advisor, my mentor and my friend.

Thanks are also due to Mr. Larry Weldon and Mr. John “The Sheriff” Lawlor for making this project in Konarka Technologies happen. With your courtesy, proficiency and support, I had experienced an exciting, formative and successful internship. I will miss the time at Konarka New Bedford and your sense of humor in the future.

Special thanks go to Sue, Tony, John, Dan “The Man” and all other people in shop floor. All of you were supportive and helpful; you generously shared your experience and patiently answered my copious questions. All of these make me happy working at Konarka.

Last but not the least, I would like to thank my friends, classmates and colleagues. It’s nice working with you and I learn a lot from you. Lastly and most importantly I want to thank my team members: Ming, Jason and Susheel for support throughout the course of the project. Thanks for giving me your unconditional friendship.

Thanks again to all these people.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1 Waste Reduction</td>
<td>30</td>
</tr>
<tr>
<td>3.1.1.1 Product Transport &amp; Human Movement Waste</td>
<td>31</td>
</tr>
<tr>
<td>3.1.1.2 Inventory &amp; Inconsistent Flow</td>
<td>32</td>
</tr>
<tr>
<td>3.1.1.3 Over-processing Waste</td>
<td>32</td>
</tr>
<tr>
<td>3.1.1.4 Defects Waste</td>
<td>33</td>
</tr>
<tr>
<td>3.1.2 Kaizen</td>
<td>33</td>
</tr>
<tr>
<td>3.2 5S Methodology</td>
<td>34</td>
</tr>
<tr>
<td>3.2.1 Objectives of the 5S Methodology</td>
<td>37</td>
</tr>
<tr>
<td>Chapter 4: Methodology</td>
<td>38</td>
</tr>
<tr>
<td>4.1 Improvements</td>
<td>38</td>
</tr>
<tr>
<td>4.2 Kaizen for Flow Improvement</td>
<td>38</td>
</tr>
<tr>
<td>4.2.1 The Kaizen Event</td>
<td>38</td>
</tr>
<tr>
<td>4.2.2 The Kaizen Team</td>
<td>39</td>
</tr>
<tr>
<td>4.2.3 Meeting I</td>
<td>39</td>
</tr>
<tr>
<td>4.2.4 Meeting II</td>
<td>39</td>
</tr>
<tr>
<td>4.2.5 Meeting III</td>
<td>40</td>
</tr>
<tr>
<td>4.3 5S Audit</td>
<td>41</td>
</tr>
<tr>
<td>4.4 Kaizen Board</td>
<td>45</td>
</tr>
<tr>
<td>4.5 Layout Improvement</td>
<td>45</td>
</tr>
<tr>
<td>4.5.1 Current Layout</td>
<td>46</td>
</tr>
<tr>
<td>4.5.2 Observation and Experimentation</td>
<td>46</td>
</tr>
<tr>
<td>4.5.3 Mapping</td>
<td>47</td>
</tr>
<tr>
<td>4.5.4 Issue Identification</td>
<td>47</td>
</tr>
<tr>
<td>4.6 Kanban Board</td>
<td>51</td>
</tr>
<tr>
<td>4.7 Tracking System</td>
<td>52</td>
</tr>
<tr>
<td>4.8 Production Scheduling Tool</td>
<td>52</td>
</tr>
<tr>
<td>Chapter 5: Results</td>
<td>54</td>
</tr>
<tr>
<td>5.1 5S Audit</td>
<td>54</td>
</tr>
<tr>
<td>5.1.1 Operators and Management Audit</td>
<td>57</td>
</tr>
<tr>
<td>5.2 Kaizen Board</td>
<td>59</td>
</tr>
</tbody>
</table>
Chapter 5: Kaizen for Flow Improvement

5.3 Kaizen for Flow Improvement ..................................................................................................................60
  5.3.1 Spaghetti diagram .............................................................................................................................60
  5.3.2 Improved Layout ..................................................................................................................................64
  5.3.3 Implementation Plan ..........................................................................................................................69

5.4 Kanban Board .............................................................................................................................................70
  5.4.1 Operators Approach .........................................................................................................................70
  5.4.2 Layout of the Board ..........................................................................................................................70
  5.4.3 Board Utilization ................................................................................................................................72
  5.4.4 Physical Board ...................................................................................................................................74

Chapter 6: Recommendations and Future works .............................................................................................76
  6.1 5S Methodology and Kaizen Board ........................................................................................................76
  6.2 Layout Improvement ................................................................................................................................76
  6.3 Kanban Board ...........................................................................................................................................77
  6.4 Process and Machinery ........................................................................................................................77

Chapter 7: Conclusion .........................................................................................................................................79

Bibliography .....................................................................................................................................................81

Appendix A: Power Plastic Products .................................................................................................................83
Appendix B: Kanban Board Details ..................................................................................................................84
List of Figures

Figure 1 – Coated layers in Konarka's Power Plastic ..........................................................11
Figure 2 - 20 Lane wide, 6 modules Product .....................................................................12
Figure 3 - Total Energy Collected in one day ....................................................................15
Figure 4 - Product Architecture ..........................................................................................17
Figure 5 - Coating Process ..................................................................................................18
Figure 6 - Finishing Processes ............................................................................................19
Figure 7 - Plant Layout and Processes Flow .......................................................................21
Figure 8 - Designed Information Flow ...............................................................................28
Figure 9 - Continuous Improvement Cycle .........................................................................34
Figure 10 - 5S Steps ............................................................................................................35
Figure 11 - Red Tag Station .................................................................................................42
Figure 12 - Current Layout ..................................................................................................49
Figure 13 - Current Layout - Issues ....................................................................................50
Figure 14 - 5S Performances ...............................................................................................57
Figure 15 - 5S Audit Breakdown .........................................................................................58
Figure 16 - Kaizen Board ....................................................................................................60
Figure 17 – Spaghetti Diagram ..........................................................................................62
Figure 18 - Spaghetti Diagram Reworked .........................................................................63
Figure 19 - Improved Layout ..............................................................................................66
Figure 20 - Improved Layout - Process Flow .....................................................................67
Figure 21 - Improved Layout - Material Flow .....................................................................68
Figure 22 - Kanban Board Schematic ...............................................................................72
Figure 23 - Kanban Board Section 1 ..................................................................................72
Figure 24 - Kanban Board, Section 2 and 3 .....................................................................73
Figure 25 - Kanban Board ..................................................................................................75
List of Tables

Table 1 - 5S Audit................................................................................................................................................... 44
Table 2 - 5S Audit Results....................................................................................................................................... 54
Table 3 - Material Movement - Current Layout...................................................................................................... 65
Table 4 - Material Movement Reduction............................................................................................................... 65
Chapter 1: Introduction

Konarka Technologies is the world leader in organic photovoltaic technology. Currently it manufactures thin film OPV solar panels with a continuous roll-to-roll printing techniques and is operating in a former Polaroid manufacturing facility. With the adoption of a reliable continuous roll-to-roll Polaroid printing technology, all the coating processes are operating consistently. On the other hand, the finishing processes are still labor intensive and new to the company. The overall focus of this MEng project is on the improvement of the finishing operations that occur in the manufacturing facility of Konarka Technologies. This thesis report, however, focuses primarily on the development and implementation of a framework for continuous improvement culture, using tools such as the 5S methodology, Kaizen event and Kanban board.

1.1 Company Background

Konarka Technologies was started in 2001 by a group of scientists at the University of Massachusetts, Lowell. The team was led by Dr. Sukant Tripathy, an internationally renowned material scientist at UMASS, Dr. Alan Heeger, a Nobel Laureate in Chemistry, and Howard Berke, the current Executive Chairman of the company. The vision of the company is to “imagine a world free of carbon emissions, a world where even the poorest, most remote village has Internet access & electricity, and a world where power is safe, plentiful and truly green.” [1]

The organic photovoltaic technology developed by the founding members led to investments of over $170 million in startup capital and government research grants. The company currently has investment collaborations with companies such as Chevron, Total and Massachusetts Green energy Fund etc.

Konarka Technologies has a staff of over 100 people in 2 locations; Lowell, MA and New Bedford, MA. The R&D facilities and corporate office as located in Lowell, MA that also has a small-scale pilot manufacturing unit. In the first quarter of 2009, the company expanded to
a 250,000 sq. ft. manufacturing plant in New Bedford, MA. This facility was formerly a Polaroid plant with a low energy footprint and a continuous roll-to-roll manufacturing capability.

1.2 Markets
The Company’s product portfolio caters to 3 markets namely, Portable Power, Remote Power and Building Integrated Photo Voltacis (BIPV) applications. The Portable Power markets consist mainly of charging units for small portable devices such as mobile phones and laptops whereas the Remote Power markets use large sized panels to cover carports, awnings and tents which provide power to electric car charging ports, advertising boards etc. The company caters to these markets through two kinds of channels; direct sales and sales to other manufacturers who integrate these components into their products. The third market is the BIPV applications where transparent solar panels are sandwiched between sheets of glass and used as windows, retractable shades and greenhouses.

Konarka Technologies is now focusing on shifting towards manufacturing larger solar panels and hence is concentrating more on the BIPV market. This shift has led to the evolution of the product & manufacturing processes, which will be described in the later sections. [1]

1.3 Product: Power Plastic
Power plastic is thin, flexible and lightweight solar panel, which converts solar energy into electricity by passing sunlight through a specialized polymer material. This photo-reactive polymer material is the heart of OPV and is a Konarka’s patented technology. Konarka’s founder Alan Heeger won the Nobel Prize in 2000 for synthesizing this polymer. In addition to this polymer patent Konarka technology is also protected by over 350 patents in research and manufacturing of OPV panels. They are constantly improving the performance and have achieved a 8.3% efficiency (NREL certified).

Further layers included within Power Plastic are shown in Figure 1.
- Transparent Electrode - This forms as the cathode and acts as the source for electrons.
- Printed Active Materials – Photo reactive polymer
- Primary Electrode – This Silver layer acts as the anode, which collects the electrons.
- Substrate – This is a conductive layer on which the anode, cathode and active polymer are coated.
- Transparent Packaging: These layers, which are present on either side, help protect the organic polymer and other layers from degradation.

The different layers are coated on the substrate in lanes, which are about half inch wide. These lanes are connected to each other in a series connection. This type of printing gives it the striped appearance that is shown in Figure 2. The number of lanes in a product determines the voltage rating. Konarka typically produces 20 and 40 lane panels. These lanes are connected on each end to a buss bar, which is used for making external
connections. The roll is divided into 1-foot long sections during the coating process. Each section is called a module and multiple modules are connected in parallel to form a panel of the required size and current rating.

![Image of a 20 lane wide, 6 modules Product](image)

**Figure 2 - 20 Lane wide, 6 modules Product [1]**

Characteristics that determine Product Variety:

- Density of the primary electrode – opaque and grid silver patterns
- Transparency of the active polymer – BIPV applications require higher transparency levels
- Color of the active polymer – red, green, gray
- Packaging material - clear or matt finish encapsulation
- Length of the panel – can range from 1 module to 11 modules in length
- Width of the panel – can be either 20 lane or 40 lane wide, producing 8 or 16 volts respectively.

As mentioned in earlier sections, Konarka is currently focusing on BIPV application and hence the product is being altered to meet the specific demands of the market. Transparent polymer with slightly reduced efficiency is being produced specifically for the BIPV market. 3 polymer color options are offered to appeal to wide range of customers. The dimension of the product is also defined by the size of the window in which it would be integrated. The company is moving towards wider formats to accommodate large windows (60 lane product). Also the gap between modules is being eliminated to have seamless window
integrated panels. All these changes add complexity to the operations in terms of increased product range and modified manufacturing processes to accommodate these above mentioned changes. [1]

1.4 Photovoltaic Industry Overview
Photovoltaics are the fastest growing power-generation technology, with an average annual increase of 60% in power-generating capacity from 2004 to 2009 (up to 21 GW in power generated in 2009). With the sun producing approximately 1 kW/m² of energy on a sunny day, photovoltaic technology is a promising renewable energy source for the world’s energy needs. If all of the sun’s energy that strikes the earth is collected for one hour, it is enough to meet the world’s energy needs for one year. [2]

There are many different types of photovoltaic technologies, which are differentiated based on the material and manufacturing process, and these can be roughly divided into three types. The most common form of solar panels is the bulk crystalline silicon (c-Si, or just Si) solar cell. This technology capitalizes on the well-developed semiconductor industry that processes silicon ingots for use in semiconductor devices, and as such, the Si solar panel industry is also well developed. However, these cells are on the order of hundreds of micrometers thick, and due to the use of large quantities of Si material, the cost per panel is high. [3]

Consequently, the solar photovoltaic market is trending towards thin-film solar panels; although the efficiency may be slightly lower compared to Si solar cells, the material costs are significantly reduced. Thin-film solar panels can be deposited on glass or on flexible substrates, which allows for flexibility of the panels; Si solar panels can only be deposited onto rigid glass. Amorphous silicon (a-Si), copper indium gallium selenide (CIGS) and cadmium telluride (CdTe) are the three most common thin-film solar panel materials. Typically, these panels are manufactured using physical vapor deposition (PVD) or chemical vapor deposition (CVD) processes and may require vacuum conditions, and this increases the manufacturing costs and process complexity. These processes are also size-
limited and difficult to scale up. Moreover, CIGS and CdTe require toxic materials in its manufacturing processes and are toxic at the end of life, which presents an additional challenge in manufacturing and recycling the panels.

Because of the limitations of the above thin-film solar technologies, alternate inexpensive and non-toxic materials and large-scale manufacturing technologies are being explored. This category includes dye-sensitized solar cells and organic photovoltaics (OPVs). Because of the ability for the materials to be processed in a solution form, the solar panels can be manufactured using a roll-to-roll process by coating or printing the active materials on a flexible substrate. The solar conversion efficiency of these panels is quite low, but the organic solar panels have the lowest manufacturing complexity, and the organic materials used can have various colors and transparencies, allowing for greater customization in the solar panels.
During morning hours, Power Plastic begins collecting energy earlier. During midday hours, Power Plastic energy collection increases at a faster rate, due to our superior thermal coefficient. Power Plastic continues to collect energy later in the day, while others "flatline."

Moreover, the low-light electricity generation capacity in organic photovoltaics is much higher than in other technologies, allowing the panels to generate electricity even indoors or on cloudy days. Thus, the total energy collected by OPVs is comparable to other technologies, even though the solar conversion efficiency is lower (see Figure 3 above). Konarka Technologies is a world leader in the roll-to-roll manufacturing of organic photovoltaics.

The three metrics used to judge the performance of organic photovoltaic technology relative to other photovoltaics and forms of energy are cost, solar conversion efficiency and lifetime. Currently, Konarka is able to achieve an 8.3% efficiency and a 5-year lifetime in a laboratory setting. However, to increase its competitive advantage, these three
performance factors have to improve through improvements in R&D and manufacturing, as the efficiency is much lower compared to silicon cells that achieve a solar conversion efficiency of 18%. [4]

1.5 Manufacturing Processes

1.5.1 Manufacturing Facility
The manufacturing site is a 250,000 sq. ft. former Polaroid facility located in New Bedford, MA. Polaroid’s world leading film production plant gave Konarka great starting advantages. With some changes of Polaroid’s film producing facility, Konarka currently manufactures thin film OPV solar panels with its continuous roll-to-roll printing technique. This equipment allows Konarka to produce panels as wide as 60 inches.

1.5.2 Process Overview
Thin film OPV solar panels are made using an electronic printing technology that coat layers of material onto a transparent plastic sheet. A schematic layout of different layers of the product is shown in Figure 4.

The print head can have 10 lanes, 20 lanes, or 40 lanes slits for liquid coating onto the plastic web. The print head must be precisely adjusted for desired product architecture.
After the solar panels have been properly coated, it will go through a finishing process that encapsulates the solar panels between two plastic barriers. Therefore, the entire manufacturing process can be categorized into coating processes and finishing processes. With the adoption of continuous roll-to-roll printing technology, all the coating processes are and operating reliably. Currently, the finishing processes are still labor intensive and new to the company. This project focuses primarily on the finishing processes. More details about the whole manufacturing process are given in the following paragraphs.

1.5.3 Coating Processes

The coating processes consist of a total of 6 layers printed on top of the substrate:
• Laser Scoring of Transparent Electrode,
• Hole Blocking Layer,
• Semiconductor Layer,
• Hole Injections Layer,
• PEDOT Layer,
• Silver Electrode.

The coating process, which runs on a continuous web that is up to 4,000 feet long, can run 100 ft/min. This process takes place in a clean room environment, and the precision of different coating layers will affect the functionality of the solar panels. After silver electrode coating, the product will be transported to the finishing processes to turn it into a complete panel (Figure 5).

**Figure 5 - Coating Process.** This is a continuous web process with 5 separate roll coating stages

### 1.5.4 Finishing Processes

The bussing process is considered the start of finishing process. The finishing process schematic is shown in Figure 6.
After coating, the solar panels will be stored in a roll format waiting to be finished. In the initial bussing process, the panels will be unrolled, and then bussed with conductive side bus bars, and then rolled again for storage. Similarly, another proprietary process after bussing, will require rolling and unrolling of the panels.

Then, the panels are unrolled and cut or “sheeted” to desired length followed by top and bottom lamination with plastic barriers and adhesives. An automated laser-cutting machine cuts the laminated panels on three sides (front, left, and right). This automated machine currently cannot cut the fourth side because the laser cannot move fast enough to cut the ending edge as it moves. All four edges will have a 1-inch margin of laminated material for packaging. The sheeting, lamination, and 3 sides laser cut processes are then streamed together.

After lamination, the panels will be visually inspected for aesthetic defects such as lamination bubbles or adhesive clots. Then, the panels will be trimmed on the 4th edge via

---

Figure 6 - Finishing Processes. During Bussing and P.P. the product is in roll format and stored in nitrogen cabinets between the processes. After sheeting and lamination the product is in panel format and it is manually handle from process to process. The panels are kept on movable tables between processes.
laser cutter followed by laser ablations of two small holes in the lamination on two bus bars for electrical connection.

The panels are then baked in an oven a minimum of 3½ hours for curing the adhesives used in lamination. Finally, the solar panels will be tested for solar power absorption layout of the plant is shown in Fig. 7 and superimposed in orange and blue is a schematic of the process flow. The process flow is a representation of the subsequent processes that each panel has to go through from coating to solar testing. The process flow, however, does not represent the actual movement of material in the shop floor (material flow). Coating is a continuous process: the roll is unwound in the first tower and wound at the end after all the layers have been printed. On the other hand, the finishing operations (from bussing to solar testing) are separated and run in batches and work-in-progress material exists between each station. The material flow is not shown on Figure 7 and will be subject of analysis in section 4.6.4 and 5.4.1.
Figure 7 - Plant Layout and Processes Flow. In orange the Coating processes and in blue all the finishing processes. In this graph WIP inventory location and material movement is not shown.
Chapter 2: Problem Statement and Objectives

2.1 Problem Statement

After an observation period, the team has decided to focus on a continuous improvement framework that will help the company shift smoothly from low to high volume production in order to meet increasing market demand.

During the initial observation period, the team has identified problems and possible areas of improvement. Each problem has been analyzed in term of two key parameters: the probability of success in solving it and the value that the improvement could bring to the company. This process has caused us to rule out some of the issues and focus where our efforts are more needed (value addition) and where our capabilities and expertise can support us in accomplish the goals we have set, also given our time constraints. The value addition given to the company has been evaluated relative to the company and its start-up nature. We think that is more important to build a solid culture and bring concepts and ideas instead of focusing on a single technical problem. That is the reason that has led us to choose our areas of focus.

The primary focus of this thesis report is the implementation of a continuous improvement framework in the organization, with the ultimate goal to boost operational performance. The new thinking was introduced into the organization through the 5S methodology and the first Kaizen event at the company. The latter was focused on finishing floor layout improvements and on the implementation of a Kanban board used to track production.

2.2 Operations Management Issues

The overall MEng team addressed the three main issues:

- Improving material movement through the shop floor to reduce wastage and increase problem visibility.
• Establishing part tracking systems that can help managers and operators track work-in-process inventory and to have accurate predictability of lead times.
• Addressing the need for a more structured platform for carrying out improvement activities in which all the operators are involved and feel a sense of ownership towards the solutions.

**Material Flow**
During our observations and interviews with the operators the team identified the need for a more structured movement of materials around the shop floor, which would include rearranging the processes on the shop floor. This could lead to better problem visibility and increasing productivity. The objective of the company for this year is to ramp up their production be able to meet a potential growth in customer demand. Given this, they will need to rearrange their shop floor to respond to this growth. There needs to be more space allotted for work-in-process inventory in order to handle larger volumes. Also the lead times for their processes have to be documented and used to accurately predict delivery dates.

**Information Flow**
The information flow and part tracking systems that exist are manual and are labor intensive. There is need for automating these systems in order to have accurate and better control over the inventory and status of the production orders. Not having track of work-in-process inventory leads to time consuming and inefficient operations for the operators such as manual counting and looking for parts. Problems are hidden and not quantified because the current performances in term of yield and time are not recorded. These problems will worsen as volumes increase and there is a need for automated part tracking and to have to system accessible to the operators.

**Platform for Improvement Activities**
Many improvements activities are currently carried out in Konarka New Bedford. The plant is undergoing major rapid changes in the processes and the equipment. The improvements
projects are numerous, overlapped and assigned to different teams, this makes hard, especially for the operators, to follow the progress of each project. Despite good communication and regular meetings between the operators and the management, suggestions and issues raised by the operators are not tackled through standardized and structured procedures. Also, the system to evaluate the performance of the shop floor is not structured and quantifying improvements is not easy.

2.3 Technical Issues
Some of the technical issues that were investigated before defining our area of focus are detailed below:

Lamination
The lamination process is where the active solar panel is sandwiched between two protective polymer sheets and bonded with an adhesive. This process is where the company is experiencing most problems. The main issue is related to air bubbles that develop in the adhesive underneath the lamination material. The bubbles do not affect the performance of the panels but they are a cosmetic issue that needs to be solved especially since the company that sees potential growth in the window integrated solar panels. However, operators and management are already focused on this problem and they have the experience and the expertise to work on it. The team feels that the value addition it can bring is not substantial and we have decided not to focus on it.

Ablation
The ablation process, which involve using a laser to remove just one of the lamination layers above the ends of buss bars, is carried out manually, panel-by-panel by the operator. It is a time consuming process and it requires manual handling of the panels that should be minimized in order to prevent scratches. Ideally this process needs to be in-line with the lamination. This will solve the issue of handling, will speed up the process and there will be less work-in-process inventory since the whole operations from sheeting to ablation will be in-line. Despite the fact that designing an in-line ablation machine would be of a great value
for the company, we feel that given the time constraints of the project the probability of success is low. Also, there are more pressing issues in the shop floor that need to be tackled first.

**Solar Testing**

As with ablation this operation is manual and since 100% of the panels are tested it is a very slow process relative to all others, especially for big panels. Having an in-line solar test station would be the ideal situation but it does not seem the biggest concern right now, both for the company and for us. Also, in terms of future plans a test on each panel may not be necessary and we think there is much more work to do upstream before focusing on solar testing.

**2.4 Project Objectives**

Based on the problems identified during the observations phase the team has decided to focus on improving the operations of the company. Our goal is not just to leave the company with tools to improve its manufacturing operations, but to explain the process that has brought us to their development and to demonstrate their effectiveness, in order to ensure future continuous improvement activities.

In terms of the short-term objectives, the main focus has been to provide some tools necessary to boost the production and to build a reliable and efficient system able to meet the future demand, since the company is expecting to grow rapidly in the future. This represents in fact another challenge: at the time of our project the company was still not running at full capacity. It is worth reiterating that Konarka Technologies was focusing on improving its manufacturing process and production during this project was focused mainly on a series of test products. That said, the team worked on the improvement of the current system always taking into consideration the future plans and perspectives of the company. The production model that was in place was working well enough in the small scale, but it would not be able to keep up with the growth that Konarka Technologies expects.
The Team worked on improving the operations carried out on the shop floor from the top level (production scheduling) to the bottom level (layout organization, standardized procedures etc.) providing tools for continuous improvement. Accordingly, we have focused the team on the following topics:

- Improving Material Flow
- Improving Information Flow
- Creating a Platform for Continuous Improvement

2.4.1 Improving Material Flow:

2.4.1.1 Layout Improvement

The team identified flaws on the current layout of the plant. They were discussed with management, operators and technicians to provide a feasible implementation plan. Susheel Gogineni’s thesis provides a detailed description of this topic [7].

2.4.1.2. Material Flow Kaizen Event

Meeting II of the Kaizen event was useful to identify, with the operators, the issues of the current layout and to confirm our observations. The meeting played an important role in giving the Kaizen Team ownership of the adopted layout improvements solutions. During Meeting III the MEng team discussed the new layout and the implementation plan.

2.4.2 Improving Information Flow

2.4.2.1 Kaizen Board

This board represents the connection between the shop floor and management. Results and trends are shown to encourage the operators to point out issues and area of improvements, knowing that they will be prioritized and addressed by the management. For details about visual system implemented at Konarka New Bedford refer to Ming Gong’s thesis [6].
2.4.2.2 Kanban Board

A Kanban board was built to display basic production information such as raw material, work-in-process and finished goods inventory’s exact location and quantity to the operators on the floor to have a visual feedback on the current manufacturing progress. Information about the availability of work-in-process (WIP) inventory at each process gives the operator a visual warning that certain specific manufacturing process is becoming the bottleneck process. Physical information boards can work very well in communicating information on the shop floor with total involvement of all the operators and act as a check on the electronic system and vice versa. This project is discussed in details in Ming Gong’s thesis [6].

2.4.2.3 Production Scheduling Tool

Currently, the company lacks an accurate planning tool that can predict lead times at each operating step and the delivery time to customer. Therefore, the team believed that developing a production-scheduling tool will greatly help improve operations and provide synergies with the other improvement activities we have implemented. For details and results relative to the production-scheduling tool, please refer to Jason Chow [5] and Susheel Gogineni’s [7] thesis.

2.4.2.4 Tracking System and Operator Interface

The team felt the necessity for the company of an automated system to keep track of inventory, work-in-process and finished goods and has focused its effort on the developing of a tracking system, a database to store the information and a user interface for the operators. These aspects of the project are treated in details refer in Jason Chow’s and Ming Gong’s thesis [5] [6].

2.4.2.5 Data Analysis

The team structured the database that will be used to collect and store the information when the tracking system will be in place. Also, statistical data analysis methods were tested on existing data (Jason Chow’s thesis [5]).
2.4.3 Creating a Platform for Continuous Improvement

2.4.3.1 5S Methodology and Framework

The methodology has been introduced to the company at all levels as the principal instrument to identify areas of focus and to keep track of the improvement. The focus has especially been in involving the operators in the whole process showing, at the same time, its value to the management and providing them with tool to manage it.

2.4.3.2 Kaizen Event

The first Kaizen event at Konarka Technologies took place. It differs from continuous improvements because it has been characterized by a short and intense effort and it was focused to a specific area and managed to resolution. It required effort and commitment from the participants and the organizers. The event was focused on layout improvement and the introduction of the 5S methodology. Also, the operators were trained for the utilization of the Kanban board during the last meeting.
2.5 Thesis Focus
This thesis reports on the 5S methodology and the Kaizen event: tools used to create the platform for continuous improvement at Konarka Technologies. The Kanban board, directly linked to these projects, is briefly discussed (Details can be found in Gong’s work [6]). The improved material flow, outcome of the Kaizen event, is examined in its major point (Details in Gogineni’s thesis [7]). Finally the functioning of the Kanban board, presented in the Kaizen event, is explained (See Gong’s thesis [6] for specifics).
Chapter 3: Literature Review

3.1 Lean Manufacturing

Lean manufacturing is a production practice that increases the effectiveness of the company's resources for value creation for the end customer. In other words, this practice increases or maintains the value of its product to the company's customer while it lowers manufacturing cost. The lean concept is centered on preserving value while reducing work and resource use.

The lean philosophy is originally derived from the Toyota Production System (TPS) [8]. TPS is renowned for its waste reduction practices and achievements that also improve overall customer value. The success of Toyota relied heavily on its TPS philosophy and concepts.

Lean practices include production flow improvement and are centered around optimization of the use of resources, whether time or capital.

The two major lean concepts are smoothing work flow (Just in Time) and human oriented autonomination (smart automation which focuses on what humans do best and empower humans with automated machines/systems). Currently, Konarka, as a startup company, still lacks a robust structured information gathering and sharing system. Therefore, our work at the company focuses mainly on smoothing workflow, consolidating information sharing, and other operation improvements. As such, the two lean implementations we seek to achieve are waste reduction and Kaizen continuous improvement.

3.1.1 Waste Reduction

In lean manufacturing, waste is a loose term that describes any ineffective usage of resources. All unnecessary materials, resources, and non-value added work are considered waste. Specifically, there are product transport & human movement waste, inventory &
inconsistent flow, over-processing waste, and defect wastes [9]. In the following literature review, applicable theory and examples will be discussed in details.

3.1.1.1 Product Transport & Human Movement Waste

Product transport & human movement waste are mostly productive time and resources wasted on non-value added work. Usually, this can be reduced via improving the process flow, factory layout, and possibly the machines. Historically, perhaps the most famous implementation of this is Henry Ford’s moving assembly line [10].

Henry Ford saw workers in automobile industry waste a lot of time walking back and forth, getting different tools and parts. To reduce all of these movement wastes, Ford introduced the moving assembly line that drastically reduced people’s movement within the factory. The assembly line moved the automobile smoothly in an in-line assembly plant where all the automobile parts were assembled onto the car at different workstations. Thus, workers didn’t have to move at all, and each worker just needed to handle a specific simple assembly task with a designated tool. This revolutionary manufacturing idea soon has spread throughout the world, and fundamentally has boosted manufacturing capacity (especially automobile) to an unprecedented level.

Similarly, the factory layout is crucial to product transport and human movement waste reduction. Common practices include Value Stream Mapping or Process Stream Mapping, which originated from Toyota [9]. At Toyota, it is also known as “material and information flow system”. The five steps of this Value Stream Mapping implementation are followed:

1. Identify the product or service
2. Understand and Identify the current layout, manufacturing steps, process delays, and information flows of the factory
3. Evaluate the current process flow map and identify possible areas of improvement
4. Design a future layout and process stream map
5. Implement the improvements, get feedback and adjust accordingly
Ideally, Value Stream Mapping also identifies the value-added processes. Thus, operational managers can minimize the non-value added processes and focuses on the big value added processes. In Konarka, however, the target products are solar panels that are coated in a roll-to-roll manufacturing process; therefore, our main objective would be to organize and smooth production flow to reduce movement waste. An organized layout will facilitate material movement and minimize worker idleness due to lost parts or unorganized material handling.

3.1.1.2 Inventory & Inconsistent Flow

Three main reasons for keeping inventory are: to buffer against lead time, to offset uncertainties, and to take advantage of economy of scale (bulk transport). Work-in-process (WIP) inventory is created to offset different process variations so that it can smooth out the production line. On the other hand, finished inventory work is a buffer against production lead-time. There is raw material inventory, WIP inventory, and finished goods inventory. Focusing on the finishing side of Konarka’s manufacturing facility, we will look closely at managing WIP inventory.

Just in Time (JIT) production is a practice of reducing WIP inventory with continuous and smooth production processes. This will require detailed process time study and scheduling improvements. It is also essential to make the fluctuating or problematic process more apparent so that people can identify the problem as soon as possible.

Barcode or RFID identifications are also commonly used to track the work-in-process inventory throughout the production line. An accompanying database can systematically track the exact quantity, quality, and location of the WIP inventory. On the shop floor, it may also be easier to work with a more physical form of inventory tracking such as a physical information board.

3.1.1.3 Over-processing Waste

Over-processing waste refers to the ineffective manufacturing process or design used in the facility. Designed for Manufacturing (DFM) and machine automation practices (e.g. laser
trimming and ablation machine) can be implemented to reduce such over-processing waste. These improvements, however, require a longer development phase and fall outside of the scope of our project.

3.1.1.4 Defects Waste
Solar panel defects are a major manufacturing problem at Konarka. Many panels with low efficiency and aesthetic defects such as bubbles or adhesive overflow would become scrap, later recycled for silver. Removing these defective panels at early stage of the process also avoid over-processing waste. It is essential for the company to establish and maintain a robust yield tracking that facilitate production yield improvement. Currently, most defects occur at the coating and lamination processes, and permanent employees are already working on them.

3.1.2 Kaizen
Kaizen is a Japanese word meaning “improvement”, and is commonly used to refer to continuous improvement [11]. It was developed by Japanese businesses during the restoration period after the World War II. When applied in manufacturing, kaizen signifies companywide activities that continuously improve the manufacturing process and systems involving all employees.

Kaizen is usually implemented as a standardized and periodic activity within the company to achieve lean manufacturing. It seeks to implement the scientific method of hypothesis, testing, learning, and improvement to every corner of the factory with involvement of all of its workforce. In some companies such as Toyota, there are teams that are formed solely for managing kaizen activities within the company. A standardized cycle of kaizen activity may include the following.

1. Standardize operations and systems
2. Measure operation performance
3. Set performance goal
4. Obtain feedback from all workers; innovate ideas
5. Standardize new systems
6. Repeat

As a continuous improvement model, kaizen seeks to find the root causes of problems and unceasingly improve operations. The active involvement of all the employees have profound benefits such as improved teamwork, morale, personal discipline, and voice for suggestions. Such company cultures usually contribute to a company's success.

3.2 5S Methodology

The 5S methodology ([12], [13], [14], [15], [16]) is a tool used to improve operational performance. It involves the organization at all the level and instills ownership of the process in each employees. The procedure is an effective way used in several companies to implement a continuous improvement culture and quantify its result. The key step and the most challenging one is to establish, especially in the operator (the closest person to the processes) a commitment to improve. At this point the improvement can actually begin, this will lead to gain visible wins that will increase the motivation of the team, giving them a sense of ownership of the whole improvement process and increasing their commitment to the new philosophy (Figure 9).

![Continuous Improvement Cycle](image)

**Figure 9 - Continuous Improvement Cycle [15]**
The 5S are 5 steps that have to be followed by the operator and management to achieve the set goals. The 5S's originally correspond to the Japanese words: seiri, seiton, seiso, seiketsu and shitsuke, the English equivalent of which are: sort, straighten, shine, standardize, sustain (Figure 10).

The first 3S will lead to visible and practical results and are led by the shop floor. However, these steps have to be supported by the management which objective is to provide standardize procedures and sustainability for the continuous improvement.

**Figure 10 - 5S Steps. First three S are Shop Floor led while the last two are led by the management [15]**

**Sort:** The first step involves identify all the unnecessary items (tools, parts, work-in-process inventory) in the work area and then if not needed remove them. It is suggested to apply to 48-hour rule in order to evaluate whether an item is necessary or not. If something is going to be used in the following 48 hours it belongs there, otherwise must be disposed. It is important during implementation of sorting to look at everything: material, supplies,
paperwork and not just at the core equipment. Also, in order for the procedure to be effective is has to be carried out by a team and not a single operator. The sorting stage is a big opportunity to reorganize the shop floor and to prioritize tools as per requirement and keeping them in easily accessible places.

**Set in Order:** The next step right after Sorting is Straight or Set In Order. Everything is in place and there is a place for everything is the idea that has to be followed while thinking about this step. The workplace should be arranged to ease the work carried out there and to increase the flow of work. Everything has a clearly designed space and it is kept in that space. The goal is to promote efficient workflow and decrease time wasted to look for what is needed; operators should know where things are at a glance. The Straighten step helps to make material and tools accessible and to make

**Shine:** The aim of the Shine step is to maintain cleanliness as part of the daily work. Cleaning involved all the workspaces and equipment. They should be kept clean and organized through regular daily actions. Every operator is responsible for keeping the work area clean and orderly and a coordinator for the cleaning operations is clearly defined. Implementing Shine makes cleaning and inspection easier and makes errors stand out immediately.

**Standardize:** Standardize begins the cultural change. After successfully working through the first three steps, the physical changes made should become the standard for that work area. This step has to be led by the management that will provide documented standard operating procedures, 5S training and regular meetings.

**Sustain:** The final step is to maintain the benefits attained through the 5S changes. This could be the hardest step to implement. Focus has to be maintained on the new procedures in order not to allow falling back into the old ways. Sustain is also an opportunity to seek for improvement, constantly reviewing the procedure and looking for chances for further development.
3.2.1 Objectives of the 5S Methodology

In order to successfully implement the 5S methodology, as most of the tools of lean manufacturing, it is important that all the people involved understand its goals and objectives. It has to be clear that the adoption is not and end itself.

**Improve Productivity:**

Reducing time wasted to look for tools and material locating each piece of equipment in a defined location and getting rid of everything that is not necessary will result in an increased productivity of the plant.

**Improve Plant Maintenance:**

Through the 5S each operator will feel ownership of part of the plant. He will be responsible for keeping it tidy and clean and will notice potential problems before they spread out in the organization.

**Improve Quality:**

Lack of cleanliness and a disorganized environment can have a serious impact on the quality of the product manufactured in the facility. Also, it may impact the image of the company from the perspective of either customers or investors, whereas a well-organized facility sends a message of a well-organized company. In addition to that, reduced movement of material and standardized procedures help in keeping the quality of the product high.

**Improve Safety:**

Through 5S it is possible to improve also Safety. Layout improvements, standardized procedures in place, clear pathways can significantly contribute to increase the safety of the workplace.
Chapter 4: Methodology

4.1 Improvements

The people at Konarka, from the management to the operations, were involved at each stage of the process, and their feedback was evaluated in order to direct the efforts in the right way and provide the organization the maximum added value. In this project, the author always looked for the right balance between optimal solution and implementation, working on the project while always focusing on the final objective: bringing the lean and continuous improvement culture in the organization and reducing waste in all its forms.

This thesis focuses primarily on the implementation of a continuous improvement framework, and reports on the development and deployment of tools to implement the 5S methodology, such as 5S Audit, Kaizen board and Kanban board. Also, it discusses the Kaizen event that led to the improved layout and its implementation plan.

4.2 Kaizen for Flow Improvement

In organizing the first kaizen event at Konarka Technologies the author had to face the additional challenge of introducing the Kaizen team to the culture, the goals and the terminology of continuous improvement. The event was structured in two meetings plus an implementation stage to follow. The first was an introduction to these topics and a way to encourage a different approach to issues in the shop floor. The second meeting was seeking more interaction with the operators. Its purpose was to discuss ideas openly but in a structured manner, and the role of the team was to provide structure and guide the Kaizen Team’s efforts. The third and final meeting was dedicated to the implementation stage. Operators were trained to use the board and the new layout was explained to them.

4.2.1 The Kaizen Event

A Kaizen event is a focused effort to make the leap. It differs from continuous improvements because a short and an intense effort characterize it; focusing in a specific
area or process, it is managed to high resolution. It requires efforts and commitment from
the participants and the organizers. [17]

4.2.2 The Kaizen Team
Operators of the shop floor, the operations manager, the head of the operators and
engineers formed the Team. The event was strongly supported by the top management.

4.2.3 Meeting I
During Meeting I, the 5S methodology was introduced, and all its steps explained, focusing
on the goals of the process in order to involve the operators as much as possible. After the
introductory part we gave an overview of our projects: the information board [6] and the
possibilities of improvement for the layout [7].

The first step of the continuous improvement cycle is to build the culture and the
commitment to improve. In order to do that, Meeting I was dedicated to explain the goals of
such system and set the future path. The idea was to demonstrate the operators and the
management how powerful a tool such as the 5S methodology can be and to show the
importance of discussion. The author presented the concept of a Kaizen information board
(described below) to show how it could help the operators and make their work easier. Our
goal was to involve them and give them ownership of the project.

At the end of the meeting, the team was satisfied with the results. Yet, there was room for
improvement especially in finding a balance among people that tend to be too talkative and
people that are less. In order to solve this issue it was decided to propose a more
structured and guided discussion for Meeting II. This helped to increase participation and
to give everybody an opportunity to express concerns and solve them.

4.2.4 Meeting II
Meeting II was the core of the Kaizen event. The Kaizen Team was given the opportunity to
think about the content of the Meeting I and assimilate the information given. The focus of
this event was on three main topics: the 5S audit, layout improvements and the Kaizen
information board. The discussion started from the team’s suggestions and ideas on the three topics, getting back feedback from the Kaizen Team. The purpose was to involve the operators in the discussion and to give them ownership of the projects. The intention is that seeing the solution implemented will spread the continuous improvement culture and let the improvement cycle continue.

The 5S audit was fully explained to the operators as criteria of evaluation of the performance of the shop floor and the whole organization. Tangible examples of good and bad situations were provided to lead the Kaizen team to discuss how to improve the audit itself. Racks and machines never utilized in the shop floor were used to give an idea of unneeded items. Labeled tools, such as scissors and tape, were used as good example for sorting.

Problems with the current layout were pointed out and again discussed with the Kaizen Team. Our solutions were presented and reviewed according to the Kaizen Team’s feedback. Finally we showed our concept of and information board and demonstrated its impact on the shop floor.

4.2.5 Meeting III
The adopted solutions were presented to the Kaizen Team during the third meeting.

First of all, the Team was guided through the new layout and the reasoning beyond it. The improved layout was the result of the operators’ feedback; we made clear that our efforts were directed to solve the issues that they pointed out, individually during our informal interviews and as a group during Meeting II. The layout was explained, first on a board and then directly on the shop floor walking the operators through the new material flows.

The Kaizen board was presented during the meeting. The red tagging station and the section dedicated to operators’ suggestion were emphasized as the place where the operators can have their say about the situation on the shop floor. It was made clear the management’s responsibility is to review these sections, identify priorities and tackle
issues. It is essential that all the ideas are evaluated and the solution effectively implemented in order to build and sustain the continuous improvement culture. Also, it is important to keep track of the various improvement projects to guarantee a full involvement of the operators: this is the purpose of the third section of the board.

Lastly, the operators were trained in the utilization of the Kanban board. We presented the Kanban board simulating the path of each panel step by step through all the processes from coating to shipping. This was a useful exercise and an opportunity for the operators to raise doubts or concerns. It was explained that the purpose of the board is to simplify their work and to facilitate the communication in the shop floor, and that the manual work that has to be done on the board is necessary.

The strong participation of the Kaizen Team in this meeting was one measure of the success of the projects. Bringing the meeting in the shop floor was a good idea to increase the involvement of the Kaizen team. It was easier to demonstrate our solutions and to show directly how they are going to affect the daily job carried out in the shop floor. In addition, seeing all the projects physically implemented, increased the attention and the curiosity of the operators.

4.3 5S Audit
The 5S methodology is one of the various ways to evaluate the performance of an organization. The author proposed an audit [18] with questions divided into the 5 categories: Sort, Straighten, Shine, Standardize, Sustain (Table 1). This division makes the problems more apparent and it is easier to identify areas where intervention is more needed.

Sort: The audit inquires the unneeded equipment, material and inventory present in the shop floor and procedures established to remove them (red tagging). The goal is to reduce waste and idling time of the operators and it is achieved through relocating equipment that is not unnecessary or not immediately needed.
A red tagging system was developed to standardize the identification and marking of unneeded items on the shop floor. A Red Tags section (Figure 11) was created in the Kaizen board to make the tags easily available. It includes a tag holders and detailed instructions for the utilization of the tags.

**Figure 11 - Red Tag Station, Included in the Kaizen Board. The right section is an explanation of the Red Tags while on the left Red Tags are kept**

**Set in Order:** The section's goal is to inspect whether tools and material in use have a designated location and to inquire if they are placed in such location. It looks at labeling of WIP and equipment location with the goal of achieving straightforward identification of equipment and material on the shop floor.
**Shine:** Cleaning involves not just the workstations, but also paperwork and notice boards’ organization. This section wants to address issues in the cleaning operations and clarify whether they depend on lack of coordination and procedures.

**Standardize:** The questions in this section have the goal of preventing the area from having abnormal operating condition. The “normal” operating conditions have to be set by the management and they must be updated regularly. The operators have to be trained, have to fully understand the 5S methodology and have clear goals.

**Sustain:** The last section looks at how the organization self-disciplines itself to follow the rules that have been set. This stage implies involvement of the personnel and regular revisions of the procedures in place.

During Meeting II, the audit was used to explain the 5S methodology, applying abstract concepts to an environment the operators were familiar with: their shop floor. In the future, the audit will be filled on regular basis by the head of the operators to keep track of the performances of the organization and compare them with the goals set. The results of the audit will be posted on the Kanban board together with the status of the Kaizen activities. Details of the Kanban board will be discussed in section 5.5 and in Gong’s thesis [6].
Table 1 - 5S Audit. The proposed Audit to evaluate the performance of the organization.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>CRITERIA</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sort</td>
<td>Distinguish between what is needed and not needed</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td></td>
<td>Procedures are established to identify unnecessary items</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unneeded equipment, storage, furniture, etc. is not present on the shop floor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information or items on bulletin boards, etc. are up-to-date and clear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unneeded inventory, supplies, parts, or materials is not present on the shop floor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aisles, stairways, corners etc. are free of items</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unnecessary items on the shop floor are tagged clearly</td>
<td></td>
</tr>
<tr>
<td>Sort Through &amp; Discard Unused Items</td>
<td>A place for everything and everything in its place</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td></td>
<td>All tools and material have a specific location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All tools and material are placed in the designated location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work in progress inventory has a specific location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work in progress inventory is placed in the designated location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work in progress inventory quantities are marked and accurate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work surfaces and equipment locations are identified and labeled</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The maximum and minimum allowable quantities are indicated on storage racks</td>
<td></td>
</tr>
<tr>
<td>Straighten / Set in Order</td>
<td>Routine discipline maintaining a clean and organized workplace</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td></td>
<td>Equipment, computers, work surfaces, and storage areas are clean</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Garbage and scrap are collected and disposed correctly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paperwork is filed daily</td>
<td></td>
</tr>
<tr>
<td></td>
<td>There is a person taking responsibility for coordinating cleaning operations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Floor is swept and equipment is cleaned regularly</td>
<td></td>
</tr>
<tr>
<td>Cleaning is a Method of Inspection, Look for Hidden Defects</td>
<td>Specific cleaning and organizing tasks have been developed and assigned for the work area</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td></td>
<td>Equipment, computers, work surfaces, and storage areas are clean</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Staff is trained and fully understands 5S procedures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5S standards are clearly displayed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual management tools identify if work is complete</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improvement memos are regularly generated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Everyone is involved in the improvement activities</td>
<td></td>
</tr>
<tr>
<td>Standardize</td>
<td>Stick to the rules (self-discipline)</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td></td>
<td>Standardized operating procedures (cleaning and work) are followed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5S documentation and instructions are current</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5S audits occur regularly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procedures are up-to-date and regularly reviewed</td>
<td></td>
</tr>
</tbody>
</table>
4.4 Kaizen Board

The team installed a Kaizen board on the shop floor that displays the kaizen activities, suggestions, quarterly targets and the monthly 5S audit. It is important to have a visible documentation of the improvements in a way that is accessible to everyone involved in the Kaizen team. This board is a platform to display the improvements achieved by previous events and to voice ideas for future events. This board acts as a communication medium among the operators involved in the kaizen activities, process engineers and any other stakeholders in the production and operations regarding the potential problem that exists on the shop floor. It will have information about possible improvements, ongoing kaizen initiatives and the progress of the company in the 5S’s. [19]

The Kaizen Board is divided into 3 sections – Kaizen events section which displays ongoing and future events; 5S audit section which displays the results of the monthly audit; Quarterly targets section which defines short term production goals that helps operators think about possible improvements. All these sections would help sustain the culture and improve participation by the operators on the shop floor.

4.5 Layout Improvement

A proposed layout (detailed in Gogineni’s thesis [7]) was presented to the top management, at first and then during the Kaizen event as a base for discussion. The final proposed layout is the result of a series of iterative stages that have involved the organization at all levels.

Improvements were quantified in term of reduction of movement of material, optimization of material flow and increased visual control. Moving material is an unnecessary operation that lean manufacturing seeks to remove waste; also, it is not recommendable in the particular case of Konarka Technologies because handling of the panels can result in scratches or permanent damage due to bending. The team provided the company with detailed plan for implementing the proposed solutions in different stages.
Sections 4.5.1 through 4.5.3 I will explain the methodology used to study the current layout including feedback from Konarka’s personnel. The proposed layout and the improvements will be discussed in Chapter 5.

4.5.1 Current Layout
There are 7 steps involved in the finishing process that follows the coating process. These processes are spread across 2 large warehouse rooms. The finished goods inventory, packaging and shipping is also done in these 2 rooms. Of the 7 steps involved in the finishing stage, the product is in a roll form during the first 3 operations and then gets sheeted into individual panels which make their way through the remaining value-adding steps. The rolls are stored in pin racks and are handled using modified forklifts. The handling of individual panels is more difficult than the rolls owing to the wide product mix manufactured by Konarka. The longer panels (e.g., 11 module long and 40 lane wide, 12ft x 3ft) are stored on flat top metal tables covered with scratch proofing material and are handled manually by a team of technicians. Also un laminated OPVs degrade when exposed to oxygen hence must be stored in Nitrogen cabinets before they are encapsulated in a barrier material during one of the finishing steps.

The study of the layout can be divided in three subsequent stages: Observation and Experimentation, Mapping and Issues Identification. These stages will be further explained in section 4.5.2 and 4.5.3.

4.5.2 Observation and Experimentation
During the first stage we observed all the various steps of the finishing process. The team developed a deep understanding of the product and the processes carried out in Konarka New Bedford. Conversations with management and operators helped us in this process, but we realized that observing was not enough to properly identifying the issues and provide thoughtful recommendation. In order to overcome this challenge, the finishing operations were studied even closer: the team members worked on the shop floor for two weeks looking at the operations from a new perspective. Working directly in all the finishing
processes, we had the opportunity to zoom in from the big picture to every detail of the shop floor allowing us to see the small details that even the top management may miss. Working shoulder-to-shoulder with the operators, the team collected enough information and credibility to identify area of improvements and provide recommendations.

4.5.3 Mapping
The next stage of the layout study was the update of the layout drawing. The finishing area during the past months underwent a series of changes to keep up with the continuous modification in the finishing processes. However, the plant layout was not updated to reflect these changes. The author work consisted in identifying, measuring and labeling every machine, rack and cabinet in the shop floor and update the layout drawing. The update file was useful to study the material flow and to visualize the proposed improvement. It was used the drawing during the Kaizen event to draw on it. With the cooperation of the operators we were able to make a spaghetti diagram to display the movement of material. The spaghetti diagram will be explained in Chapter 5.

4.5.4 Issue Identification
The final stage of the study of the current layout is the identification of its flaws in order to provide the company some suggestions for improvement.

The main problem we identified was the lack of visual control of the whole process. The finishing process is in fact, divided into two rooms. In one of those, all the operations including ablation are carried out. In the other one, solar testing and storage of final products takes place. Not having all the processes in one room constitutes a serious hindrance to visual control, communication and information sharing in the shop floor. Another factor to consider is that finished goods and products in and out of the solar testing are stored in the same room. The fact that there is not a specific area designated for finished goods constitutes a problem.

All work-in-process inventory that has to be laminated is temporarily stored in nitrogen cabinet. After our observations, we realized that there is no procedure in place that
indicates specifically in which cabinet a certain roll should be stored. The lack of a procedure creates confusion among the operators, and a considerable amount of time is wasted looking for each roll. Furthermore, the location of the cabinets is not optimized. We believe that the rationale beyond their placement is related to ease of installation instead of optimization of the process.

Another issue with the current layout and the general organization of the shop floor is that there is no designated location to hold laminated panels (At this point the product is not in roll form. Instead, it is enclosed in a barrier that prevents oxidation. Laminated panels do not have to be stored in nitrogen). Also, panels are stored and moved in moving tables, which makes even harder to identify a proper location for each product in and out of each process.

The finishing area floor layout was mapped. Based on the measurement and documentation of the available resources, the author was able to create an AutoCAD drawing of the layout. This was color coded to distinguish between machines, inventory and administrative equipment. The finishing process is spread across 2 rooms. Most of the operations are done in the larger room and the smaller room is mainly used for solar testing and shipping. The red dotted line represents a clean room environment, which is essential during some of the processing stages. The author also marked out all the unused machines on the layout so that we can clearly identify issues (Figure 12 and 13).
Figure 12 - Current Layout. No specific location is designated for WIP inventory. Tables for movement and cutting of panels are dispersed in the shop floor as well as nitrogen cabinets. The dotted red line identifies the clean room.
Figure 13 - Current Layout. Areas where issues were identified are marked on the drawing of the current layout shown in Figure 11.
4.6 Kanban Board

The team has designed and implemented a Kanban board to display production information. At this stage, we thought that the best way to proceed for Konarka is a physical information board. At this level of production, a physical board is still manageable and it will increase the participation and the involvement of the operators. The team has provided a plan for a future implementation of a digital board in the future.

Currently there is no system in place that provides information about the number or the location of panels at each processing step. It is important to display basic production information like “raw material”, “work-in-process” and “finished goods” inventory to the operators and even schedules on the floor to have a visual feedback on the current situation. In addition, boards that display daily targets to be met by the operators could improve productivity by motivating them to achieve the set goal. Information about the availability of raw material at each process gives the operator a visual warning when he is about to run out of certain product. These small cues can help smooth the system operation. Fundamentally all this information should be available in electronic form but physical information boards can work very well in communicating information on the shop floor and act as a check on the electronic system (which is still under development (see Chow's thesis [5]).

The board was discussed with the Operations Manager and the IT person at Konarka as a tool to link the production with a new production database system being developed (see Chow [5]). Afterwards it went through another refining stage during the Kaizen event with the operators. The board has the particular characteristic to be useful both in the shop floor and the management. We emphasized this aspect to maximize collaborations and involvement of both sides. More detailed information about the information board and other visual systems can be found in Ming Gong’s work [6].
4.7 Tracking System

The first stage of this project was to develop a tracking system scheme, which illustrates the flow of material and where barcodes are printed and read. We have discussed the feasibility of this system with the stakeholders in this project, and both our group and the stakeholders feel that the implementation of this system will allow Konarka to greatly reduce its operating costs. This is done by reducing unnecessary inventory through the tracking system and also determining which processes require immediate attention to increase the yield rates. In this phase, we identified the need of the company and sought a tradeoff between an ideal system and a system implementable in the short term yet open to future upgrades. The first barcode printer, for example, was located at the bussing step, despite the fact that it would ideally be better at the end of the coating stage. However, the typical production rates for the coater made initial implementation of an in-line printer difficult. As a result, we decided that the ideal location was on the bussing machine that is separated from the other processes, is easily accessible and can start and stop without major problems. While thinking about the schemes, we had the following things in mind: The economic constraints, existing system around the equipment, and minimization of the purchase of new equipment. Detailed information on the data analysis and operator interface design can be found in Jason Chow’s thesis [5].

4.8 Production Scheduling Tool

In our pursuit of reducing waste on the shop floor, mainly in terms of the ongoing inventory, we worked on improving the shop floor layout and established systems for part tracking. To truly benefit from these improvements, we needed to plan production effectively. Improper production planning can make even the most efficient layout to fail. Also the data from the tracking systems needed to be well utilized to better plan production. Currently, the company lacks a planning tool that can predict lead times at each operating step and the delivery time to customer. Therefore we believe that developing a production-scheduling tool will greatly help improve operations and provide synergies with the other improvement activities we have implemented. The production scheduling
tool allows the production scheduler to determine the number of hours required to process a given number of goods, operators, machines and hours to allocate to each process, allowing for optimal resource allocation. For details and results relative to the production-scheduling tool, please refer to Jason Chow [5] and Susheel Gogineni [7] thesis.
Chapter 5: Results

5.1 5S Audit

Results of the data collected from the audit are shown in Table 2. The last column is the average score for each question. It is important to consider that the audit was filled after one day of training about the 5S, definitely not enough to change people’s mindset. These are data that must be analyzed carefully, and should not be considered representative of the absolute performance of the company. However, they are enlightening about operators’ current beliefs.

Table 2 - 5S Audit Results. Details of the averaged results of the Audit filled during the Kaizen event.

<table>
<thead>
<tr>
<th>CATEGORY / CRITERIA</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sort</strong> Distinguish between what is needed and not needed</td>
<td></td>
</tr>
<tr>
<td>Procedures are established to identify unnecessary items</td>
<td>2.6</td>
</tr>
<tr>
<td>Unneeded equipment, storage, furniture, etc. is not present on the shop floor</td>
<td>3.3</td>
</tr>
<tr>
<td>Information or items on bulletin boards, etc. are up-to-date and clear</td>
<td>3.7</td>
</tr>
<tr>
<td>Unneeded inventory, supplies, parts, or materials is not present on the shop floor</td>
<td>2.9</td>
</tr>
<tr>
<td>Aisles, stairways, corners etc. are free of items</td>
<td>3.6</td>
</tr>
<tr>
<td>Unnecessary items on the shop floor are tagged clearly</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Sort Through &amp; Discard Unused Items</strong></td>
<td></td>
</tr>
<tr>
<td>A place for everything and everything in its place</td>
<td></td>
</tr>
<tr>
<td>All tools and material have a specific location</td>
<td>1.7</td>
</tr>
<tr>
<td>All tools and material are placed in the designated location</td>
<td>1.4</td>
</tr>
<tr>
<td>Work in progress inventory has a specific location</td>
<td>3.5</td>
</tr>
<tr>
<td>Work in progress inventory is placed in the designated location</td>
<td>3.5</td>
</tr>
<tr>
<td>Work in progress inventory quantities are marked and accurate</td>
<td>2.8</td>
</tr>
<tr>
<td>Work surfaces and equipment locations are identified and labeled</td>
<td>2.1</td>
</tr>
<tr>
<td>The maximum and minimum allowable quantities are indicated on storage racks</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Shine</strong> Routine discipline maintaining a clean and organized workplace</td>
<td></td>
</tr>
<tr>
<td>Equipment, computers, work surfaces, and storage areas are clean</td>
<td>2.4</td>
</tr>
<tr>
<td>Garbage and scrap are collected and disposed correctly</td>
<td>3.1</td>
</tr>
<tr>
<td>Paperwork is filed daily</td>
<td>3.2</td>
</tr>
<tr>
<td>There is a person taking responsibility for coordinating cleaning operations</td>
<td>1.0</td>
</tr>
<tr>
<td>Floor is swept and equipment is cleaned regularly</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Standardize</strong> Preventing the area from having abnormal operating conditions</td>
<td></td>
</tr>
<tr>
<td>Specific cleaning and organizing tasks have been developed and assigned for the work area</td>
<td>1.6</td>
</tr>
<tr>
<td>Staff is trained and fully understands 5S procedures</td>
<td>1.1</td>
</tr>
<tr>
<td>5S standards are clearly displayed</td>
<td>1.1</td>
</tr>
<tr>
<td>Visual management tools identify if work is complete</td>
<td>1.4</td>
</tr>
<tr>
<td>Improvement memos are regularly generated</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Sustain</strong> Stick to the rules (self-discipline)</td>
<td></td>
</tr>
<tr>
<td>Everyone is involved in the improvement activities</td>
<td>1.4</td>
</tr>
<tr>
<td>Standardized operating procedures (cleaning and work) are followed</td>
<td>2.9</td>
</tr>
<tr>
<td>5S documentation and instructions are current</td>
<td>1.3</td>
</tr>
<tr>
<td>5S audits occur regularly</td>
<td>0.9</td>
</tr>
<tr>
<td>Procedures are up-to-date and regularly reviewed</td>
<td>2.4</td>
</tr>
</tbody>
</table>
From the results it is possible to draw the following conclusion:

**Sorting** is not a problem in people's perception. According to the audit, unnecessary items are not present although this result goes against what we observed. Despite operators indicated lack of procedures in place to remove unnecessary items, they do not feel the need to change the current situation.

The shop floor actually has plenty of unneeded equipment, mostly because of the rapid changes in the process that leave behind old machinery not used and not removed. The operators are not aware of the benefits of sorting, so to encourage them the author started the red tagging process.

As a result, several items were red tagged and then removed from the clean room area:

- Laser table,
- Unwinding and winding machine,
- Two pin racks,
- Metal table,
- Cutting table
- Cold storage,
- 3 Wall racks.

The results of the **Set in Order** section show that while people are aware that tools do not have a specific location. However, they believe that the location and placement of work-in-process inventory is well determined. The score of the question related to WIP inventory is in fact high which means that operators believe that WIP has a specific location and it is placed there.

This contrasts with our observation. It is true that WIP has a location but this cannot be a generic nitrogen cabinet. Setting in order would mean knowing which specific cabined is designated to contain which specific roll/panel. The team noticed that the location of WIP inventory either in nitrogen cabinet or in moving tables is one of the biggest problems in
the shop floor and the problem will only increase with the forecasted growing production volume. Again, the operators perceive that defining a location means only the nitrogen cabinet location. Yet, they spend a considerable amount of time looking for rolls in the cabinets and each cabinet have to be opened to determine its content. Also, shortage of storage room for test rolls leads to moving these rolls to cabinets that are designed to hold rolls for production. Despite the high score from the operators, a reorganization of the nitrogen cabinets is one the key improvements that our proposed layout suggests.

For the **Shine** section it is evident that cleaning operations are indeed carried out but with little of coordination. In this case, what the team observed matches the results of the audit. The shop floor is neat and cleaned regularly. Yet, the absence of a person in charge of cleaning could lead people to overlook this task and bad habits can develop and grow.

**Standardize** is the S that has performed worst in the audit. This can emerge also from the previous sections where all the questions related to some sort of standardization got low score. Part of the reason of the poor rating is because of the lack of 5S training; one meeting is definitely not enough to give fully understanding of the 5S methodology, its goals and purpose. Of course the lack of any long term production at this stage of the company's development would also contribute to lack of standardization.

The last step of the 5S ladder is **Sustain**, and the audit shows that this S is performing well. However, we understood that what is more evident to people is just what is strictly related to the operations and the machine. The team observed that there are standardized procedures that explain how to operate the machines and these procedures are reviewed regularly. Yet, such procedures do not exist for operations equally important like movement of material and tool location.

The results of the audit are presented in a radar graph shown in Figure 14. The author provided the same tool to the management to keep track of the future audit that will take place on regular base. The graph gives a visual representation of the current performance of the company evaluated through the 5S methodology. Each extreme of the pentagon
represents one of the 5S, the closer the line is to the corner the better the performance is, with values that go from 0 to 4. In addition, a numeric score is provided for each category together with the total average score. The results of the audit are compared with the goal set and regularly upgraded by the management.

![5S Performance Chart]

Figure 14 - 5S Performances. Responses are ranked on a 0-4 scale. This result is for all shop floor personnel.

5.1.1 Operators and Management Audit

Even more interesting is looking at the results of the audit if they are broken down into operators and management's answers (Figure 15). By management, in this case, is meant shop floor management: all those people that do not solely work on the machine but also schedule production, supervise operations or have a responsibility role because of their long experience with the company.
Figure 15 - 5S Audit Breakdown. The data from Fig. 12 had been broken down between machine operators and shop floor managers.

The audit shows how the rating of the management is lower in every section of the 5S. On one hand, it is good that the management is aware that there is room and necessity for improvement; on the other hand there is the immediate necessity to build in the operators the culture for improvement. According to the audit, taking into account our observations, the operators do not see many of the current problems of the shop floor.

A hindrance in engaging the operators in the improvement activities is that Konarka New Bedford is undergoing frequent changes, it is hard to keep the pace with that, and some of the employees think that it is not worth improving something that will be changed anyway. With the first Kaizen event the author did the first step toward creating an effective continuous improvement culture in place in the company, and the Kaizen board will be a breakthrough communication means between the operators, that will identify problems and the management that will decide which project to carry out accordingly to the future plans.
5.2 Kaizen Board

A Kaizen Improvements board was successfully implemented on the shop floor in a central location accessible to all the operators. The operators were trained during Meeting III on the purpose of the board and ways to update and utilize the features of the board. The Kaizen board’s development and results are described in Gong’s thesis [6].

This board, together with regular Kaizen event, are the main tools to sustain the continuous improvement. This will work as a reminder of the specific short-term goals set as targets by the management and also of the long-term never ending work on continuous improvement.

The board is divided into three sections: Monthly 5S Audit, Goals and Methods and Kaizen Project (Figure 16).

*Monthly 5S Audits:* in this section the latest 5S audit and its results are shown. This part of the board is meant to work as a reminder of the parameters on which the organization is evaluated and to offer inspiration for improvement. In the bottom part of this section it was built the Red Tag station, which holds red tags and provide instruction for their usage.

*Goals and Methods:* the central part of the board displays the current goals and the suggestions from the operators. It is important to keep in mind the goals that the company is aiming to reach; this will help to have common intent and direction. Equally important is the section dedicated to the suggestion from the operators. They are the people who will make the continuous improvement run and the best ideas always come from the closest people to the process. The suggestions relative to issues that the management decides to tackle will be moved into the next section of the board.

*Kaizen Project:* the Kaizen projects that are carried out are moved in this section. The projects are divided according to their status and move vertically toward the bottom of the board where successfully completed project are shown. Again, completed Kaizen events will bring in the operators the motivation necessary to make their commitment to improve grows.
5.3 Kaizen for Flow Improvement

The participation and contributions of the operators in the discussion and execution of the Kaizen event was impressive. The role of the management and of the technical personnel is to translate these suggestions into opportunity of growth and deal with the problems. In this case, the team took this role and made the results of the Kaizen tangible implementing all the tools and the solutions discussed. Only by seeing their solution adopted will the operators have the incentive to keep identifying areas of improvement.

Despite a lack of a quantitative measure of parameters such as people participation and commitment to improve and the fact that the continuous improvement culture gives long-term results not measurable in the timeframe of the project, the seed of this new culture was planted and the direction to follow to seek for improvements indicated.

As explained in the methodology section the author used the Kaizen event as an opportunity to introduce everybody to the new methodology. The team guided the first event proposing our solutions as one of many possibilities to solve an issue and encourage discussion.

5.3.1 Spaghetti diagram

In order to clearly point out all the problems in the current layout, the operators were asked to map the flow of materials in the finishing areas. We handed them drawings of the current layout map, created and asked them to draw the exact flow of materials that they currently follow. We also asked them to point out the issues that find as they are mapping their movement. Each of the operators drew the sections they work with on the direct and daily basis and combined of the movement maps to create a spaghetti diagram of the
layout. The layout map created in the previous stage of the project greatly assisted us in this exercise. The resulting “spaghetti diagram” is shown in Figure 17.

The diagram was drawn on a projector during the Kaizen event to make explicit to the operators the flaws of the current layout. Figure 18 represents the same diagram that the author reworked with the path that material follow in the shop floor. Make clearer what the difference is between the two. This was a very successful exercise as we get feedbacks from the operators about the issues previously identified, new issues that we may have overlooked were identified, and most importantly this exercise gave the operators an opportunity to see the issues on their own without anybody pointing them out. This process ensured that the improvement layout ideas were not pushed on the operators but were welcomed as they now feel the need for change.
Figure 17 – Spaghetti Diagram. Drawn on a projector during Meeting II of the Kaizen event. It shows the flow of material from WIP inventory location to each process.
Figure 18 - Spaghetti Diagram Reworked. Same diagram of Figure 16 reworked after Meeting II
5.3.2 Improved Layout

The proposed improved layout shown in Figure 19 tackles all the issue identified in 4.5.4.

- Clean room area is enlarged
- The solar testing process is moved in the same room of other processes, ensuring an increased visual control of the whole finishing process. In order to further increase the visual control, the flow of material through the process is organized in a double U shape following the model of the Toyota production cell.
- Unnecessary material and unused equipment are removed from the shop floor.
- There is a dedicated area for finished products and for shipping
- Areas for WIP panels are clearly designated
- Nitrogen cabinets are placed rationally in the shop floor, close to each process and procedures are in place to allocate each piece of material in the right location.

Looking at the 5S audit the changes in the layout constitutes serious improvement especially in the Sort and Set in Order section. With the help of standardized procedures in place the improvements would be even greater.

Figure 20 shows the proposed layout with the process flow and Figure 21 indicates the flow of WIP material with the new layout.

The impact of this can be seen by looking at the total material travel path length for the “before and after” states. For the before layout (Fig.18) the author calculated that from coating to shipping each roll/panel is moved in and out work-in-process inventory for about 1,490 feet (Details in Table 3).
Table 3 - Material Movement, Current Layout

<table>
<thead>
<tr>
<th>Process</th>
<th>From Inventory [feet]</th>
<th>To Inventory [feet]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bussing</td>
<td>245</td>
<td>245</td>
</tr>
<tr>
<td>Added Value</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Sheeting + Lamination</td>
<td>290</td>
<td>25</td>
</tr>
<tr>
<td>Ablation</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Solar Testing</td>
<td>90</td>
<td>25</td>
</tr>
</tbody>
</table>

**TOT** 1,490 feet

For the proposed or “after” layout, the calculated approximate path of material is about 255 feet with a reduction of some 85% compared to the present layout (Details in Table 4).

Table 4 - Material Movement Reduction

<table>
<thead>
<tr>
<th>Process</th>
<th>From Inventory [feet]</th>
<th>To Inventory [feet]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bussing</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Added Value</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Sheeting + Lamination</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td>Ablation</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Solar Testing</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>

**TOT** 255 feet

The Pilot Area in the new layout is an area designated for testing. Test rolls will be placed in nitrogen cabinets and hand-sheeted in this area, ready for lamination. This process is currently located in the empty space between Raw Material and Finished Products, the new location will ensure proximity to the laminator, reduce material movement and risk of damaging the panels. The emptied area can be used, in the future, to increase either the room dedicated to Raw Material or Finished Products.
Figure 19 - Improved Layout. Relocation of the Solar Testing and the Pilot area, reorganization of the nitrogen cabinets and of the Finished Products and Packaging area.
Figure 20 - Improved Layout. Process Flow through the finishing operations from Bussing to Solar Testing. The Slitter machine is currently not used.
Figure 21 - Improved Layout. Material Flow in/out the relocated WIP inventory areas. To be compared with the previous situation shown in Figure 17.
5.3.3 Implementation Plan

The implementation of the layout improvement was proposed in separate steps. The proposed layout requires several changes, and movement of heavy and complex equipment, especially the solar tables.

The team discussed the solutions with technicians, electricians and maintenance personnel to provide a thoughtful, feasible and detailed plan for implementation. As a result we recommended:

1. Expansion of the clean room,
2. Reorganization of the nitrogen cabinets,
3. Reorganization of the WIP area after the laminator to and from the baking process
4. Movement of the ablation laser
5. Movement of the Mini-one Sun
6. Movement of the Big-one Sun

The plan is to move the mini one-sun and make room to create the U-shape that will be adopted also in phase 2. The ablation machine is moved accordingly. The nitrogen cabinets are moved into the optimized locations. The location for WIP after lamination is demarked clearly on the floor and same thing for the panels coming from baking. Also, the clean room is expanded to the limit of the new testing area. This will provide more space for movement of material.

This simple solution can give an idea of the completed layout improvements because the process flow will be the same. It requires the movement of just a few pieces of equipment. In this phase, all the unneeded material is first tagged and then removed. The latest step is to move all the solar testing tables into the laminator room.
5.4 Kanban Board

An inventory tracking board was designed and implemented to help operators and operations managers to track the progress of the production order and have control over the count and location of work-in-process inventory. This section is a brief description of the board, which is thoroughly discussed in Ming Gong’s thesis [6].

5.4.1 Operators Approach

The Kanban board is a solution to the inventory-tracking problem and to the flaws in the information sharing system currently in place in Konarka Technologies. The tool is useful both to the management and the operators. It will smooth the transition from the current system to the database system that is in the implementation stage, but not reliable yet. Also, it will be useful to visualize at a glance the production situation in the shop floor, and will be helpful in scheduling production. It is an important tool to keep track of the location of WIP and visualize the work that has to be done and the objectives of production.

The board went through an iterative revising process, first with the management and then with the operators during the Kaizen event. One of the challenges was to find a tradeoff between the information that the management wanted to see on the board (detailed) and what the operators need to see. The board is meant to simplify the shop floor and the operators do not have to perceive it as something impose to them and something that will give them extra work.

Going through this iterative process the team designed a board that with the necessary tradeoffs meets the needs of all the people in the organization.

5.4.2 Layout of the Board

The board has a total of 38 divided into 3 sections (A schematic of the board is shown in Figure 22). Each line represents a roll that moves horizontally once it goes through a process. Each column of the boards is a process that is carried out in the finishing area. (The board does not consider the coating process because it is generally done in one day

70
and the final product is a roll stored in a nitrogen cabinet). The first column of the board: “To be bussed” keeps track of each roll that was coated and is stored somewhere in the shop floor.

The roll card is color coded accordingly to the color of the roll. At the present time, Konarka offers 3 color: Red, Green, Blue in 3 varieties: Light, Medium Dark. This and other characteristic of the roll are written in the first digits of the barcode. To sum up, the roll card carries the characteristics of the roll both through the code printed on it and its color.

In the first section of the board the product is still in a roll format. After the roll is sheeted, the board keeps track of panels or batch of panels, this happens in the second and third section. The cards move from one section to the other and fit into pockets that leave out just the more important information (e.g. date of each process and comments may be hidden because they are not always needed). The column that represents each process is divided into two sections: one is for the card and the other one is for the location of the roll/panels.

The distinction between the second and third section is in term of Production Orders. Talking to the management we realized that the way to get the most out of the board is to somehow link its functioning to the new database and inventory management system that is going to be implemented in Konarka. The system is not reliable for now, and the board will be a useful tool to double check the information wasting the minimum amount of resources. Two different Production Orders are made: one moves the parts through lamination and backing, the other through ablation and solar testing. This is because of the nature of the processes themselves: ablation and solar testing are slow and labor intensive while lamination is mostly automated.
5.4.3 Board Utilization

The operator moves the card once a process is completed and writes down the location of the designated column. The operation that is currently in process is marked with a magnetic tag and it is easily recognizable. The usage of the board is straightforward while the product is moving in roll format because the whole roll is worked in one step (Figure 22).

Figure 23 - Kanban Board Section 1. Each rectangle is a pocket, the Roll Card are inserted in the pockets and moved horizontally once the respective manufacturing process is completed. Each Roll Card represents a roll and holds with it several Panel Batch Cards.
The roll card holds with it several other cards that we called panel batch cards (Figure 21). The roll is not usually sheeted all together and this is when the panel batch card plays its role. The batch that is sheeted is represented by one of the card on the back of the roll card and is moved to the next location. Also, the size of the batch is written on the board and track is kept of the remaining size of the roll. The roll card is not removed from its location until all the panels are sheeted. The batch at this point can be handle easily and its card moves through the finishing processes. If for some reason a batch is broken down a new panel batch card can be used.

Figure 24 - Kanban Board, Section 2 and 3. The roll is seldom finished all together. The Roll Card is broken down in Panel Batch Cards. They represent batches of panels that are processes together and move horizontally through the finishing operations.
5.4.4. Physical Board
A 4' x 8' T-DexTracker™ system on a roll around shelf was purchased. This board allows us to keep track of work-in-process inventory for the entire finishing process, up to 38 different ongoing process runs. It has compartments for T-cards as well as whiteboard space for comments. The entire board is magnetic for ease-of-use, and this board can be relocated easily because of its wheeled standalone frame. See figure 25 for details.
Figure 25 - Kanban Board. Each column section represents a process. The Board is horizontally divided in three sections: 20, 40 Lanes and Test. The small yellow tags are nitrogen cabinets for rolls, the green one racks for panels.
Chapter 6: Recommendations and Future works

6.1 5S Methodology and Kaizen Board

It is recommended that Konarka Technologies keeps pushing the implementation of the continuous improvement culture in the organization, using the provided tools as a guideline. Although this process requires time and effort, it is absolutely necessary to ensure the company the growth that it is pursuing.

Konarka has forecasted an exponential growth in demand and this will most likely lead to hiring new employees not familiar with the company’s modus operandi. Right now the workforce in the New Bedford Manufacturing plant is small (15-20 operators), and this is the right moment to extensively train them and make this workforce the pillar of the future expansion. The best way to do that is to involve the personnel in activities such as Kaizen events giving them ownership of the shop floor to incentivize ideas and increase motivation and responsibilities.

The author provided tools for continuous improvement such as the 5S methodology, the Kaizen board and introducing the concept of Kaizen event by example; leaving the organization with these tools and the task to sustain them. This year, when the main goal of the company is not to increase revenue but to get ready to ramp up production, it is absolutely the right time to work on these aspects and achieve long lasting results.

6.2 Layout Improvement

Konarka Technologies should consider each future change in the floor layout in terms of the long-term benefits even if this goes against the short time convenience of the solution. The 5S criteria and the optimization of material flow and inventory location can be used as guidelines to follow in each future change of the layout.

Everything is changing rapidly in Konarka New Bedford, and this has been one of the biggest challenges we faced. Given that the shop floor of the facility will go through several
changes in the following months, the team is aware of the fact that the proposed layout is a temporary solution. This is why our proposal wants to be a methodology to follow for future changes, more that a definitive solution.

6.3 Kanban Board

We recommend that the company substitute the Kanban board with a digital system in the future, when production volume will increase and the automated production data system is up and running. The design of such a board will be similar and it will show the same results, however, a computer system will update the information more rapidly and reliably. The digital board will interface with the tracking system and the database that will be in place, and will provide production information to the people in the shop floor.

We have designed the board to meet the current needs of the current organization. In the future, the board, in its current fashion, will not be the right tool to use. Moving on the board thousands of panel per process per day, when several processes will run in parallel for 24 hours per day, will be too time consuming if not completely unmanageable.

6.4 Process and Machinery

As a short-term goal, the implementation of the tracking system is the first priority. Konarka can use this period of low production to test the system, and make it reliable and ready for full production.

Looking more ahead in the future, we recommend looking into continuous manufacturing process. The product is a perfect candidate for continuous production and we recommend developing equipment and machinery to go toward this direction. The main advantages will be: increased throughput and elimination of work-in-process inventory. The latter will lead to more space in the shop floor and reduction of material handling.

The finishing processes have to be improved or in some case rethought to achieve this goal. Much has been done on the laminator, but making it reliable at higher speed is necessary to keep up with the speed of the coater. Furthermore, we recommend developing the ablation
laser and solar testing process to have them in-line after the laminator. This will be a turning point in the shop floor: they are currently the bottlenecks of the process and require movement of material that is likely to damage the panels.
Chapter 7: Conclusion

The team after an observation period has identified, prioritized and tackled issues at the New Bedford manufacturing plant of Konarka Technologies. The author designed and successfully implemented a framework for continuous improvement, with satisfaction of both the management and the operators. The 5S methodology was provided as the guidelines for sustainable improvements and a Kaizen board was designed to visualize goals and results.

Following the 5S and the waste reduction philosophy, the team proposed an improved layout, providing a detailed implementation plan. Accordingly, the first phase of the plan was conducted. A Kanban board used to keep track of WIP was implemented by the team and operators trained for its effective usage during the Kaizen event. The team designed a database to collect production information and used statistical approach to determine the yield, process rate, and setup and cleanup times at each process. Last but not least, a production-scheduling spreadsheet was developed to calculate lead-time for production.

The most important factors in ensuring the success of the project was that it involved the operators. Our solutions, supported by the management, always went through several iterations with the operators: the final user of our tools and the most important people in the implementation of the continuous improvement culture.

One of the reasons for the success of the project was the involvement of the operators. The MEng Team saw their growing participation and increasing interest during the project. We gained their trust being able to demonstrate that our primary goal was to add value to the company and provide it with tools to help its future growth, becoming the point of contact between the operators and the management. This was one of our objectives and the Kaizen event was the first step to achieving it.

The operators felt the ownership of the solutions and they started looking at the shop floor from different perspectives. The value of the Kaizen and the Kanban board was appreciated
and they were effectively utilized. The impact of the several projects on the company was evident. Each of those was implemented, and instructions on how to proceed to ensure their future sustainability were provided with great satisfaction of the management.
Bibliography


Appendix A: Power Plastic Products [1]
Appendix B: Kanban Board Details