Information Tracking and Sharing in Organic Photovoltaic Panel Manufacturing

by

Ming Gong
B.S. in Chemical Engineering,
University of California, Berkeley, 2010

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

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Abstract

The MIT MEng team of four worked with Konarka Technologies, a world leading organic solar panel manufacturer, on production tracking and analysis as well as various operational improvement projects. MIT's collaborative improvement projects at Konarka's manufacturing facility were focused on information system and operations in the finishing processes after solar panels have been coated. This thesis report, however, focuses primarily on information tracking and sharing in Konarka's manufacturing facility, specifically including the barcode tracking system for production tracking, operator interfaces for the system, production tracking (Kanban card) board, and Kaizen continuous improvement board. A barcode tracking system for solar panel and associated user interfaces portion was developed to increase process and inventory accountability. However, because of the intricate SQL database, it may still be difficult for any operator to access this information in the recent future. Hence, physical representative information boards were developed to alleviate this communication complexity. One Kanban (card style) board was implemented to keep track of production information, and another Kaizen (continuous improvement) board was established to keep track of all the continuous activities on the shop floor. Based on various reviews and discussions, these improvement projects served as useful tools for the company's production ramp-up development.

Keywords: barcode, tracking system, production tracking, lean, Kanban, Kanban board, Kaizen, Kaizen board, information board, card, card board

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

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Chapter 1: Introduction

With the increasing demand of clean energy around the world, solar power is emerging as one of the most popular high-tech manufacturing industries. Konarka Technologies, Inc. is a world leading manufacturer of lightweight, flexible organic photovoltaic (OPV) solar panels [1]. These solar panels, as shown in Appendix B, are manufactured using multi-layers coating technology. With the adoption of Polaroid's reliable continuous roll-to-roll printing technology, all the coating processes are streamlined and operating consistently. On the other hand, the finishing processes are rather labor intensive and new to the company. In 2011, the company plans to expand its production capacity and finish its ramp-up upgrade of its facility by the end of the year.

1.1 Thesis Focus

There are numerous improvement projects completed by the MIT team in collaboration with Konarka Technologies, Inc. This thesis report, however, focuses primarily on information tracking and sharing in Konarka's manufacturing facility, specifically including the barcode tracking system for production tracking, operator interfaces for the system, production tracking (Kanban card) board, and Kaizen continuous improvement board. The goal is to achieve a more transparent and collaboration production environment where problems can be easily identified. This is especially important for high volume production. Such production operational information can also serve as a bench mark for production and improvement progress.

Other relevant projects focuses include production scheduling and data analysis (Jason Chow's thesis [5]), Kaizen 5S continuous improvement (Gregorio Colaci's thesis [6]), and shop floor layout improvement (Susheel Gogineni's thesis [7]).

1.2 Company Background

Konarka Technologies is the world leader in organic photovoltaic technology. The company 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 and a light in every home, and a world where power is plentiful, safe, 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 which also has a small scale pilot production capacity. 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.

1.3 Markets

The Company's product portfolio caters to three markets: Portable Power, Remote Power and Building Integrated Photo Voltaic (BIPV) applications. The Potable 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]

1.4 Product - Power Plastic

Power plastic is thin, flexible and lightweight solar panel that 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 are currently at 8.3% efficiency (NREL certified). [1]

Further layers included with in power plastic are shown in the 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.

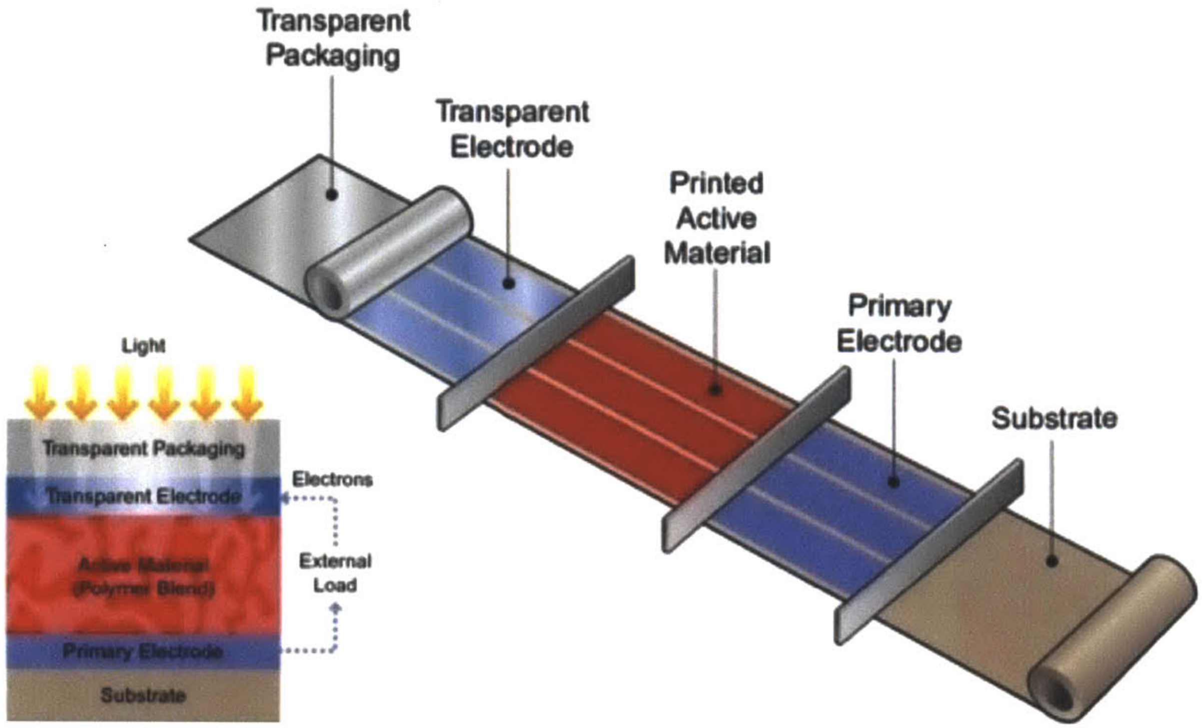

Figure 1 - Layers of Materials in Konarka's Power Plastic Solar Panels and Respective Functions for Energy Generation [1]

The different layers are coated on the substrate in lanes that 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 the 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 usually 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 electrical current rating. Currently, the company is also considering to move toward continuous coating without module division.

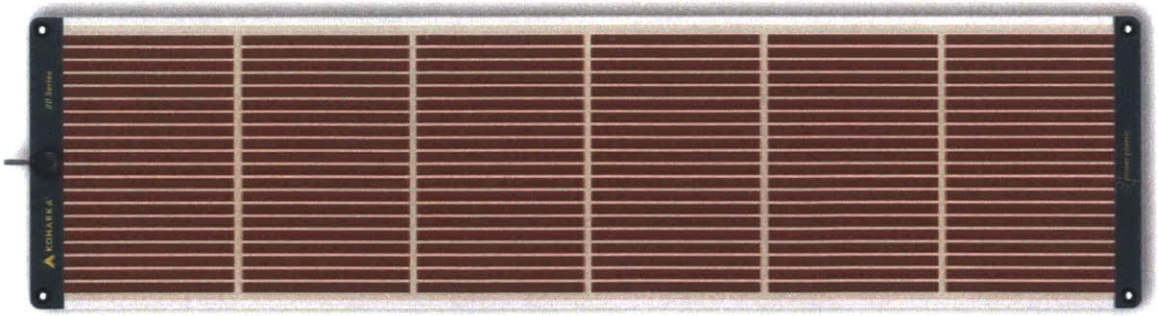

Figure 2 – Sample Mat-finished Solar Panel: 20 Lane Wide, 6 Modules (code name 620) [1]

Characteristics that determine product variety:

- Density of the primary silver electrode – complete coverage or grid silver patterns
- Transparency of the active polymer – building-integrated photovoltaics (BIPV) applications require higher transparency levels, thus various polymer thickness and efficiency
- Color of the active polymer – red, green, gray, and possibly blue later
- Packaging material - clear or matt plastic finish encapsulation
- Length of the panel – can range from 1 module to 14 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 seam less 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.

1.5 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/m^2 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.

There are many different types of photovoltaic technologies that 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.

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 sizelimited 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. 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 below). Konarka Technologies is a world leader in the roll-to-roll manufacturing of organic photovoltaics.

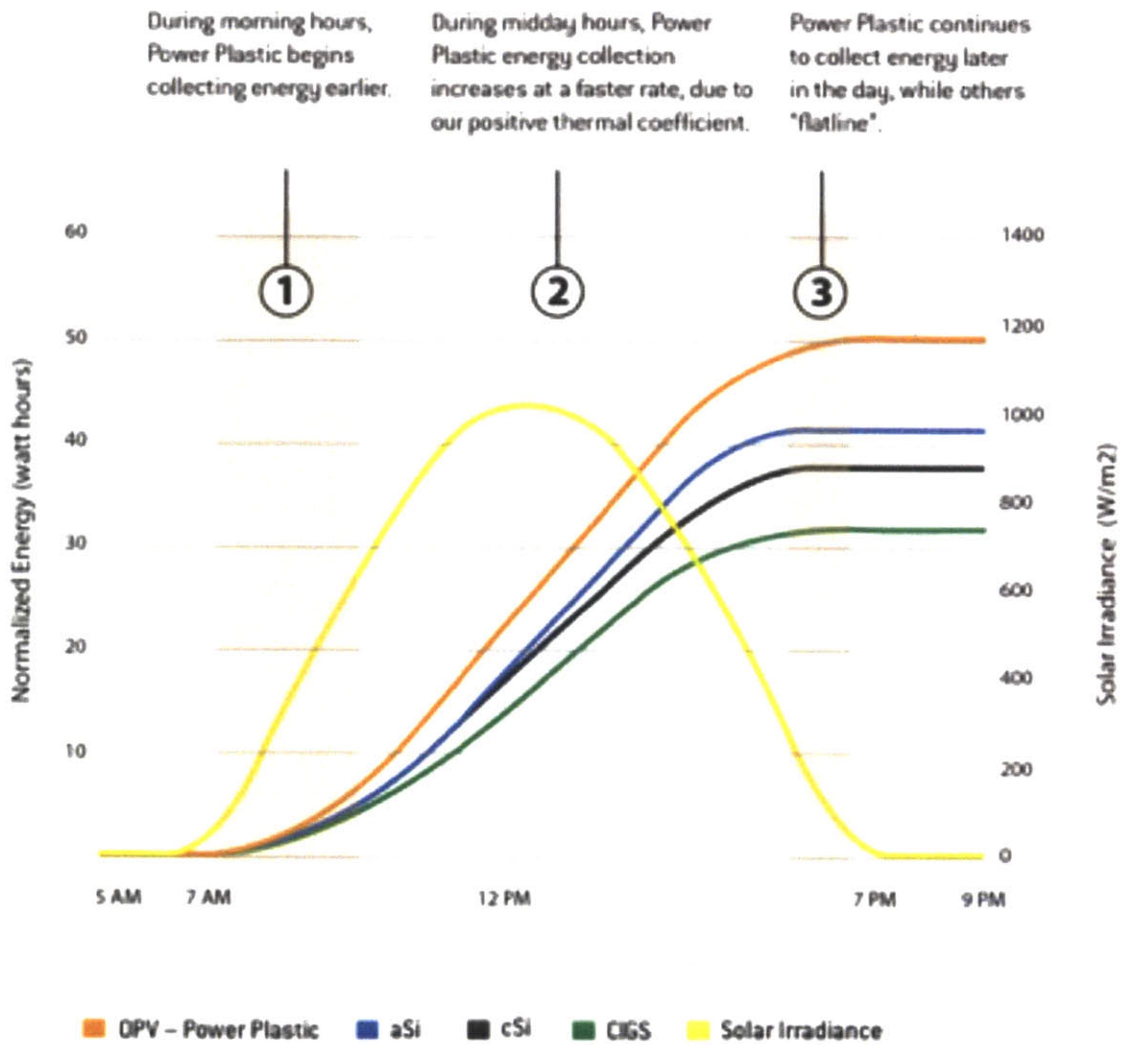

Figure 3 – Energy Generation throughout the day by Different Solar Panels (per watt equivalent panel) [1]

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 a 8.3% efficiency and a 5-year lifetime in a laboratory setting, and its cost per watt is comparable to that of Si solar panels. 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].

1.6 Manufacturing Processes

1.6.1 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 a great starting advantages. With some changes of Polaroid's film producing facility, Konarka currently manufactures the active portions of the thin film OPV solar panels with its continuous roll-to-roll printing technique. The equipment allows Konarka to produce panels as wide as 60 inches. This facility has the capacity to produce millions of square feet of solar panels per year, enough to generate 1 Gigawatt of energy.

1.6.2 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 below in figure 4.

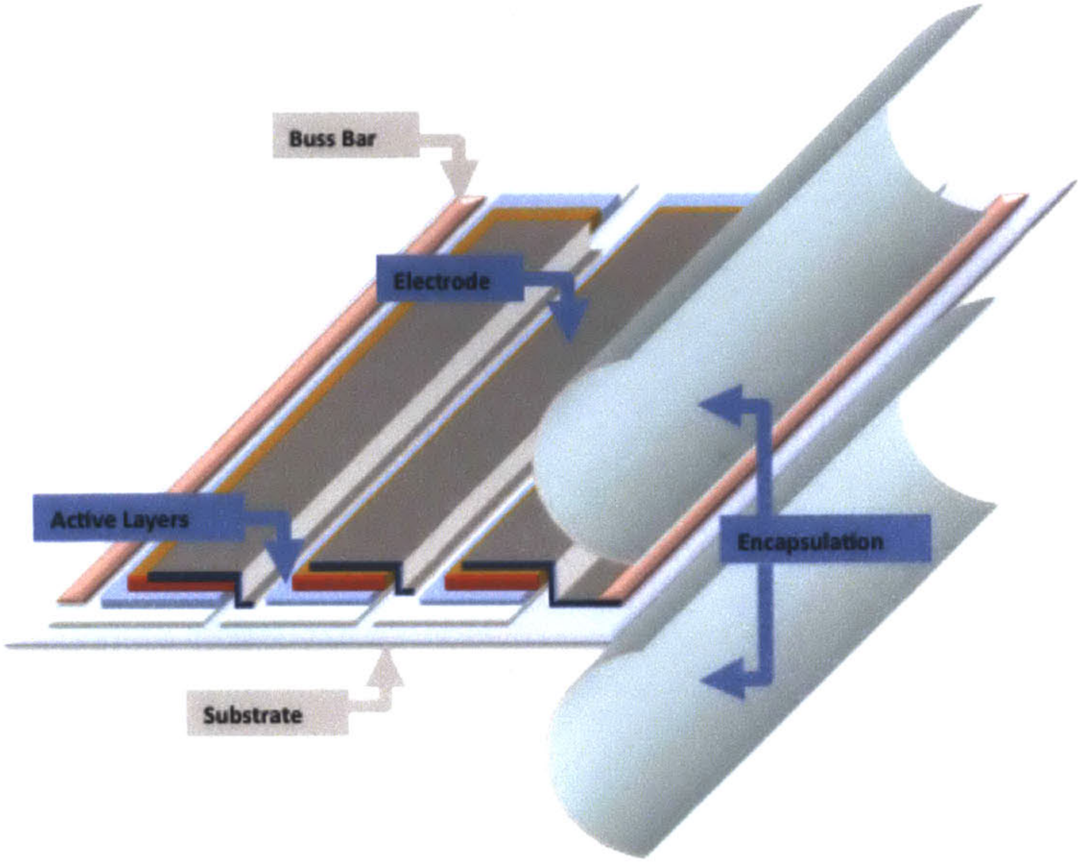

Figure 4 - Konarka Solar Panel Overall Architecture featuring Active Layers, Electrode, Bus Bar, Substrate, and Laminated Encapsulation [1]

The print head can have 10 lane, 20 lane, or 40 lane 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, they will go through a finishing process that encapsulates (or laminates) 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 fully coupled and operating reliably. Currently, the finishing processes are still labor intensive and new to the company. This project focuses primarily on the finishing processes; thus, more details on the finishing processes will be discussed below.

1.6.3 Coating Processes

The coating processes schematic diagram is shown in figure 5.

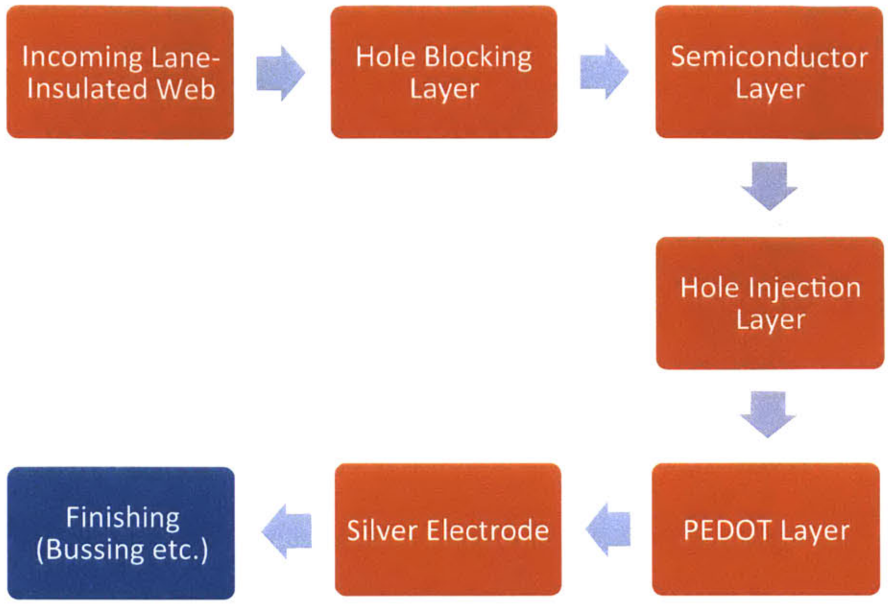

Figure 5 - Coating Processes Schematic Diagram

The coating process, which runs on a continuous web, can run up to 100 ft/min. This web-based 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, up to 4,000 ft roll, will be transported to the finishing processes.

1.6.4 Finishing Processes

After the solar panels are coated, they must be encapsulated with plastic sheets because, otherwise, the polymers would react with oxygen. The bussing process is considered the start of finishing process. Bussing is basically sticking on two conductive metal strips on two sides of the solar panels for electrical connection. The finishing process schematic is shown below in figure 6. Note: C.P.[1] is a proprietary process as noted in the figure.

[1] This is a proprietary process of the company.

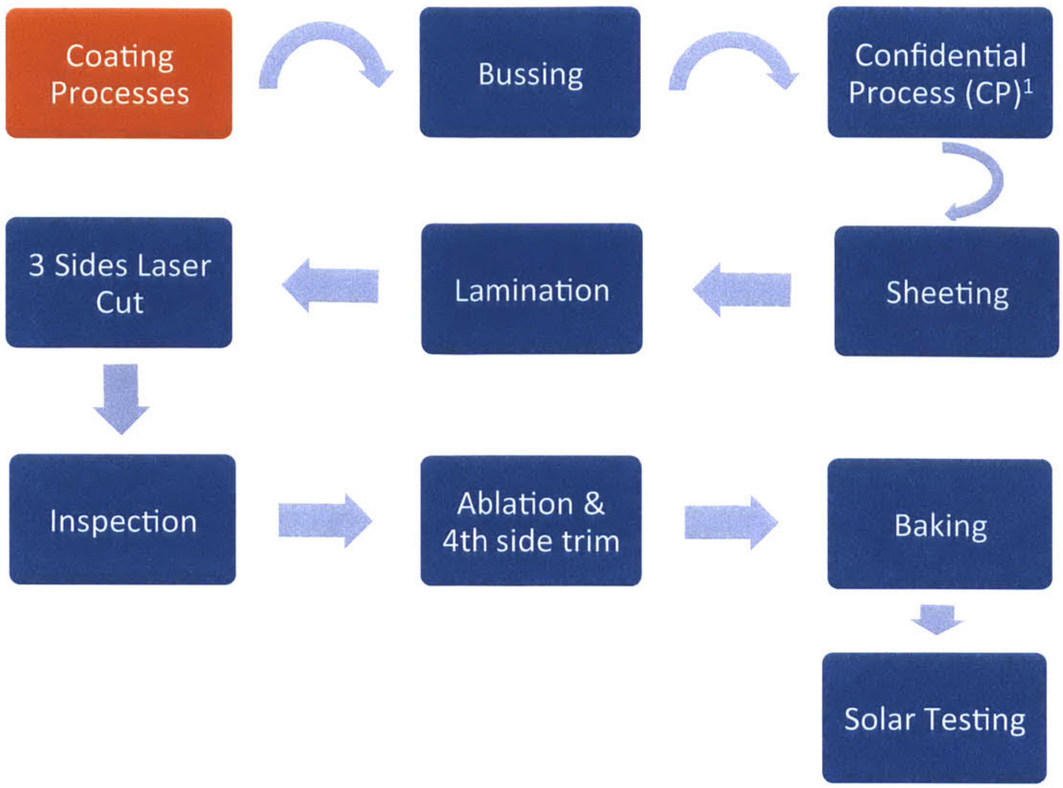

Figure 6 - Finishing Processes Schematic Diagram

After coating, the solar panels are stored in a roll format waiting to be finished. In the bussing process, the panels are unrolled, bussed with conductive side bus bars, and then rolled again for storage. Similarly, another confidential processing (C.P.) step requires rolling and unrolling of the panels.

Then, the panels are unrolled and cut or "sheeted" to the desired length followed by top and bottom lamination with plastic barriers and adhesives. An automated laser cutting machine will precisely cut the laminated panels on three sides (front, left, and right). This automated machine currently cannot cut the fourth side because the laser cannot move quick and reliable enough to cut the ending edge. All four edges will have a one inch margin of laminated material for packaging purpose. The sheeting, lamination, and three 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. During actual production, however, this may be very labor intensive and can take place after baking. The panels are usually baked in an oven for at least 3.5 hours for curing the adhesives used in lamination. Then, the panels will then be (4^{th} side) trimmed and laser ablated (two small holes) on two bus bars for electrical connection.

Finally, the solar panels will be tested for solar power absorption performance before packaging and shipping.

At present, the bottleneck process is typically the lamination process, which currently laminates at roughly 10 ft/min. Because of the labor intensiveness of the finishing processes and the lack of personnel, the finishing processes cannot run in a continuous coupled fashion. Most employees are scheduled to work at various processes at different work days, so that any process can become the actual bottleneck process. This may cause confusion on the shop floor; therefore, the scheduling and organization of the finishing processes are vital for manufacturing operations. The current overall plant layout is shown in figure 7.

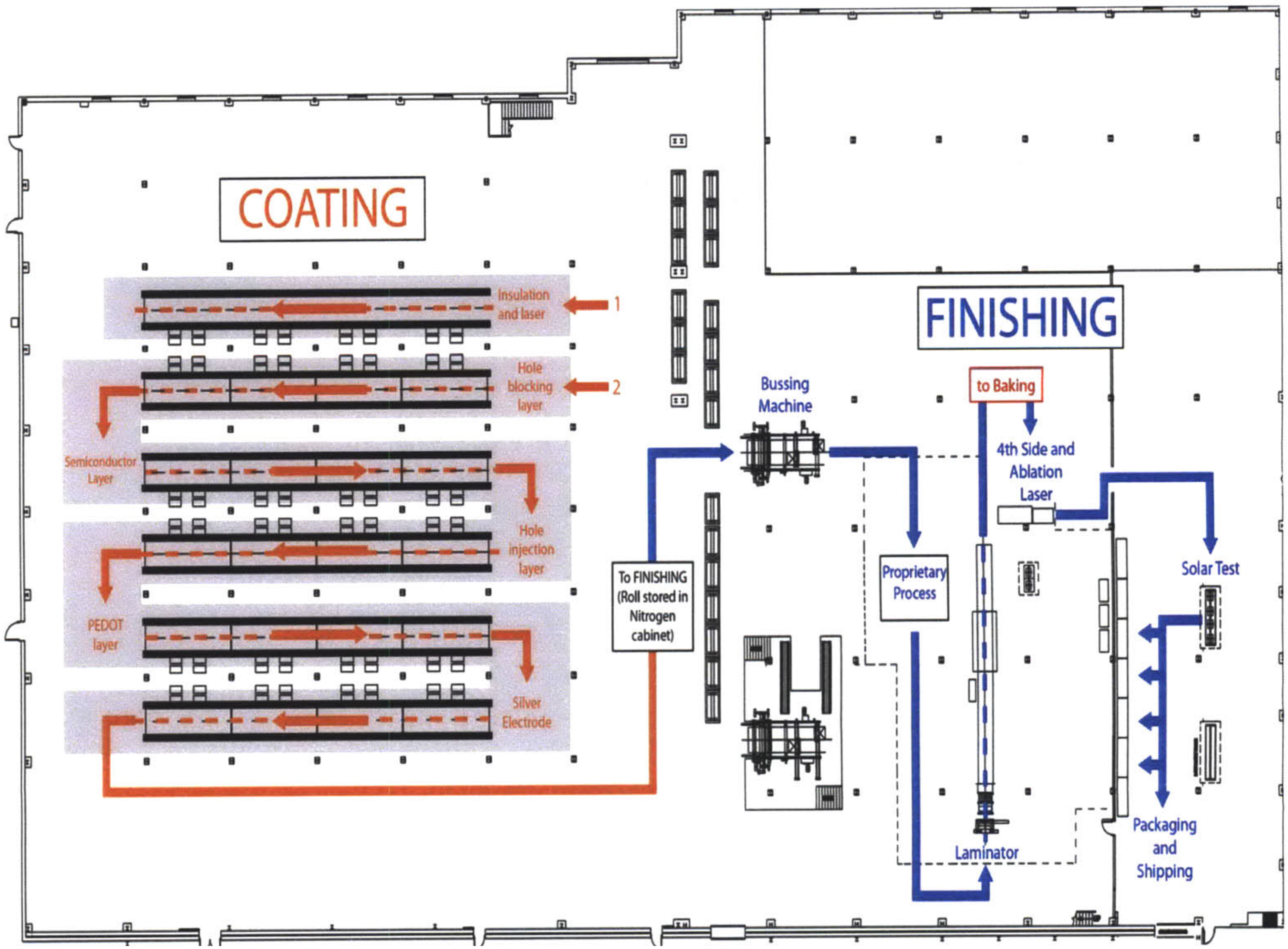
COATING
Insulation and laser
1
Hole blocking layer
2
Semiconductor Layer
Hole injection layer
PEDOT layer
Silver Electrode
To FINISHING (Roll stored in Nitrogen cabinet)
FINISHING
Bussing Machine
to Baking
4th Side and Ablation Laser
Proprietary Process
Solar Test
Laminator
Packaging and Shipping

Figure 7 - Current Konarka New Bedford Plant Layout and Manufacturing Processes as of June, 2011

Chapter 2: Problem Statement and Objectives

2.1 Problem Statement

During the initial observation period, the MIT MEng team has identified several 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 believe that it is more important to build a solid culture and bring concepts and ideas instead of focusing on a single technical problem given the project timeline and company situation.

2.1.1 Material Flow

During the group's observations and interviews with the operators the team has identified that there is scope for improvement in the way the various processes are arranged on the shop floor. We have identified the need for a more structured movement of materials around 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 growth in customer demand. Given this, they will need to rearrange their shop floor to reflect this growth. There needs to be more space allotted for work in progress 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.

2.1.2 Production Information Tracking and Sharing

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. The software SQL database is not easily accessible to shop floor operators; thus, a shop floor manager may resort to manually input production information on papers that are spread out in the facility. Inventory information can be centralized and organized better using an immediately implementable Kanban board or using a fully automated barcode tracking system.

The effectiveness of this system impacts the overall production performance and the ability to identify bottleneck for future improvements. Ambiguous or inaccessible information of work in process (WIP) inventory leads to inefficient operations for all the operators who need them. A tracking system should minimize or eliminate manual counting and locating WIP. In addition, there may be a delay of production problem because the immediate performances such as yield and production time are not as presented simultaneously with the ongoing process. An information tracking and sharing system can be of greater value for high volume production where the company is headed.

2.1.3 Operations

The two main issues of focus were improving material movement through the shop floor to reduce wastage and increase problem visibility, and establishing part tracking systems that can help managers and operators track work in progress inventory and to have accurate predictability of lead times. Also there is a 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.

2.1.4 Other Issues

For the indicated reasons we decided to focus on the problems listed above. However, other issues that we have identified are listed below to give the reader a complete overview of our work and the operations carried out in the shop floor.

Lamination

The lamination is the finishing process where the company is experiencing the most machinery 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 growth potential in the window integrated solar panels (BIPV). 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 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 we envision this process in-line right after the lamination. This will solve the issue of handling, will speed up the process and there will be less work-in-process (WIP) inventory since the whole operation 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 labor intensive since 100% of the panels are tested. Ablation and solar testing are the slowest processes, especially for large panels. Having an inline solar test station would be the ideal situation but it does not seem the biggest concern right now. Automating or even semi-automating solar test also seems rather difficult given the small ablated holes for electrical connections. Also, in terms of future plans, a test on each panel may not be necessary and we believe there is much more value-adding work to do upstream before focusing on solar testing.

2.2 Objectives

To sum up, after an observation period we have defined our short and long term goals for the project. The ambitious long-term objective is to establish a lean culture in the organization, a culture that will lead Konarka toward a path of continuous improvement. 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 make the company able to stand on its own feet.

In terms of the short-term objectives, the main focus has been to provide some tools 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 an improvement of its manufacturing process and production was focused mainly on a series of test product. That said, we have worked on the improvement of the current system but 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 understands the immediate urgency of tracking inventory, work in process and finished goods and has focused its effort on the developing of a tracking system and a database to store the information. In addition to that, we have 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.)

Therefore, the team, as a whole, has decided to focus on two main areas: information tracking & analysis and operational improvement.

- Information Tracking and Analysis
    - Inventory barcode tracking system framework
    - Operator interface for tracking system
    - Production data statistical analysis [5]
    - Kanban production information board

- Operational Improvement
    - Production scheduling tool
    - Kaizen activity and 5S methodology [6]
    - Kaizen board
    - Shop floor layout improvement [7]

This thesis report's primary focus involve all the information tracking and sharing in both material flow as well as shop floor operations because of the indivisible nature of the two. Each group member' thesis takes a different approach of the work project, and their primary focus are noted in the references above.

Chapter 3: Literature Review

Information sharing is the first step of lean manufacturing improvements because it makes problems more transparent and easily identifiable. 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 the product to the company's customer while reducing its manufacturing cost. The lean concept is centered on preserving value while reducing work and resource use. [9]

The lean philosophy was derived from the Toyota Production System (TPS). [2] 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 involve production flow improvement and is 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 autonomation (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 work flow, consolidating information sharing, and other operational improvements. Specifically, a barcode (both UV 2D matrix and 1D barcode) tracking system is implemented, and a Kanban card style information board and a Kaizen continuous improvement board will be created on the shop floor to facilitate information tracking and sharing. Details of related literature reviews of 2D matrix barcode tracking system, Kanban, and Kaizen are followed.

3.1 Inventory Tracking & Just in Time

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 Progress (WIP) inventory allows continuous operations of machines even if some particular machines are currently down for repair. These inventories are created to offset different process variations so that they can smooth out the production line, and finished inventories is a buffer against production lead time (i.e. delivery time reduction because of inventory in stock). There are raw material inventory, WIP inventory, and finished goods inventory. As a part of the team's focus on the finishing side of Konarka's manufacturing facility, we looks closely at managing WIP inventory and updating related scheduling tools.

Just in Time (JIT) production is a practice of reducing WIP inventory with continuous and smooth production processes. This requires detailed process time study and scheduling procedures. 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 commonly used to track the work in progress 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 and especially for the transition phase to fully automated tracking, however, it would be easier to work with a more physical form of inventory tracking such as a physical Kanban style information board.

3.2 UV 2D Matrix Barcode Tracking

Similar to conventional 1D barcodes, a 2D data matrix is simply a more accurate and less conspicuous barcode system. The barcode used on solar panels is a UV 2D matrix that is printed on the solar incidence side of the plastic web between solar modules. This printing process takes place right after coating or during bussing. UV 2D barcodes are preferable for aesthetic reasons as they become unnoticeable after lamination. These barcodes are then obscured during lamination because the two plastic transparent sheets would enclose the solar panels and make the further barcode reading impossible. Therefore, another UV 2D barcode will be printed on the back of the bus bar for continuous tracking purpose. A realistic barcodes picture is shown in figure 8, and a 2D UV barcode picture is shown in figure 9.

Figure 8 - 1D Standard Barcode and 2D Data Matrix Barcode Sample Printouts [20]

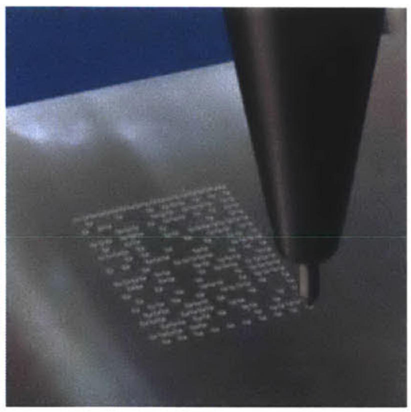

Figure 9 - UV 2D Data Matrix Barcode Printing Schematic [20]

3.3 Kanban

Kanban in Japanese means "billboard" or "signboard". As a part of JIT production, Kanban is a scheduling system that uses a "signboard" to signal the exact current demand for a specific part in the production process. Kanban style board simplifies the part transition process, and clearly resembles what part is needed, when it is needed, and how much of it is needed. In addition to scheduling, since Kanban board represents the demand for parts in the system, it also represents the current manufacturing problems and progress. Traditionally, Kanban is used to monitor WIP inventory movements as well as other raw material movements. Kanban cards can be used to signal the need for some material that requires transport from warehouses or even purchase from other suppliers.

The idea originates from Toyota in the late 1940s. Toyota began to apply store and shelf-stocking techniques to the factory floor, similar to inventory management in a supermarket. This way, all processes are viewed as customers with certain demand, and the WIP inventory or materials are kept to the minimal to satisfy production needs.

Traditional "push" systems schedule production via forecasted demand and as a result push material through from the beginning. Kanban, however, is a "pull" system that allows the supply of production to be clearly defined by each process need, with the final process being customer demand. This gets rid of excess inventory and make the bottleneck problem more apparent because many Kanban boards would be unfilled at a station. A pull system is therefore more effective than a push system where supply time varies and demand is difficult to forecast. Thus, a pull system is more effective in non-automated production such as Konarka's finishing processes because of large variation in process time.

Recently, electronic Kanban system has also been developed that can synchronize easily with online software database. This is seen as the next stage of development for Konarka's transform toward ramp-up and automation.

3.4 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. These Kaizen improvements can be large-scale improvement during major facility updates or small-scale fine-tuning of operations during regular production.

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 endless cycles of standardizing operations, measuring performance, setting improvement goals, plan and implement changes, gauge new system, and standardize the new operations. To put more simply, it is essentially a cycle of "Plan, Do, Check, and Act". A pictorial depiction of a Kaizen "PDCA" cycle diagram is also shown in figure 10.

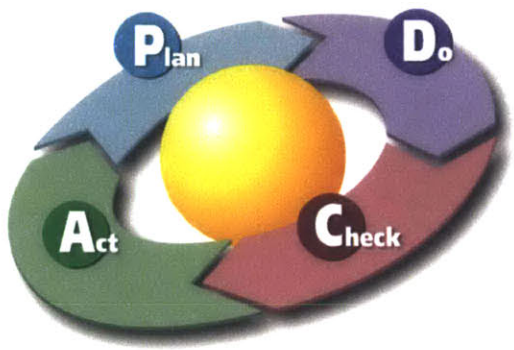

Figure 10 - Kaizen Continuous Improvement PDCA Cycle Schematic Diagram [9]

As a continuous improvement model, Kaizen seeks to find the root causes of problems and persistently 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.

3.4.1 5S Methodology

The 5S methodology is a tool used to improve operational performance. It involves the organization at all levels and instills a sense of ownership into each employee. The procedure is an effective tool used in several companies to implement a continuous improvement culture with quantifiable results. The key and most challenging step is to establish, especially in the operator who is the closest person to the processes, a commitment to improve. Only at this level, improvements can actually begin. Such continuous improvement culture will also lead to visible gains that will increase the motivation of the team, their sense of ownership of operations and improvement processes, and their commitment to the new philosophy. This 5S methodology and culture form a beneficial cycle as depicted by figure 11.

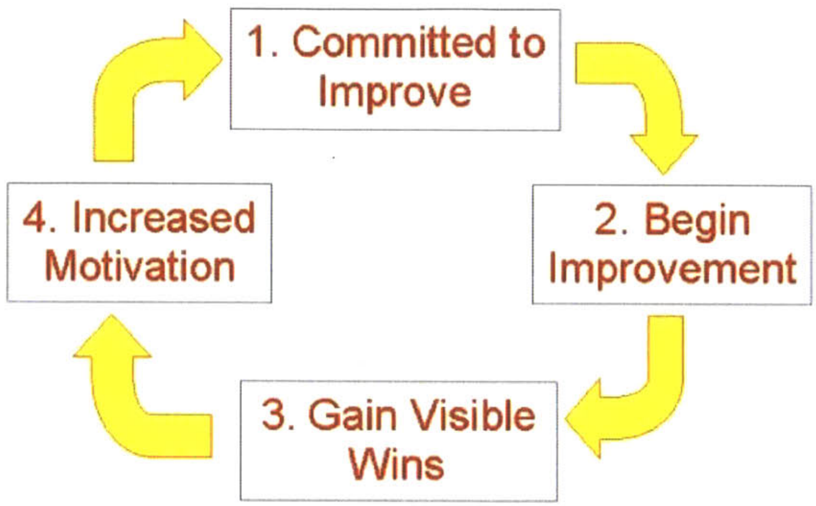

Figure 11 - Kaizen Continuous Improvement 5S Motivation Cycle Schematic Diagram [13]

The 5S method presents 5 improvement steps that have to be followed by the operator and management to achieve the set goals. The 5S originally correspond to the Japanese words: *seiri, seiton, seiso, seiketsu and shitsuke*, the English equivalent of which are: *sort, straighten, shine, standardize, sustain* (figure 12).

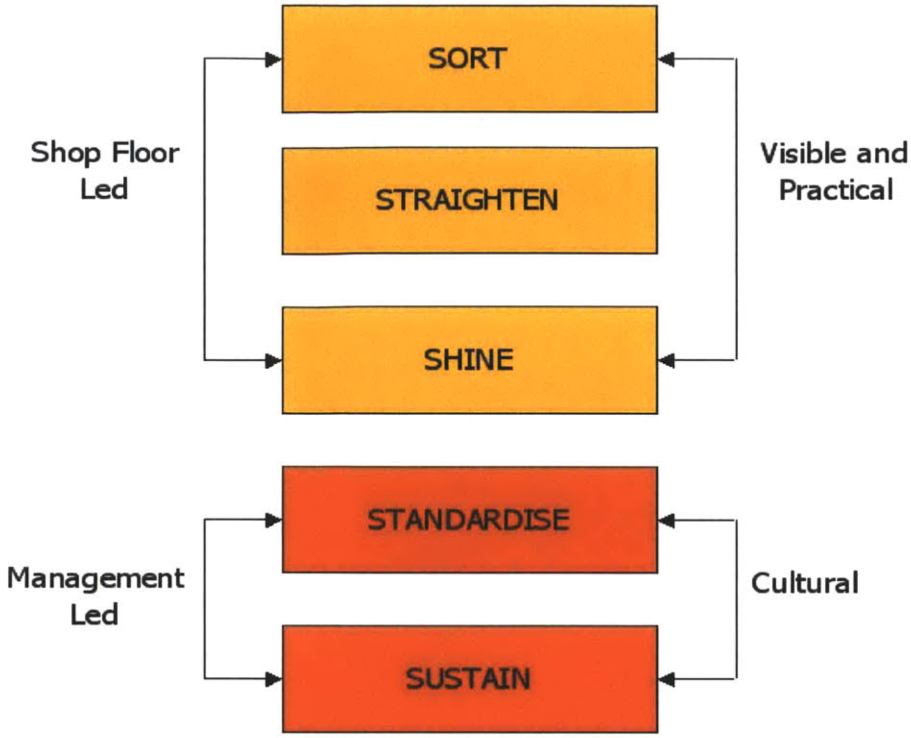

Figure 12 – Kaizen 5S Methods Schematic Diagram[13]

The first 3S will lead to visible and practical results and are led by the shop floor operators to organize the processes and clean the workspace. The next two steps, however, have to be supported by the management which objective is to provide standardize procedures and sustainability for the continuous improvement. Refer to Gregorio Colaci's thesis for in-depth description of 5S method [6].

3.4.2 Kaizen Board

The continuous improvement activities framework is developed using the 5S methodology, but it is also important to have a visible documentation of the improvements in a way that is accessible to everyone involved in the Kaizen team. There must be a platform that can display the improvements achieved by previous events and for voicing ideas for future events. Such a board presents a clear idea of all the ongoing updates in the facility as well as notable improvement ideas.

Chapter 4: Methodology

4.1 Team Projects and Contributions

The group has worked collectively focusing on the final objective: bringing lean and continuous improvement culture to the organization in preparation for production ramp-up. To achieve this objective, we have worked with many employees at Konarka, from the management to the operators, and at each stage of the process we have constantly obtained their feedback in order to direct our efforts in the right direction and provide the organization with the maximum added value.

Two parallel approaches were carried out by the group, namely information tracking & analysis and operational improvement. Each approach was broken down into actual projects and completed with contributions from all members as described in the following paragraphs. The main contributors to each project are listed in the parenthesis.

- Information Tracking and Analysis
    - Inventory barcode tracking system framework (the entire team)
    - Operator interface for tracking system (Gogineni []and the author)
    - Production data statistical analysis (Chow) [5]
    - Kanban production information board (the entire team)
- Operational Improvement
    - Production scheduling tool (mostly by Chow) [5]
    - Kaizen activity and 5S methodology (Gogineni [7], and Colaci [6])
    - Kaizen board (Gogineni [7], Colaci [6], and the author)
    - Shop floor layout improvement (Gogineni [7] and Colaci [6])

Because of the nature of this work project, many related tasks such as presentations, interviews, data sheets and other tasks are completed by various team members or collectively at different stage of our stay at Konarka. The group worked collaboratively on project planning for tracking system, Kanban board, Kaizen activity and board, and layout improvements. In addition to various project planning and other tasks, the author had major contributions on operator interface and Kanban board development.

As mentioned earlier, this thesis focuses on all the information tracking and sharing projects including the tracking system, operator interface, Kanban board, and Kaizen board. Due to the nature of this work project, certain project developments inevitably overlap in group members' thesis; however, the operator interface and Kanban board are only explained in detail in this thesis. Please refer to Gregorio Colaci's thesis for detailed Kaizen 5S improvement methodologies [6], Susheel Gogineni's thesis for in-depth shop floor layout improvement methodologies [7], Jason Chow's thesis for data analysis and production scheduling [5].

4.2 Information System Overview

The processes information system as of May, 2011 uses a manual paper recording method. All WIP inventory information is kept and organized by one shop floor manager, and the information is passed to production scheduler to prioritize production orders. The current WIP status and related information enables the scheduler to schedule production for the next few days; problematic manufacturing processes can also be addressed accordingly. This previous information system scheme is shown in figure 13 below.

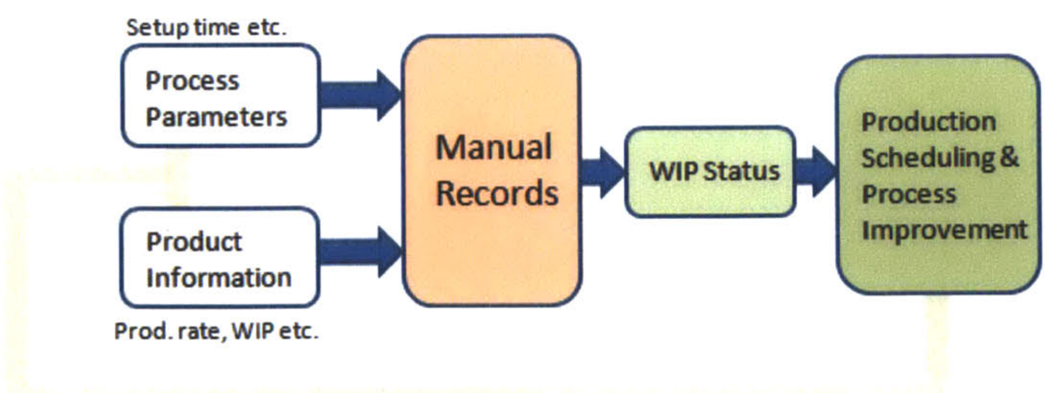

Figure 13 - Previous Information System Schematic Diagram as of May, 2011

Since such information is not readily shared with all the operators on the shop floor, communication between operators and managers can be strenuous at times. Solar panel counts and location information is prone to misrepresentation with temporary paper tags in multiple locations. The team worked with Konarka engineers to bring about a more automatic barcode tracking system. Due to extensive nature of this project, however, our team also proposed a short-term implementable physical Kanban information board to aid the information tracking and sharing system during the transitional period before the barcode system is online. Detailed information regarding this Kanban board is discussed in section 4.4. This transitional information system is shown in figure 14 below.

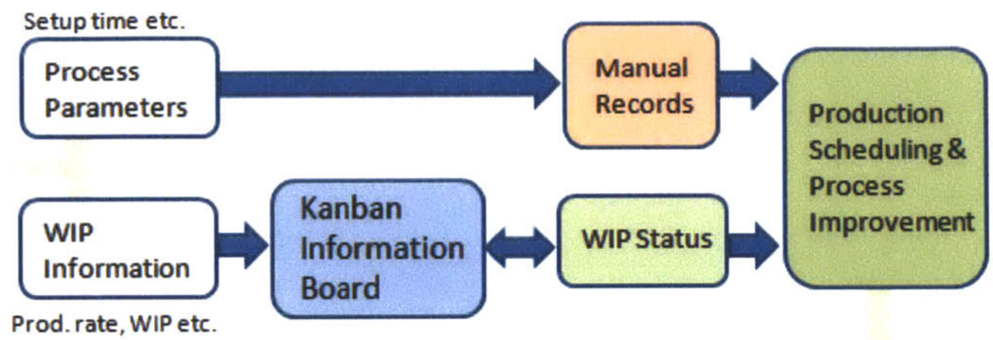

Figure 14 – Short-term Implementable Information System Schematic Diagram as of August, 2011

The complete barcode tracking system also requires a set of operator interfaces for gathering process parameters from all the operators. Then, all the WIP information and process parameters such as setup times are recorded in an online database. Kanban production board can serves as verification of the WIP status information recorded from the barcode tracking system. Ultimately, updated WIP status information and previous data analysis enable managers to better schedule future operations and improve corresponding processes. The designed information system scheme that our team and Konarka engineers work toward is shown in figure 15 below. After our team leaves the company, Konarka engineers will continue this information system development working toward this designed system shown in figure 15.

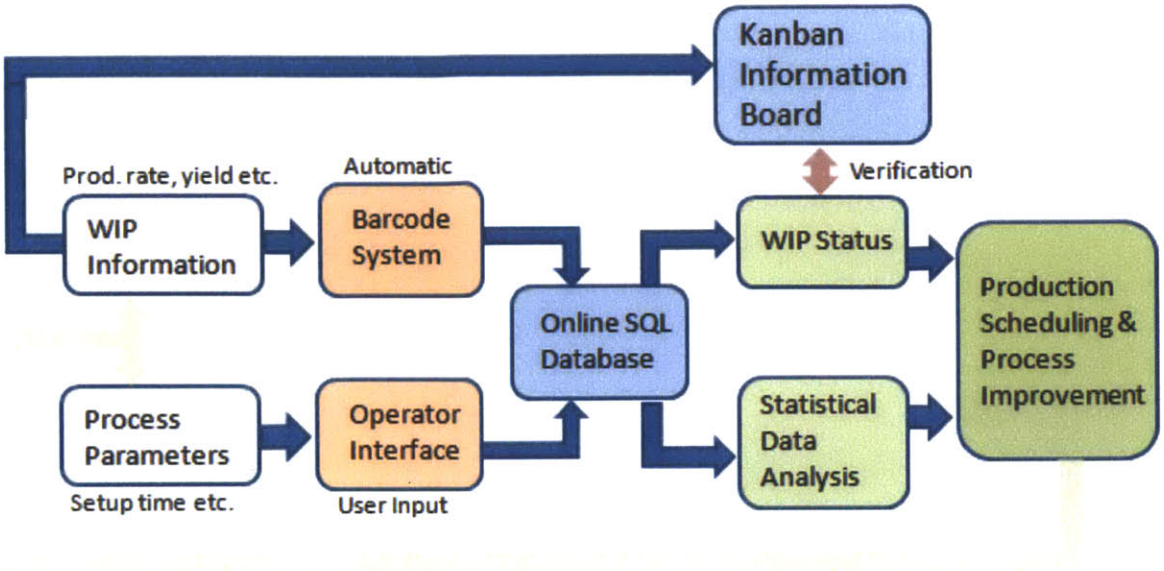

Figure 15 - Designed Information System (Currently Under Development) Schematic Diagram

4.3 Tracking System & Inventory Accountability

4.3.1 Tracking System Development

The team has developed a tracking system schematic that illustrates the flow of material and where barcodes would be printed and read. We have discussed the feasibility of this system with the stakeholders in this project, and both our group and the stakeholders believe that the implementation of this system will allow Konarka to reduce its operating costs.

This tracking system increases inventory accountability and overall system performance by making any production problems more apparent. At the current stage, we have worked toward an ideal fully-automated system as well as an implementable system in the short term. The first UV 2D matrix barcode printer, for example, has been located at the bussing station for current testing and troubleshooting purposes. Ideally, the printer would be at the end of the coating processes, but since the coating processes are fast, reliable and difficult to adjust, the isolated bussing machine serves as an ideal testing station for the new barcode system. The bussing machine currently runs independently from all other processes which is why it requires rolling and unrolling of the OPV roll.

4.3.2 Solar Panel Barcode Convention

The barcode convention developed by Konarka is a fourteen bit letter/number barcode. This barcode carries nine pieces of information (nine sections). A sample barcode is shown below in table 1.

Table 1 - Sample Barcode and Corresponding Barcode Individual Bit Denotation Information

	Lanes	Shade	Color	Type	Year ending	Julian Date			Coated Roll Number	Cut	Sequence Number			
Sample Barcode	2	D	R	S	1	3	2	0	A	1	1	0	2	9

The legend for corresponding pieces of information and respective meaning is followed in table 2.

Table 2 - Barcode Denotation Convention for Available Options

Section	Barcode	Denotation
Lanes	2	20 lane
	4	40 lane
Shade	D	Dark
	M	Medium
	L	Light
Color	R	Red
	G	Green
	B	Blue (future replacement of gray)
Type	S	Segment
	C	Continuous
	T	Test
Year ending	1	2011
Julian Date	320	Number of the day = 320 = 16Nov
Coated Roll Number	A	A-Z; up to 26 rolls in one day
Cut	1	Cut number Ex: Cut 1, 2 two cuts coated side by side then slit
Coated Sequence Number	1029	Coated Sequence Panel Number 1,029 from this roll

As described above in table 2, there are two types of panel lanes width, 20 lane and 40 lane, noted by a single numeric bit. The solar panels have three shade options, three color options, and three types. For panel type, segment means the solar panel roll is printed in modules where each module is roughly one foot long separated on a roll by a 10mm or 2mm section without silver back electrodes. The continuous panel, however, does not have any gap in between and therefore has a slightly better efficiency. The current production year is only recorded with one bit using a numerical input; this can be changed later if necessary. The Julian date uses three bits to represents any day of the year. The coated roll number uses one bit with a letter input based on the assumption that no more than 26 rolls will be produced in a day, which is a valid assumption considering each roll is hundreds of feet in length. "Cut" means whether the roll will be slit along the printed direction to make multiple narrower rolls (panels with fewer lanes). Therefore, "cut" of 1 means that the roll doesn't need to be slit, and "cut" of 2 means the roll needs to be split down the middle. Lastly, the coated sequence number is a tracking number for each solar module if it is segmented. If it is a continuous roll then the sequence numbers would be separated by one foot. In other words, for a continuous roll, a barcode is printed every foot down the line.

The above barcode convention is for tracking solar modules using the UV 2D matrix barcode. After lamination, another regular 1D barcode is proposed to be printed on the solar panel for keeping track of every panel. As described in previous section, each solar panel can have many modules with a common panel type convention. For example, 720 means a panel with 7 modules and each module is 20 lanes, whereas 1140 means 11 modules and 40 lanes product.

The barcode tracking system our team has developed is integral to tracking yield and production rate data. Furthermore, with the new barcode system's accountability, material defect or production bottleneck could be easily identified, and such information could be shared among production managers or all the operators via the database or synchronizing with the physical board on the shop floor. Working closely with Konarka operators and managers, we have developed a detailed tracking system design shown in the results and discussion section followed.

Since all the processes are currently not streamlined, it is also crucial to keep track of ongoing processes and corresponding setup and cleanup cost. Operator interfaces are developed to assist operators inputting related information.

4.3.3 Operator Interface

The MEng team has designed an operator interface that will allow the operators to input the information into the database with ease, showing them exactly what they need and minimizing the possibility of mistakes and confusion. User friendliness is vital for any modern human operated machinery as the Three Mile Island incident has taught us.

"...inconsistent user interface was one of the major causes of the Three Mile Island nuclear accident in 1979. Some indicator lights indicated normal as red, some as green..." [14]

The database that the group has worked on not only serves as an information storage tool but also as a tool to share this information throughout the organization. The team has envisioned the database and tracking system in such a way that an operator itself that provide the input information to the database. It is in fact the closest to the process; the system itself can identify problems with appropriate statistical analysis tools. If the task of production data tracking is spread among the operators instead of being a duty of the management, the probability of success should be improved.

The team, working in close contact with Konarka's IT experts and the operators on the shop floor, functioned as a point of contact and reference between the two. Using MATLAB Graphic User Interfaces (GUI), our team has developed a user interface at each station to identify the information needed, and added extra features requested by the operators. The interface is consistent at each process and its operator's input to maximize its friendliness.

In addition, a series of standardized procedure has been developed for an effective and consistent use of the tracking system. Our first objective is to build a robust system, but to do that we need to rely on established procedures making the flow of information smooth and reliable.

The operator interface constitutes a link between the database and the operators. It triggers the record of data and keeps track of additional information such as setup time and problems during the process. It is important that all the personnel in the shop floor understand the importance of this tool and sees it as an added value rather than an extra task. Detailed desired process parameters collected via operator interfaces are shown in table 3 below. Screenshots of operator interfaces developed by Susheel and the author are shown in the results and discussion section in the following chapter.

Table 3 – Desired Finishing Process Paramenters Collected with Operator Interfaces

Bussing Parameters	**Proprietary Proc. Parameters**	**Lamination Parameters**
Process Run #	Process Run #	Process Run #
Roll #	Roll #	Roll #
Operators	Operators	Operators
Date & Time Start	Date & Time Start	Date & Time Start
Date & Time End	Date & Time End	Date & Time End
Equipment Name	Equipment Name	Equipment Name
Bussing Material	Material	**Top Web & Bottom Web**
North Lot #	Lot #	Part Number
South Lot #	Run Length (m)	Tension
North Meters Bussed	Temp. (hotshoe top)	Surface Energy
South Meters Bussed	Temp. (hotshoe middle)	Surface Finish (Matte, Clear)
Speed	Temp. (hotshoe bottom)	
Temperature	Temp. (nip roll 1)	**Top Delo & Bottom Delo**
Relative Humidity	Temp. (nip roll 2)	Ch/B
Pressure	Speed	Exp Date
Unwind Tension		Pot Pressure
Takeup Tension		Line Temp.
Web Tension		
Ablation Parameters	**Solar Testing Parameters**	**Phoseon Light**
Process Run #	Process Run #	Top Dose (mJ/cm^2)
Operators	Operators	Bottom Dose (mJ/cm^2)
Date & Time Start	Date & Time Start	
Date & Time End	Date & Time End	Top Temp
Equipment Name	Equipment Name	Bottom Temp
	Vmax	Laminator Speed
	Pmax	Phoseon Knob Setting

	Efficiency Fill Factor Voc Isc Testing Area	Sheeter Unwind Tension Conveyor Speed Room Temp Relative Humidity Start Delo Use (g) End Delo Use (g) Top Roll Use (ft) Bottom Roll Use (ft)
	Module Parameters Module Barcode # Roll # *Scan time at each process* *Good/Bad for each process* Module Width Process Run # for Bussing Process Run # for PP Process Run # for Lamination Process Run # for Ablation Process Run # for Solar Testing	**Panel Parameters** Panel Barcode # Module Barcode #s # Modules *Scan time for each process* *Good/Bad for each process* Solar Testing Data Batch Tag for Baking Process Run # for Bussing Process Run # for PP Process Run # for Lamination Process Run # for Ablation Process Run # for Solar Testing

4.4 Physical Kanban Production Tracking Boards

4.4.1 Shop Floor Information Sharing

As discussed in the earlier sections, there is a plan to implement a tracking system using data matrix that can be read with a barcode reader and transfer the data to an online database. This database is stored online in *Microsoft Dynamics*, and can be accessed by production managers. This information, however, rarely finds its way back to the shop floor especially with the difficulty of ongoing barcode tracking system development. Additionally, most operators are unfamiliar with the SQL online database, and the system still lack a user friendly output display. To compensate for all of these technical difficulties, another simpler physical representation tracking board can be rather effective on the shop floor. A Kanban card style information board is proposed to keep track of all the work in progress (WIP) inventory.

It is important to display basic production information such as raw material, work in progress and finished goods inventory location and quantity to the operators on the floor to have a visual feedback on the current manufacturing progress. In addition, boards that display daily production goals constantly communicate a sense of urgency which could improve productivity by motivating employees to achieve the set goal. This is especially effective in an interactive Kanban board. Production goals are generally set by schedulers with consideration of product priority, availability of machines and operators.

Information about the availability of work in progress (WIP) inventory at each process gives the operator a visual warning that a specific manufacturing process is becoming the bottleneck process. Bottleneck process improvement is usually the most cost effective way to increase productivity. All of this information will be available in electronic form in a database, but is inaccessible to the operators for the short term because of tracking system implementation difficulties and software user interfacing. In the interim physical information boards (Kanban production board and Kaizen improvement board) are excellent at communicating information on the shop floor with total involvement of all the operators and serving as a check on the electronic system and vice versa.

A Kanban board is a physical card board system that keep track of WIP inventory's exact location and amount as well as the current manufacturing progress. Operators on the shop floor can move the card from one slot to the next representing completion of a processing a batch of material. This board also helps the operators to locate the entire inventory more easily.

4.4.2 Kanban Production Tracking Board

Current tracking information is updated by a shop floor manager at each inventory location. A sizable amount of time is spent by operators to obtain an accurate update of this information to grasp the current production progress. The Kanban board can add value to schedulers, operators and managers via providing a centralized, organized, and interactive production information sharing platform.

The Kanban board holds a card for each roll and panel batch that is currently in the system. These cards are placed in appropriate slots that provide information about the location of the roll. There are slots allocated for WIP storage between any two manufacturing processes such as before bussing or before lamination to indicate the inventory has been processed up to that point, and is available for the following process. As the roll moves to the next stage, the card is also moved accordingly to indicate completion of the process. The location of the inventory is also commented next to the card using the naming convention developed during our material flow project. These cards are color coded to indicate the product color such as dark red, light red, dark green, etc. Also the slots are categorized to represent the width of the roll such as 20, 40 or 60 lane. This gives the viewer a clear snap shot of the inventory in the system and corresponding progress.

The Kanban board is divided into 3 sections, categorized by production orders. The first one that tracks the product in the roll form, and then the next production order #1 (PO1) tracks the panels in batch form once they are sheeted and laminated. Production order #2 (PO2) tracks the solar panels in smaller batches because of the slow and labor-intensive laser ablation process. A new roll card is created when a roll enters the system after the coating process. The roll card has many PO1 and PO2 cards behind it that contain information about the originating roll. The roll cards' journey stops before the sheeting and lamination step. Thereafter, a panel batch PO1 card from the roll folder is taken out every time the roll is used to make a batch of panels. After the entire roll has been sheeted, the roll card can be discarded and all subsequent solar panels will be represented with PO1 cards. A similar card transition will take place between PO1 and PO2 before ablation process.

4.4.3 Kanban Production Tracking Board Overall Design

The board tracks WIP inventory by production orders. First, it tracks the product in the roll form, and then in the next section another production order tracks the panels in batch form once they are sheeted and laminated. Since ablation process is extremely labor intensive and slow, sometimes a second batch panel production order (PO2) tracks the solar panels in many smaller batches due to the slow and labor intensive laser ablation process. The complete Kanban production tracking board design is shown in table 4 and enlarged versions for each section is shown in figure 16 to 18.

Table 4 - Kanban Production Order Tracking Board Design (separated sections based on production order)

Inventory Tracking Board

Width	Roll Inventory Tracking						
	To be bussed	LC	To be C.P.	LC	To be sheeted	Count	LC
20 lane	DR20|003	NC3	LG20|007★	NC3	DR20|006		NC3
	LG20|005	NC3					
40 lane	DG40|002★	NC3	LR40|009	NC3			
	DG40|003	NC3					
	LR40|003	NC3					

Width	Panel - 1st Production Order						Panel - 2nd Production Order													
	To be Laminated	Count	Loc	To be Baked	Count	Loc	to be Ablated		Count	Loc	To be Tested		Count	Loc	To be Shipped		Count	Loc
20 lane	PO1/1234★		NC3	PO1/1234		NC3	1234	1234		NC3	1234	1234		NC3	1234	1234		NC3
	PO1/1234		NC3	PO1/1234		NC3	1234	1234			1234	1234			1234			
							1234				1234				1234			
											1234							
40 lane	PO1/1234		NC3	PO1/1234		NC3	1234	1234		NC3	1234	1234			1234	1234		
	PO1/1234		NC3	PO1/1234		NC3	1234	1234			1234							
	PO1/1234		NC3	PO1/1234		NC3												

This board holds a card for each roll and panel batch that is currently in the system. These cards are placed in slots corresponding to the progress of the panel and the location of the roll. There are slots allocated for WIP storage between any two manufacturing processes such as before bussing or before lamination to indicate the inventory has been processed up to that point, and is available for the following corresponding process. As the roll moves to the next stage, the card is also moved accordingly to indicate completion of the process. The column "LC" means location of the inventory, and there will be space on its side for comments on each piece of inventory. The location of the inventory is commented in the "LC" column according the naming convention used during the material flow project (See Susheel Gogineni's thesis [7]). Each magnet (denoted by a star) represents materials currently being processed. Each horizontal row represents one entire roll of solar panels. The board has slots for placing cards and white board writing space next to the location for writing other information such as panel progress counts or problems.

These cards are color coded to indicate the product color and shade such as dark red, light red, dark green, etc. Also the slots are categorized to represent the width of the roll such as 20 lanes, 40 lanes or 60 lanes. This gives the viewer a clear snap shot of the inventory in the system and corresponding progress. Each block on the board represents a card. These cards have information about the roll such as color (dark red, light red, light green, etc), length of the roll at coating, width of the roll (20 lane, 40 lane, 60 lane) and whether the roll is continuous or is divided into modules. This information is displayed in the visible part of the card that sticks out from the card slot. In addition the card also contains information such as coating date, bussing date. Operators can also add comments, such as defective panels information, about the roll or batch on the card. A card is moved to across the board as it is being processed.

4.4.4 Kanban Roll Inventory Cards Board Design

After a roll has been completed on the coating line, a new roll card and many corresponding PO1 and PO2 cards are created to account for this roll. A typical PO1 card will represent a batch on the order of hundreds of panels, and a typical PO2 card will represent a batch on the order of tens of panels. Batch size is also highly dependent on the panel size especially in length. All the PO1 and PO2 cards stay behind the roll card until the roll has been sheeted. Each operator is responsible for moving the card and updating relevant information after a processing step is complete. The roll card is moved to the next slot only after it has been completely processed, otherwise, it would keep a note of exact progress in the comment section (preferably on the board).

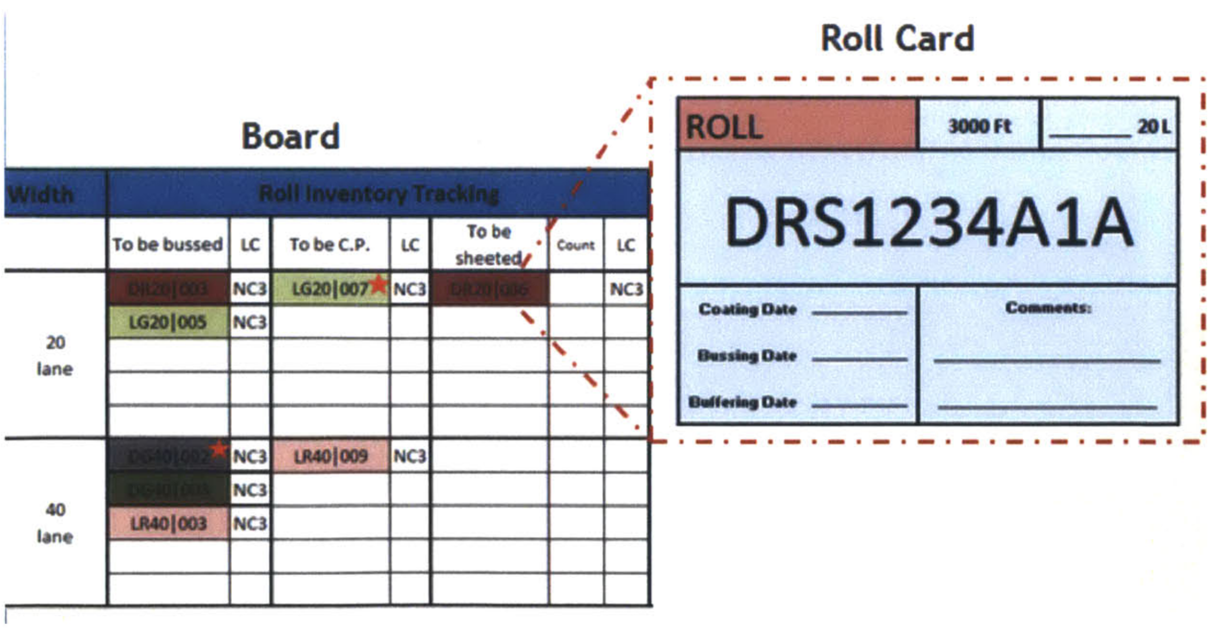

Figure 16 - Roll (of Solar Panels) Inventory Production Tracking Board and Card Design

After sheeting, the panels wait to be laminated. Here, the roll card is replaced with PO1 cards representing batches of panels. The roll card, however, keeps notes of its roll length waiting to be sheeted, and is discarded after it has been completely sheeted in which case only PO1 cards (and PO2 cards behind the last PO1 card) are left on that row of the board. Typically, changes along the process would mandate more PO1 and PO2 cards to be created to keep track of the most up-to-date production information.

4.4.5 Kanban PO1 and PO2 Cards Board Design

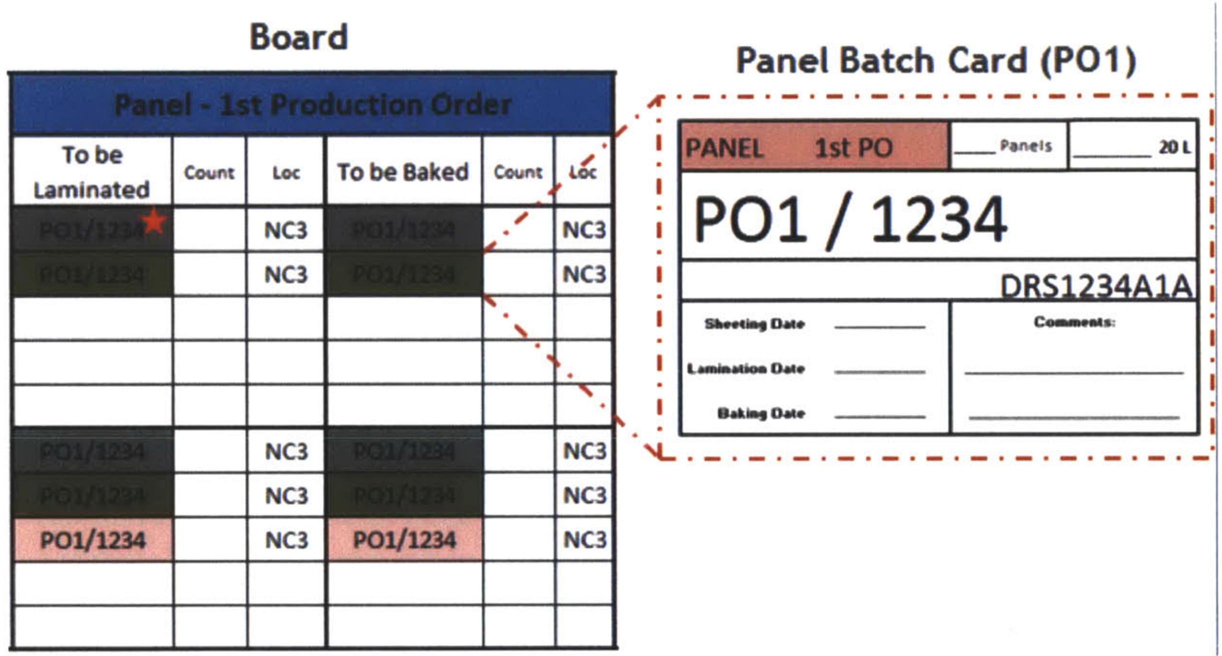

Figure 17 - PO1 Inventory Tracking Board and Card Design

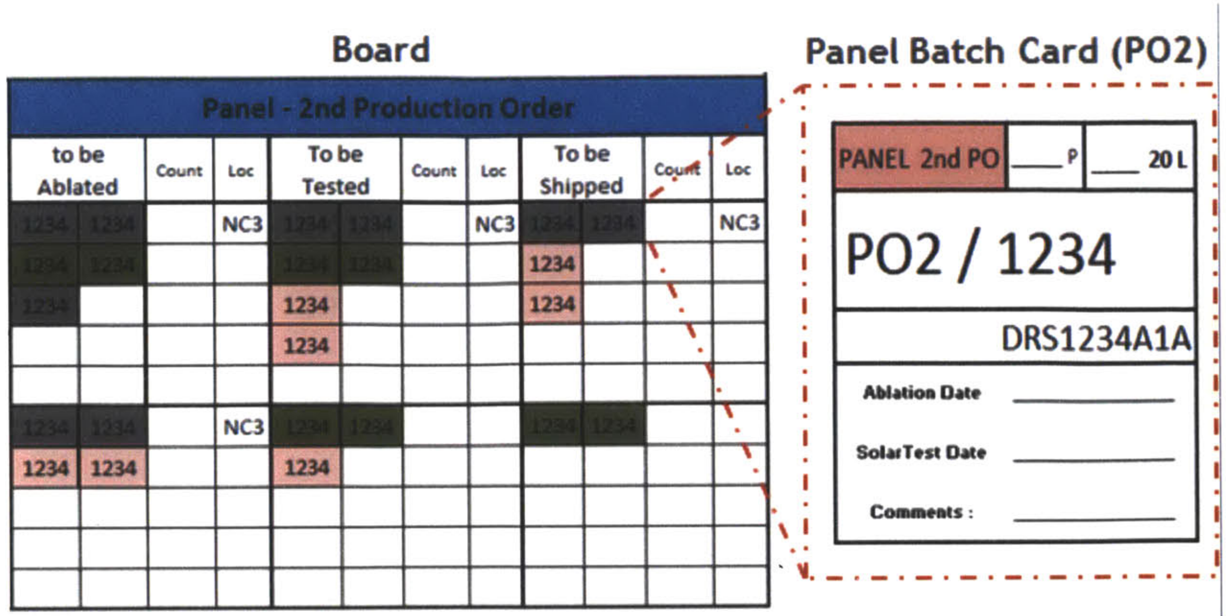

Figure 18 - PO2 Inventory Tracking Board and Card Design

Similarly, PO1 cards move along until they have been baked and are waiting to be ablated. A similar transition from PO1 to PO2 cards would take place here. PO1 cards usually represent larger batches of panels, and would be broken down to small batches in PO2 before ablation.

An operator only needs to update the Kanban board after major process completion or before he leaves the facility. PO2 cards are discarded or recycled after their corresponding batches of panels have been solar tested.

The Kanban card board basically operates as we designed. The actual board and card's appearance, however, was constrained by the equipment available for purchase, which is discussed in the following implementation portion of the results and discussion section.

4.5 Kaizen Continuous Improvement Board

The team has installed a Kaizen board on the shop floor that displays the Kaizen activities, suggestions, quarterly targets and the monthly 5S audit. This board acts a communication medium between the operators involved in the Kaizen activities, process engineers and any other stakeholders in the production and operations regarding the potential problems that exist on the shop floor, possible improvements, ongoing Kaizen initiatives and the progress of the company in the 5S's. [19]

The Kaizen Board is divided into four sections – Kaizen events section which displays on going, and future events, 5S audit section which displays the results of the monthly audit, Quarterly targets section which defines short term production goals which can help operators think about possible improvements, and a past achievement section. All these sections would help inculcate the continuous culture and improve participation by the operators on the shop floor.

4.5.1 Layout of the board

The Layout of the board is divided into 4 sections; the first one is the monthly 5S audit filled out by the shop floor operators, followed by a second section that lists quarterly targets set by management for the company and an employee suggestion area where operators can give ideas for improvements to reach the targets. These two sections are followed by a Kaizen event progress section which tracks the progress of ongoing improvement activities. (see figure 19)

4.5.2 5S Monthly Audit Display

A 5s audit is typically conducted periodically by the foreman on the shop floor and the results of the survey will be displayed on the board so as the clearly point out the possible areas of improvement. This survey can also be updated after each successful Kaizen event so that improvements can be clearly visualized. We believe this can help increase employee participation in the continuous improvement events. This also helps us categorize the Kaizen improvements into Sort, Straighten, and Shine etc. and ensures focus on issues on which we have low ratings. This defines the current stage of the system. The survey is available in the Appendix C.

4.5.3 Goals and Methods

This section is divided into 2 parts. One part defines the goals that we need to achieve and the other defines the means to achieve the goals. The quarterly targets part defines where the company needs to be by the end of the current quarter and are assigned priority numbers. This acts as a forum for the management to define company's growth direction.

The second part is where employee suggestions can be collected. Employees can see the goals and current situation on the 5S board and suggest ideas that will help achieve the above mentioned goals. They can write their ideas and place the card in the Kaizen ideas sections. The date on which the idea was put on the board is also recorded to ensure that all the ideas are looked into by the Kaizen team without any delays.

4.5.4 Kaizen Project Status

This section tracks the status of the Kaizen projects through the various stages from review to implementation. Some of the ideas from the employee suggestions section are selected and the cards are moved to the Kaizen project section of the board. This section has 8 buckets which represent the status of the event.

- Review by Kaizen Team
- Review by Management
- Approved Projects
- Planning (PLAN)
- Implementation(DO)
- Compare Results (CHECK)
- Analyze Issues (ACT)
- Successfully Completed

Continous Improvement Board

Monthly 5S Audit

Category	Criteria	0	1	2	3	4
Sort	**Distinguish between what is needed and not needed**	0	1	2	3	4
Sort Through & Discard Unused Items	Procedures are established to identify unnecessary items					
	Unneeded **equipment,** storage, furniture, etc. is not present on the shop floor					
	Information or items on bulletin boards, etc. are up-to-date and clear					
	Unneeded **inventory,** supplies, parts, or **materials** is not present on the shop floor					
	Aisles, stairways, corners etc. are free of items					
	Unnecessary items on the shop floor are tagged clearly					
Straighten	**A place for everything and everything in its place**	0	1	2	3	4
Use Labels, Signs & Colors to identify Normal vs. Abnormal Conditions	All tools and material have a specific location					
	All tools and material are placed in the designated location					
	Work in progress inventory has a specific location					
	Work in progress inventory is placed in the designeted location					
	Work in progress inventory quantities are marked and accurate					
	Work surfaces and equipment locations are identified and labeled					
	The maximum and minimum allowable quantities are indicated on storage racks					
Shine	**Routine discipline maintaining a clean and organized workplace**	0	1	2	3	4
Cleaning is a Method of Inspection, Look for Hidden Defects	Equipment, computers, work surfaces, and storage areas are clean					
	Garbage and scrap are collected and disposed correctly					
	Paperwork is filed daily					
	There is a person taking responsability for coordinating cleaning operations					
	Floor is swept and equipment is cleaned regularly					
Standardize	**Preventing the area from having abnormal operating conditions**	0	1	2	3	4
Standardize the Rules to Make 5S a Habit	Specific cleaning and organizing tasks have been developed and assigned for the work area					
	Staff is trained and fully understands 5S procedures					
	5S standards are clearly displayed					
	Visual management tools identify if work is complete					
	Improvement memos are regularly generated					
Sustain	**Stick to the rules (self-discipline)**	0	1	2	3	4
Sustaining plans are developed to ensure accountability	Everyone is involved in the improvement activities					
	Standardized operating procedures (cleaning and work) are followed					
	5S documentation and instructions are current					
	5S audits occur regularly					
	Procedures are up-to-date and regularly reviewed					

Goals and Methods

Quarterly Targets	
Sort Score to reach 3	3
Standardize Score to reach 3	2
Laminator Yield to increase to 90%	4

Employee Suggestions

Kaizen Ideas	Date

Kaizen Projects

Status	Project	Date
Review by Kaizen Team		
Review by Management		
Approved Projects		
Planning (PLAN)		
Implementation (DO)		
Compare Results (CHECK)		
Analyse Issues (ACT)		
Successfully Completed		

Figure 19 - Kaizen Continuous Improvement Board Design

Chapter 5: Results and Discussion

Konarka's manufacturing facility is undergoing major process and system updates, and current operations produce solar panels mostly for various process testing purposes. Hence, current actual production data is unavailable, and the changes implemented by the group cannot be reflected on actual quantifiable productivity measures. However, past production data and analysis can be found in Jason Chow's thesis [5], and feedback from operators and management can be found in Susheel Gogineni and Gregorio Colaci's thesis [6,7].

5.1 UV 2D Barcode Tracking

The UV 2D barcode printer was already operational when our team started working at Konarka. The UV barcode reader (Keyence SR600), however, experienced some problems with the UV lamp angle and data matrix recognition [22]. Working at the bussing station, our team attempted to adjust the lighting condition as well as the matrix recognition software with the barcode reader without success. Working with Konarka's tracking system team, we have determined that we had to go with a new UV barcode reader from InData Systems™. Particularly, the tracking system team purchased InData Systems™ LDS4620 cordless hand held UV barcode reader as shown in figure 39 in Appendix A. It is a robust barcode reader that scans both 1D and 2D barcodes. A picture of this barcode reader is shown in figure 32 in Appendix A. The UV barcode reader has been implemented in the bussing station to track production. However, due to the testing and updates of the manufacturing facility, quantifiable production data is still unavailable. Currently, the plan is to continue with integrating this barcode reader at other stations and the automatic version of this barcode reader that is capable for faster readings.

5.2 Barcode Tracking System Design

The current barcode tracking system is still under development. Therefore, only the tracking system design is presented in this section. The implementation is done in phases, and we were able to obtain some past data and some processing data at some of the processing stations. This analysis can be found in Jason Chow's thesis [5].

This tracking system is designed to track the flow of material through the finishing stages of OPV manufacturing, which are defined as all the processes after the coating process.

The overall tracking system is shown in Fig. 20. . The three tests shown in figure 16 are visual inspections for aesthetic defects whereas the last "mA" current test is solar power performance test. The red bins are rejection bins where defective panels would be removed and corresponding defect information recorded into the database via the barcode tracking system for future review.

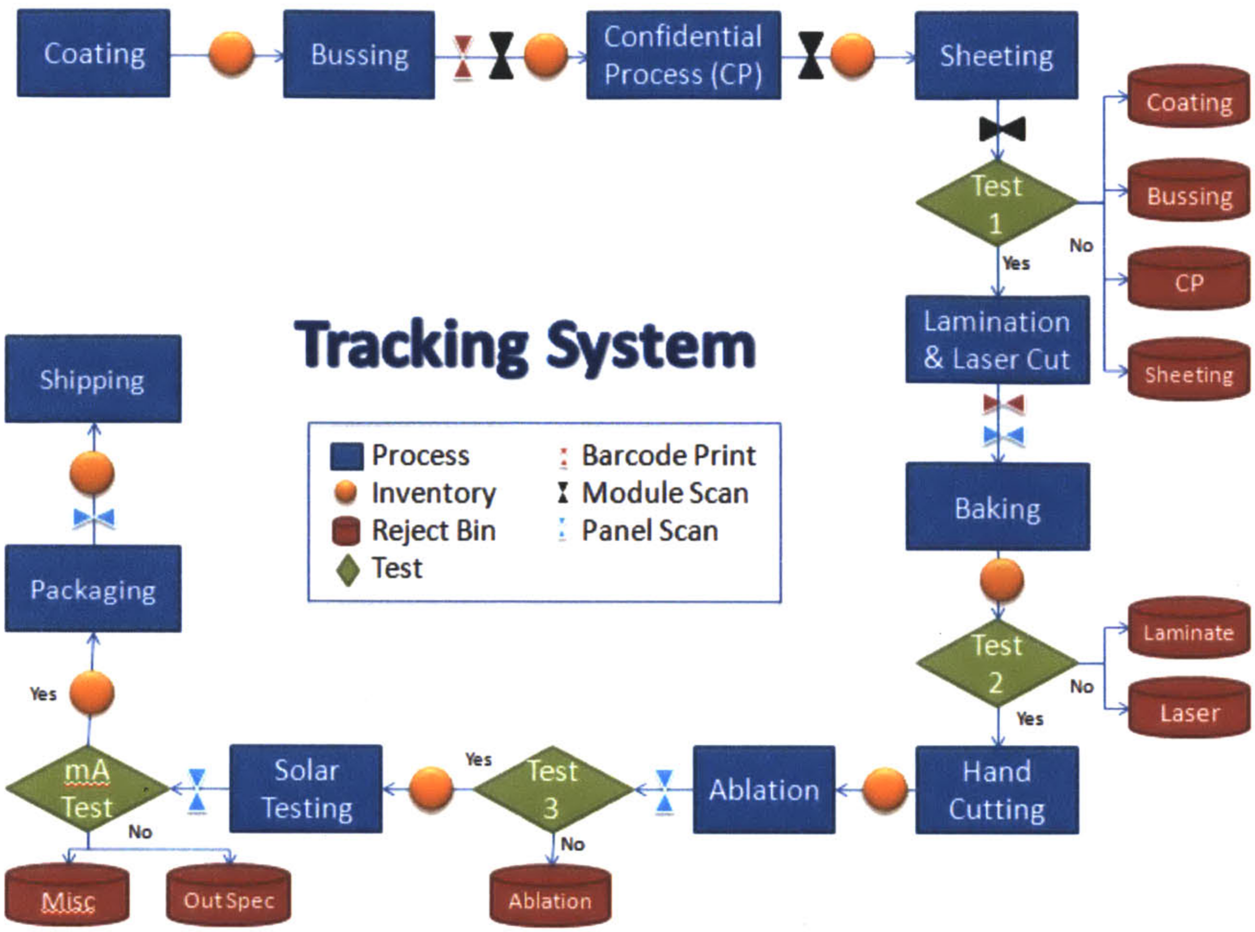

Figure 20 – Barcode Electronic Tracking System Schematic Diagram

Bussing is the 1st stage of finishing. At the bussing station a UV 2D data matrix code is printed on each of the modules and is read immediately by an in-line reader and entered into a database. The reading process also doubles as a verification system that checks the integrity of the printed data matrix code. At this stage all the modules are considered good and the same is reflected in the database. Any issues that are identified during the bussing process are tagged by physically marking the specific module with a colored marker or sticker for removal after sheeting. This process will later be automated. After bussing the roll is wound and sent to the C.P. station. See figure 21 for details.

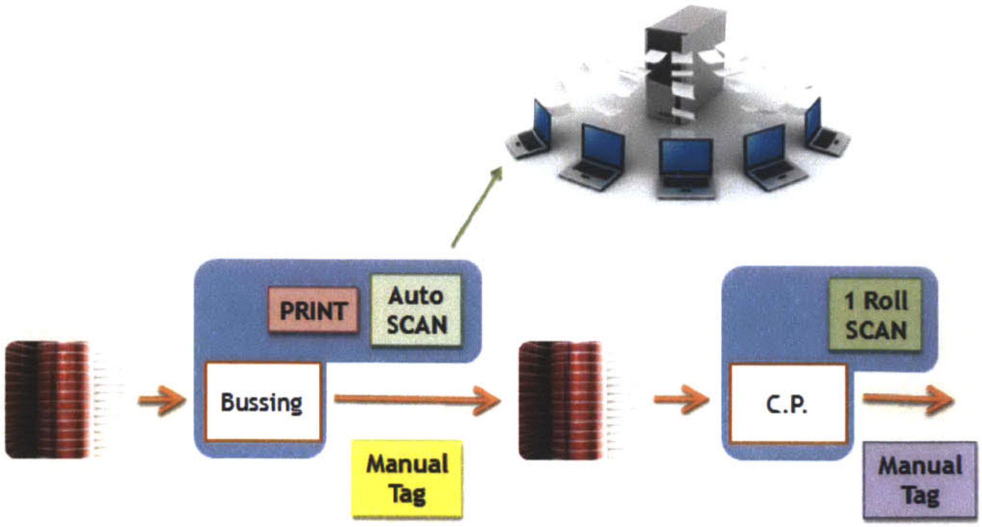

Figure 21 – Roll Product Tracking at Bussing and C.P. Workstations Concept

At the confidential process (C.P.) station, not all the individual modules are not read, but only the first good and last good modules are read. This marks all the modules in between these two series of numbers as good. This avoids reading all the modules again and is still accurate as no modules are removed from the roll at this stage. Any problems that occur during the C.P. stage is tagged with color markers or stickers similar to the bussing step. The roll is wound and sent to the sheeter after which defective panels can be removed.

The roll is next sheeted into individual panels. A panel consists of one or more modules. This is the first stage where bad panels can be removed from the roll, and associated information can be entered into the database. The stickers or markings made during the C.P. and bussing steps are helpful in identifying the bad panels. The bad panels are scanned using a hand scanner and are categorized according to the type of issue.

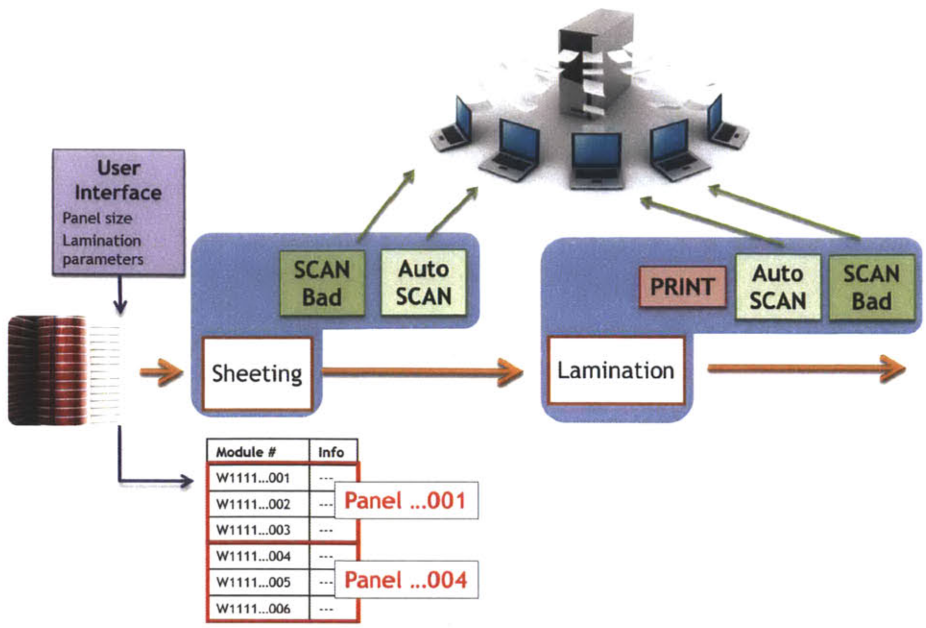

Figure 22 – Panel Tracking at Sheeting and Lamination Workstations Concept

As seen in figure 22, the remaining good panels make their way to the laminator through a series of conveyer belts. The UV data matrix cannot be read once the panels are laminated with UV blocking barrier material. Hence a second UV 2D barcode is reprinted on the barrier material along with a product code.

These panels are read once again before entering into the laminator and the information hence captured is attached to the new barcode printed on the barrier material. The new panel barcode should contain information about all the modules that make that panel. This read helps in verifying the information collected in the database till this stage, hence making the system error proof. The printed barcode is read again by an in-line reader and this information is entered into the database.

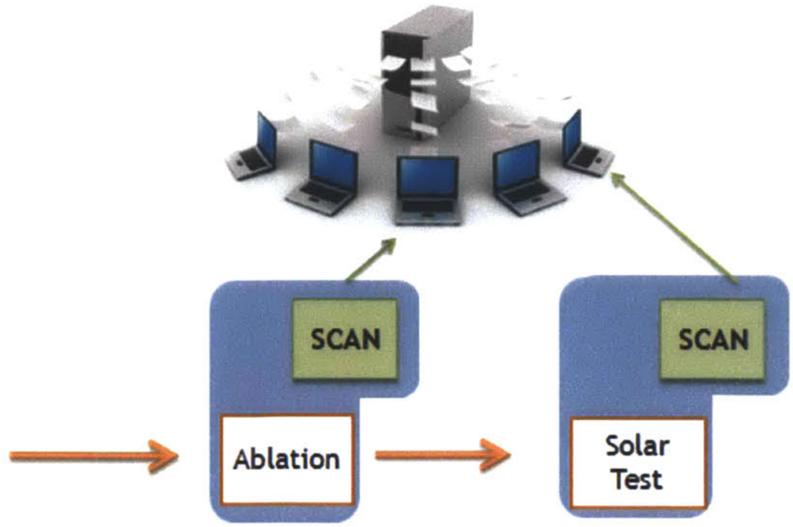

Figure 23 – Panel Tracking at Ablation and Solar Testing Workstations Concept

At the end of the laminator, there is a quality check station where all the bad panels are tagged using a hand scanner and categorized according to the type of issue. After this, the panels are sent for baking, close inspection, and ablation where they are scanned again using a hand scanner mounted directly on the machine. Occasionally, in case of failure of laser cuts in the lamination machine, another manual hand cut takes place after inspection to trim the panel edge to desired dimensions. In case of any mistakes during the ablation process, the operator can manually tag them as bad from the workstation located next to the machine. Finally the panels are scanned once again at the solar tester and are tagged as bad in case they do not meet required voltage or current specifications.

5.3 Tracking System Implementation

Based on the tracking system, we worked with Konarka's tracking system team on the implementation stage. We propose to carry out the implementation in 3 phases, and currently are at phase 2 of the implementation process.

Phase 1 – This is the hardware verification phase where all the printers and scanners are being tested. During this phase we have installed the inline data matrix reader on the bussing machine and have successfully collected data. We have faced quite a few challenges during this phase, especially in getting a reading from the UV data matrix. As stated before, using the new InData Systems equipments, the tracking team has completed hardware verification.

Phase 2 – Once the hardware is verified, the readers were implemented at the lamination stage and hand held scanners were being tested and installed at the downstream stages. The second UV barcode printer and reader will be synchronized with the UV 2D barcode reader between sheeting and lamination. All barcode printer and readers will be tested for high speed tracking up to 30 ft/min.

Phase 3 – After testing the system with the current stage of implementation we propose to move the printing of UV data matrix from the bussing step upstream to the coating step. This will help us to track the rolls of material at all the processing steps, including the WIP after coating. The bussing stage will use a similar system as the current C.P. step.

5.4 Operator Interfaces

As part of the barcode tracking system, the software development side of the project is crucial for the success of the entire system. Teams of engineers are working on barcode tracking software, and our team has been requested to present an operator user interface template for the system. A series of graphical user interfaces for the tracking system have been created without actual callbacks. This set of interfaces can be integrated with the company's tracking system softwares that is currently under development. Alternatively, these interfaces can serve as a graphical template for interface designs.

A MATLAB Graphical User Interface (GUI) program has been used to develop templates of a series of operator interfaces for this barcode tracking system. MATLAB GUI, similar to Visual Basic, allows the user to create a realistic graphical user interface with relative ease. Operator interfaces developed by Susheel Gogineni and the author are shown below in figures 24 to 33.

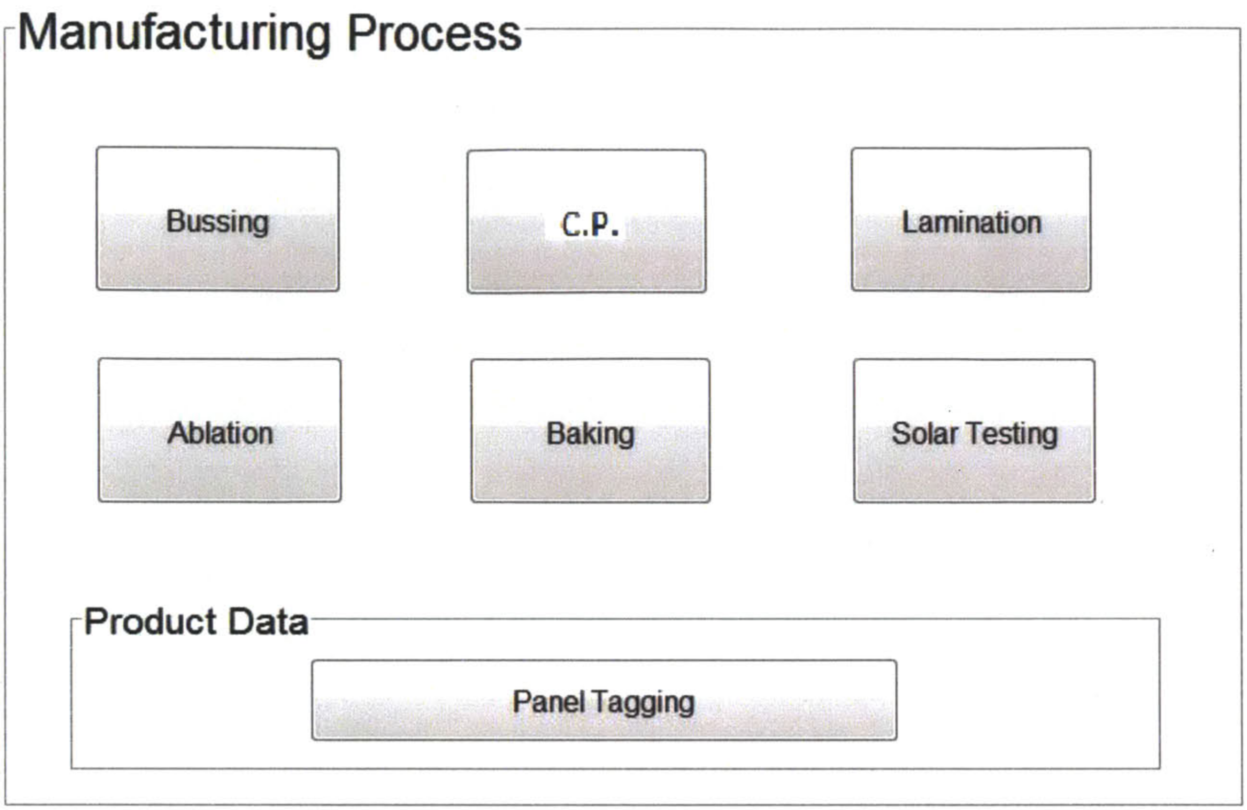

Figure 24 - Barcode Tracking System Operator Interface Home Menu Page Template

Figure 24 above shows the home menu for the barcode tracking system. This page allows the user to go to any of the six primary finishing processes as well as a panel quality tagging process. Click on any finishing process to start an individual manufacturing process or setup. For the bussing, C.P., and lamination processes, there are significant setup times involved. To more accurately account for such setup times, an automatic time counter and operator input are proposed. An automatic time counter is proposed to start ticking as soon as the bussing, C.P., or lamination button is pressed, and the count stops when the operator press starts to finish setup (as shown later). This requires all operators to follow a structured operational procedure while using the tracking system. Another setup time manually inputted by the operator is required in the later interfaces.

A panel tagging button and subsequent interface is used to record solar panel quality information including various defects and related information. Ideally, each workstation is capable of running multiple tracking system interfaces so that the panel tagging interface can also be run concurrently with any other process.

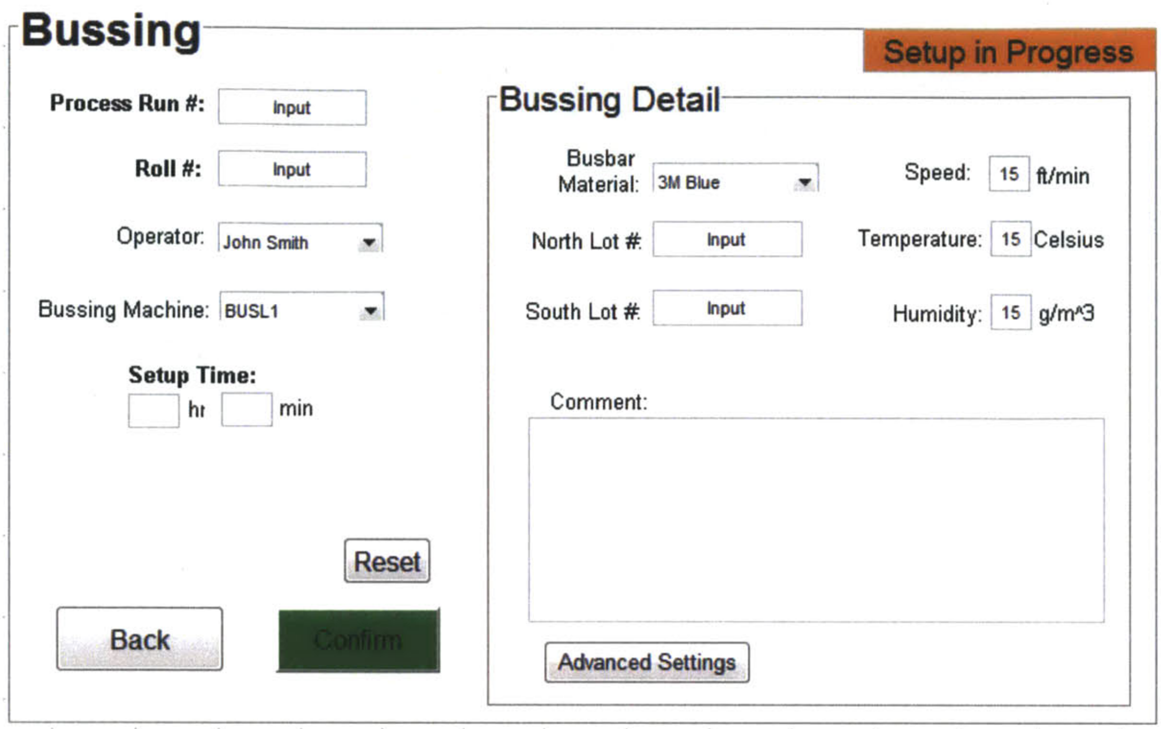

Figure 25 - Bussing Setup Input Page Operator Interface Template

Figure 25 is the bussing setup page. Here, the operator can input all relevant process information such as process run #, roll #, setup time, and bussing speed. The "Confirm" button finishes the bussing setup operation and moves on to the next "Bussing in Progress" screen. Advanced settings shown in figure 26 contain more detailed process parameters that are not changed frequently, and it will mostly be used by engineers. The comment section allows the user to record any other unforeseen problems or concerns.

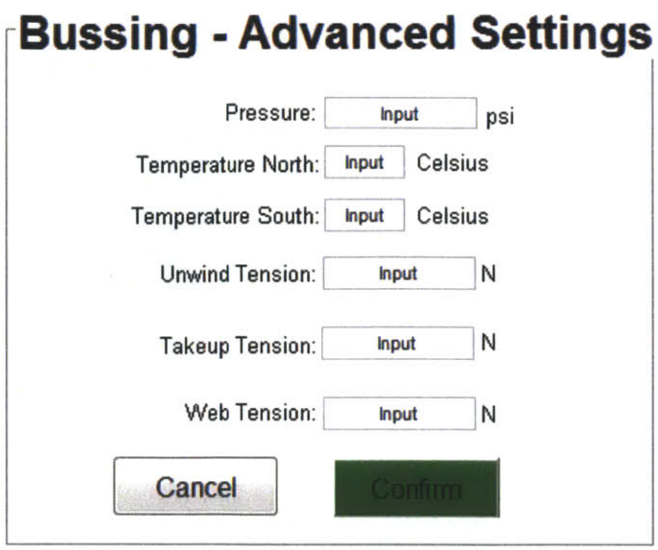

Figure 26 - Bussing Advanced Settings Input Page Operator Interface Template

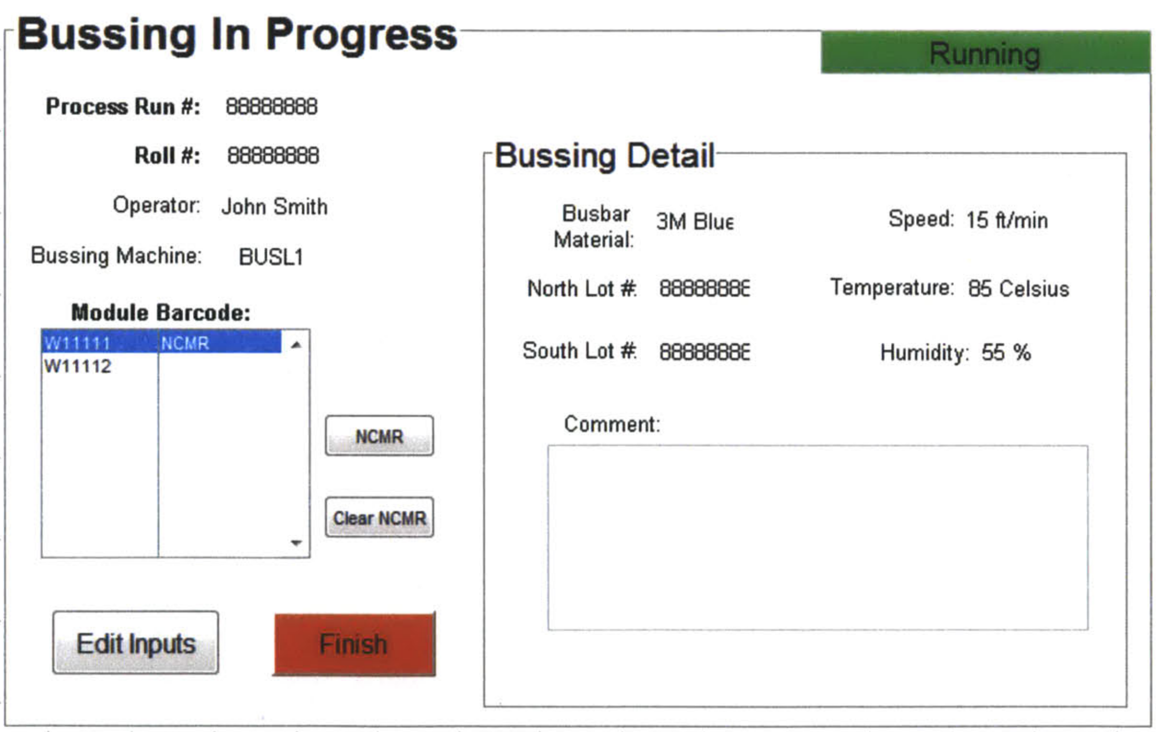

Figure 27 - Bussing In Progress Monitoring Page Operator Interface Template

Figure 27 is the "Bussing in Progress" screen. In this screen, all the process parameters are fixed and the scanned solar module barcode will be updated in a list as it is being read by a barcode reader right after it has been printed. NCMR stands for Non Conforming Material Review. The "NCMR" button will record the module status as NCMR instead of clear, and this information will be passed down to later processes that can further review the module or panel as good or defective, and remove the defective panels. In case the operator changes any process parameter, the user can also change it via "Edit Inputs" button that leads to "Bussing – Edit Inputs" page shown in figure 28.

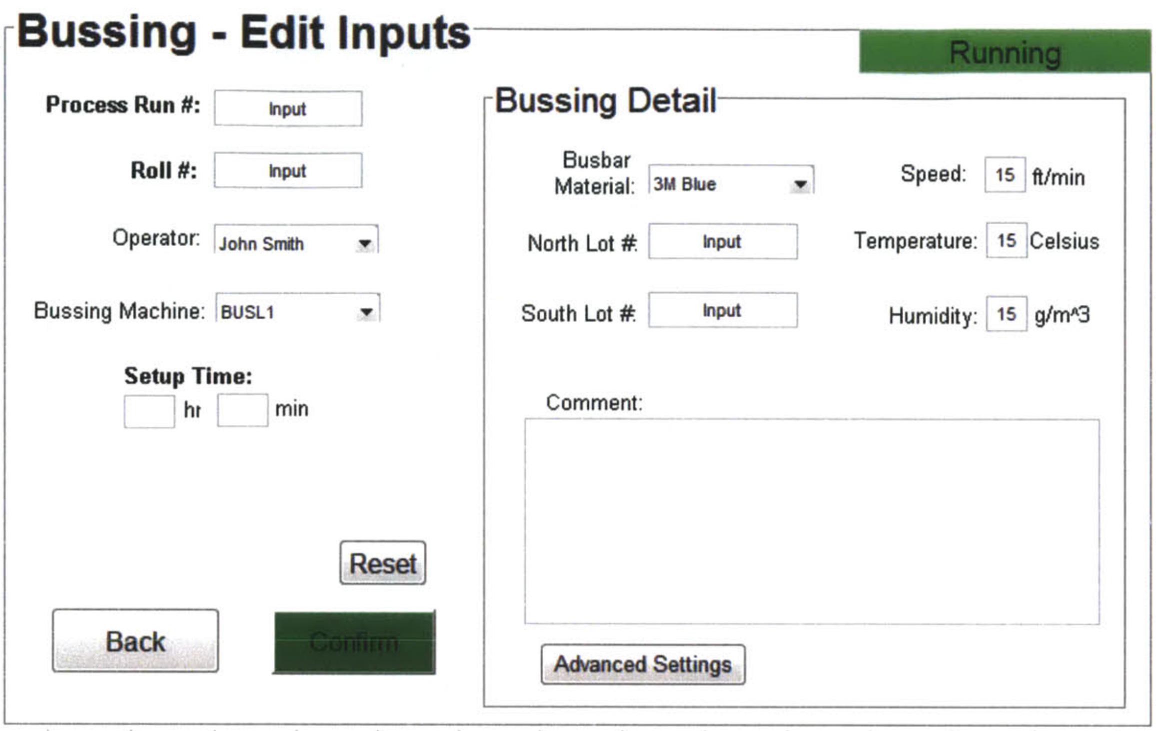

Figure 28 - Bussing Edit Inputs Page Operator Interface Template

The "Bussing – Edit Inputs" screen in figure 28 is very much like the setup page, and the "Confirm" button takes the user back to "Bussing in Progress".

Finishing the "Bussing in Progress" leads back to the home menu. All operational information will be recorded in the database. The above explanation details the bussing operator interface. In the following, only representative interfaces will be shown, and the user experience is similar to that of bussing operation.

The lamination process has many process parameters as it is the most complex machine in the finishing area. The lamination process usually is also coupled with the sheeting process which cuts the roll product into sectioned solar panels. Each solar panels may contain many modules (each module is roughly one foot long). The naming convention is to have the number of modules followed by two digits representing number of lanes. For example, 340 means three modules and forty lanes solar panel and 1160 means eleven modules and sixty lanes solar panel. For "Lamination in Progress", each solar panel will be sheeted appropriately. Another barcode will be printed onto the panel and read immediately after lamination. Each panel may have many modules, and all of this information will be displayed on the screen while lamination machine is running.

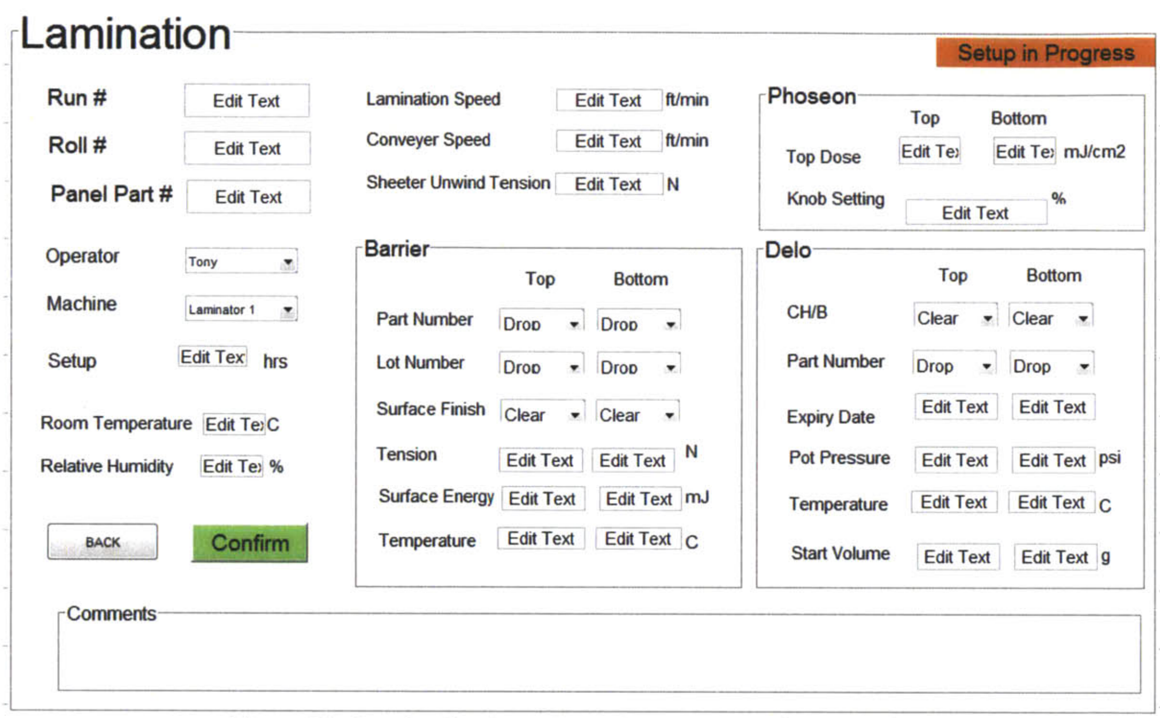

Figure 29 - Lamination Setup Page Operator Interface Template

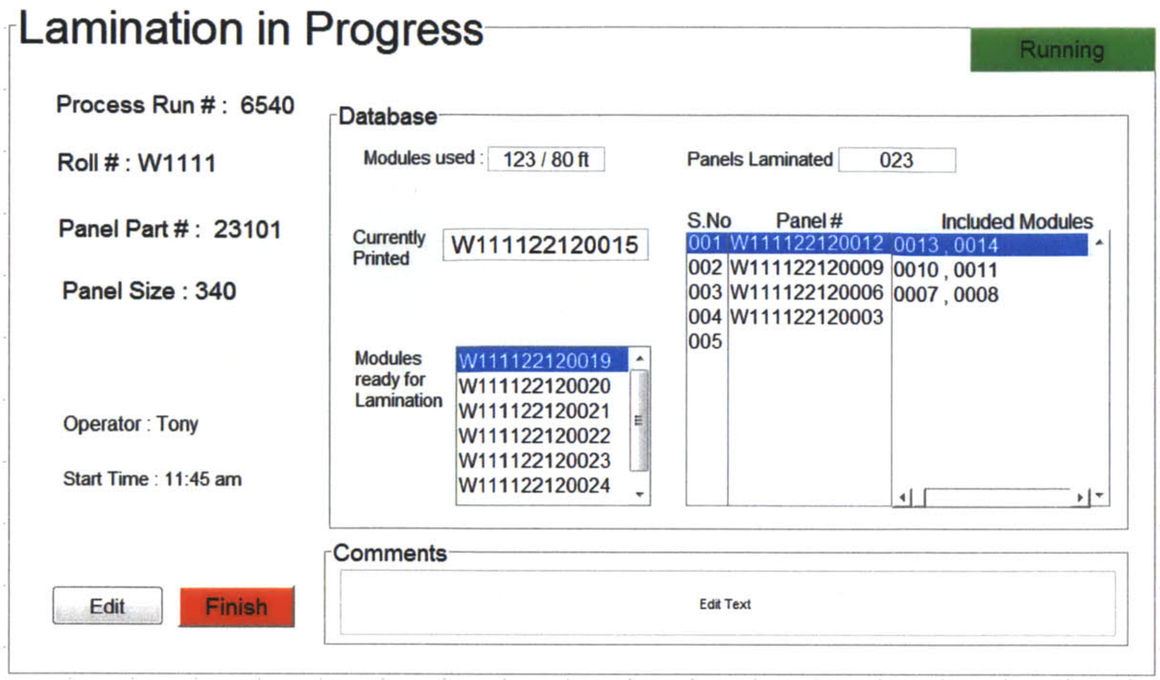

Figure 30 - Lamination In Progress Page Operator Interface Template

The ablation process is still very labor intensive. The figure 31 interface will keep track of all the ablated panels as they are read by a barcode reader, and the tagging option to record any defective panels.

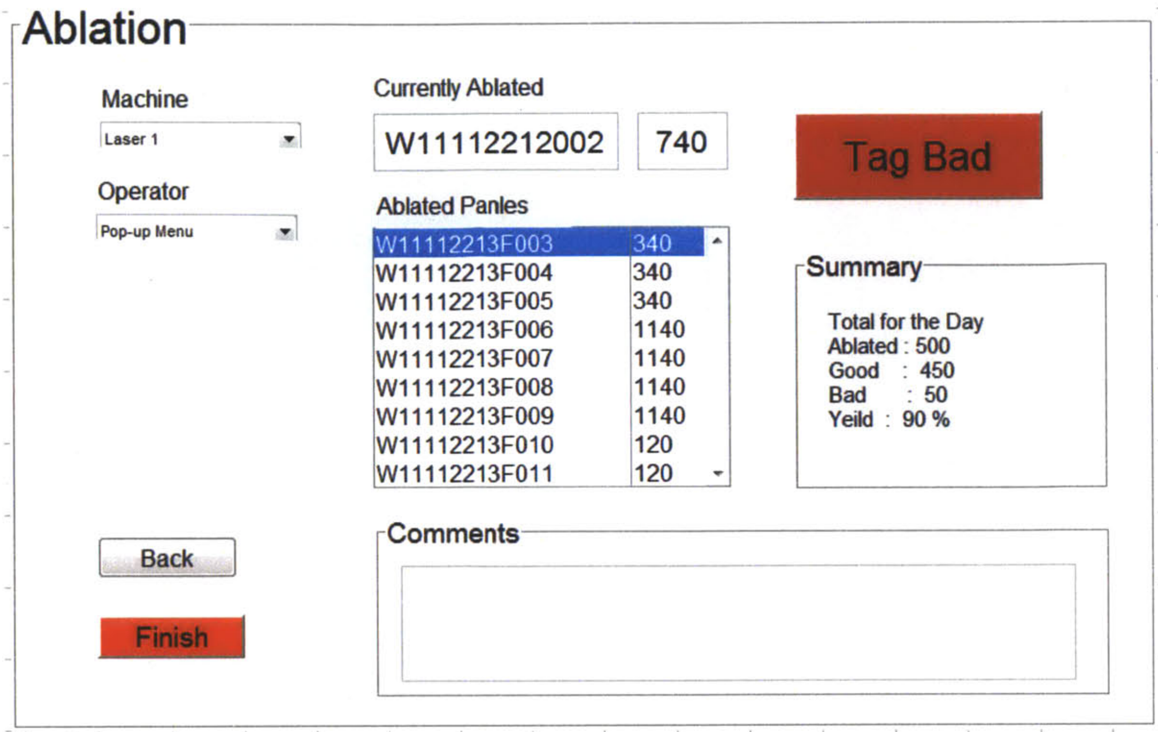

Figure 31 - Ablation Workstation Operator Interface Template

After ablation, the panels will be baked for an extended amount of time to cure the adhesives. Panels will be baked in batches, and the operator needs to keep track of the panel range in each batch.

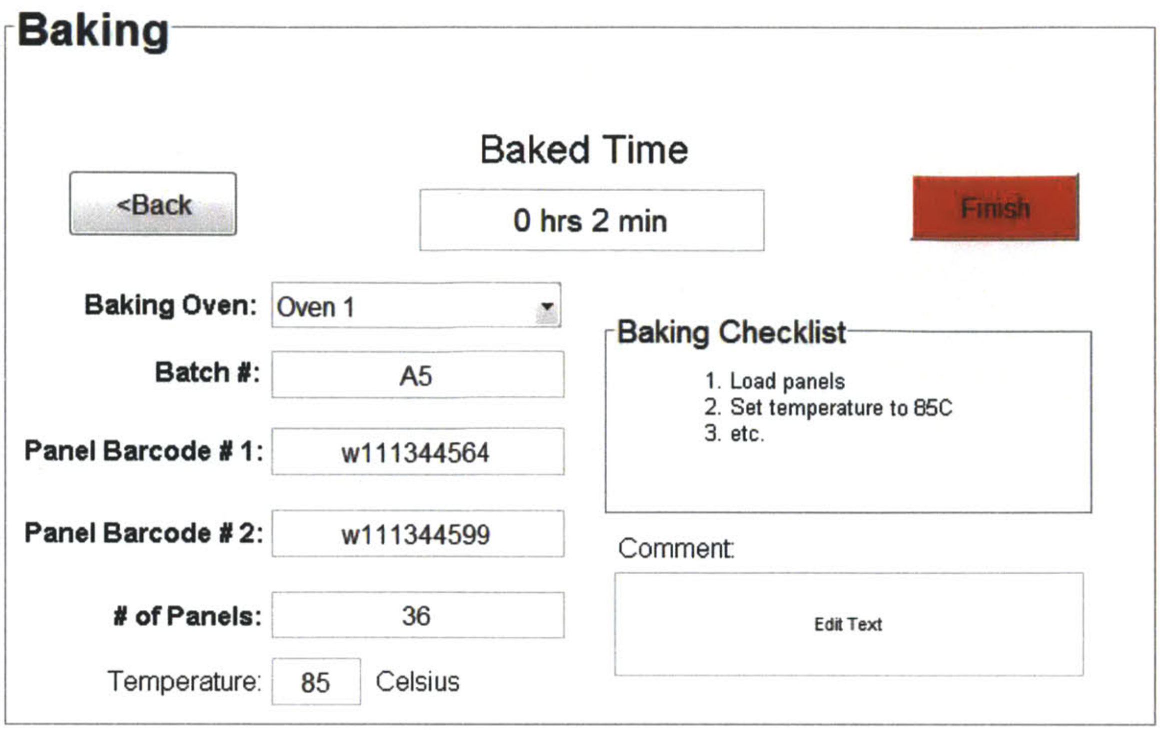

Figure 32 - Baking Process Operator Interface Template

Questionable panels must be reviewed at an inspection table. There are also designated inspection table after major processes such as lamination. The panel tagging interface shown in figure 33 allows the user to tag a panel defective and the exact quality issue associated with it. Such information is critical for manufacturing yield improvement.

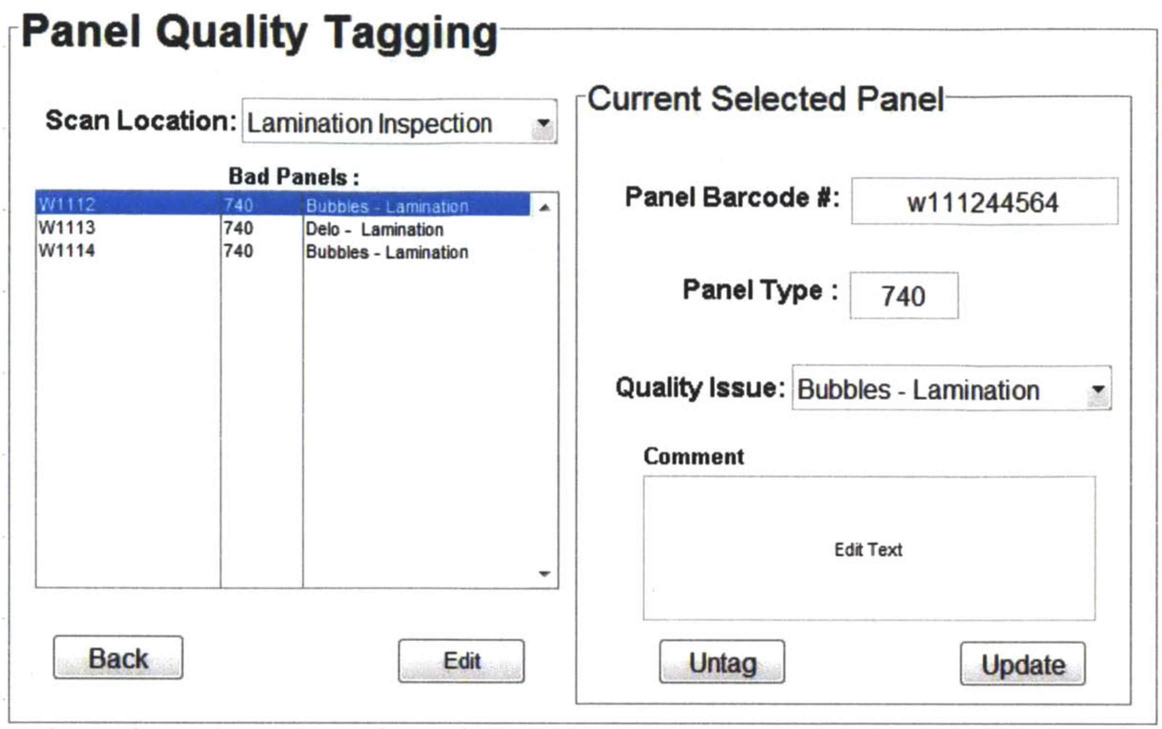

Figure 33 - Panel Quality Tagging Page Operator Interface Template

This concludes our operator interface designed with MATLAB GUI. Other interfaces are shown in figure 37 in Appendix A. With the help of Konarka's IT team, these interfaces are currently under development in Konarka's Lowell research facility.

5.5 Kanban Information Board Implementation

The purpose of this production information board is to track WIP inventory and production information. This is particularly important for the interim period before the barcode system becomes online.

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 34 for details.

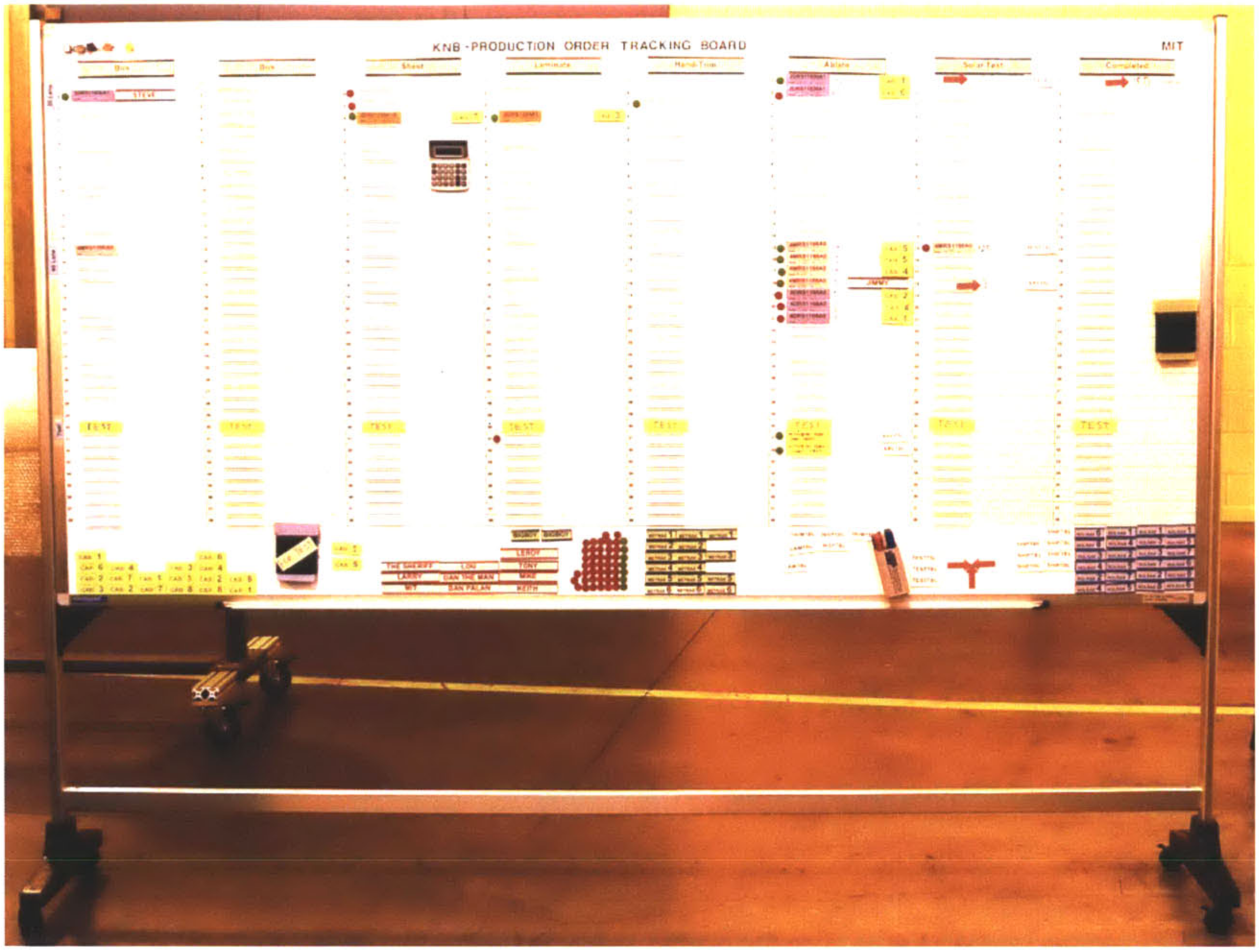

Figure 34 - Kanban Production Order Tracking Board (purchased from Magnatag [16])

Roll and panel batch cards are generated after the roll has been coated, and the lot of four cards (one roll card and three panel batch cards) are inserted to the "bus" column waiting to be bussed. The representative card moves across the row as explained earlier until it hits the "completed" column waiting to be shipped to the customers.

This board comes with multiple magnetic tagging features to help users identify the exact location and status of WIP solar panels. As seen from figure 35, a name tag indicates the operator who is responsible for the current roll of solar panels, and the roll card header has the barcode information as well as the roll/panel and production order information.

Figure 35 – Kanban Production Tracking Board Zoomed to Roll Inventory Tracking Section

A green circle tag signifies that the roll or batch of solar panels are being processed, an arrow means the batch of panels is separately located suggestive of different stages of manufacturing process, and a location tag indicates the inventory location. The board is updated either when the operator finishes a roll/panel batch or when the operator leaves the workstation. For example, if an operator ablated part of a batch of panels from nitrogen cabinet 1 for the day, then he should update the exact panel counts accordingly as in figure 36. Recently, company is reconsidering merging the two panel batch production orders to one single production order, so it may be unnecessary to segregate the board into sections.

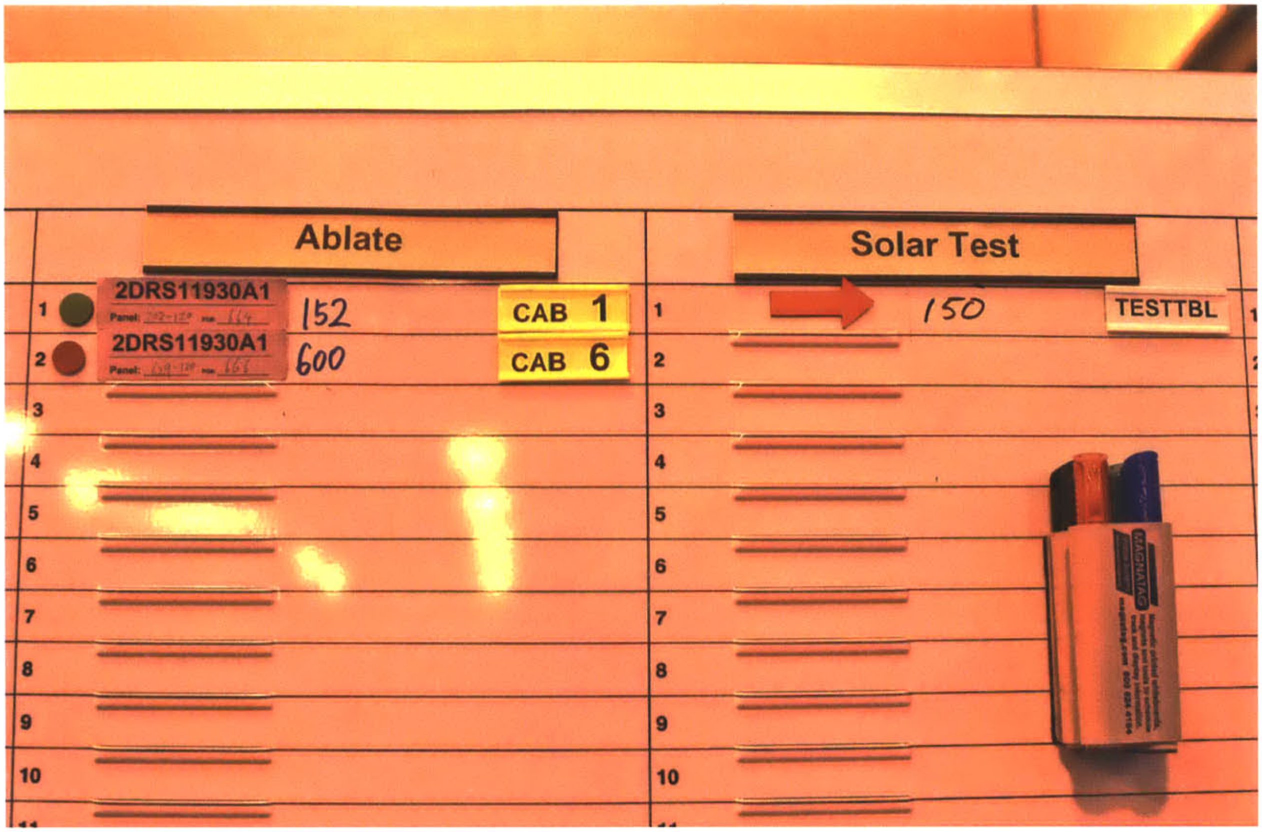

Figure 36 – Kanban Production Tracking Board Zoomed to Panel Batch Tracking Section

5.6 Kaizen Continuous Improvement Board Implementation

Recall the purpose of a kaizen board is to keep track of all the improvement projects in the facility. A Kaizen improvement board was implemented on the shop floor in a central location accessible to all the operators. The operators were trained on the purpose of the board and ways to update and utilize the features of the board.

The board has been implemented and placed in a easily accessible location on the shop floor. See figure 37 for details. The results of the 5S survey conducted by the Kaizen team during the material flow Kaizen event are updated on the board. A foreman has been assigned to update the survey on a monthly basis. Management has updated the targets that they plan to achieve in this quarter. Since they are currently in the process of making their machines robust, most of the targets are set towards increasing the overall yield. The operations manager is responsible for updating this section of the board. The operators were proactive in suggesting ideas and are getting used to the concept of using the board. We have updated some of our ideas also in the suggestions section. The layout improvement Kaizen event (see Gogineni's thesis [7]) has been added to the Kaizen projects section. This improvement project is currently in the implementation section. Some of the completed activities like production scheduling tools are placed in the finished projects section. This provides a good base on which the company can build a continuous improvement culture.

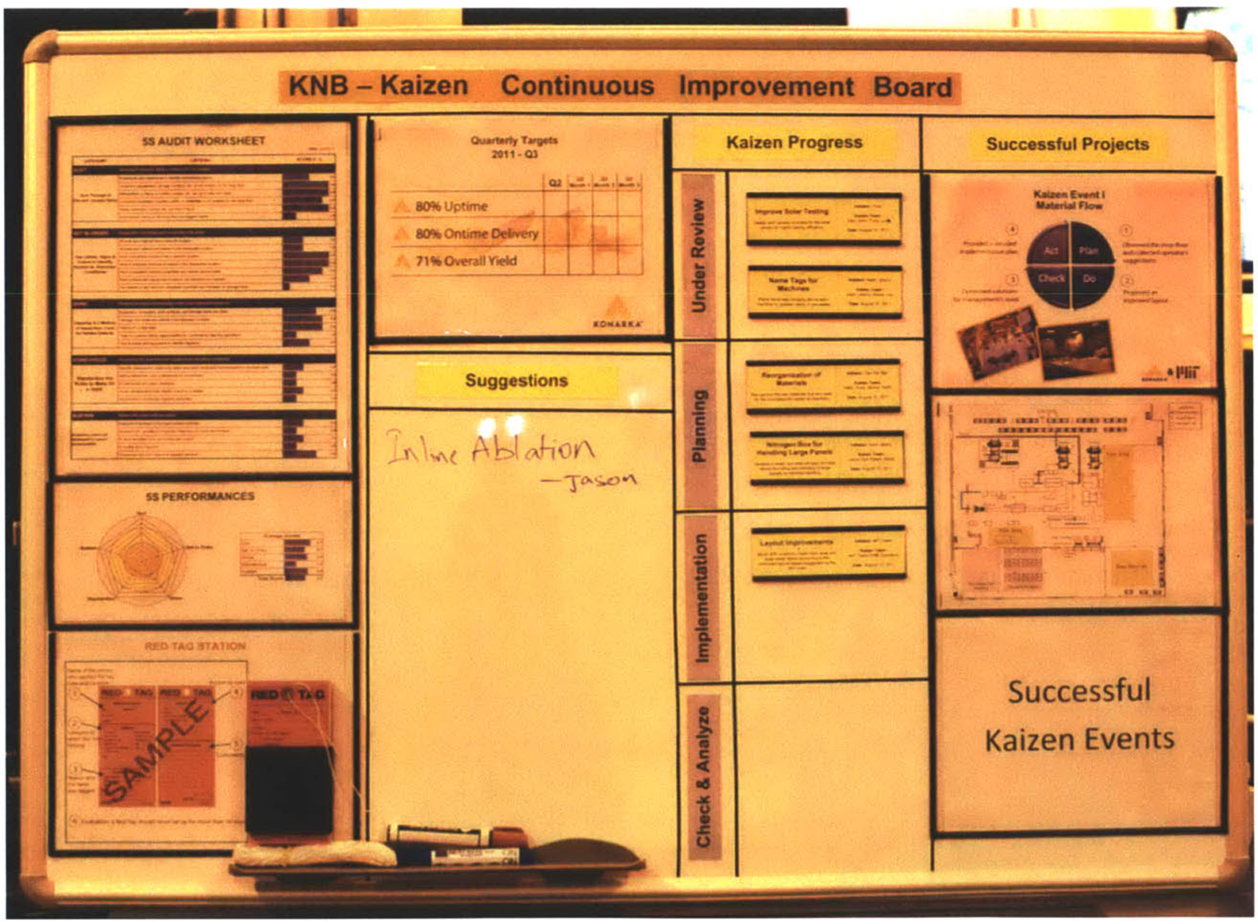

Figure 37 - Kaizen Continuous Improvement Board

Chapter 6: Recommendation and Further Work

6.1 Barcode Tracking System

The barcode hardware has been validated, and the UV 2D barcode printer and reader should be moved to the end of the coating processes soon. Nevertheless, the barcode tracking system implementation is delayed by software development need.

The team has developed a complete set of tracking system operator interfaces for all major finishing processes. However, these MATLAB GUI interfaces are not implemented as the company's chief software team has been busy with other database works. Unfortunately, our M.Eng. team lacks the expertise to carry out this database software integration; therefore, it is recommended the company's software team assist in the implementation of user interfaces. Considering the span of ongoing software development and the number of Konarka's programmers, the team recommends the company hire additional programmers to work on tracking system software. The panel tagging interface could be especially beneficial because not only does it replaces manual marker tagging, it also inputs the related defect information to the database. The tracking database should be synchronized with the established Kanban card board daily to minimize confusion.

In future ramp-up production, it is also desirable to integrate an electronic form of Kanban card board with the database. Ideally, all the tracking system would be automated, and corresponding comments or batch material movements can be recorded with a scan of a barcode. In the mid to long-term future, the visual defect detection process should also be automated for mass production, and defect information can trigger corresponding responses or alarm. Later processes can take corrective actions to minimize further value addition or possibility for confusion. An electronic display can be installed on the shop floor for information sharing.

6.2 Kanban Production Tracking Board

The team has implemented a tracking system physical framework, particularly in a Kanban card board form. The Kanban card board solves the current urgent tracking need. In the current transition phase toward fully automated tracking, the physical Kanban card board serves as a simple and reliable transitional tracking system. It also helps operators to organize inventory and maintain manufacturing progress.

The next step would be to replace the physical Kanban board with an electronic Kanban display board and synchronize it with the database automatically. However, such a transform may require significant software updates. Considering the current need of Konarka, the group recommends utilizing the Kanban board and improving the board based on actual shop floor needs instead in the near future.

6.3 Kaizen Continuous Improvement Board

In terms of operations improvement, a Kaizen continuous improvement framework is established with the Kaizen board. The first major Kaizen event has been layout improvement [7]. Typically, however, Kaizen represents continuous fine tuning of operations. The Kaizen board allows all employees to contribute to shop floor improvements by taking inputs and surveys from them, and it also presents improvement method and progress to give employees a sense of ownership as well as understanding of the current facility changes.

A physical board is simple and perfect for keeping track of improvement activities. The next step would be to maintain the continuous improvement framework. Regular Kaizen activity reviews and major Kaizen projects should be schedule every quarter to uphold continuous improvement culture.

6.4 Other Process Improvement

Base on the team's interactive interviews at the company, it is desirable for the bussing process to be streamed together with C.P. In the long term future, bussing and C.P. can be streamed with sheeting and lamination as well. The ablation and fourth side cut process should be automated in the mid to long term future. Solar testing can be rather difficult to automate, but perhaps not every panel needs to be tested. Another inline baking unit with the lamination machine can also drastically improve productivity.

Chapter 7: Conclusion

The group has worked on numerous exciting projects with many unforeseen challenges focusing on information tracking and sharing as well as operational improvements. Overall, with the support of Konarka employees, the team has implemented a Kanban production tracking board to increase the current operations and inventory accountability, executed the first Kaizen event (layout improvement), and established a barcode tracking system and improvement frameworks to facilitate ongoing development of tracking system and continuous improvements. Konarka's software team in Lowell is still working on the barcode software system including the implementation of the operator interfaces, and it appears that this operator interfaces development will be delayed with the software team currently preoccupied by the online database development. After a number of iterative improvements, the Kanban production tracking board has been test used by the shop floor manager with favorable results; this completes our team's short term implementable information system as shown in figure 14 in section 4.2 of the methodology section. The management team is also receptive of the Kaizen board and layout improvement plans.

Unfortunately, updated quantifiable production data is currently unavailable because the company is still at the stage of testing and process changes. However, past production data and analysis can be found in Jason Chow's thesis [5]. Because of the extent of these projects considerable further work is still desirable to perfect the tracking system for production ramp-up. Continuous improvement is also an ongoing process. The established information tracking and sharing framework serves as a starting foundation for the mass production monitoring system in the future.

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Appendix A – Tracking System

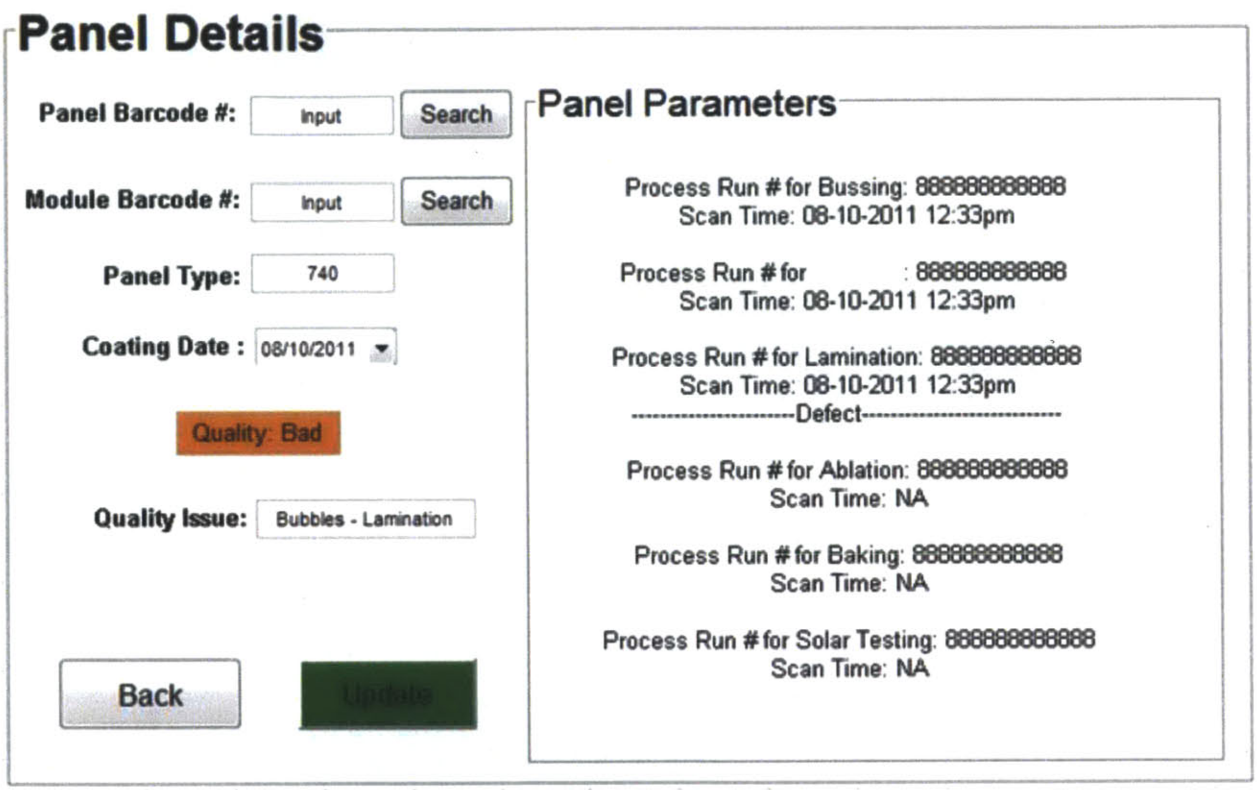

Figure 38 – Solar Panel Detailed Process Information Interface Template

Figure 39 - InData Systems™ Cordless UV 2D Matrix Reader LDS4620 [21]

Appendix B – Konarka Solar Panels

Figure 40 – Building Integrated Photovoltaic (BIPV) Solar Panel Applications

Figure 41 – City Viewed Through the Transparent BIPV Panels

Figure 42 – OPV Panel Applications in Portable Products

Appendix C – 5S Survey [17]

KNB Finishing Operations - 5S AUDIT WORKSHEET

Name: ______________________

Date: ______________________

CATEGORY	CRITERIA	Score				
Sort	**Distinguish between what is needed and not needed**	**0**	**1**	**2**	**3**	**4**
Sort Through & Discard Unused Items	Procedures are established to identify unnecessary items					
	Unneeded **equipment,** storage, furniture, etc. is not present on the shop floor					
	Information or items on bulletin boards, etc. are up-to-date and clear					
	Unneeded **inventory,** supplies, parts, or **materials** is not present on the shop floor					
	Aisles, stairways, corners etc. are free of items					
	Unnecessary items on the shop floor are tagged clearly					
Straighten / Set in Orde	**A place for everything and everything in its place**	**0**	**1**	**2**	**3**	**4**
Use Labels, Signs & Colors to identify Normal vs. Abnormal Conditions	All tools and material have a specific location					
	All tools and material are placed in the designated location					
	Work in progress inventory has a specific location					
	Work in progress inventory is placed in the designeted location					
	Work in progress inventory quantities are marked and accurate					
	Work surfaces and equipment locations are identified and labeled					
	The maximum and minimum allowable quantities are indicated on storage racks					
Shine	**Routine discipline maintaining a clean and organized workplace**	**0**	**1**	**2**	**3**	**4**
Cleaning is a Method of Inspection, Look for Hidden Defects	Equipment, computers, work surfaces, and storage areas are clean					
	Garbage and scrap are collected and disposed correctly					
	Paperwork is filed daily					
	There is a person taking responsability for coordinating cleaning operations					
	Floor is swept and equipment is cleaned regularly					
Standardize	**Preventing the area from having abnormal operating conditions**	**0**	**1**	**2**	**3**	**4**
Standardize the Rules to Make 5S a Habit	area					
	Staff is trained and fully understands 5S procedures					
	5S standards are clearly displayed					
	Visual management tools identify if work is complete					
	Improvement memos are regularly generated					
Sustain	**Stick to the rules (self-discipline)**	**0**	**1**	**2**	**3**	**4**
Sustaining plans are developed to ensure accountability	Everyone is involved in the improvement activities					
	Standardized operating procedures (cleaning and work) are followed					
	5S documentation and instructions are current					
	5S audits occur regularly					
	Procedures are up-to-date and regularly reviewed					
Comments						