Implementing Lean Manufacturing In Amphenol TCS GBX Backplane Production line

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Abstract

The goal of this project was to make recommendations to improve for Amphenol TCS according to the principle of lean manufacturing. The primary objective was to improve the quality as well as productivity of the GBX production system. From gathering data and verification, a set of recommendations was created on how Amphenol TCS can optimize the operation of manufacturing floor.

Acknowledgements

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We would like to thank the many Amphenol TCS engineers especially, Ski Wang, Xin Zhang, Weili Lin, David Diao, and Kim Taber. Finally, we would also like to thank our Advisor's Professor Kevin Rong, and Professor Gao, for there efforts in aiding the completion of our project.

Authorship Page

Each member of the team helped with designing, administering, and compiling the Production analysis. Yung Wei Tang worked on gathering much of the data from the production line, as well as being key translator for all company visits. Also Yungwai Tang wrote the sections on Lean manufacturing, as working on sections for the Introduction, Results, and Conclusions. Andrew Anderson worked with much of the groups to help analyze the gathered information, also help create the guidelines on which to measure the production line. With the help from all the project partners the researchers were created many suggestions Also Andrew Anderson formatted the paper, wrote the Introduction, Methodology, and helped with writing the Background and Results sections. All members of the group also participated in multiple presentations held at Amphenol TCS in Changzhou, as well as at HUST University.

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Nomenclature

WPI-	Worcester Polytechnic Institute
HUST-	Huazhong University of Science and Technology
ATCS-	Amphenol TCS
MIT-	Massachusetts Institute of Technology
VA-	Value Add
NVA-	Non Value Add
JIT-	Just In Time
WIP-	Work In Process
ID-	Identification
5S-	Sort, Set in Order, Shine, Standardize, Sustain

1. Introduction

As one of the world's largest manufacturer of electronic and fiber optic connectors, Amphenol Corporation is regularly provides a full-spectrum of solution for the converging technologies of voice, communications, industrial/ automotive and military/ aerospace products.[1] Amphenol is also a world leader in high-speed, high-density connection systems, designing and manufacturing the industry's leading high-speed, high-density connectors and backplane systems[2]. To help continue in productive growth, Amphenol is constantly striving to the productivity and output of their operations. Their goal is to satisfy the customer with the exact product, quality, quantity, and price in the shortest amount of time.

The goal of this study is to develop a complete system analysis of the GBX production, by using simulation software such as Arena Simulation Software, as well as identifying wastes and make recommendations for improvement. With the guidance of the simulation software and production analysis researchers will generate multiple suggestions based on lean principals in hope to improve the overall production of the GBX Backplane production line. To do so the company hopes to increase productivity and improve the quality of goods produced by the company, while at the same time reducing costs, total lead time, human effort, and inventory levels.

The gaps of the project are to understand principles of lean manufacturing, and how to implement these concepts into the GBX production line. Furthermore, researchers need to learn the Arena simulating software, which not only can help to understand the

[1] From Amphenol TCS website
[2] From Amphenol TCS website

complex relationships and identify opportunities for improvement but also model processes to define, document and communicate.

Incompletion of the project, researchers hope to achieve their goals, which will provide them multiple number suggestions. Some of these suggestions will be to eliminate the bottleneck while the rest will use the principals of lean to make suggestions to improve the productivity of the GBX production. Also with the information provided by Arena Simulating Software well enough to present a brief introduction of using guide to the company engineers.

2. Background

This Chapter contains research on the principals of Lean Manufacturing. This research was done because Amphenol TCS hoping to use many of the principals of this operations management theory to improve its production outputs. Research was also done to look at how other manufacturing companies around the world have used Lean Manufacturing to help improve their production lines. It was important for researchers to see what process was taken to help formulate their ideas and methods of how to improve production lines.

Multiple ATCS engineers were also consulted in order to gain insight about the current status of the production line. Their feedback into the current production process proved useful in discovering the bottlenecking problem of the operations. Finally, it proved useful in helping understand any limitations, as well as questions about the process that needed any further questioning.

2.1. Amphenol TCS

As previously mentioned Amphenol Corporation is one of the world's largest manufacturer of electronic and fiber optic connectors, cable assembly and interconnects systems. By providing a full-spectrum of solutions for the telecommunication technologies in areas of voice, video and data communications, the company is quickly becoming a leader in high-speed, high-density connection systems, designing and manufacturing the industry's leading high-speed, high-density connectors and backplane systems.[3] Amphenol TCS continually solves system design challenges with integrated

[3] Amphenol TCS website

interconnect solutions for application in the networking, communications, storage, and computer server markets.

Amphenol has a 70 years history of delivering innovation and value, and an established leadership position in all the market it serves. It was founded in 1968 as a division of Teradyne Inc. and was acquired by Amphenol Corporation in December of 2005.[4] ATCS locates its manufacturing sites around the world, to provide the most value to their customers. Manufacturing facilities with high volume manufacturing facilities are located in Mexico, Malaysia and China. While their local sales and applications engineering supports are available around the world, including the business and technology centers which are located in New Hampshire, North Carolina, and Ireland.[5]

2.2. GBX and Backplane Production

A backplane refers to the large circuit board that contains sockets for expansion cards. The circuit board connects several connectors in parallel to each other, so that each pin of each connector is linked to the same relative pin of all the other connectors, forming a computer bus. There are two major types of Backplanes that are often used. First, is an active backplanes, contains units to work in addition to the sockets, logical circuitry that performs computing functions. Second, passive backplanes contain almost no computing circuitry.[6] Generally, most computers have used active backplanes. In fact, the terms motherboard and backplane have been coordinated. But recently, some companies have been a move toward passive backplanes, with the active component such

[4] Amphenol TCS website
[5] Amphenol TCS website
[6] GBX product Manuel

as the CPU inserted on an additional card. Passive backplanes make it easier to repair faulty components and to upgrade to new components.[7]

The GBX production line is one of the many production lines that are currently used by Amphenol TCS in order to produce backplane connectors that will be used in many of the computers and motherboards that are in use today. This production line uses both human impute as well and machine technology to help create many of the communication software that is constantly in most of the telecommunication production around the world. There are five workstations in this non-automated production system, that each has useful variables in the production of many different types or forms of backplane production depending on customer demand.

The GBX is one of many productions that are constantly used in the ATCS. This type of connector is a two pieces device that connects two printed circuit boards. Receptacle connectors and pin connectors are through-hole devices with eye-of-the needle compliant pin contacts**.** It is a high-density optimized differential connector with a choice of density configurations. GBX provides increased density, exceptional impedance matching, and low crosstalk. The GBX connector family consists of modular configurations with custom power and guidance modules.

2.3. Detailed description for GBX Production line

After developing a clear mission and objective the researchers, visited Amphenol TCS, to personally study the GBX production line. By doing this, researchers' wanted to properly recorded and measure every step in the GBX production line. To start researchers described the current working commends for each step in the procedure. This

[7] Interview with Kim Taber

gave researchers ideas on how to measure the production line and develop a unified measuring system. The other goal was that through mapping the production line, researchers would be able to mapping the production line with required simulation software (Arena Simulation Software).

The first station in the GBX production line is the Receive and Inspect station. At this station raw materials are brought into the system, and checked for initial damage. The first step is that the operator will grab units from a bucket that contains the raw stock. They will then quickly inspect the raw material to make sure that there is no damage to the unit. Such damage that can occur is chipping and or cracking to the raw material from original care. Once visual inspection is completed, operator will place units onto a conveyor belt that which leads to next process (Domino Marking). For this step the operator moves very little because everything is right in front of operator. This operator also is typically sitting in a chair. The only movement that can be accounted for is just the foot or two that the operator reaches form the raw stock to the conveyor belt.

The next station in the GBX production line is called Domino Marking. This operation is mostly autonomous, in which the operator is the same as the Receive and Inspect. For this station each unit will be marked with an initial id tag unique to each unit. As the pieces moves down the conveyor belt, each unit will be put under a spray marking the units on one side. Each unit will be sprayed with an identification number, which is as fallows. The first row says, TCS then year then number of week in that year. The second row is the material number of the device, and the third row is GBX then the year and due date.

Each unit will then continue down track until it will fall into bucket that will collect units that will be used for collection. It is important to note that some times at the end of the line there is an extra worker whose job is to inspect the units to see if there was any smudging. Also this person is then responsible for making everything work properly.

Figure 1: Domino Marking

The third Station in the GBX production line is called the housing and preparing station. For this station after a number of units are marked, an operator will grab material for the bucket from the previous station. The operator will locate units from the bucket into trays. These trays typically contain three hundred and sixty four units before being shipped off to the next station.

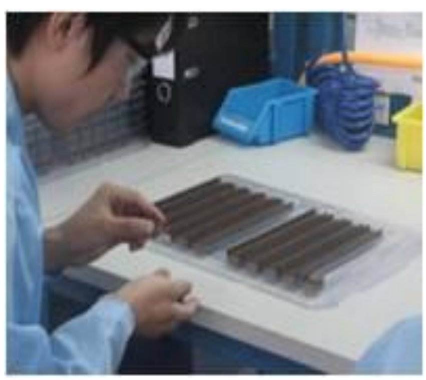


Figure 2: Housing and Preparing

The forth Station is called the Signal Insertion. At this station signal pins are inserted into the units. This operation is completed half machine and half by operator.

To start this operation, the operator will receive full trays of marked units, which will be delivered by the Housing and preparing operator. Then the trays are lined up on one side for in and on side for completed with Signal pins. The operator then will take the marked units and place them into the holding device. This device normally holds 30 units per device but changes depending on the type of product being produced.

Once the holding device is filled the operator will close the holding device and locked and then brought to the signal insertion machine this distance is about three feet. The operator will then take a finished holding device out of the machine and replace it with the holding device that was just loaded. The operator will press a green button, closing a glass door and the machine will begin to operate. While the machine is running, the operator will unload the holding device, and reload it with new units. Once done the machine stops and the door opens the operator will repeat the aforementioned cycle. The completed units are put on a tray that will be filled before being handed to the Signal Installation workstation.

Figure 3: Signal Insertion

The next step in the GBX operation is called Shield Insertion, in which the Shield devices are loaded into each unit completing the physical additions to the production line. There are two operators in the station, one of is loading units into holding devices and putting the devices into machine; the other is taking the devices out of the machine and unloading units from holding devices into trays. To start this operation the loading operator takes the trays with signal pins to the shield workstation. Then this operation will then load these units in groups of six into the shield holding device, lock and bring to machine. Then load the holding device into the machine and press the green button. The machine will run and shortly stop. The un-loading operator will then take this holding device out of the machine; the operator will then unload the holding device and pass the empty holding device to the loading operator. There are two holding devices so there is a cycle to this operation.

Figure 4: Shield Insertion

After the Shield Insertion workstation begins the testing portion of the production line, starting with the Hi-Pot Test. This station has one operator who uses the Hi-Pot machine to examine the electrical connections of the backplane devices. For this operation, the operator in Hi-Pot testing needs to pick up the trays from the shield station and start doing the electrical shorted testing. The worker needs to pick up a certain amount of units from the tray generally four of five depending on the size of the units, and put them into the testing machine after that the operator will pick them up and put back into another tray.

Figure 5: Hi Pot Test

The Hardware insertion process is a very limited piece of the operation and is only used in specific types of Backplane modules. This hardware device used for alignment and also helps improve the functionality of the devices. For this operation the operator will receive trays from Hi-Pot testing and put each unit into the pin insertion machine one by one. Similar to the Hi-pot test, once the units are in the device the operator will then press the green button. The device will clamp down on the device inserting the hardware devices into the backplane. Upon completion of this step the operator will then load into a tray, which will then be brought to the Final Inspection process step.

In this station, there are two operators doing visual inspections of the backplane devices. Before starting working on the inspection, the operators will receive competed trays of backplane that have already gone through the whole process. These two operators will randomly pick up 12 units from a tray and use microscope to make sure that there is no bend pins and that the pins and shield devices are all in line. After that the operators have to use magnifying glass to look over the rest of parts until the full tray is completed. When this is done the operator will then cover the tray and load the completed units into the necessary packing locations.

Figure 6: Final Inspection

2.4. Lean Manufacturing

In past few years companies around the world have been involved in converting manufacturing facilities and their organization form traditional mass production to an innovative production system know as lean manufacturing. Lean manufacturing is a term first used in the book *The Machine that Changed the World* by James Womack and Daniel Jones, which describes the manufacturing philosophy pioneered by Toyota(OIE book).[8] Lean manufacturing is practices at Toyota under the name Toyota Production System. This paper goes over how to develop, evaluate, and implement lean manufacturing into the GBX production at Amphenol.

Lean is a set of management practices that is based off the Toyota Production Systems, which has help lead Toyota to become one of the most successful automotive companies in the world. The Toyota Production System was developed to improve quality and productivity and is predicted upon two philosophies that are central to the Japanese culture: elimination of waste and respect for people. The term "Lean

[8] Fred Thompson, *Fordism, Post-Fordism and the Flexible System of Production*, Willamette university, Salem, Oregon

Production" made popular by a book entitled "the Machine that changed the World" by a bunch of MIT researchers (ohno).

The beginning of lean can be dated back to the 1940s. At this time Toyota was studying the US supermarkets with a view to applying some of their management techniques to their work. This interest was because in a supermarket the customer can get what is needed at the time needed in the amount needed. The supermarket only stocks what it believes it will sell and the customer only takes what they need because their supply is assured. With this in mind, it was the beginning of Toyota's early view on lean processes. The process goes to this store to get its needed components and the store then replenishes those components. It is the rate of this replenishment, which is controlled by kanban (tapping 2002), which give permission to produce. In 1953 Toyota applied this logic in their main production factory. (OIE Book) As a result Toyota is today one of the worlds most productive manufacturing company to date.

2.4.1. Waste

The theory of cutting waste is essential in the Toyota Production System, waste as defined by Fujio Cho (Toyota's President) is "anything other that the minimum amount of equipment, materials, parts and workers which are absolutely essential to production." Or According to tapping (2002) "the ultimate lean target is the total elimination of waste. Waste, or muda, is anything that adds cost to the product without adding value" (p. 41). In doing so there was the identification of seven types of waste:

1. Waste of overproducing: Producing components that are neither intended for stock nor planned for sale immediately.

2. Waste of waiting: Refers to the idle time between operations.

3. Waste of transport: Moving material more than necessary.

4. Waste of processing: Doing more to the product than necessary and the customer is willing to pay.

5. Waste of inventory: Excess of stock from raw materials to finished goods.

6. Waste of motion: Any motion that is not necessary to the completion of an operation.

7. Waste of defects and spoilage: Defective parts that are produced and need to be reworked.

This definition of lean leaves no room for surplus or safety stock. No safety stocks are allowed because if you cannot use it now, you do not need to make it now; that would be waste. Hidden inventor in storage areas, transit systems, carousels, and conveyors is a key target for inventory reduction. The typical process for elimination of waste are: focused factory networks, group technology, and quality at the source, Just in Time production, uniform plant loading, kanban production control systems, and minimized setup times.

2.4.2. Value Added vs. Non-Value Added

Another way of looking at how to measure value added can be done. Knowing that value added is an activity is "value added" if, and only if the fallowing two conditions are met. First the customer must be willing to pay for the activity. Second the activity must change the "form, fit, or function" of the product, making it closer to the end product that the customer wants and will pay for. To finalize the lean thinking the activity must be done right the first time.

A more detailed way of identifying waste is to look at if the process or step is Value Added (VA) or Non-Value Added (NVA). The process that makes the transforming of aw material into finished goods is the objective of any manufacturing company (Tapping, 2002), transformations possible are the result of two different activities: those that add value and those that do not. VA activities are considered the actions and the process elements that accomplish those transformations and add value to the product from the perspective of the customer (e. g., tubing, stamping, welding, painting, etc.). NVA activities are the process elements that don't add value to the product from the perspective of the customer such as setting up, waiting for materials, and moving materials.

In the past companies have been focused on the value-added steps (Corner, 2001). The goal was to reduce the value-added component of lead time and not pay too much attention to the non-value-added activities. Today, lean manufacturing strives to improve as much as possible the value-added component of lead time, but focus first on reducing the non-value-added component of lead time.

2.4.3. Value Stream Mapping:

Value stream mapping, is a critical first step in lean implication because it takes a lot of the complexity and confusion out of the whole operation. The mapping process involves examining and recording all the activates that occur as a product is transformed from raw material to a finished product. Mapping creates a high-level look at the total efficiency, not the independent efficiencies generated by the individual cells or work groups. A value stream map contains all data relative to this flow to the customer. It captures both value added and non-value added activity. The value stream mapping process in an effective way of capturing the current situation, identifying the long term lean vision, and developing a plan to help get to that vision.

2.4.4. One Piece Continuous Flow

For the theory of one piece continuous flow, a company will have to understand the value of a pull system. A pull system help establish the flow operating philosophy. The basic premise says not to make a part until the next operation. Then with one piece flow says that the basis of the flow of processing is that one-piece flow is predominant in a facility's operations. This means that parts do not collect between operations. Each operation in the process is working on the next part for the following operation.

In a more in-depth look into a one-piece flow, you can look at the process step by step. First as the products are created one by one, it is possible to shorten the specified product's production lead time. By doing this unnecessary inventory between each processes can be eliminated. Also the multi-process worker concept can decrease the number of workers needed, and there for increase overall productivity. Because of this as workers become multi-functional they can participate in the total system of a factory and thereby feel better about their jobs. By becoming multi-functional, each worker attains the knowledge to engage in teamwork and help each other when need, hopefully leading to a better working environment, which is the key of lean manufacturing.

2.4.5. Just in Time Production

As companies begin changing there manufacturing strategies, one common notion is to implement a just in time process of material procurement and distribution. JIT is one of the pillars of the lean manufacturing systems. It is one of the most popular lean tools since it is one of the tangible. The JIT concept forces on producing the appropriate units in the required quantities are the necessary time and delivering them to the correct location. The results include a decrease in raw materials and work in progress (WIP) inventories, increased cash flow and the creation of available floor space for new business.

The JIT concept is simple" order the materials only when they are needed, purchase only the needed materials to manufacture the product. Fabrication departments and assembly operations produce only what is needed, the change to the next order. WPI is ensured to be 100% quality and moved directly to the next process. All parts are consumed in a brief period and cash is not invested in materials that will not be sold promptly.

If the company achieve just in time ideals managers can expect to see operational benefits that include unnecessary inventories are eliminated, stores and warehouses are not needed, material carrying costs are diminished, and the ratio of capital turnover increases. This type of production is a key tool in hoping to keep a pull system of production. The pull system makes JIT possible by transferring the responsibility of JIT form the materials management group to the production system.

2.4.6. Lean Vocabulary:

When working with lean there are many word that are often used that are essential to the understanding of Lean Principals. The following vocabularies are the basic knowledge of understanding Lean Manufacturing. By using these words, it helps to analyze production processes and also makes improvements on each production line. Professor Wang (2007) defined the following lean terms.

Value: A capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer.

Value-added: Any activity that increases the market form or function of the product or service. (These are things the customer is willing to pay for.)

Non-Value-added: Any activity that does not add market form or function or is not necessary. (These activities should be eliminated, simplified, reduced, or integrated. These are things that customer does not want to pay for.)

Throughput Time: The time required for a product to proceed from concept to launch, order to delivery, or raw materials into the hands of customer. This includes both processing and queue time. Contrast with processing time and lead-time.

Lead Time; The total time a customer must wait to receive a product after placing an order. When a scheduling and production systems are running at or below capacity, lead time and throughput time are the same. When demand exceeds the capacity of a system, there is additional waiting time before the start of scheduling and production, and lead-time exceeds throughput time. There are five major components of Lead Time, and Queue Time is the greatest contributor to the overall lead-time.

•**Queue:** Amount of time a job is waiting at a work center before operation begins.

•**Setup:** Time required preparing the work center for operation.

•**Run:** Time needed to run the order through the operation.

•**Wait:** Amount of time the job is at a work center before being moved to the next work center

•**Move:** Transit time between work centers.

Cycle Time: The time required to complete one cycle of an operation. If cycle time for every operation in a complete process can be reduced to equal takt time, product can be made in one-piece flow.

Takt Time: The available production time divided by the rate of customer demand. Takt time sets the pace of production to match the rate of customer demand and becomes the heartbeat of any lean system.

$$\text{Takt time} = \frac{\text{Time available during the period}}{\text{Customer demand in the period}}$$

Equation 1 Takt Time cited from Wang, S, (2007)

2.5. Arena Simulation Software

To help analyze this system the company helped used a program called Arena Simulation software. By using this tool to help map out the system, Amphenol TCS was able to create an effective and active value stream map for the system. By doing this and with the proper analysis of the system the company is able to measure out the ideal production of the GBX production line. It will also be able to see what bottlenecks occur, and what the work in progress will be at each station. This is really effective because it helps determine what parts of the system are their target areas.

To see how effective this program can be and the true value of value stream mapping for the system, a copy of the process is shown below

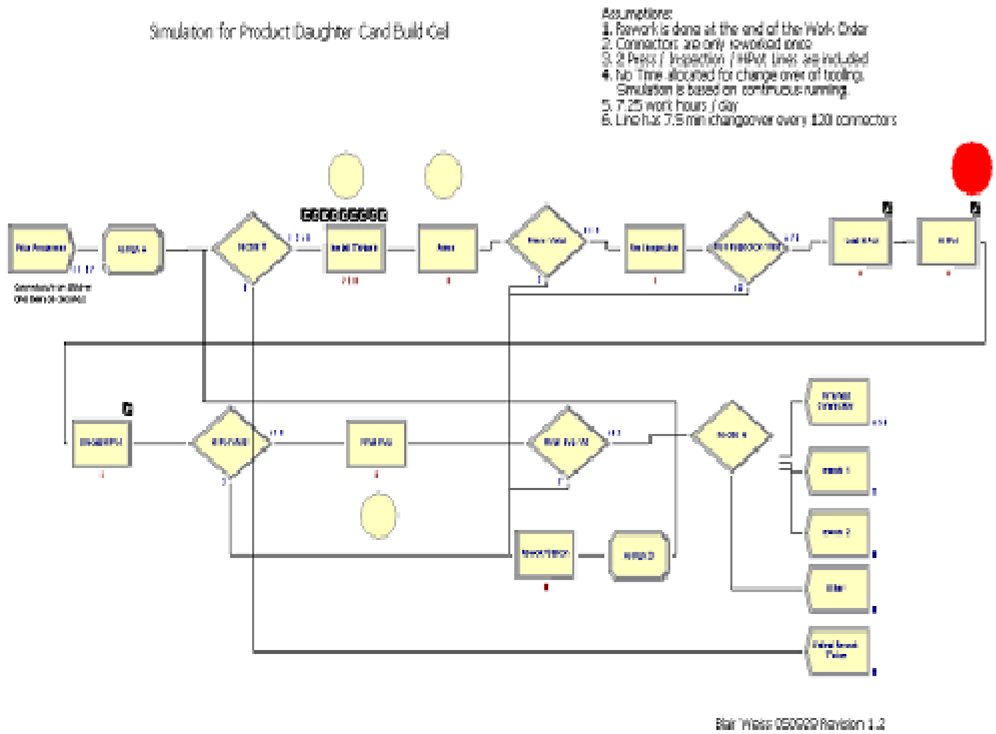


Figure 7: Example of Arena Model

In this process you can see the many complicated steps that happened while in the production of the GBX production of the backplane. As you can see the work in progress is marked be fore and after each step, and it can also show there the bottle next happen as shown in step four. Now with this information, the company can then break it up even more so that each process can be analyzed more specifically by looking at it in a very meticulous way. As shown below, the process can be use to look at all the individual step 4 where the shields are placed into the wafer.

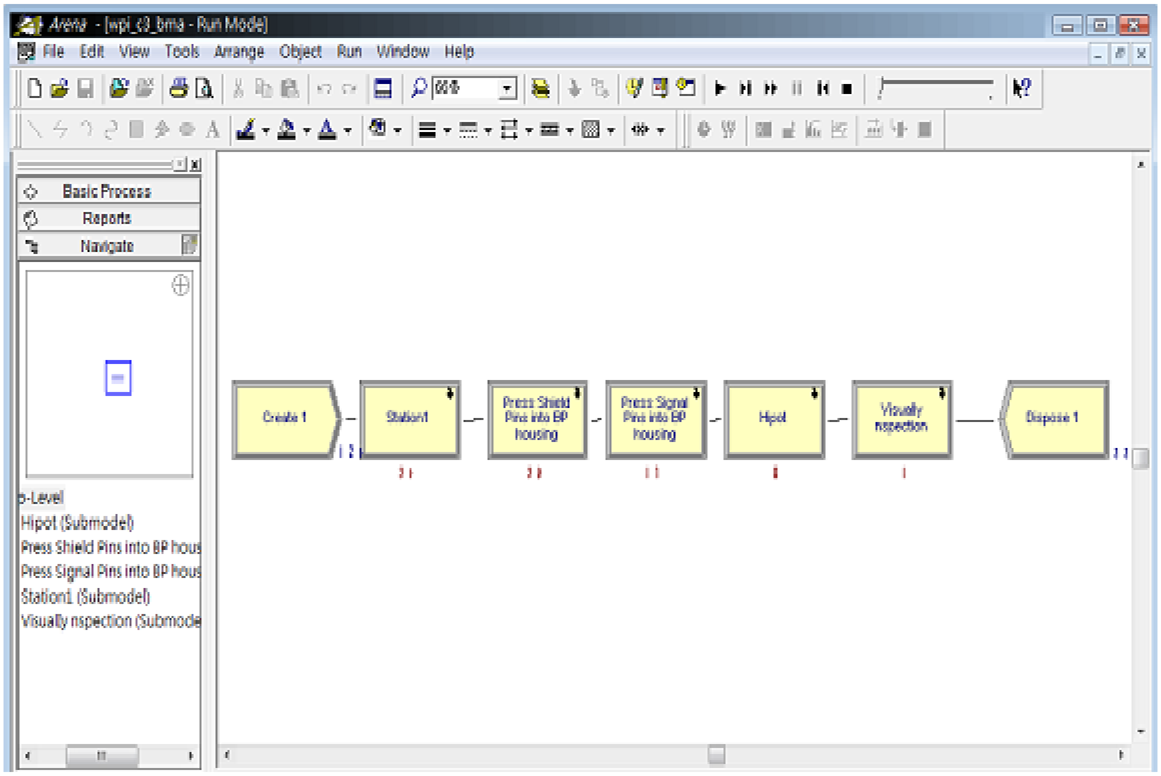


Figure 8: Simulation for Backplane Product

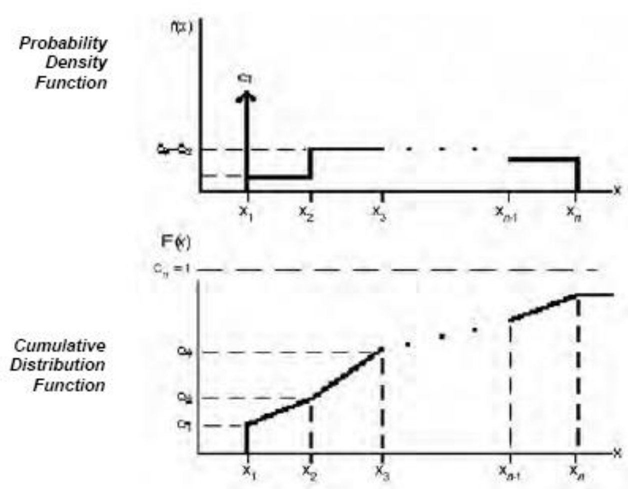
2.6. Probability Distributions

When using Arena Simulation Software, it is necessary to understand the proper distribution method that is being measured to accurately represent the production line. Every random variable is a function defined on a state space equipped with a probability distribution in Probability Theory. The distribution assigns a probability to every subset that is more accurately every measurable subset of its state space in some ways which the probability axioms are satisfied. The Probability distribution is probability measures defined over a state space instead of the sample space. A random variable then defines a probability measure on the sample space by assigning a subset of the sample space the probability of its inverse image in the state space.

To start understanding the different types of distribution it is important to note that there are many types but for this project we only considered four Continuous, Normal, Triangular, and Uniform.

“The continuous empirical distribution is often used to incorporate actual data for continuous random variables directly into the model. This distribution can be used as an alternative to a theoretical distribution that has been fitted to the data, such as in data that have a multimodal profile or where there are significant outliers.

Continuous	CONTINUOUS($CumP_1$, Val_1, . . ., $CumP_n$, Val_n) (c_1, x_1, . . ., c_n, x_n)



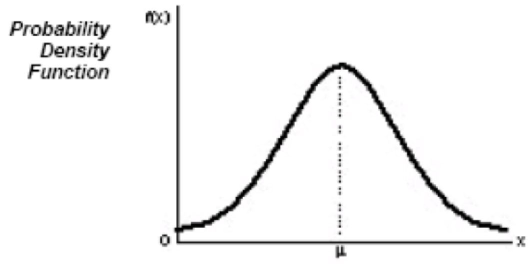
$$f(x) = \begin{cases} c_1 & \text{if } x = x_1 \text{ (a mass of probability } c_1 \text{ at } x_1\text{)} \\ c_j - c_{j-1} & \text{if } x_{j-1} \leq x < x_j, \text{ for } j = 2, 3, \ldots, n \\ 0 & \text{if } x < x_1 \text{ or } x \geq x_n \end{cases}$$

Figure 9: Continuous Distribution

Cited from Arena User’s Guide (2005)

The normal distribution is used in situations in which the central limit theorem applies’ i.e.k quantities that are sums of other quantities. It is also used empirically for many processes that appear to have a symmetric distribution. Because the theoretical range is from negative infinitive to positive infinitive, the distribution should only be used for positive quantities like processing times.

Normal(μ, σ) **NORMAL(Mean, StdDev) or NORM(Mean, StdDev)**



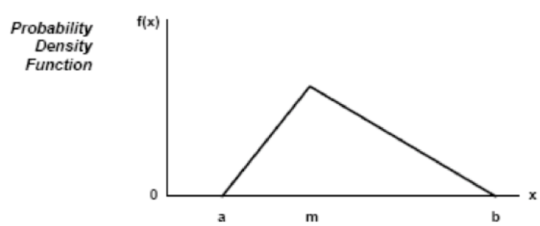
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)} \quad \text{for all real } x$$

Figure 10: Normal Distribution Graph

Cited from Arena User's Guide (2005)

The triangular distribution is commonly used in situations is which the exact form of the distribution is not know, but estimates (or guesses) for the minimum, maximum, and most likely values are available. The triangular distribution is easier to use and explain than other distributions that many be used in this situation (e.g., the beta distribution).

Triangular(*a, m, b*) **TRIANGULAR(Min, Mode, Max) or TRIA(Min, Mode, Max)**



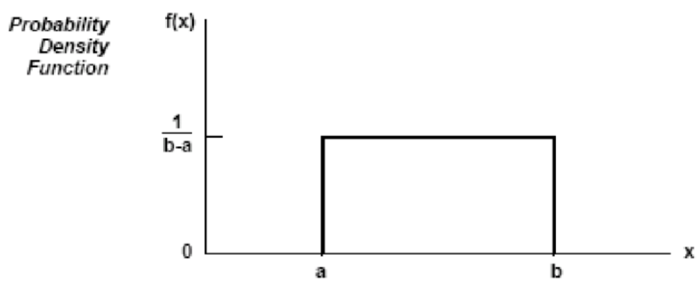
$$f(x) = \begin{cases} \dfrac{2(x-a)}{(m-a)(b-a)} & \text{for } a \leq x \leq m \\ \dfrac{2(b-x)}{(b-m)(b-a)} & \text{for } m \leq x \leq b \\ 0 & \text{otherwise} \end{cases}$$

Figure 11: Triangular Distribution Graph

Cited from Arena User's Guide (2005)

The uniform distribution is used when all values over a finite range are considered to be equally likely. It is sometimes used when no information other than the range is available. The uniform distribution has a larger variance than other distributions that are used when information is lacking (e.g., the triangular distribution)."

Uniform(a, b) **UNIFORM(Min, Max) or UNIF(Min, Max)**



$$f(x) = \begin{cases} \dfrac{1}{b-a} & \text{for } a \le x \le b \\ 0 & \text{otherwise} \end{cases}$$

Figure 12: Uniform Distribution Graph

Cited from Arena User's Guide (2005)

3. Methodology

The procedures for this research project have been chosen to meet each of the project objectives. First to make sure researchers had a first-hand knowledge of the production flow and to be familiar with the activities being performed at the floor shop, the researchers made multiple trips to Amphenol, in both the Nashua, New Hampshire as well as in Changzhou, China. At each of these visits the researchers went through the facility and identified each operation process, from the introduction of raw materials to finished goods, identified all the places where inventory is stored between the processes, and observed how the material flowed from one operation to another.

Each machine would be measured one hundred times, thoroughly measuring all machine time, machine down time, operator time, waiting time, and transfer time per workstation. The size of measurements was carefully constructed to accurately determined in order to observer the production under numerous operators, and times of the day to see results of production under all different stresses. With this data gathered recommendations would be generated in order to illuminate waste. Also with the knowledge of all times researchers were able to produce results.

On these visits the initial reactions of the GBX production by the Amphenol Engineers was recorded to gather only their preliminary reactions, so that later these reactions could be used as guidelines to where researchers could concentrate there studies. These interviews would also be used later to be developed into concrete recommendations for improvement in production. Interviews were conducted with Amphenol engineers to obtain their opinion on the GBX production line, which was then used in the overall analysis. Inspections to other manufacturing companies who have used lean manufacturing to improve there overall production as well as the implantations process that was taken by said company.

Analysis was also done form the quality collected information that was given by the company to the researchers. The information that was analyzed was the rates of defections as well as rate of variations of the GBX production line. Amphenol TCS Changzhou as well as the Nashua had various documents and data tables available for this form of analysis. These charts included production charts, which included work levels, and expected rates of production for each type of GBS production. There was also information available, in regards to weekly abnormal MC DT, Final yield per shift, performance per shirt, and also scrap per shirt. These data sheets were also supplemented by production measurements of each process in the GBX production.

3.1. Visit to Nashua, New Hampshire

Upon receiving the mission statement from Amphenol, the researchers were invited to attend one of the Amphenol TCS facilities located in Nashua, New Hampshire. The goal of doing this was to introduce the researchers to the ATCS, and to help start there background research on the desired production line, Upon the first visit to the company researchers were introduced to the facility, there production lines, as well as the engineers who help designed the process. The main engineer that the researchers would be working with was Kim Taber, who is the chief operational engineer for the GBX production line. Kim would become are key contact with Nashua, in the fallowing seven weeks as the researchers became introduced to the production line.

Upon these trips the main goal for the researcher, both the Mexicali and the Changzhou group, was to map out the production line. Doing these initial reactions were formed, as well as ideas on how to properly measure out the production line. The researchers also measured/mapped two production lines, the Ventura and the GBX production lines. It was important to note that while these were the initial reactions were made, that the researchers also noted that the production lines in Changzhou, as well as in Mexicali would be very different. Apart form there being multiple production lines going on at once the international production lines were producing in a Hi-volume atmosphere, while in Nashua everything was being produced in a low-volume production lines.

Also on these trips researcher also looked upon the production line under multiple production layouts. For instance upon the first visit to the company it was the end of there third quarter, and there were many orders to be produced. Because of this the production line was being run at a faster rate then the norm. Also researcher also experienced the GBX production line with one and two work cells. This caused major difference of production, as well as average down time. All this information was recorded and helped form the initial suggestion of the researchers.

By doing this researchers were able to see the production line and able to witness the line under different stresses as well as other factors. This type of analysis was essential for helping researchers comprehend the production line. Due to this new comprehension suggestions were created on how to remodel the production line to help with the flow of production and create less transfer time and lead-time.

3.2. Visits to Changzhou, China

The Visits to the Changzhou facility of Amphenol were very similar to those in Nashua. The researchers started each trip by examining the current state and method of production in operation. For each visit this was a little different, upon the first visit, it was more of an introduction to the process of the company. This was the primary introduction to both the company as well as the production line for the HUST students. This was also necessary for all researchers because it was noted that there were many differences between the Changzhou facility and that of the Nashua plant. It was noted that there were less operators as well as a closer workspace for the production line. All of these factors were all noted and brought into consideration when looking at the overall production line.

Then once the researchers all witnessed the production line, and were able to make there initial notes, the researchers meet with members of the company to determine what researcher and initial suggestions have been made upon the visits to the Nashua complex. Then during these initial meetings the objectives of the companies and the researchers were explained and unified so that each party had a clear understanding of the value to project.

After this initial visit with the Changzhou facility the researchers' objectives became clearer. Each time that the production line was visited measurements were made to properly analyze the production line. Also researchers properly created methods on how to analyze the production line. In doing so the transfer time, waiting time, and machine times were all defined. These measurements would then be organized in an excel file to later be used to help produce the arena files that would be later used to help prove all suggestions.

Then once this was done there each researcher would then begin timing the production line. By doing this it would give an understanding of the production line for all researchers. Also the researchers decided to provide sufficient scientific evidence of the production rates of the GBX production line that each process and procedure needed to be recorded at least 100 times. Doing this did take time but also would provide enough information so that a satisfactory average could be concluded.

Then upon gathering this information the process line had to be modeled, to properly represent the model. To do this researcher's had to gather deeper understanding of program leaning the use of sub-models, and proper distribution charts. To properly understand this researchers meet with members of the HUST graduate program to help gather knowledge on proper modeling methods. Once completed an accurate model of the current production line was created, helping to define the bottleneck as well as, the WIP and other measurements were calculated and analyzed.

Later with the knowledge of Arena, researchers would use the program to help probe all recommendations. For each recommendation a model would be created showing the productivity of each process. This information can then be analyzed to show the WIP amount of waste time and other important factors. These suggestions can then be shown to the company to help reinforce the suggestions.

3.3. Interviews with Amphenol Engineers

Engineers form both Nashua and Changzhou was interviewed to gain their opinions on the productivity of the GBX production line. Each interview consisted of a navigational proportion where each engineer would walk through the production line with the researchers. Each Engineer was told to freely express there feelings on the GBX production line. Then after the engineer would then be asked their opinions on the each step in the production line. Each Engineer was then asked whichever part of the production line they saw as their problem with the production line. Secondly, responses were recorded as to what the engineers' first impressions of the production line and if there were asked if they had an unlimited budget what would they do to increase the productivity of the production line. The engineers were then asked a series of questions directed to help establish their overall opinions of production line. After initial observations were recorded, engineers were then asked questions that would also greater help the researchers understand the methods and systems that the information was recorded for the production line.

4. Results

Analysis of collected data uncovered various repeating trends, and also uncovered some unique ideas for the improvement of the GBX backplane production line. Section 4.7 discusses the limitations and errors of this study. However, it is necessary to address some of those limitations prior to presenting the results. It was found that the data recorded might have been skewed slightly due to inconsistencies in the analysis procedure. This may be due to that it was found that operators generally worked faster when they knew they were being recorded. Also some of the data might have been slightly misreported because sometimes the values were recorded on non-scientific materials such as cell phones instead of stopwatches or other measuring device. But still researchers feel that the data gathered is more then sufficient and is completely valid.

4.1. Nashua, Production Analysis

As a result of all the software and careful analysis of the system, the researchers were able to break down the full process of the GBX production line. By doing this it the locations of NVA actions would be identified and also researchers would be able to identify the patterns of the system. To start the times for each station were measured, and calculated, to show the average operation per 24 units; also what the standard deviation was calculated to see how many variances in times depending on the workers output under different circumstances. The results can be seen in *Table 1: Nashua Production Rates.*

The first station where the original units are all contained in a bucket and a worker will then take these units and put them on a production line to be marked. The average time for 24 units to be inked was about 1:15.69 minutes. The standard deviation was 7.67 seconds. Between the first and the second station, there will be a transporter that brings the bucket with marked units from the first to the second station. This is wasted time as well as hopefully a considerable spot where work in progress occurred. For the second station, the average time for 24 units to be line up in a tray was 1:23.47 minutes, and the stander deviation was 9.69 seconds.

The third station, were a worker takes unites from tray and put into a fixture, putting the fixture into machine and waiting for a short period of time. Picking them out then take put back into trays. (24 pieces at a time) The average time for 24 units to be inserted pins was 1:17.3 minutes, and the stander deviation was 5.13 seconds. The forth station, a worker gets units from tray and puts them into other fixture, putting the fixture into machine and waiting for inserting shields. Picking them out then take put back into tray again. The average time for inserting shields was 1:22.15 minutes and the stander deviation was 6.24 seconds.

The fifth station, and the beginning of the inspection steps, the average time for the test was 1:08.84 minutes, and the stander deviation was 14.74 seconds. The last station was to inspect the alignment of pins by microscope. The average time for optic inspection was 1:20.64 minutes and the stander deviation was 15.9 seconds. With these results, Amphenol was able improve with the ideals of lean manufacturing

Process	Average Time	Standard Deviation
Domino Marking	1:15.69	7.67
Housing and Preparing	1:23.47	9.69
Signal Insertion	1:17.3	5.13
Shield Insertion	1:22.15	6.24
Hi- Pot Test	1:08.84	14.74
Final Inspection	1:20.64	15.9

Table 1: Nashua Production Rates

4.3. Changzhou Production Analysis

While in Changzhou the researchers were able to measure out the production line, by measuring distance traveled per station, the operation process time and many other arrangements. As a result the researchers were able to break down the full process of the GBX production line, in a way to properly identify the bottleneck of the Changzhou production line. By doing this it the locations of NVA actions would be identified and also researchers would be able to identify the patterns of the system. The difference in production times can be easily viewed in Table 2: Changzhou Cycle Times.

As mentioned in the mythology researcher, the primary step took by the researchers started my mapping out the production line. Making sure to measure everything from distance traveled number of operators, to how long each process started. To start the times for each station were measured, and calculated, to show the average operation per 30 units; also what the standard deviation was calculated to see how many variances in times depending on the workers output under different circumstances. The reason for choosing to measure out 30 units at a time was due to the fact that that is the smallest whole number of units that fits in every machine.

The first that was measured was the Domino Marking. The researchers broke this process into two parts, receive and inspect and the time that the units were on the actual device. For the Receive and Inspect this time was dependent on the operator. For the receive and inspect portion of this station was primarily all the man time added to the production line. This was a NVA step in which took an average of 1.5 seconds per unit. On average it took 12.9 seconds for each unit to travel down the conveyor belt on the machine. This was the rate of entry and depending on what stage of production the company was in this could be speed faster depending on how many products needed to be in the system at the time. Even with these measurements researchers calculated that the average time it took for 30 units to enter the system was 58.6 seconds, but has a high standard deviation of 5.3 seconds. It was noted that this time is very dependent on how fast the company desires to produce at that particular moment.

For the housing station researchers measured the time that it took for the operator to grab the bucket form Domino Marking, and bring to there station, this took an average of 5.2 seconds for transportation which is a NVA step. Operation happened only when the operator would be out of units to place into holding trays, which is such a spontaneous action that the researchers decided not to measure this process. The other action in the Housing process that was measured was the time it took the operator to place 30 units from the bucket into the trays. The step took an average of 38.9 seconds, and had a standard deviation of 4.7 seconds.

Researchers found that the next two phases of the production line were areas, which caused a lot of wasted time in the operation. The first station was the Signal Insertion; this process was broken down into two sections. The machine time, which is a VA procedure, and operator time, which is non-value added. The machine time like the Domino marking was dependent on the company demands, being that it could be run at different rates. But after talking to the engineers at the facility the researchers learned that the machine runs at full speed unless there is a problem with other steps in the production line. So at full speed the machine time for the Signal Insertion is 56.5 seconds. The operator time was broken down into two steps, the first being the unloading time which took an average of 17.9 seconds and a loading time of 14.5 seconds. When the transfer time is added the cycle time for the operator is only 35.9 seconds. As a result there is an average of 20.4 seconds that the operator is waiting for the machine, which adds waste to the system.

The next station is Shield insertion, in this station there are typically two operators working at a one time. First the researchers decided to measure out how long it took for 30 units to pass through the system; it was found that the cycle time of this operation was 79.75 seconds, with a standard deviation of almost 9 seconds. Due to the very long cycle time researchers decided to look in the Shield Insertion with more detail. First the time it took for the loading operator took 12.38 seconds, per six units, and the unloading operator took 6.98 seconds, per six units. But since this time was only measured for one holding devise researchers then had to multiply the units by 5 so it was in proportion to 30 units. This resulted in a loading time of 61.9 seconds, and the unloading time of 34.9 seconds it was found that he unloading operator typically waited 4 seconds per turn. Even though these times seem high it was important to note that there were two fixtures so multiple actions were happening at once. As for the Machine time the researchers noted that it took 31 seconds, it was noted that because the man time was a longer then that of the machine, there would be a lot of machine down time.

The next station is the Hi-Pot Test, in this station there is only one operator, also it is noted that this station is all non-value added, but still is important for production. For this process it took 68.80 seconds, with a lot of deviation. This was due to there not always being parts to examine; it was found that often this operator would be waiting on the Shield operators. If there were parts regularly available it this cycle time would be much quicker, this is due to the very short machine time of 2.02 seconds. The final station that was measured was the Final Inspection. For this station there are two operators, in which the whole process has no value added to the parts. It was measured that the cycle time for the Final Inspection the average cycle time for 30 units to pass through the system was about 49.9 seconds.

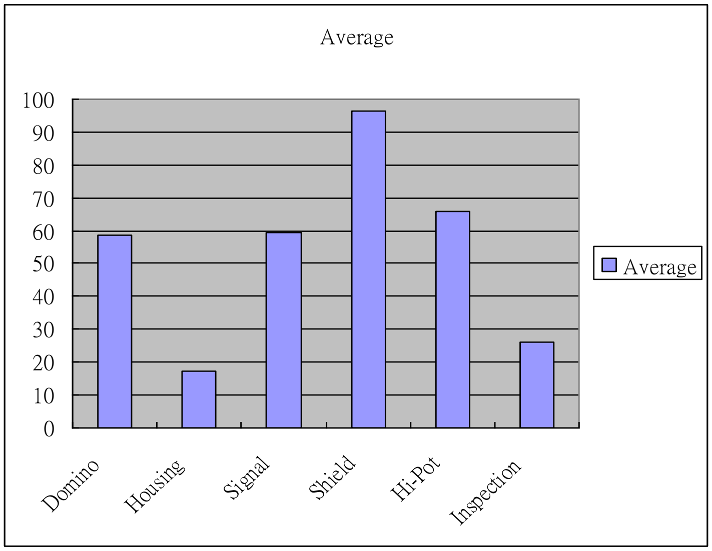


Table 2: Changzhou Cycle Times

4.4. Identifying Wasteful Activities

As one of the major goals of this project was to improve the productivity of the GBX production line, the researcher's main goal was to not just measure the production rates of the process but also to determine the bottleneck. By looking at the cycle times that were gathered, it was easily noted that the bottleneck of the production line was in the Shield Insertion station. The company desires that the production line produces 30 units per 60 seconds, but the cycle time in the Shield Insertion is averaged to be 96.5 seconds, which is far from there desired amount output. A major reason for this problem was that there was a very inconstant production times causing massive machine downtime during production. So researchers then looked into attempting to reduce the cycle time of this station, to do this researchers need to reduce the operator time and make it to be closer to the machine time. Here are the analyses of signal and shield insertions.

4.4.1. Signal insertion

Before doing the mathematical calculation, we need to define the average times of each motion in both signal and shield stations. The machine time took on average 56.5 seconds; the unloading time took about 17.9 seconds, the loading time: 14.5 seconds, the transfer time is 2 seconds, and the time that it took to press the machine button was once second. To determine the operator time and operator's waiting time in signal station, researchers added several motion times together. Bellow are the calculations, which will show not only the operating time of works in this station is faster than machine working time but also the station will not be a bottleneck at all.

$$\text{Unloading Time} + \text{Loading Time} = \text{Man Time}$$

$$17.9 + 14.5 = 32.4\text{s}$$

Equation 2: Signal Insertion Equation # 1

$$\text{Machine Time} - (\text{Unloading} + \text{Loading} + \text{Transfer Time} + \text{Pressing Button}) = \text{Worker Waiting time}$$

$$56.5 - (17.9 + 14.5 + 2 + 1) = 21.1\text{s}$$

Equation 3: Signal Insertion Equation # 2

4.4.2. Shield insertion

After analyzing the cycle times and talking to Amphenol engineers it was determined that the Shield Insertion station is the bottleneck of the production line. With this being determined researchers set out to identify the full production process. To do these researchers broke down every process of the Shield Insertion. The fallowing measurements were made in and used to help generate the suggestions. First the machine Time was 6.2 seconds. The time that it took for the loading operator to fulfill their job description was 15.15 seconds; this included an average of 12.38 seconds for loading the holding device. The time that it took for the unloading operator to fulfill there job description was 10.54 seconds, which included the 6.98 seconds that it took to unload the holding device. The other measurements that were made were that it took one second to go from placing the holding device and pressing the button. It took 1.77 seconds for the operator to put in as well as take out the holding device into the machine time. Lastly it was found that the average down time for the machine was 9.75 seconds. Also a series of calculation were made to identify all the wasteful activates, which fallow.

Loading Time+ Put in Time+ Pressing Button= Loading Operator time

12.38+1.77+1=15.15

Equation 4: Shield Insertion Equation # 1

Unloading Time+ Take Out Time+ Transfer Time= Unloading Operator Time

6.98+ 1.77+1.79=10.54

Equation 5: Shield Insertion Equation # 2

Loading Operator time- Machine Time= Machine Down Time

15.15-

Equation 6: Shield Insertion Equation # 3

6.2= 8.95

(Unloading Operator Time+ Machine Down Time)/2= Average Waiting Time

(10.54+8.95)/2=9.75

Equation 7: Shield Insertion Equation # 4

(Machine Time+ Average Waiting Time)*5= Cycle time for 30 units

$$(6.2+9.75)*5=79.75$$

Equation 8: Shield Insertion Equation # 5

With this know researchers identified multiple reasons for the bottleneck, the major being that the machine down time is too long to produce enough units. On the other hand, the operators in this stop have to work faster than usual to keep up the productivity. This also caused an unbalanced flow for the operation. This can be viewed in the figured bellow which shows the process flow for the Shield Insertion station.

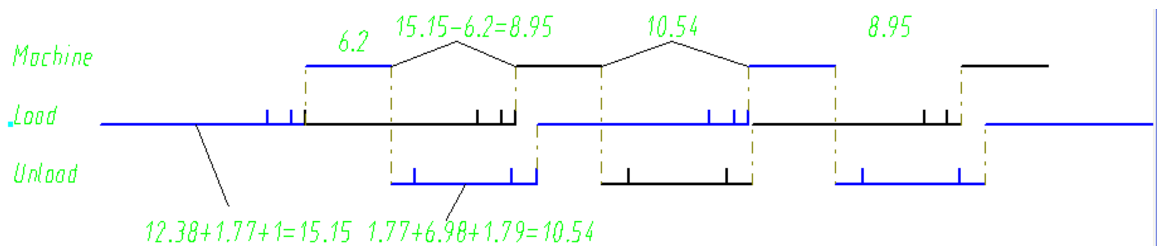


Figure 13: Shield Insertion Process Flow Diagram.

4.4.3. Hi-Pot Testing

By looking at the data that was gathered this station was the second bottleneck of the production line. This station also had a cycle time that exceeded the company demands. It was found that this is because the previous station (shield insertion) cannot provide enough materials consistently to perform the electrical short testing. But if there were material present the cycle time would increase because the operation per 5 units is only 7.32 seconds.

4.5. Using Arena Simulation Software

Upon completion of data analysis the company recommends that the researchers use the Arena Simulation Software to help provide evidence on the current and feature production state. So when all data was recoded researcher's next operation was to being mapping out the production line by using Arena Simulation Software. The researchers first created a model that mapped out the current production line. This model included cells for all working station where the gathered information was placed into the respective cell. When model was completed it could simulate the production line.

When this was done researchers looked at the report and found some interesting information. First Arena clearly labeled the WIP in the system at a time. It was noted that in the Shield Insertion that there was an average of 156 pieces waiting to be operated on. As a result the cycle time for the units to go through the whole system took 32.05 minutes, and an overall output of 1260 units, which was under the company's desired goal of 1500 units. So again it was noted that the Shield Insertion would have to be modified.

After the suggestion/recommendations, which are defined in Section 4.6 were always known. The new measurements were made, and implemented into the model to simulate what would happen. As a result according to the report that was produced there was a dramatic improvement in the number of WIP produced. In the number of suggestions that were simulated it showed that the average WIP would be at most 5 units. Due to this the total cycle time decreased from 32.05 to 25.54 seconds. Also the number of products produced improved to 1530, which are above the company's desired rates.

4.6. Recommendations

To start with the recommendations researchers decided to focus on the bottleneck of the production line. After careful analysis of the production line under multiple days it was determined that Shield Insertion was the buffer of the production line. With this knowledge known researchers' determined created three recommendations to improve this bottleneck in hopes of reducing the WIP that was being produced, and hopefully eliminate it form the system.

4.6.1. Adding Fixtures

The first suggestion is very simple and can easily be implemented into the production line. For this suggestion the researchers suggest that by simply adding one more holding device the productivity will actually increase. To start for the Shield process there are two operators involved in solution 1, first is called loader operator and second is called unloading operator. This solution has to be added at least one holding device (two will be better because the extra forth fixture will be a buffer in this station and whenever they need it they can use it right the way.) The major thing that has been changed in this solution is the job description. The loader only needs to load units into holding devices and pass to the unloaded man next to him. The unloaded man not only just unloads units from fixtures into trays but also needs to put fixtures into and take out of the machine.

The reason why we changed the job description is that loading units is roughly about 3.5 seconds longer than unloading, and that means the unloaded man has 3.5 seconds of waiting time; therefore, we make the unloaded man to do an extra work which belonged to loader. In this case, the operating times for each works will be almost the same which means that the station achieves one piece flow

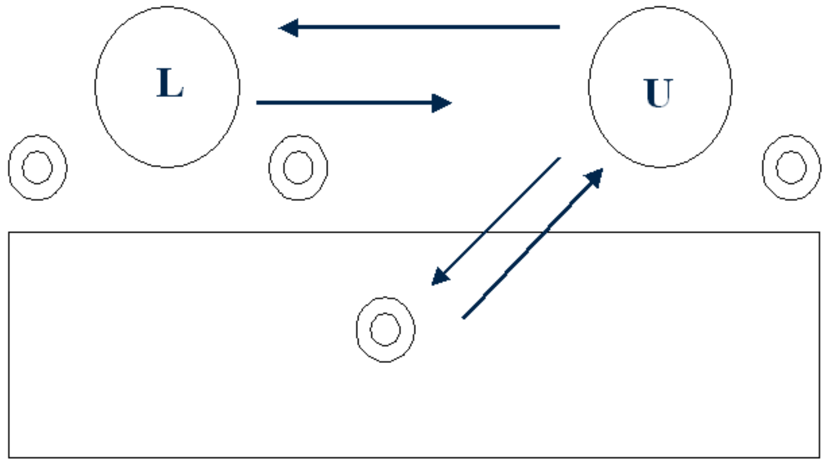


Figure 14: Adding Fixture

4.6.2. Help from Signal Operator

There are three operators involved in solution 3, first is Called Signal Operator, Second and third are called Loader and Unloaded from Shield Insertion. This solution has to be added 2 extra holding devices. The operator in Signal Insertion will fill out 1 or 2 holding devices and pass it or them to the next station (Shield Insertion). The operators in Shied Insertion will receive 1 out of every 4 or 5 holding devices. Here are the details for job description.

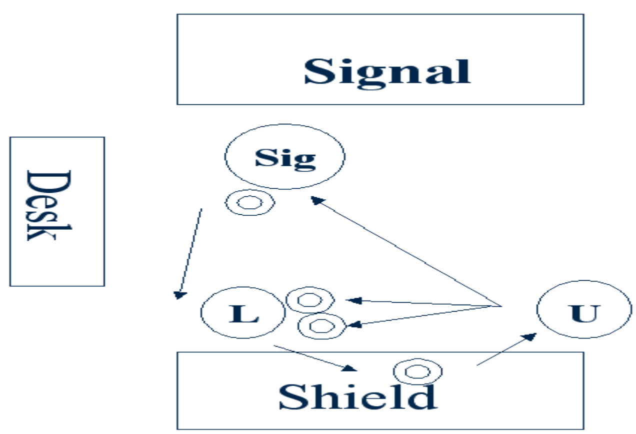


Figure 15: Shield Installation with Help From Signal Operator

In order to operate this suggestion successfully, we need to fill out 2 fixtures as buffers before starting the process. The Signal Operator will keep doing the work as normal but during the waiting time which is about 20~30 seconds, he needs to help loading one or more fixtures for Shield Insertion. While he completes loading fixtures, he will pass it or them to an operator who loads units into holding devices in Shield Insertion. The Loader from Shield Insertion will continue doing the Operation as usual, but when the Signal Operator passes a completed holding device to him, it will create a buffer. The Unloaded Operator does the same work as before; just every one out of four or five Holding Devices will be sent to Signal desk.

Signal Insertion			
Before (sec.)		After (sec.)	
Machine Time	56.5	Machine Time	56.5
Man Time	36.1	Man Time	36.1
Wait Time	20.4	Wait Time	0-10
Shield Insertion			
Machine Time	31	Machine Time	31
Man Time	44	Man Time	16
Wait Time	41.5	Wait Time	17.5

Table 2: Change in Downtime

4.6.3. Additional Operator

In the third solution the researchers suggested that by adding an extra operator, to help with the workload of the loading operator as well as adding another holding device, productivity will increase. As a result there will be three operators involved in solution 3, first is called transporter, Second and third are called Loading and Unloading operators. In this suggestion the job description for each operator in this solution is very simple. The loading operator job is loading units into fixtures. The transporter will pick up completed fixtures from loader and put them into machine. After the inserting shield is completed, the transporter will take the fixtures out of machine and pass them to unloaded man. The unloaded man will unload units from fixtures into tray and pass the empty fixtures to transporter.

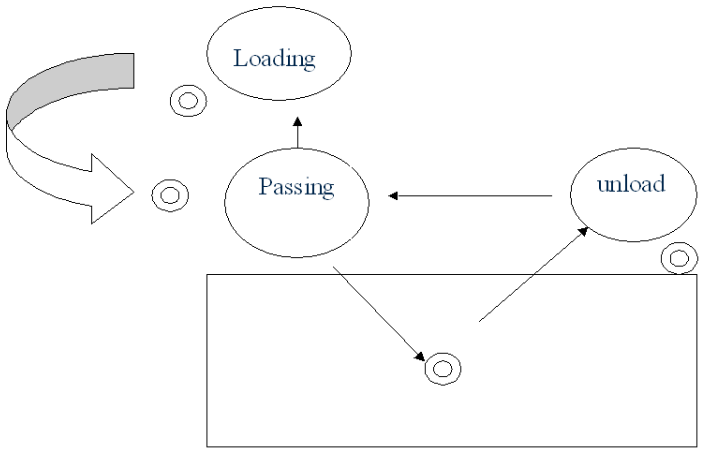


Figure 16: Shield Installation with Additional Operator

4.6.4. Advantages and Disadvantages

The advantage of the first solution is that the waiting times of the machine in Shield Insertion and the Operator in Signal Insertion will be eliminated, and it will increase the efficiency of the Shield Insertion enormously. It will also reduce the workload. According to the speed of the Loading Units into holding devices in Shield Insertion is the battle of the whole production line, and the Loading Operator cannot keep the constant loading speed equal or less than 12 seconds per 6 units, we use the waiting time of the Operator in Signal Insertion to reduce the workload of Loading Operator in Shield Insertion. Therefore, the Loading Operator will have a little bit more rest time and less chances to make mistakes. The disadvantage of the solution is that the job description of the Operator in Signal Insertion is more complex than before. They will get confused when passing around the holding devices back and forward if they do not have good communications between each operator.

The advantage of the second solution is that we do not need to spend any extra fun on adding operators but it will keep up the working efficiency by changing the job description. The disadvantage of the solution is that the company needs to get two extra holding devices, and the workload of each operator in Shield Insertion will increase extremely, and they will have no rest time until the next shifting. According to increase their workload, they might make more mistakes by prostration of mind and spirit.

The advantage of the third solution is that not only each operator in Shield Insertion will have a simple job description but also will keep a high efficient work. All of the operators will easily keep up the company demand which will make each unit in 2 seconds. The disadvantage is that the company needs to pay an extra worker and two holding devices. Because of adding one more operator in Shield Insertion, the working area between two stations will have limited space. That might affect operators' working attitude. Also the difference in production rates can easily be seen by *Table*

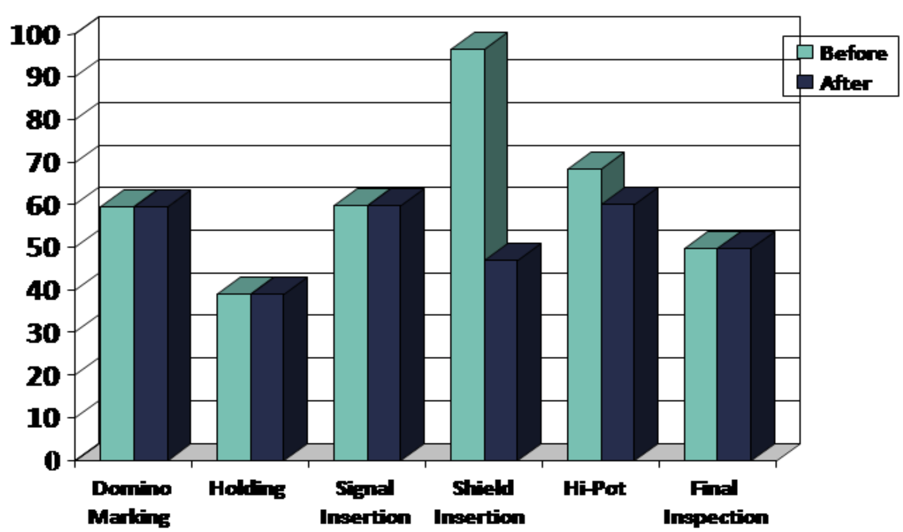


Table 3: Change in Cycle Times

4.6.5. Domino Marking Improvements

Researchers also made a number of recommendations that would also help the Domino Marking Station. The first suggestion is to combine the Domino Marking operator and the Housing Preparing operator. The other suggestion is to implement another Domino Marking machine. These recommendations will be described below.

4.6.5.1 Combining Domino Marking and Housing/Preparing

In this suggestion, we will combine Domino Marking and Housing Preparing because the cycle times of each station are much lower than the company demand (30 units per 60 seconds). By Combining the Domino Marking and the Holding Device to be with the same operator, this will cut down on space needed as well as an operator. Also this might be help with for the extra operator for Shield Installation.

For this suggestion to function properly the operator in Domino Marking has to label certain amounts of units first then start putting units into trays. The most important thing is that the operator has to fill units into trays in time before the signal station needs them; otherwise, it will slow down the whole production line. The benefit of the suggestion is that the company can possibly save the money from hiring an extra operator, but the disadvantage will be the operator who is between these two stations has to work harder than before which means the operator will have less rest time.

4.6.5.2 Adding Extra Production Unit

By adding a fixture more initial products will enter the system, creating less downtime for all operations. In the suggestion, it is suggested to introduce another Domino Marking machine. This would also be in addition to the previous recommendation of combining the operators from Domino and Housing. By adding an extra feeding machine, the machine will provide more products and fewer mistakes; the efficiency of this station will increase enormously. The extra operator from Domino marking can be relocated to other stations that need help to solve their bottleneck problems. The only disadvantage is that the feeding machine is very expensive and will need extra space which was currently limited for extra use.

4.6.6. Changing Machine Locations

For these Suggestions the researchers used the ideals of six sigma to help try and cut down the transfer time and the production layout to become more efficient. Also with the ideas form 5S and other principals researchers hoped to create a more beneficial process flow for the GBX production line.

4.6.7. Re-arrange full production layout

In this recommendation it is recommended to redesign the whole production line. This is because using the ideas of lean, creating a clockwise flow of products it will cut down on transfer time between workstations. Also It will cut down on distance traveled because all operations will flow in one direction. Also it is proven that by moving from left to right is more productive due that most operators will be right handed. A diagram of this suggestion fallows.

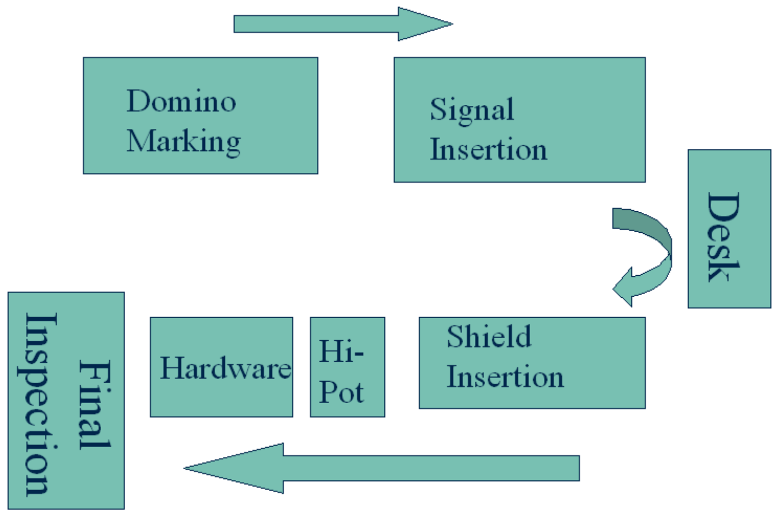


Figure 17: Rearrangement of Production line

It was found that by rearranging the production line for creating a clockwise flow and it will not only cut down the transfer time but also the distances between each station. All operations will flow to one direction, and operator will not need to walk some unnecessary or redundant distances. This suggestion may not be implemented because the production line has to stop for a long period of time to relocate machines. But with the help of arena the benefits of this change will be easily noticed.

4.7. Continuous One Piece Flow

By analyzing the process at Amphenol, the group was able to determine the line and work flow of the operation. This helped determine where continuous flow occurred and did not occur throughout the operation. There were two problems that were noted, first by using the plastic box as a tool for transferring by batches between most the stations, and not continually using the same tray, this would cause stoppage and unnecessary delay in the flow. But according to the lean principals of flow, there should be no more batch process and inventory to reduce the lead-time. This will help minimize the non-value-added process (the on load and unload motion)

To solve this problem and help with the installation of lean practices through the GBX production system, Amphenol was able to hopefully redesign their process flow to help limit the process time and cost to the company. As shown in the figure below:

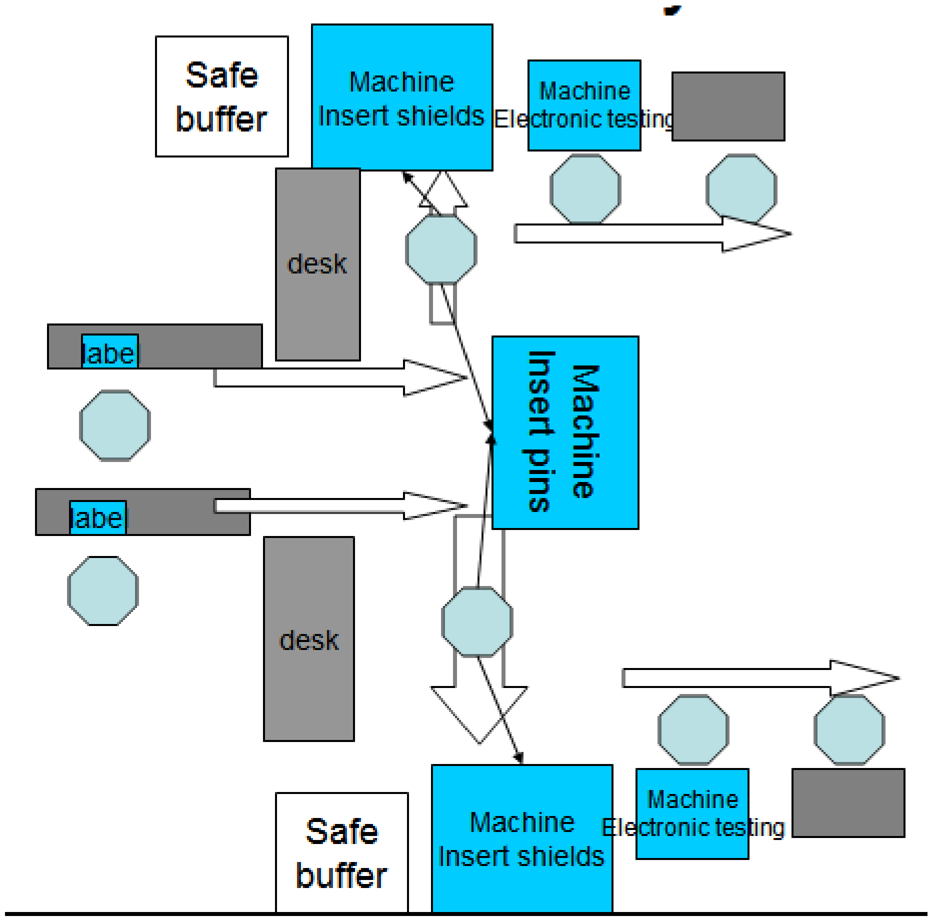


Figure 18: New production line

As you can see with this process it is a much more fluid and linear flow to the process. This will help cause better process out come, as well as fewer workers in the process. All in all, the goal was to show how lean manufacturing would improve the GBX system, and if run correctly this process will continue to help improve the companies outputs for the year.

4.8. Hidden Factory

The number of shippable units may increase but the additional units should have been manufactured correctly in the fist place. In contrast, resources that cause output to rise are classified as value-added work this was a prime example of hidden factory in the process. Another part of the process that was found to cause of a lot of hidden factory was when if a part was not labeled correctly, the part would be taken out of the system and then brought to another worker who would have to take the piece and fix the part. This is a step that is non-value aided and should not exist under proper lean practices.

4.9. Limitations and Error

The recognitions of limitation and error in the collection of the data and the analysis of results are critically important to increase the overall validity of research findings. It is also important to acknowledge alternative interpretations and viewpoints. In conceding uncertainty, the project group can make conclusions more credible (Barnett). The largest portion of the research paper exposed to limitations and error was that of data collection and inconstancies of the production line.

It is important to note that the data gathered is dependent on the operators working on the line at the time. It was even noticed in the data that there was tremendous variations in the time due to many factors, such as operator, time of day, companies demand, and machine failure to name a few. There were many other variations that can be recorded and other factors.

This project also had some limitations. First being that the researchers only had a limited time to visit the company and measure the production line. Due to this the machine times were only measured a in limited experiences, and under limited conditions. The company also only wanted one of many GBX productions to be measured.

Finally there was also a light limitation due to commutation problems. In the facility in Changzhou the primary language for operators was Chinese. Due to this there were limited engineers that were able to communicate with the research group. Also with limited knowledge of English some ideas couldn’t be properly expressed.

5. Conclusions and Recommendations

The goal of this project was to establish recommendations for Amphenol TCS for their Changzhou, China facility, to increase the productivity of their GBX Backplane production line. The primary objective was to evaluate the current production line, identifying all wasteful activities, and generate guidelines for further development. The production line was measured under multiple stresses and occasions, making sure to recoded the production line at least a hundred times per operation. In doing so the project group gathered factual information from the production line and compared it to the information provided by the company. Data was analyzed examining trends and unique opinions. Key findings emerged and were summarized so conclusions and recommendations, regarding improvements to the full productivity of the production line, could be drawn from them.

Results also showed the current cycle rates of the production line. In doing so the project group was able to identify all wasteful activities, by determined all non-value added processes. Also the bottleneck of the production system was identified as the Shield Insertion process. This seemed rather intuitive after the initial introduction to the production line, as it was visually slower then other operations and down time for machine was clearly noticed. Also after conversations with Amphenol engineers they clearly relaxed this fact too. Possible reasons for the higher cycle times for this station it could be due to infrequent production rates, and operator time s. Also the machine time was very quick in comparison to those other operations.

Upon the completion of the production line, the Researchers created a number of suggestions on methods that will help the overall production rate of the production line.

This is very important for the company and hopefully will help them in the long run to help make GBX a more profitable production line. To start with the data that was analyzed in the previous section, Researchers stated to identifying the waste, and determining the buffers of the GBX production line.

In the project, by gathering data from Amphenol TCS, were then able to analyze the GBX production line and provided suggestions. Overall, we successfully achieved the company's requests, which gave them multiple suggestions not only to solve the bottleneck of the production line but also show them the improvement of productivity.

In our suggestions, all of them can increase the output of production line enormously. According to prove our proposals are effective, the project group built a production stream map in Arena simulating software and plugged our data that ware gathered in Changzhou. The result shows the output of the production line per hour is 1530 units, which exceed the company's demand (1500 units). Researchers then offered multiple suggestions to the company, and they can implement any of them into their production line according to different kinds of circumstances. Researchers later learned from the Changzhou Facility were starting to implement some suggestions by the beginning of August 2007.

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