Design and Implementation of an Automated Assembly Line for a Manufacturing Facility

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Abstract *— As the field of automation has become more widespread, more companies, still mostly using manual labor, are looking into it to increase their productivity. However the transition between manual operation and automatic operation is not always smooth. Several considerations need to be taken in order to ensure proper implementation of the system. The purpose of this work is to show an example of how this was achieved on a Manufacturing Facility. During the last few decades, this company has been manufacturing electronic parts for electrical vehicles using mainly hand assembly. However during recent years the company has been introducing new equipment in order to maximize its resources. After witnessing the success obtained by integrating automated equipment into our production lines, the company has decided to start focusing into this area and research how it can be applied to further improve our systems. The biggest and most recent project in which the company got involved consisted in the creation of a whole automated assembly line. This line is already running. This paper reviews the major steps needed to implement the line, its function as well as some of the major improvements we need to implement to continue improving it.*

Key Words *– Automation, Lean Design, Lean Manufacturing, Robotics.*

RESEARCH BACKGROUND

The purpose of this paper is to document the design, development and implementation of a new automated line. The line was developed at a Manufacturing Facility in Carolina, Puerto Rico. This company manufactures electronic equipment such as controllers for electrical vehicles. For years, manufacture at this facility has consisted mostly of hand assembly operations; however during the last years management has made a big effort to introduce new technologies in order to make the assembly process more efficient.

As part of this process, the company started to look towards the field of automation as one of the most promising options. It was expected that this alternative would allow the company to be able to create a more robust assembly process, which in turn allowed for increased productivity and efficiency. The goal was to create an assembly line that could run completely or almost completely in an automated way, with minimum interaction with operators.

One of the biggest constraints for the creation of this line was that it was going to be created entirely by the company with minimum external help. This was an issue due to the general lack of expertise within this area that existed throughout the company.

Although we had not much experience in the filed of automation, one area in which we have had some success, however was in the implementation of Lean Manufacturing techniques and strategies for improving our processes. During the last years the company has invested much time and resources studying these techniques, which has allowed the company to increase its efficiency and profits by identifying and reducing waste all across the different stages of the manufacturing process [1]. Given the success we have had with lean techniques, it was decided to include them as part of the creation process for this new assembly line. Part of the initiatives that we undertook as part of this effort included preparing time studies to calculate the line cycle time, evaluating material flow and kanban systems to ensure proper accessibility of material to the line and preparing layout alternatives that offered the most effective use of the space available as well as good material flow between the different areas.

Normally lean thinking is applied to existing processes, which are evaluated and modified to increase their efficiency. However, recent years have seen the increase of lean initiatives directed not only at the different production areas, but to the design phase as well. This is known as Lean Design. Lean design differentiates from traditional lean methods by aiming at the beginning stages of a process, trying to reduce or eliminate waste before it is generated and ensuring that the equipment is as efficient, and reliable as possible. By ensuring that a design is as efficient as possible from its creation, it is possible to avoid further modifications or improvements on the future [2].

In order to be able to use lean design, the first step is to be able to identify exactly what are the needs and capabilities that the system being designed will have. This information can be obtained by careful examination of the customer requirements. Understanding exactly what the customer needs allows the designer to avoid the mistakes of over or under engineering the system.

Over-engineering a system means creating a system which is more complex and that provides more, usually unnecessary, options than what the customer needs. A system with those characteristics may be hard to utilize, support and sustain and may in the long run become a burden more than a solution.

Under-engineering on the other hand refers to the creation of systems which either just barely comply with the minimum requirements or use parts and components of the lowest cost possible, regardless of reliability. Aside from the inherent reliability issues, these systems are hard to maintain and may create safety issues as time passes on.

Ideally, a good lean system would be designed so it is in the middle of these two extremes. The system should be easy to understand, operate and sustain, yet not cheap. On the other hand it should have the capability to satisfy all of the customer needs and requirements without being overly complicated.

Having already some background into the field of lean manufacturing, we needed to perform some research into the field of automation in order to begin to develop our ideal assembly line. In order to be able to integrate the concept of lean design with the concepts of automation, it was important to understand the importance of automated equipment, particularly robots, as part of lean manufacturing initiatives [3].

The use of robots in the field of manufacturing has been in increase during the last decades. Robots are recognized for their flexibility, reliability and repeatability; characteristics that make them ideal for lean initiatives. The capabilities of these robots have been further increased during the last years with the advent of tool changing stations that allow single robots to perform multiple different operations.

Even so, robots and machines cannot be naturally part of a lean process by themselves, several considerations need to be taken and accounted for to integrate them into the process [4]. Some of the considerations that need to be taken include:

- Line production rate requirement
- Space availability for robotic operations
- Cycle time requirements by station
- Repair time of equipment
- Human machine interface requirements
- Product handling requirements
- Maintenance requirements
- Safety standards guidelines
- Transportation requirements
- Allowable scrap rate
- Budget available for the entire system

Aside from these considerations it is also important to know the system requirements as expected from the customer and to also be able to identify the project constraints. Knowing exactly the customer requirements during the design phase allowed us to concentrate our efforts on implementing the desired features while not adding any unnecessary ones or overdesigning. Understanding the system constraints on the other hand allowed us to place sufficient efforts into those areas, so that they did not become a burden during later steps of the development of the project.

RESEARCH PROJECT METHODOLOGY

When designing our system, the first step was to define and understand the system requirements and constraints. In order to understand the customer requirements, periodic design meetings were held between the customers, the suppliers design Engineers and Production personnel. Also, product specs, material datasheets and supplier specifications were discussed. Following these steps helped to sped up the process, allowing every part of the team to work in unison towards the end goal. In order to determine the line constraints, the process were divided into each of its several sub processes, so that each one could be evaluated individually [5].

In order to increase the efficiency of the line, we wanted to follow the principles of one piece and continuous flow, trying to balance the cycle time of all of the stations and avoiding overproduction on each of them [6]. We also wanted to avoid excessive handling while transporting the units from one station to the next one. Another constraint that we had at the moment was the space available to develop the new assembly line.

In order to balance the cycle time of the stations, every step of the process was evaluated, taking in consideration the maximum amount of time that each station could take. In this way, we identified the operation that would require the longest time to be completed and then this time was used as the guideline by which each other station would have to comply while performing its assigned part of the assembly. However, most of these times were estimated, as we did not have enough experience with several of the equipment that was supposed to be used on this line. Based on what we expected was going to be our longest step we assumed that every station should have a maximum cycle time of around three minutes.

Other of the main problems identified during the design phase of the line was the lack of space required for it. Assembly lines can be designed in different forms and orientations (straight, L shaped, U shaped, etc.). However with the company's current space constraints, none of these traditional options were viable. After some research a new option was presented to us in the form of a flexible plastic chain conveyor. This is a modular type of conveyor that can be assembled into almost any type of configuration as needed. In our case the conveyor was configured as shown in Figure 1.

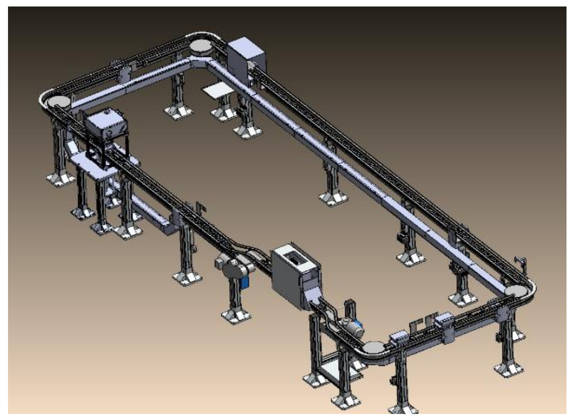

Figure 1
Flexible Link Conveyor

This conveyor was able to provide us with a simple solution to our space and logistics problems, allowing us to create a line sufficiently large using reduced space. In order to maximize the space all of the required equipment was located on the inside part of the conveyor, while operators were able to work on the outside side. This layout can be seen on Figure 2.

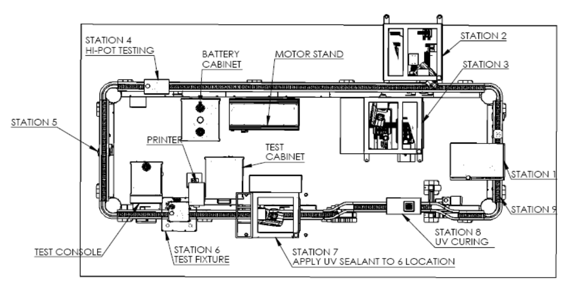

Figure 2
Proposed Assembly Line Layout

After designing the configuration of the conveyor and the equipment needed, the next step was to perform a re-layout of the area were the line was going to be assembled. The chosen area was one with several hand assembly tables for performing Touch-Up operations. In order to fit the line, 8 tables were relocated to nearby areas while 3 additional tables were eliminated. It was found that these stations performed redundant operations which actually were not required. The previous and proposed layouts for the area can be seen below on Figures 3 and 4.

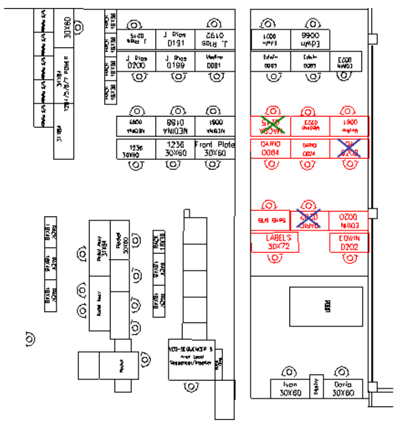

Figure 3
Previous Plant Layout

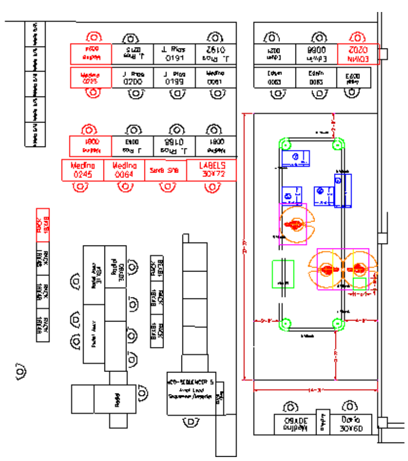

Figure 4
Proposed Plant Layout

Once we had the conveyor, the different stations were layout around it as shown in Figure 2. The original idea was that the line was going to be completely automatic however, after considering several factors it was decided that some of the stations would still need manual operation. With these considerations in mind, the different stations were designed as follows:

Station #1 would be half automated, with some manual operation. It would start the process by having one operator place one empty unit into the conveyor, after which one 4 axis SCARA robot would receive the unit and apply thermal compound on it as shown in Figure 5.

Figure 5
Application of Thermal Compound on Station #1

The thermal compound is needed as a mean to improve the heat transfer characteristics of the unit and will be applied automatically by the robot. Another part of the assembly of the unit will be performed on this station by one operator, installing two small boards and three standoffs.

Stations #2 and #3 would be the most complex stations with each possessing a 6 axis robot arm, as shown in Figure 6. These stations would work together back and forth to perform several parts of the assembly. First both robot arms would work together to install several bus bars and screws. After that, the arm on station #3 would re-torque all screws again to ensure that they are correctly installed. Following this, the arm on station #2 would change tools to pick a dispensing tip and apply RTV sealant on the sides of the unit. After this is complete, both robot arms would change tools again to pick and place a logic board, place it on the unit and secure it with screws. For the instances were the robots are working together one of the robots will hold either the bus bar or logic board while the other robot arm screws them in place, an example of this can be seen in Figure 7. Custom tooling was provided to each of the robot arms to perform their operations.

Figure 6
Six Axis Robot Arm

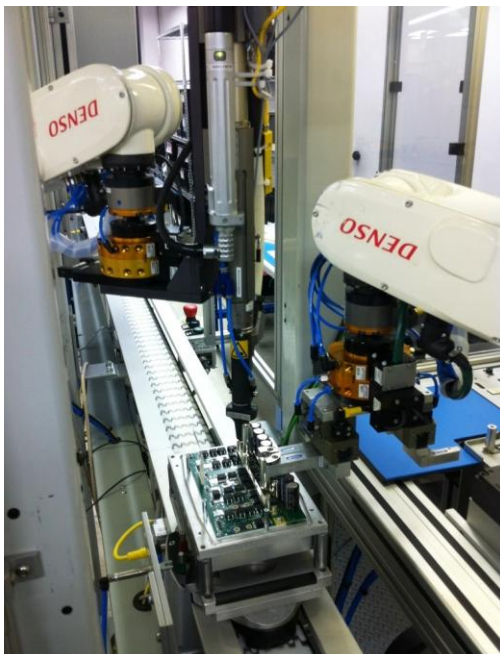

Figure 7
Robots #2 and #3 Working Together on a Unit

In order to increase the flexibility of each robot, both stations #2 and #3 were equipped with tool changing equipment that would allow each robot arm to pick and release certain tools as required to perform multiple operations. An example of such tooling system can be seen on Figure 8.

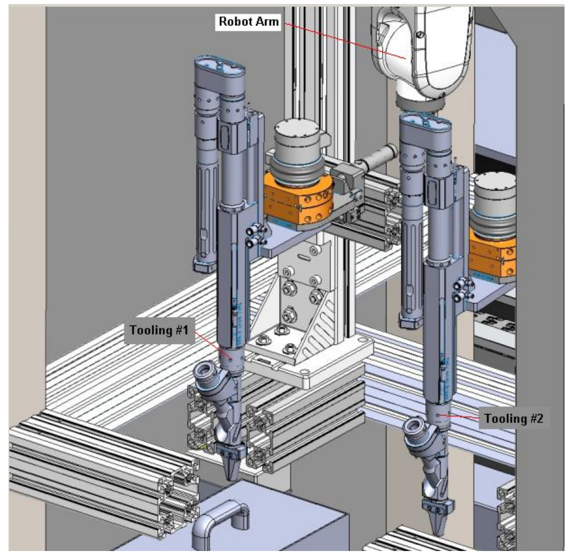

Figure 8
Tool Changing System on Station #3

On station #3 an additional system of automatic screw feeders was added to provide constant screws for the screwdrivers used by this robot arm. Using this system, replenishment for this station can be easily performed once daily without disturbing the process.

Station #4 would consist on an automated High Power testing station that will ensure that there are no unwanted electrical continuities or shorts between the different parts of the assembly.

Station #5 would also need an operator performing part of the assembly, just like station #1. On this station the unit will be automatically inspected by a simple vision system after which the operator will assemble a cover on top of the unit.

Station #6 would have an automated test stand that will verify the electrical parameters of the unit as well as simulate some of its basic functions to ensure compliance with specs. The test performed on this station is crucial in order to verify the functionality of the unit and was the station expected to take the longest time to complete, with a total time of just over three minutes.

Station #7 would use another 6 axis robot arm to apply a sealant to close the unit's cover exposed areas (see Figure 9). In order to speed up the process on this application, a UV curing epoxy was selected. This epoxy cures fast once it has been exposed to direct UV light, considerably reducing the amount of time needed before the unit can be packaged and shipped.

Figure 9
Robot #7 Applying UV Adhesive

Station #8 includes a UV light oven used to further speed up the curing time of the UV epoxy applied on station #7. After passing through this oven, the epoxy will be mostly cured and the unit will be completely sealed, this is done in order to protect it from external contamination and moisture that may affect the unit performance.

Finally, Station #9 is where the units are released and sent to storage and shipping. This operation is performed by the same operator that works on station #1.

In order to monitor and control all of the different stations an HMI (Human Machine Interface) software was installed that allowed us to create our own custom interface to control the system. This interface was supposed to allow the operators to monitor and have complete control of the entire line through its entire operation.

With all stations clearly defined, during the beginning of the year 2011, the assembly of the line was begun. In preparation, the engineers and technicians in charge of the line commenced to receive training in the fields of automation, pneumatics and PLC programming. During the next year, the parts for the line were received and it was started to be built. By the first quarter of 2012, the line started to run production.

RESEARCH PROJECT RESULTS

For this work, the goal of creating an automated assembly line was completed. We managed to design and implement an almost entirely automated line, supplementing automation equipment with hand assembly operation when needed. The assembly line is actually fully functional and in operation. Products are being made at a rate of almost 100 units per shift, although the expected rate was closer to 120 units per shift.

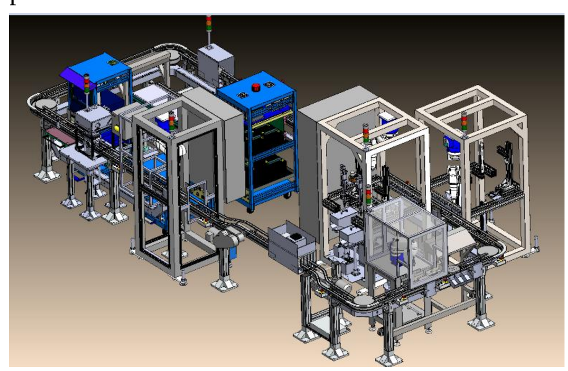

Figure 10
Complete Assembly Line Concept

However although the line was completed, there were still some areas that needed further improvement. Most of these improvements are required due to design errors or misconceptions that were unforeseen during the design stages, mostly by lack of experience with most of the equipment used. This is a normal part of lean design and the experience with these problems should allow the company to avoid them more easily in future designs [7].

One of the issues that we encountered after the installation of the line was that the cycle times did not matched what we had expected. Figure 11 shows the results of one of the time studies performed on the assembly line.

For us the most critical station was #6 since a necessary performance test is performed on this station. This was the station that was used to decide the line standard time. The average time for this station was slightly over three minutes as expected. Most of the other stations were under the estimated time. On these cases, this was not an issue since that meant we could use those stations to perform additional operations, like inspections, without affecting the process flow. However, the cycle time for stations #2 and #3, which perform operations together, exceeded the estimated time by three and a half minutes. This was something that would need to be addressed as part of future improvements.

1206AC Cycle Times

Station	Operation	Sample #1	Sample #2	Sample #3	Sample #4	Average
1	Thermal Grease Application	1:10:00	1:10:00	1:10:00	1:10:00	1:10:00
	FET & Cap Board Assy	1:19:00	1:20:00	1:20:00	1:18:00	1:19:15
	Total Station 1	**2:29:00**	**2:30:00**	**2:30:00**	**2:28:00**	**2:29:15**
2 & 3	Bus Bar Installation	3:16:05	3:01:09	2:56:05	3:10:08	3:05:52
	Retorque	1:05:07	1:02:04	1:03:09	1:03:09	1:03:22
	Epoxy Dispense	1:02:05	1:01:01	1:01:06	1:02:02	1:01:34
	Logic Placement	1:08:03	1:13:03	1:11:00	1:10:00	1:10:31
	Total Station 2&3	**6:31:20**	**6:17:17**	**6:11:20**	**6:25:19**	**6:21:19**
4	Hi-Pot Test	0:49:00	0:47:00	0:45:00	0:47:00	0:47:00
	Total Station 4	**0:49:00**	**0:47:00**	**0:45:00**	**0:47:00**	**0:47:00**
5	Cover Installation	1:30:01	1:32:08	1:34:07	1:35:02	1:32:49
	Total Station 5	**1:30:01**	**1:32:08**	**1:34:07**	**1:35:02**	**1:32:49**
6	ATS test	3:12:00	3:03:00	3:11:00	3:04:00	3:07:30
	Total Station 6	**3:12:00**	**3:03:00**	**3:11:00**	**3:04:00**	**3:07:30**
7	UV Seal Application	0:40:06	0:39:06	0:40:00	0:39:16	0:39:37
	Total Station 7	**0:40:06**	**0:39:06**	**0:40:00**	**0:39:16**	**0:39:37**
8	UV Oven (Liftgate)	6:05:00	6:02:00	6:00:00	6:00:00	6:01:45
	Total Station 8	**6:05:00**	**6:02:00**	**6:00:00**	**6:00:00**	**6:01:45**
9	Unit Retrieval	0:01:05	0:01:02	0:02:00	0:01:02	0:01:17
	Total Station 9	**0:01:05**	**0:01:02**	**0:02:00**	**0:01:02**	**0:01:17**

Figure 11
Cycle Time Study

Stations #2 and #3 also had issues related to the robots sequence and positioning. Since both robots were working on the unit at the same time, sometimes they would interfere with one another causing accidents on the assembly. Additionally, without any type of vision system to guide them, the robots could not detect bad parts and tried to assemble them, again causing accidents.

Stations #1 and #7 were additional robot arms were used also had some slight problems, however those were easily solved by changing parameters or changing the programming on their sequences.

Another issue encountered after the installation of the line was that the custom HMI that we had developed was lacking some capabilities needed for making recoveries on the line after an incident happened. For example, if one of the robot arms accidentally crashed, there was no form for the operators or technicians to return them to home position. The engineers in charge of the line needed to be called to manually home the robot arms through manual control. The HMI also wasn't able to provide sufficient information about the line as was required. Basic information such as the amount of units assembled was not easily accessible to the operators or supervisory personnel. Several improvements needed to be made into this interface before it could a reliable tool for operating the line.

Most other problems encountered on the assembly line were related to hardware or programming issues which could have been blamed on the company's general inexperience with this kind of project. However aside from those issues, the line is functional and the customer requirements are being fulfilled, which were the initial goals of the project.

Research Conclusion and Recommendations

After completing the initial steps of designing, and implementing the line, it was found that some of the required parameters were not being completely satisfied and would need further improvement. One of the major hurdles that the line had was trying to balance the cycle time of all assembly stations. The stations were we found the most problems were the stations #2 and #3. It was found that with the current design the combined stations #2 and #3 would always have a cycle time much longer than the one required for the line. Given the lack of information regarding the use of robots for these applications, the large cycle time on these stations was not expected. In order to correct this problem several changes will need to be implemented. The first option considered was adjusting the programming of robots #2 and #3 to increase their overall speed, reduce the idle time between operations, and eliminate, were possible, any long or unnecessary movements in order to speed up the assembly. This step brought some small success and did allow for some minor improvements in cycle time; however it was not able to completely solve the issue. Two other options are still under evaluation in order to reduce the stations cycle time.

The first was to modify the programming on station #3 to consolidate the operation of re-torqueing with the prior operation of placing screws, doing both steps in a single movement. This solution would eliminate the need for one of the robots for going through all of the screws location twice, once for inserting and securing them and the second for verification of their correct assembly.

The second option consisted in including a new robot after robots #2 and #3 and redistributing some of the work between the three robots. Robots #2 and #3 would continue to perform the main tasks of assembling all of the screws on the unit while the new robot would take charge of the operation of placing the RTV sealant compound.

Another area were the assembly line needs to be improved is in the installation and integration of equipment that allows the stations to detect for bad parts. As of current, the robots are not able to differentiate between good and bad parts, and this has been the root cause of several incidents. Parts out of position can cause crashes while the robots are moving, and parts with missing pieces can cause shorts or other mechanical problems down the line. In order to solve this, an optical recognition system was considered for stations #2 and #3. This system is expected to be completed by June 2012.

Finally some of the biggest issues we had with the HMI were resolved after receiving more training on how to work with this system. The ability to "Home" (take the robots back to their original position) all robots form the computer screen, without needing the use of the robots pendants was a big improvement. Vital information such as the quantity of manufactured units, current cycle time, or robot operational status was added to the screen. As we become more familiar with this software we expect to continue to add more features that will make the process even easier for the operators and helps to further automate the entire process.

One of the main goals of this project, once we started it, was to train and qualify personnel within the company in the areas of automation, robotic equipment, PLC programming, etc. With the completion of this assembly line, even at its current state, we can say that this goal was fulfilled. Over the course of almost two years, we have been able to participate in all of the steps needed for the creation of a new line, from designing the layouts, locating the equipment in place, to wiring and programming the different stations. Although, several improvements still need to be made, we expect that the success obtained in this project can help this company and its personnel to continue its growth both economical as well as professional.

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