The Final Line

A Lean and Flexible Environment for the Bose Corporation

A Major Qualifying Project report for the faculty of Worcester Polytechnic Institute in fulfillment of the requirements for the degree of Bachelor of Science

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1. Lean processes
2. Flexible design
3. Manufacturing cells

Abstract

This project was prepared for the Park Place Manufacturing plant of the Bose Corporation in Framingham, MA to design and analyze a manufacturing line, known as the Final Line. An analysis of the current state of the line was conducted, alternative designs were presented and an optimal layout was selected for implementation. The goal in designing the new Final Line was to incorporate lean principles leading to a more efficient manufacturing cell.

Acknowledgments

The team would like to acknowledge a few individuals who assisted us in our endeavors. First, we would like to thank the project liaison to the team, a Manufacturing Engineer at the Park Place Manufacturing Plant of the Bose Corporation, for his guidance and encouragement throughout the past several months. We would like to give a special thanks to the Park Place Plant Managerand the Engineering Manager for sponsoring our Kaizen Blitz workshop. Also, we send our regards to the Bose employees who attended and participated in our Kaizen Blitz workshop, especially to Mike and Hector for their continual support with the implementation of the line.

We would like to acknowledge our advisor, Professor Sharon Johnson, for her tireless efforts in supporting the team. Her constructive feedback and guidance helped make this report as thorough and informative as possible.

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Chapter 1: Introduction

The extensive research by BOSE in the fields of speaker design and psychoacoustics the human perception of sound led to the groundbreaking 901® Direct/Reflecting® speaker system in 1968. Its unprecedented approach to sound reproduction came much closer to the essence and emotional impact of live music, winning immediate acclaim. Bose products are now found wherever quality sound is important (Bose: About Bose, 2008). The Bose Corporation, through one of its manufacturing plants sponsored this project to provide real-world insight into the industrial engineering and manufacturing profession as well as to supply them with a lean, flexible cell for manufacturing some of their specialty products.

Bose's Park Place manufacturing plant in Framingham MA is responsible for handling the manufacturing and packaging of specialty products. Over the past 18 months the plant has been undergoing a transition to lean cells. This transformation has supported an increase in production efficiency at the plant. Currently Bose is seeking to create a lean and flexible Final Line cell to accommodate prototypes and low-volume, high-variety products. The present cell setup does not incorporate the lean strategies implemented throughout other lines in the plant. The goal of our project was to design a Final Line cell that would operate efficiently, while being able to adapt to changes in processing a variety of products. A strong effort was made to optimize material flow and minimize space needed. As part of their lean efforts, Bose is also focused on organization and continual improvement incorporating principles of 5S+1[1] and the Kaizen system to their operations, and these principles were also important to the project.

[1] 5S+1 is Bose method of implementation of 5S. The "+1" stands for Safety.

To find a solution to this problem our team researched past case studies, collaborated with industry professionals and designed a model of the final line cell to meet the needs and goals of Bose, while applying lean principles. An important step in achieving this was to understand as much as possible about the current final line process and how other cells in the plant operate. Research was also conducted on topics including Single Minute Exchange of Die (SMED), flexibility, line design, and material flow. Lean tools such as value stream maps and A3 were used to guide the project. Next, we developed several alternative designs based in large part on a kaizen event. Kaizen is the Japanese word for "improvement." Kaizen events are typically gatherings of different people in the industry to first map out what currently exists and second to brainstorm and develop alternative plans to improve the process (Ron 2003). The alternative designs were evaluated according to several criteria.

Another significant part of the project was to implement the proposed design and observe the results. Improvements were measured in three areas, from the operators' standpoint, the team's observations and suggestions and comparing actual operating data produced by the Final Line. We listenedto the operators' thoughts and ideas on the newly designed layout and the cohesiveness of the final line process.

This report is organized by first providing the reader with a background of information on the Bose Corporation, lean processes and other topics relevant to the project. Next, is a chapter on how the research, design, and implementation of the old line and new cell were conducted, followed by a chapter on the results gathered from the Kaizen event, research done on the line, and operator input. The results also summarize the hard data we received from performing various time studies and production runs. The conclusion chapter wraps up the entire document by summarizing the project itself as well as how we went about performing all of our tasks.

Chapter 2: Background

To gain a broader understanding of the problem at hand, we first investigated Bose, their corporate culture, and the Bose Production System (BPS). The Toyota Production System (TPS) served as a model for Bose and has changed the way of thinking and culture within the company, particularly at the Park Place plant. These lean ideals have been the driving force in the changes the team made in the Final Line production layout.

2.1 Company Overview

Amar Bose founded the Bose Corporation in 1964 on the basis that research is the driving force of innovation. To this day it remains a driving force of the company. "Bose maintains an exceptionally strong commitment to research, for it is within the discipline of research that yesterday's fiction becomes tomorrow's reality" (Bose: Our Philosophy, 2008). A company registered trademark is "Better Sound Through Research®."

Many notable Bose innovations stem from the importance they place on reflected or indirect sound. "As a student at MIT, Dr. Bose had learned that most of the sound heard by a person in a concert hall is indirect --- i.e., bounced off the ceiling and walls --- rather than direct from stage to ear" ("Inventor of the week", 1999). The 901 ® Direct/Reflecting ® speaker, introduced in 1968, used a ratio of reflected to direct sound to create a more realistic listening experience.

Since that time Bose has done research across a variety of fields. Notable developments have been a computer to test to their own quality standards, speakers and loudspeakers for arenas, high end stereos for luxury cars, Acoustic Noise Cancelling® headsets, the Auditioner ® audio demonstrator (which can determine the acoustics of any space even before it is built),

home and car surround sound systems, amplifiers for musicians, the SoundDock® system and a revolutionary suspension system for automobiles and ElectroForce® linear motors (used to test biomedical materials) (Bose: Milestones).

The Park Place in Framingham, MA operates on a two-shift schedule from 7am to 11:30pm and produces specialty Bose products. Some examples of these specialty products include a sound system custom designed for a Ferrari and head-sets for military as well as commercial pilots. Since 2007 this plant has been converting to implementation of lean cells. Lean cells are line flows that incorporate lean principles. Each cell, with the exception of the Final Line is dedicated to a particular product. The lean movement has been a popular trend in manufacturing over the past few decades. Toyota is the world leader in achieving process improvement through lean principles. Companies are seeking to achieve results similar to those demonstrated by Toyota through implementing lean methods. (Jones, 2009). Recognizing the potential of lean tools and a lean mindset, Bose has been implementing lean practices within its plants, including Park Place. These lean cells use the 5s +1 system with a focus on waste reduction.

[redacted]. Products manufactured in the Final Line cell

are built periodically according to forecasted demand. The cell must be capable of handling prototypes as well as products that are more regularly run. This includes the ability to effectively transition between these products and maintain quality. As other cells within the plant already incorporate lean principles, the final line must undergo a similar transition.

Bose encourages all employees to take ownership of their work by providing input about means of process improvement during regular small group discussions. These discussions are structured in such a way that everyone feels like they have a voice while providing new ideas for continuous improvement.

2.2 Lean Processes

The Bose Production System is based on the Toyota Production System. Toyota Corporation is world renowned for their innovations in manufacturing. As the world's largest auto maker, Toyota derives its competitive advantage through efficient production. (Bowen and Spear, 1999) This is made possible by a distinct attitude within the organization. In building a lean cell for the final line, it was important to understand the fundamentals of BPS. To better understand the philosophy behind BPS we reviewed Spear and Bowen's (1999) study of TPS. The underlying theme of the study is that precise specification enables change and optimization(Bowen and Spear, 1999). With guidance from Autoliv, a US car parts manufacturer, BPS was developed based on the principles of precise specification providing optimization. In the following sections, several aspects of lean particularly important to Bose are explored.

2.2.1 5S+1

A crucial aspect of the BPS foundation is 5S+1. This concept originated in Japan as a reference to five terms describing how to manage the workplace. (Skinner, 2001) Translated into English, 5S stands for sort, set in place, shine, standardize, and sustain, with +1 for safety. A critical step in being a lean organization is to organize the workplace. The 5S+1 principle encourage a well kept and visually clear manufacturing floor. With this foundation, other lean improvements are made possible. Industry experts consider 5S+1 as the beginning point to in implementing lean manufacturing. (Skinner, 2001) In his article written for the Society of Automobile Engineers, lean management consultant Charles Skinner cites 5S as an essential tool for becoming lean, stemming improvements that include quick changeover, total productive maintenance and mistake-proofing. (Skinner, 2001) These benefits are all objectives the new Final Line design intends to achieve. To encourage a 5S+1 workplace at Bose, this methodology is posted throughout the floor at every cell and 5S audits are conducted once a week to evaluate how well the procedure is being followed.

The 5S + 1 principle must be an important part of the Final Line cell. The original final line did not adhere to 5S + 1, a contrast from the other cells at Park Place. This was made obvious by the lack of organization within the cell. The workspace was often cluttered with WIP, trash, and idle tooling. This made it difficult, not only by impeding operations, but it also contributed to increased changeover time, periodically having to remove unnecessary material.

2.2.2 Single Minute Exchange of Die

Single Minute Exchange of Die, SMED, refers to a system of techniques that make it possible to perform equipment setup and changeover operations within the singe-minute range (Shingo 1996). Changeover is the amount of time it takes to switch one process over to another.

If changeover can be eliminated there can be a better response to customer demand and reduction of lead time which in return increases profits. This enables the ability to run multiple products without using up significant time or capacity on setup. SMED concepts were important to the final line because it produces multiple products which initially required significant setup. The concept will help us locate, analyze and then eventually fix the parts in the line that had a high changeover time.

The team had the opportunity of participating in a Kaizen Blitz workshop for the Final Line. The purpose of the workshop was to gather different industry professionals within Bose to develop a unified scheme for how the final line should be transformed into a lean cell. One activity that was performed was SMED training. First, the workshop participants observed a simulated changeover from one product to another. The tasks needed to be completed for the changeover are listed below along with issues that were identified by the group:

1. Collect Manufacturing Packages (MP)which list the steps of each operation both illustratively and in text
    a. Problem Identified: currently a clip system so they all have to manually be removed and then replaced by the next product's MPs that are in a different location.
2. Remove machinery
    a. Move press to storage area
    b. Push back urethane machine
    c. Bring rack in and table
    d. Position roller table next to other table
    e. Move other roller table away from the line
    f. Roll another rack to the side
        i. Problem Identified: no difference between the racks used
    g. Bring in new large press (takes about 30mins for it to warm up)
        i. Problem identified: Press only used on far side of line
3. Each operator then sets up their own work station
    a. Problem identified: Other operators on the manufacturing floor do not view final line as a cell so they take things out of the line such as materials and tools.
4. Torque calibrations are done by the line leader
    a. Problem identified: The same gun is used for multiple products so calibrations (done manually) take a long time because of the different required torques.

5. A Technician sets up the test booth while rest of the line gets set up
    a. Problem Identified: The technician comes by only after the line leader calls him on his cell phone.
6. Packaging put on table and tool rolled over to station

The above list is a simplified version of the changeover tasks, but demonstrates how time consuming and demanding the process was.

Next, the workshop participants took part in a simulation of a changeover using different toy cars. The point of this activity was to observe certain failures and successes in the task and to question everything. It was really emphasized that some of the best solutions were produced by questioning everything and thinking outside of the box. Based on this questioning method one group was able to determine that there was an unnecessary step, the use of screws. Skipping this operation allowed them to omit a lengthy step, which resulted in the fastest changeover time. Other good points that came out of this exercise were to define clear roles and tasks for each individual (or operator) in the process. By clearly defining the roles and tasks, participants were prepared for their particular role and knew exactly what needed to be done.

2.2.3Lean Manufacturing Cells and Flexibility

A lean manufacturing cell is a modular arrangement of the tasks done to produce a single product, or a family of related products. Cells have a defined flow, or path, and are designed to limit the amount waste in a process. They are often condensed to reduce the travel time of operators and the distance over which the product is handled thereby reducing waste and non-value added work (Irani,1999).

Ideally when developing a lean manufacturing cell it is important to define the tasks and operations as well as the order in which the must be accomplished. Each task should focus on a single element of the product and all the tasks involving the element should be done during the

same operation (Harris and Rother, 2001). Within a manufacturing cell material must presented to the operators when, where and in the order in which they need it.

Flexibility in manufacturing cells is a measure of the ability to quickly respond to changes in the system (Vakharia, Askin and Selim, 1999). Within the Final Line cell reducing changeover time between parts and having a system that accommodates changes in production volume increased flexibility.

When considering flexibility and line design it is important to consider JIT (Just in Time) that is the line should only be producing exact amount at the precise time there is demand. The line should also be able to handle flexible capacity needed to account for varying takts. These aspects of flexibility were discussed the Bose Production System University (BPSU) training material on cell design.

In order to make a line flexible the machines must be designed to be flexible, the layout must be flexible, operator tasks must be flexible, eliminate dams, material and information must flow easily and there must be standardized work and motion. A truly flexible line has high quality instructions, multi-skilled operators and visuals that indicate takt time and line status. The following are specific BPSU examples of elements of a flexible cell.

Machines designed to be flexible are

a. On wheels whenever possible
b. Narrow
c. Have wires hung overhead
d. Have quick changes and SMED assembly
e. Have smart automation
f. Machines that requiring no adjustment

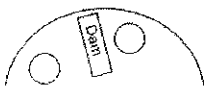
Flexible cell layout

[redacted] cells allow operators to move through their task in a continuous flow. They can attend to products at various stages of production with a minimum amount of waste. Multiple operators can easily attend to multiple machines. Thus increasing shojinka, ability to flex staffing from one cell to another

[redacted]

Eliminate Dams

Dams create divisions between operators and/or workstations they interrupt flow. If the two circles in the diagram below were machines the dam between them would result in operations wasting energy to physically avoid the dam. Thus the dam interrupts the continuous flow of material and information.



2.2.4 Continuous Improvement

Deriving its roots from TPS, continuous improvement is a strategy innate within the environment at Bose. Continuous improvement serves to keep firms on the cutting edge of technology and innovation. When used effectively it can provide a long-term competitive advantage. Additional benefits can be seen within the social environment of the company. Continuous improvement contributes to a stimulating environment in which employees feel a greater sense of being part of a unified vision across the company (Bessant and Francis 1999). For the Final Line, continuous improvement will play a pivotal role in developing a flexible cell with the ability to improve and adapt to meet the challenges in serving a variety of products.

The 5S+1 strategies present at Bose have set the tone for continuous improvement by implementing sort, set in place, shine, standardize, and sustain concepts. As previously discussed, 5S+1 is the essential tool from which other lean improvements can be made. 5S encourages strong workplace morale and boosts efficiency in line flow. (Skinner, 2001) The production cells at Bose are visually impressive. Everything is marked, labeled and set in exact order. As the original final line stood out from the other cells as clustered and disorderly, it will be important to carry 5S+1 over to the new Final Line. Effective continuous improvement requires that the methodology of 5S+1 be closely adhered to. (Lanigan, 2004) 5S creates visual clarity in the workplace, so issues are more easily identified because the employees can see when something is not right. This in turn facilitates analyzing and assessing processes for improvement because processes are more easily distinguished.

The foundation for continuous improvement under TPS is found in using specific scientific method(Bowen and Spear, 1999). The processes at Toyota continue to be developed by establishing a set of hypotheses that can be tested to find an optimal method. Essentially, operations at Toyota are set up as experiments. The principle behind this is also present at Bose. All of the work and processes within the organization are highly specified. This concept is designed to eliminate variation. Tasks are measured and sequenced down to the second and exact movement of the worker. Workers are forced to test hypothesis for improving tasks through the action of doing that process. Components of a sound scientific experiment are naturally present because everything is standardized. With controls already in place, an accurate outcome can be measured.

When workers at Bose seek to change and improve a process they use Kaizen cards. Bose has been successful at utilizing these to harness new ideas from their employees. A sound Kaizen

system can greatly benefit an organization providing small incremental improvements (Neese and Kong. 2007). Research has pointed to some important aspects for a successful Kaizen improvement system. The approach must emanate from management down through the shop floor and management must be willing to consider new ideas from the floor and work closely to initiate change when agreed upon. As found in TPS philosophy, the process for change must be exact and clearly specified. This provides a basis for employees to look back and analyze whether the Kaizen improvement were beneficial. If the initial goal was not accomplished, employees will revisit the issue and assess an alternate solution. 'Trystorming' is the process of brainstorming in action. The idea is that it enables employees and managers to work together actually trying ideas to visualize problems and solutions (Neese and Kong 2007). The visual clarity established through 5S makes trystorming possible. This strategy may prove helpful in seeing how different products on the final line will adapt to the new cell design.

Looking at Toyota, their key to success for perpetually improving is by developing countermeasures to solve problems (Bowen and Spear, 1999). The organization follows the ideal that there is no ultimate solution for any one problem. Employees seek to develop the best measure to address the issue at hand. This is not seen as a solution because there may be a superior technique if the situation changes or if an even better means is discovered. An important aspect of the final line project was trial and error. Once an initial design was in place, it was necessary to work closely with line workers to find the best practices, especially since the Bose employees working in the final line already have experience working on final line products.

It was important to make sure poor habits were not carried over to the new final line process, so every process and aspect of the new line needed to be clearly specified. Even with exceptional design and planning this new cell would not be completely optimal. Providing

appropriate direction for improvement was essential. A continuous improvement strategy was based on embedding key behaviors necessary for the learning process to evolve (Bessant and Francis. 1999). Strategic goals for the final line should be clearly communicated and put in place with a monitoring system to provide measurement against these objectives. Within the Final Line new manufacturing packages (MPs) should be created as a reference for workers to assure that they are following the specified process. Furthermore, the Kaizen system within the plant should be carried through to the Final Line cell.

2.3Implementation

Implementing a lean manufacturing cell requires planning and organization. Rother and Harris (2001) discuss the importance of the pre-implementation planning and diligent documentation of the process. They break the implementation process into four steps "Initial Process Design, Mock-Up, Debugging, and Sustaining the Flow."

The "initial process design" is the creation of a flow design, which will serve as the outline for the cell. A small group but diverse group should carry out this step. The second step, "mock-up", integrates more people. All of the production staff should be involved in this step. The cell should be physically setting up along the new flow design and operators should be familiarized with the new order of tasks, which should be recorded and standardized

In "debugging" one operator should move through production. Continuous improvement is implanted from this point forward. Operators, engineers and everyone who is part of the implementation team should look for ways the process can be improved. Those improvements should then be documented and implemented immediately. Once satisfied with the one-piece, one-operator flow additional operators can be introduced into the cell. Throughout implementation it is important to record milestones and continuously update documentation.

"Debugging" is complete when the defined metrics are met and the cell can operate at full capacity.

"Sustaining the flow" can be done in tandem with the other steps of implementation. A cell is dependent on many outside factors and in order to insure optimization within the cell external support must be well developed. Material (both raw and finished goods) flow is a major component of this external support. This should include material movement within the facilities housing the cell as well as way in which materials are received from suppliers. (Harris, Harris and Wilson, 2003)

2.4 Description and Analysis of the Original Final Line

Bose wanted the Final Line cell to be redesigned in such a way that it could be used for production of new products for Research and Development (R&D) along with high-variety, low demand products. At the start of the project, the cell was comprised of a long conveyer belt with access to tools on both sides and required nine operators to assemble the various products. During production of 901's the operators need to use tools such as screw drivers, glue machines, a press to set the glue, and assembly tape. Built Invisible production also requires screw drivers, a glue machine, and a press that is bigger and different than the 901 press. The changeover from 901 to Built Invisible products was always a long, complex process. The changeover was about an hour to an hour and a half with at least 5 of the 9 operators participating in the changeover. Refer to section 2.2.2 Single Minute Exchange of Die to learn more about changeover on a cell, and some of the specific issues identified.

Figure 1 is a simplified layout of the Final Line set up specifically to model the 901 product with specific problems noted. The issues discussed are based on observations by the WPI team as well as a Bose Manufacturing Engineer during an assembly of the 901® speakers.

Section A of Figure 1 depicts boxes of both finished goods and damaged goods placed close together on the manufacturing floor. Material handlers, even operators may get confused or misinterpret which boxes are finished goods as opposed to damaged goods, which would ultimately result in poor product manufacturing. More finished goods and piles of empty packaging boxes are shown in section B. We observed that operators had a tendency to get ahead of their work by making packaging boxes before they were actually needed. This resulted in piles of empty open boxes that became more of an obstacle rather than a time saver. The finished goods at the end of the line began to pile up while they were waiting to be retrieved by material handlers. Since this process is not done quickly enough, the boxes of finished goods ultimately became obstacles as well. Section C of the Final Line has an excess of Work in Process (WIP) and various raw materials, which makes the area disorganized and hard to maneuver in. Some aspects of the current processes within the line are faulty because the operators perform unnecessary steps when taking the raw material out of packaging, adding labels and transducers, which are implicitly portrayed in section D. By changing the layout and implementing 5s +1 the team turned this Final Line cell into a lean, highly flexible cell.

Figure 2 represents the production layout for Bose's Built Invisible. Much like the 901 layout, there are large amounts of raw material that occupy a lot of the floor which then causes obstacles for the workers and can lead to disorganization in the line. Although this product's process only requires six operations, much of the space is taken up by many tools, fixtures, raw material, and finished goods, especially since the Built Invisible units are larger in size.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Chapter 3: Methodology

The goal of this project was to create a lean and flexible Final Line work cell in order to accommodate prototypes and other low-volume, high-variety products at Bose's Framingham, MA plant. To achieve this goal, our team followed a three step process: data gathering and analysis of the original Final Line, design of the new Final Line cell and testing and implementation of the proposed design.

3.1 Data Gathering

Data gatheringrelated to the original Final Linewas an important part of the overall project. With the data collected we were able to compare and contrast different aspects of the original line and the new cell which helped support the reasoning to construct a cell design versus the outdated conveyor line design. In order to accomplish such comparisons we followed three steps; education on the BOSE Production System (BPS), collection of hard data and collection of raw data after observation.

In learning about BPS we focused on lean and 5S+1 concept through literature and Bose employees. The literature included Toyota's Production System, which they utilize within BPS,

[redacted]

In collecting data on the original Final Line we focused on five different areas to help measure improvements. These include:

I. Floor space optimization
II. LMPU (labor min/unit)
III. Standard cost
IV. Setup Time
V. Analysis of current manufacturing package (MP)
    - Analyze tools, fixtures & process to define the wasteful processes

- Updating and simplifying the MP

In collecting raw data from the original Final Line, we also focused on initial observations; note that these observations are summarized in section 2.4. Observations usually lasted between 2-3 hours during which we documented the process flow, material handling and any issues within the line.

3.2 Final Line Design

As a team we planned and then ultimately developed a common layout for the final line cell following 4 specific steps. The steps were to establish a method for designing the cell, develop alternative cell designs, participate in a Kaizen workshop and revise the cell designs based on management feedback.

In establishing a method to design the cell we explored factors that were important to the design. These included:

I. Waste elimination.
   - Waste can be addressed by reducing WIP, implementing 5S+1 and instructing operators not to work ahead.

II. Material storage.
   - Storage should increase floor space, improve flow and reduce ergonomic stress on operators.

III. Order of operations and steps within the operations.
   - Operators should be focused on one element on the product at a time and complete all tasks related to that element at once, whenever possible.

IV. Limited material handling.
   - The less an operator has to move, twist or turn material the less likely it is that damage will be incurred.

V. Layout of tools, fixtures and material.
   - Operators should be able to easily access the tools, fixtures and material they need for an operation from a specific physical location.

VI. Standardize fixtures and tool layout used across products to reduce change over time.

VII. Booth design (possibilities)

- Smaller booth with one entry window and move door to side of booth
- Various different material entry options in the booth (conveyor, wheel conveyor, plastic table)
- Smaller booth with two entry windows, one for incoming product to be tested and the other to have tugger deliver raw material

In November 2009, we participated in a Kaizen Blitz workshop. The goal of this workshop was to gather different the industry professionals within Bose to gain a unified scheme of how the final line should be transformed into a lean cell. The team consisted of a good mix of people which includedthe operators, Industrial engineers, Quality control engineers as well as many others. [redacted]

In the workshop the team assessed different assembly approaches to manufacture distinct Bose Final Line products and the effectiveness of the current processes, equipment and process flows. The design and overall layout of the new cell was a big portion of the workshop. This time was used to:

- Assemble our proposed cell design and discuss any concerns and/or modifications towards fixtures/ workstations, process flow and material handling. Since the current final line area was not accessible, extra floor space was temporarily provided to set up our cell design.
- Collaborate with industry professionals in a Kaizen Blitz Workshop for the Final Line cell
- Construct a model of the work cell design and operation suggestions
- Help organized and manage the testing and production of specified 901 units within the new cell
- Perform Kaizen events or continuous improvements where the team saw fit

After creating our criteria, we developed several alternative designs. The construction of each alternative cell was derived from the modification/improvements of the Kaizen developed

cell. The major differences between each alternative and the Kaizen cell is the number of workstations, number of operators and the orientation of the layout.

The final step in the design process was to revise the design based on the feedback.Following the workshop, a presentation of our findings, ideas and solutions was given to management. Many comments were provided which helped aid in the construction and success of the cell. They included:

VIII. The orientation of the cell [redacted]

IX. The location of the cell [redacted]

X. How readily available is the new test booth?
   - We may need to use the original test booth, which in turn will drive the new cell layout (although unlikely)

XI. How to handle the units around the cell and in/out of the test booth

3.3 Testing and Implementation

Implementation of the new cell was in large part initially determined by the kaizen blitz event. A production schedule, which later changed, was determined along with a timeline of when the products would be tested on the new cell. [redacted] Possibly one of the most important exercises during the event was when the participants actually went onto the manufacturing floor and used free space on the floor to start assembling some fixtures and

roughly placing tables and equipment in areas that would create the new cell to be lean and flexible.

[redacted]

Once the fixtures, equipment, and especially the test booth were set up in the new cell area, operations began testing out the cell [redacted] The first couple of weeks of testing the new cell included recording times of individual operations as well as serial operations from cradle to grave. These times, as well as recorded changeover time was used and compared to data from the old line to measure efficiency and flexibility of the new cell.

Throughout implementation, the workload of the operators was balanced. To maximize utilization a balance zone was created where either operator can complete a variable number of the tasks within the operation. This balance zone creates flexibility that ensures there is no waiting by either operator. Once the balance zone in the Final Line was well defined natural pull was created within the line. That is the operators were working to fulfill a demand rather than simply produce a number of products.

Chapter 4: Data and Results

[redacted] Data was gathered on the original Final Line layout and the cellular Final Line as well as the constraints and criteria of the cellular design. Since the Park Place manufacturing floor is such a dynamic environment several design alternatives were created to allow the cell and the material within it to be located in various ways. This chapter describes the data collected, the design criteria, the alternative designs and the cell implementation.

4.1 Scheduling and Takt Time

Takt time is the pace of production; it is the rate at which a single unit can be in production from start to finish. The Theoretical takt time is the time it takes to complete each task in production while the actual takt time is the maximum time a unit can be in production in order to meet demand.

[redacted]

4.2 Cell Design Criteria

Table 2 describes the 9 necessary considerations that we developed for evaluating a flexible cell. We used these criteria to compare the original line, Kaizen cell layout and alternative designs.

Table 2: Flexible Cell Design Criteria

[redacted]

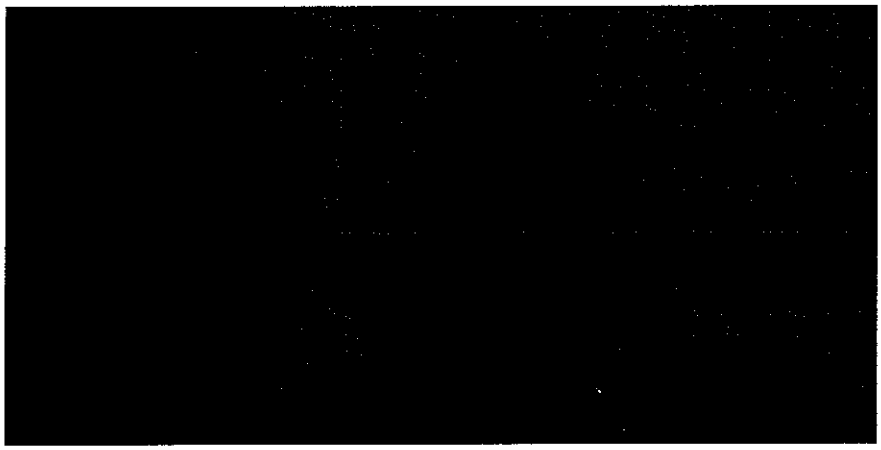
4.2.1 Original Final Line

[redacted]

[redacted]

[redacted]

[redacted]



[redacted]

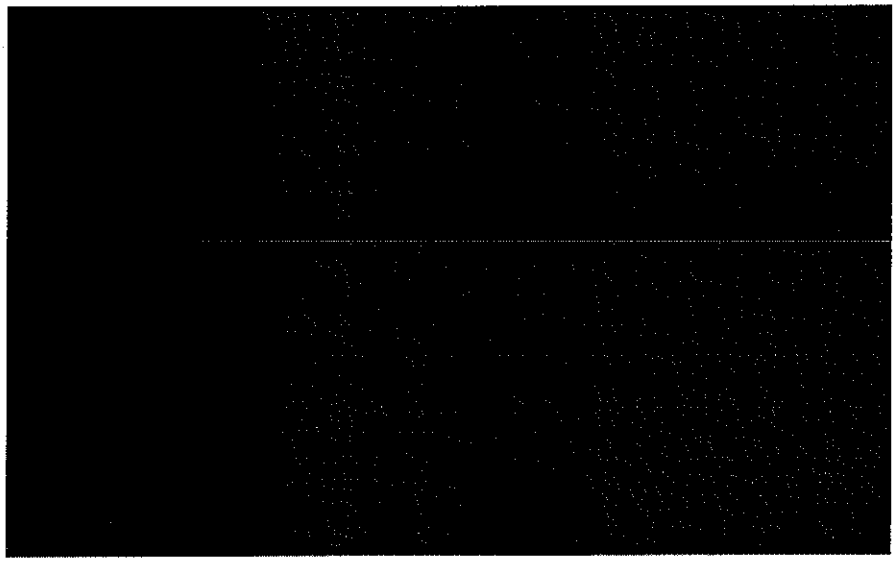
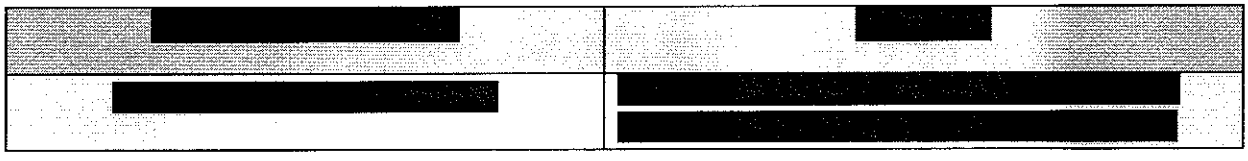
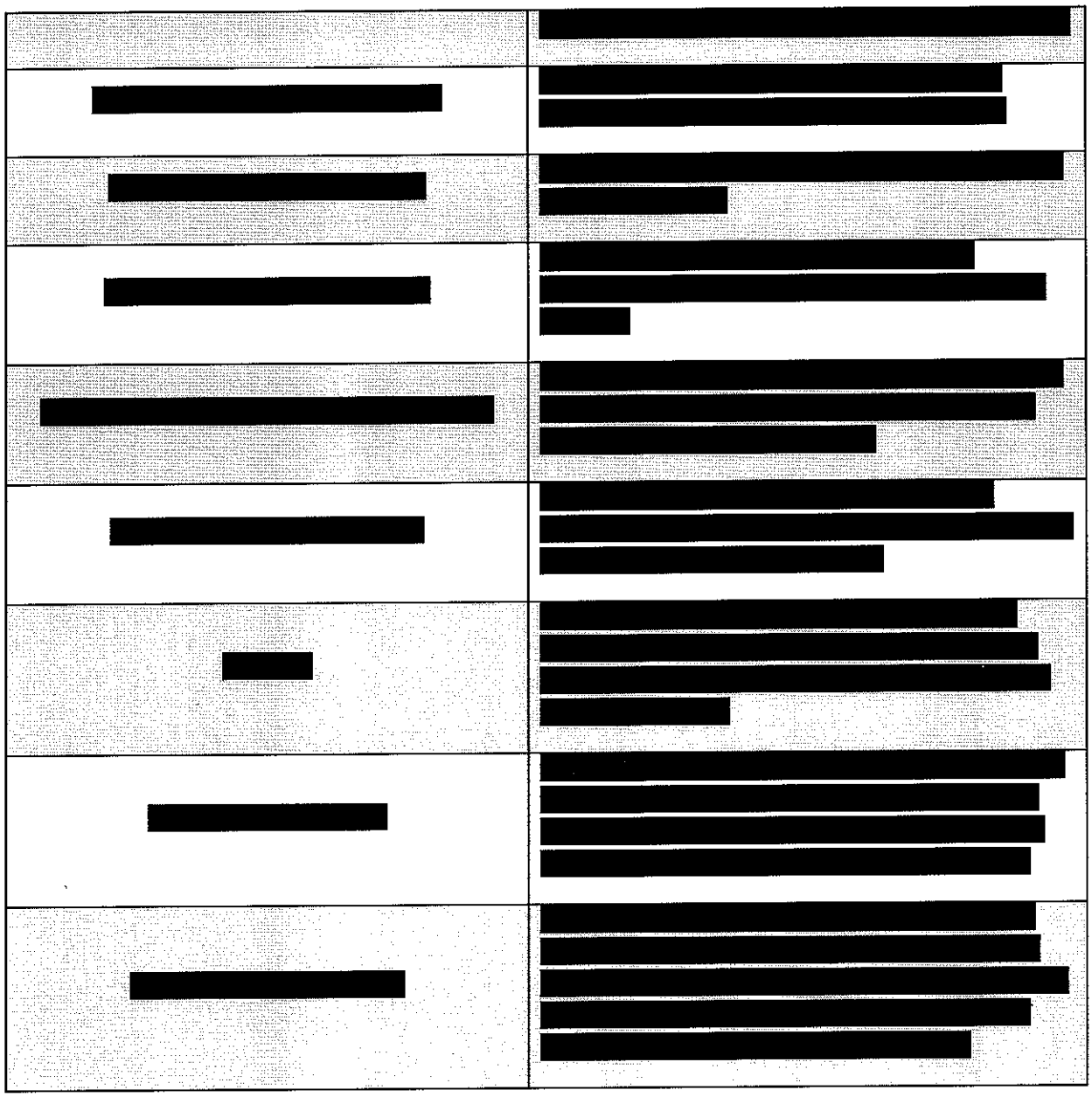


Table 3: Final Line Criteria

Original Design

[redacted]





4.2.2Final Line Cell after Kaizen Event

Figure 5 illustrates the design for the Final Line cell developed during the Kaizen event. We refer to the cell as the Bose proposed layout. This includes both 901 and Built Invisible together in one cell. Table 4 consists of the proposed BOSE final line cell layout and its comparison to the criteria.

Overall this layout triumphs over the original final line design by reducing the space required, the number of operators and being very flexible. The numbers of workstations have been reduced tremendously and the material flow issue has been handled. Specific drop up and pick up locations have been assigned as well as the use of racks and rollers for better material presentation.

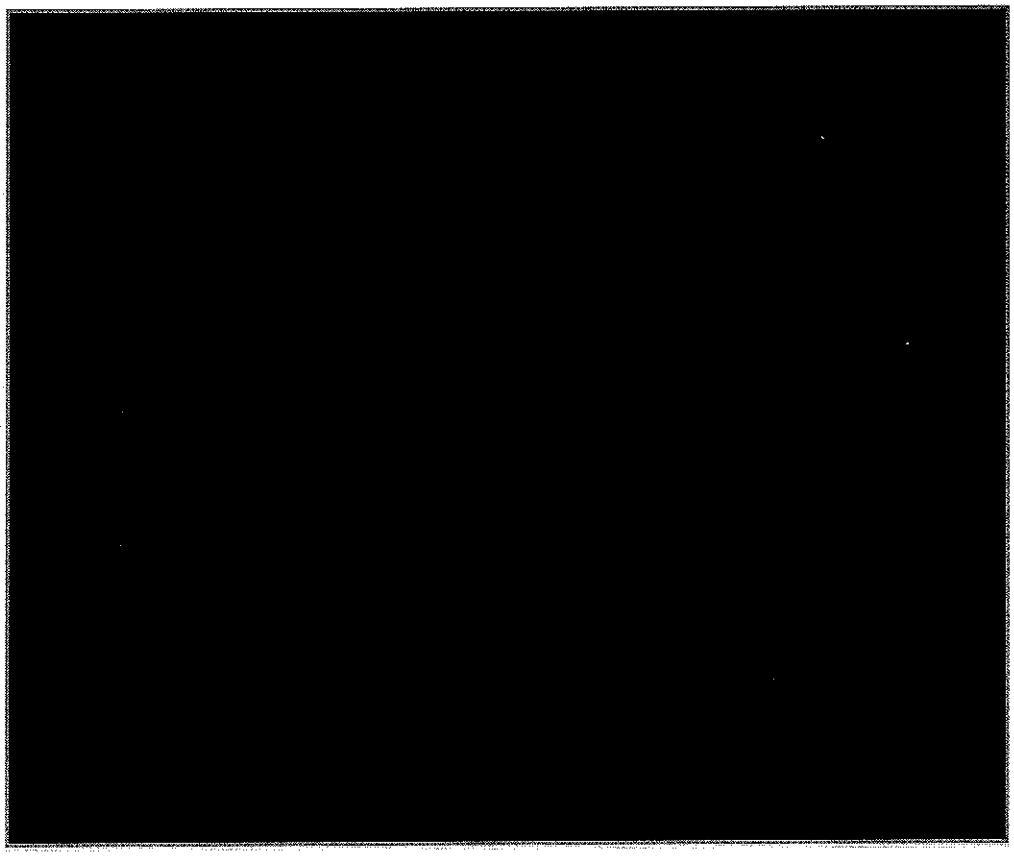
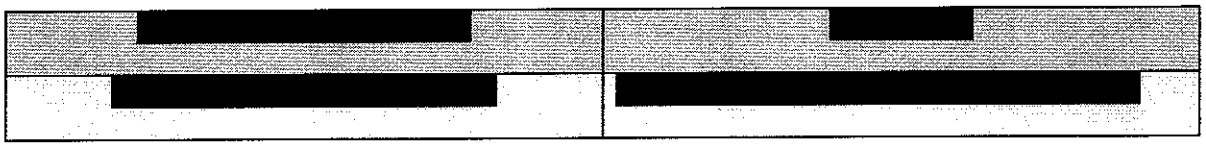
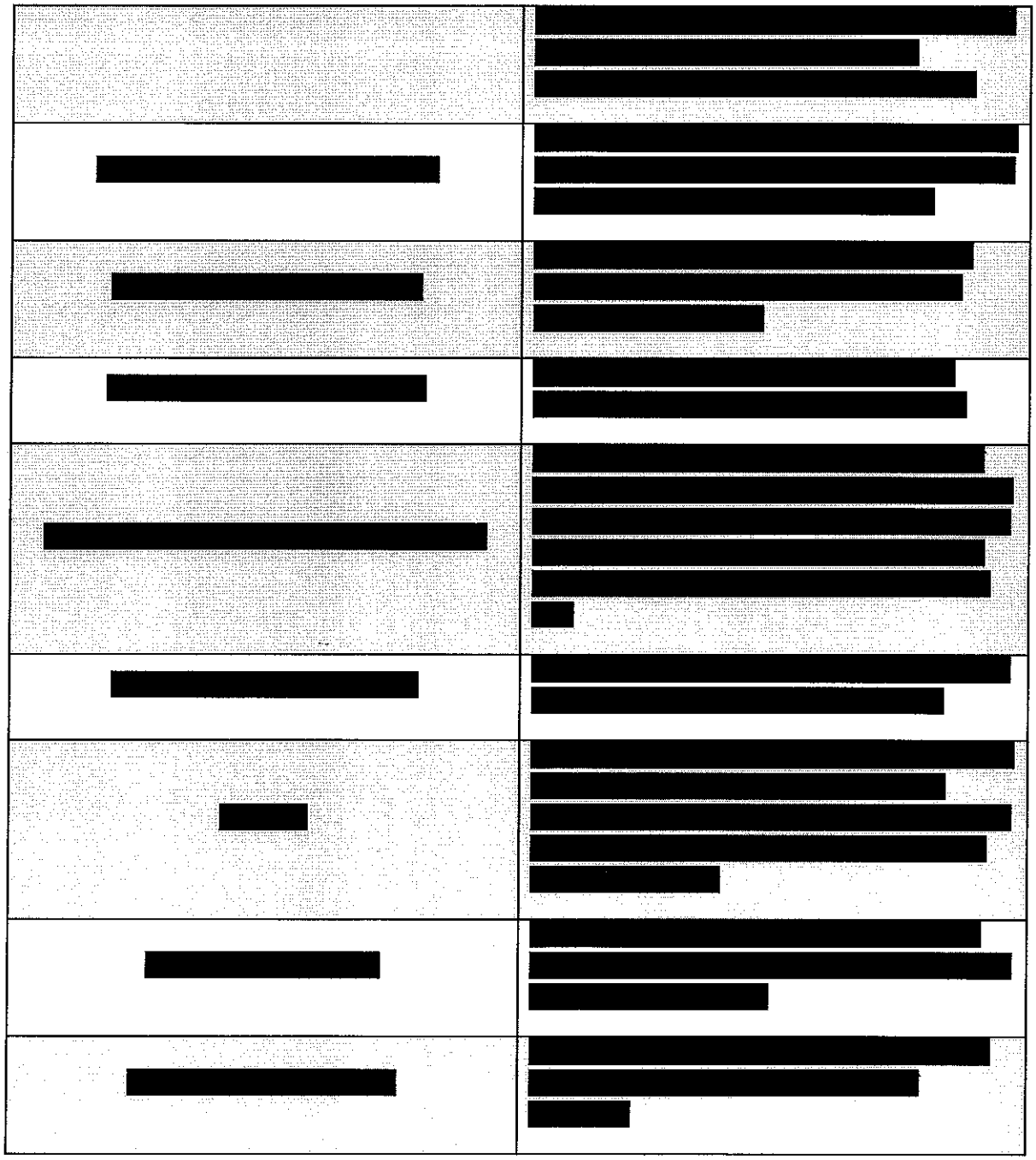


Figure 5: Final Line Cell after Kaizen Event

Table 4: New Final Line Design Criteria





4.2.3 Original Final Line vs. Final Line Cell

The obvious difference between the original and redesigned Final Line is that one was designed as a line with a long conveyor while the other is a more condensed cell. Currently the

final line would only be able to assemble one product at a time and because of the number of fixtures and workstations the changeover time is significant (approximately 60-90 minutes, involving multiple operators). Because there is currently extra capacity, the changeover time did not matter as much; however if the demand were to suddenly increase for each product the current setup would probably not be able to handle this. The new proposed cell design would be able to accommodate a sudden increase in demand because there is virtually no change over time and the cell houses stations for both major products.

Besides the apparent reduction of the number of workstations and operators for the Final Line cell, another distinction between the two is the construction of the test booth. During the Kaizen workshop the team proposed a number of possibilities of the design of the test booth. We felt that modifications could be made to the booth to better accommodate our proposed cell design. [redacted]

Another difference between the two designs is the amount of space used. We estimated that the new cell would take up 66% less space than the current setup and the savings would come out to be around $18,000 annually. This alone is a big improvement. We also figure that by changing the current setup to a 'U' shape cell design and by eliminating batch assembling, the material flow in and out of the space will be improved greatly. The operators will receive the correct amount of raw material to be built within that hour and the tuggers will collect finished

goods on a better schedule than is currently running. The current setup does not use the tugger system. Batches of raw material are delivered at the beginning of a run and then replenished as needed. Replenishment of material currently consists of having the line leader ask the appropriate person for an estimated amount of material and then he hand delivers it to the operator, which is very inefficient and unorganized. Replenishment within other cells around the manufacturing floor happens every 30 minutes as needed. With this new cell, regardless of the actual design, BOSE plans to develop a kanban system to eliminate this problem as well as implement a Kaizen improvement station in order to allow for continuous improvement on the cell.

4.2.4 A3

To further organize and document the implementation of the new cell, an A3 report was created. The name of the report comes from the size of paper it should fit on, A3 which is an 11" X 7" sheet. "Toyota believes that when you structure your problem solving around 1 page of paper, then your thinking is focused and structured" ("The Toyota A3…", 2009). An A3 is comprised of the identity of the problem, background information regarding the problem, a root cause analysis, current conditions, target conditions, a plan of action, and the results. The developed A3 for our project is shown in Figure 6.The following explains the target condition portion of the A3.

Process flows:

A: [redacted]
The worker will assemble the product at the designated workstations and then transfer for it to the booth for testing. Next it will be transferred to the packaging station where the employee will box it up and prepare it for pick up from the tugger.

B: [redacted] The worker will assemble the product at the designated workstation and then transfer

for it to the booth for testing. Next it will be transferred to the packaging station where the employee will box it up and prepare it for pick up from the tugger.

C: [redacted]

Material and equipment information:

1: The new cell area, which has direct access to the warehouse and tugger routes from both sides.

2: A designated section for prototype /other products and material storage

3: Newly designed rollers to house raw material

4: [redacted]

5: The new test booth. Smaller in size, no conveyor and sliding tunnel doors

A list of improvement predictions based on the target conditions is listed below:

- The new area and cell design will save BOSE floor space, which will result in serious money savings
- There will be virtually no changeover time (as compared to ~30minutes for the original line)
- Each major product has its own designated workstations, which allows for no confusion and possibly building two different products at once
- The new rollers [redacted] allow for virtually no WIP and raw material to be strewn about.
- Following the calculated TAKT time will allow for a more efficient schedule on how many and when to product each product

Having fewer workers in the cell assembling the product will allow for less man handling as well as keeping up with the desired TAKT time.

Further details and explanations for the root cause analysis are listed below:

<u>Problem 1</u> = WIP/Raw material strewn about

- Material Handling issues both on the line and in the warehouse
  - Lack of communication (and timeliness) between the line and warehouse
    - No real kanban system set in place to replenish material (so it may come in excess or not at all)
      - Final Line was last on the list to be transformed into a lean operating system, so kanban was pushed back

<u>Problem 2</u>= Number of workers

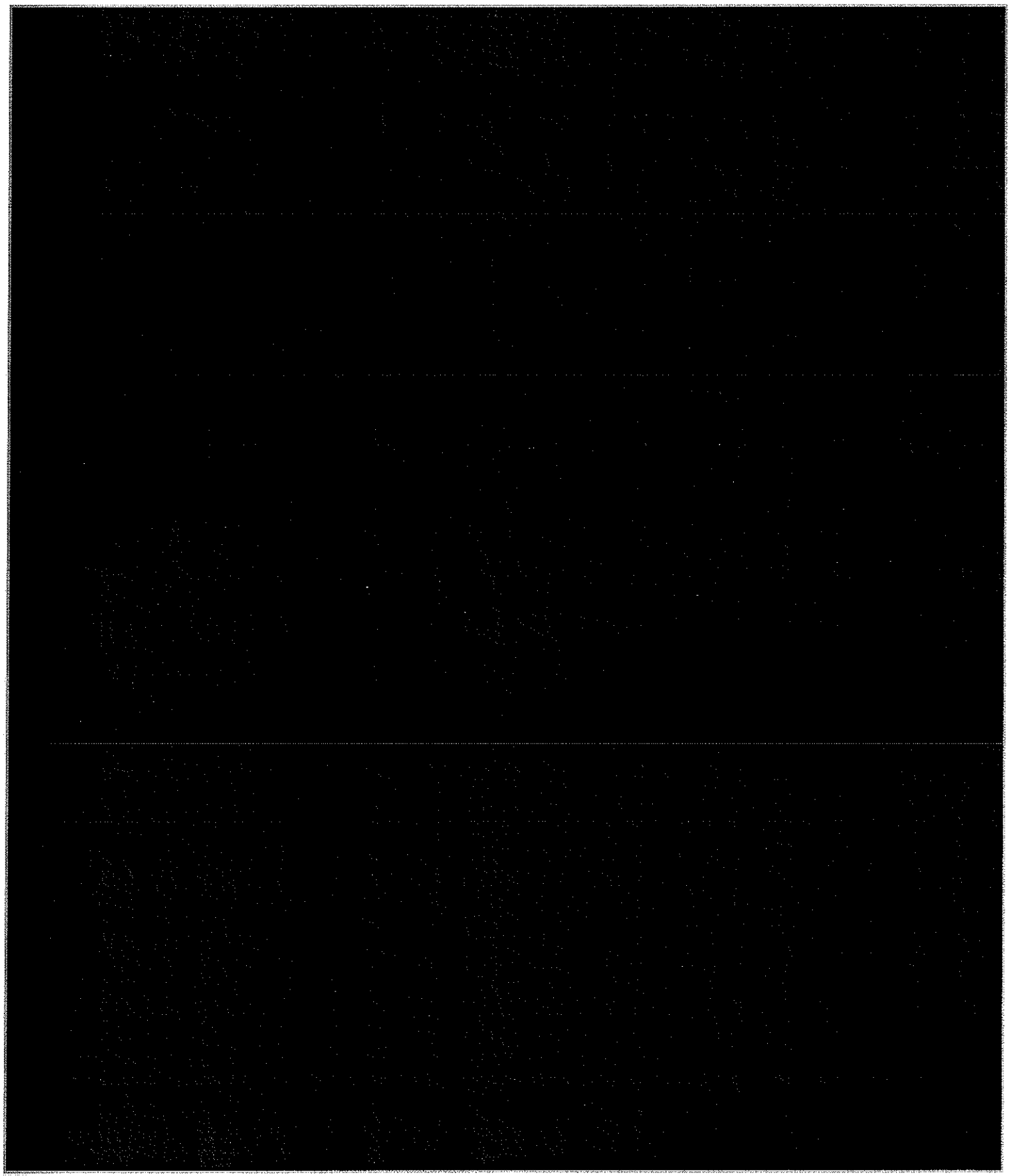
- Too many workers in the Final Line

- The number was based on product MP and conveyor design
  - MP's were too detailed which caused for more unnecessary workers
  - Conveyor design needed more employees to accept products as they came down the line

Problem 3= Employee working ahead

- Slow start and conveyor design
  - Because of the conveyor design too much time passes before the worker in the last operation becomes antsy and begins to work ahead

The new design solves was designed and implemented to solve the issues previous listed as the root cause analysis.



4.3 Alternative Designs

Based on the design produced during the Kaizen event, [redacted], we proposed several alternative cell designs for the final line in accordance with the known constraints. The designs are similar to the proposed BOSE cell design, however with a few changes in the look and organization of each station.

4.3.1 Alternative Design 1

[redacted]

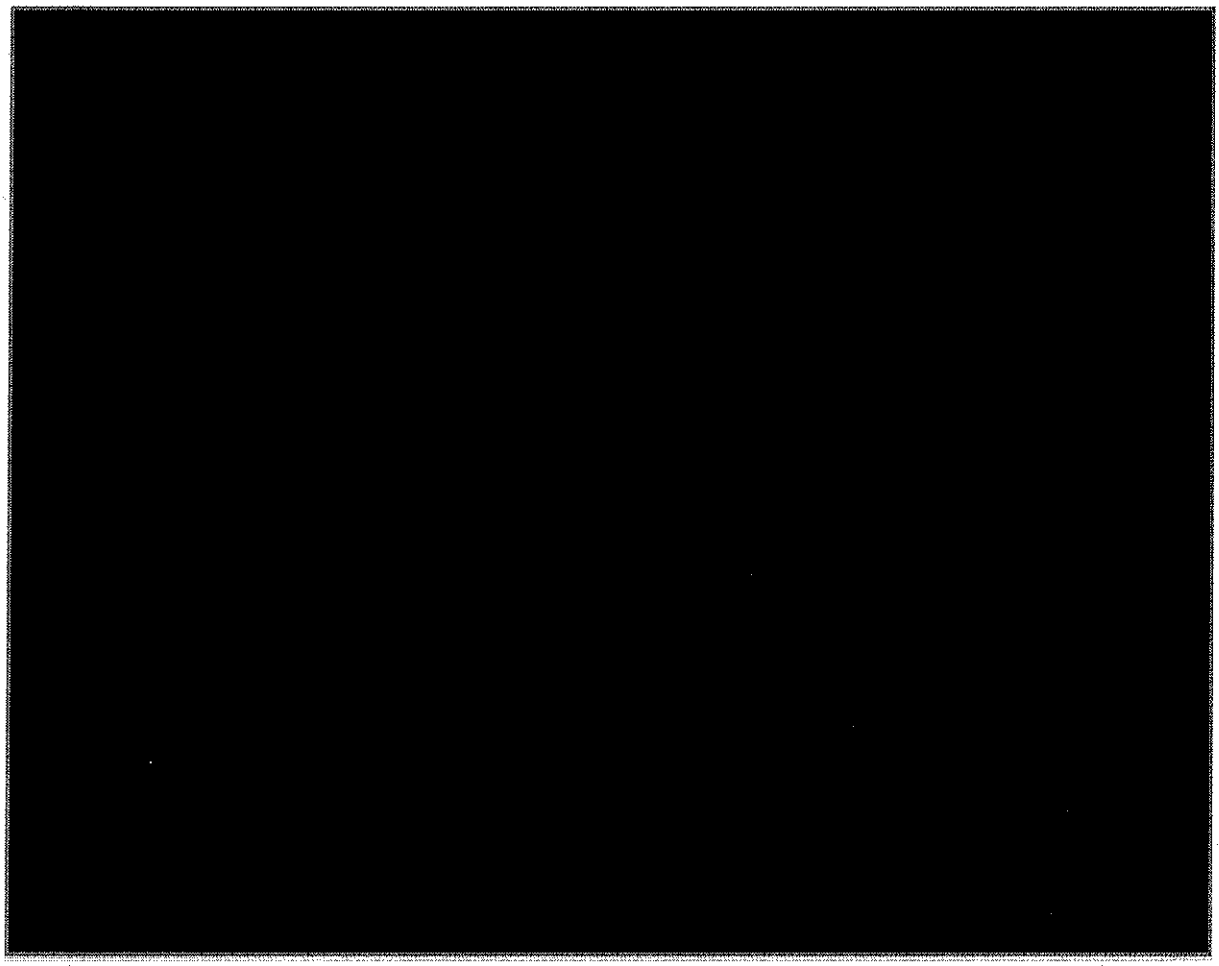
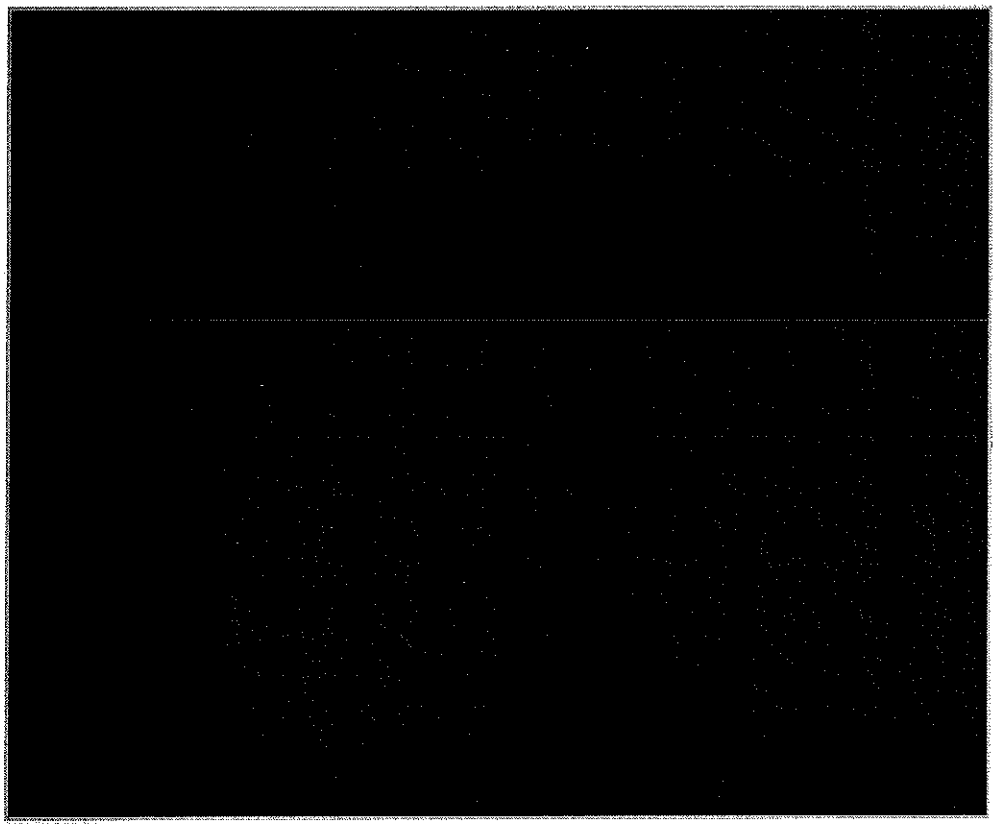


Table 5: Alternative Design Criteria 1

Flexible Cell Design Criteria	Comparison
1. Design Machines for Flexibility.	Similar to the BOSE proposed cell. Separate stations per major product, however flexible enough to allow for new product assembly.
2. Design Cell Layout for Flexibility	Similar to the BOSE proposed cell.
3. Look at the Total Plant Layout	Follows BOSES's BPS ideals and will incorporate a Kaizen station for improvement.
4. Eliminate Dams within the Cell	There are essentially no dams within this cell. The operator has a clear path when walking to each station.
5. Look at Material Flow in and out of the Line	There is a designated spot for material drop-off and delivery. There will be a kanban system in place for material replenishment.
6. Design Line around Operators	Similar to the BOSE proposed cell. The packing station has been moved to allow for a more 'U' shaped cell and to have the material moving in one fluid direction.
7. SMED	This cell design does follow fairly closely to SMED. Operator(s) have the specific tools and fixtures they need and nothing more as well as more specific set of instructions. (new MP)
8. Organize Job Rotation	Similar to BOSE proposed cell.
9. Standardize Work/Motion	Similar to BOSE proposed cell.

[redacted]

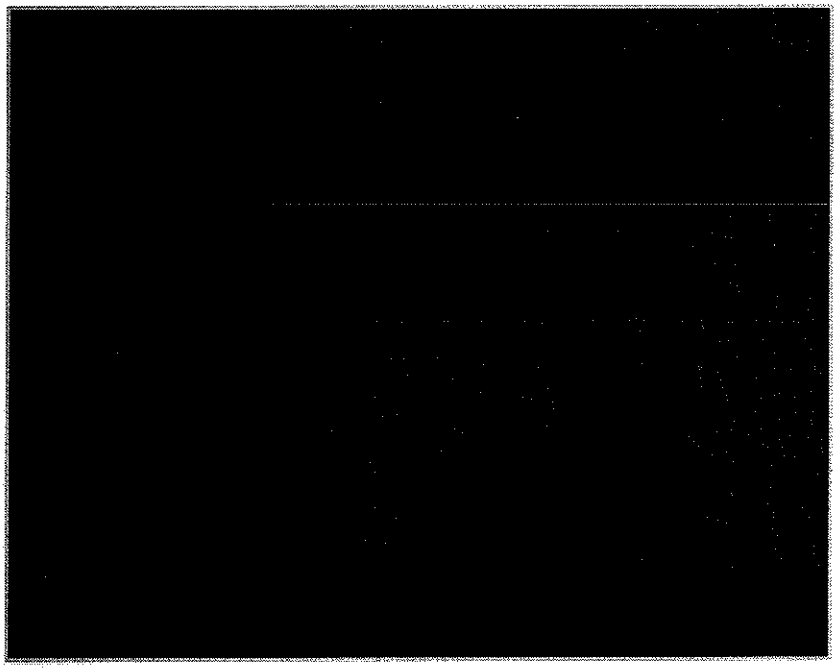


[redacted]

Table 6: Alternative Design Criteria 2

Flexible Cell Design Criteria	Comparison
1. Design Machines for Flexibility.	There will be one set of each necessary machinery and fixtures and will be shared per product
2. Design Cell Layout for Flexibility	Cell is rather flexible, however does not leave the option to have both major products done at one time since there is only one workstation. Because of this, the one workstation will be very flexible with some fixtures stationary (B.I press), while others will be easily removable. This cell could easily allow for another operator if necessary, even on the one workstation. (the workstation would need to be bigger than what is currently available)
3. Look at the Total Plant Layout	Follows BOSE's BPS ideals more closely than the original final line layout
4. Eliminate Dams within the Cell	This design allows for essentially no dams
5. Look at Material Flow in and out of the Line	There will be a designated drop-off and receive spot within the cell. Since there is only one workstation, one test booth and the packing station, the unit does not need to travel very far to the end. (a.k.a less material handling = less possibility for damage/scrap)
6. Design Line around Operators	This cell is designed specifically around the operator. It requires less movement and 'effort'.
7. SMED	This cell will follow SMED as long as the one workstation and fixtures are truly flexible. Having the correct tooling and basic materials pre-set on racks will limit the changeover time. There will however be a changeover time (moving fixtures, etc) but it will be rather small
8. Organize Job Rotation	Job rotation will be highly organized. Operator will have new MP and will assemble unit on one table, put on roller conveyor to go to the booth, tested, and then moved to packaging on cart.
9. Standardize Work/Motion	The assembly will mostly be on the one workstation therefore having motion very reduced. MP will be redesigned to allow for this one-station design

[redacted]



[redacted]

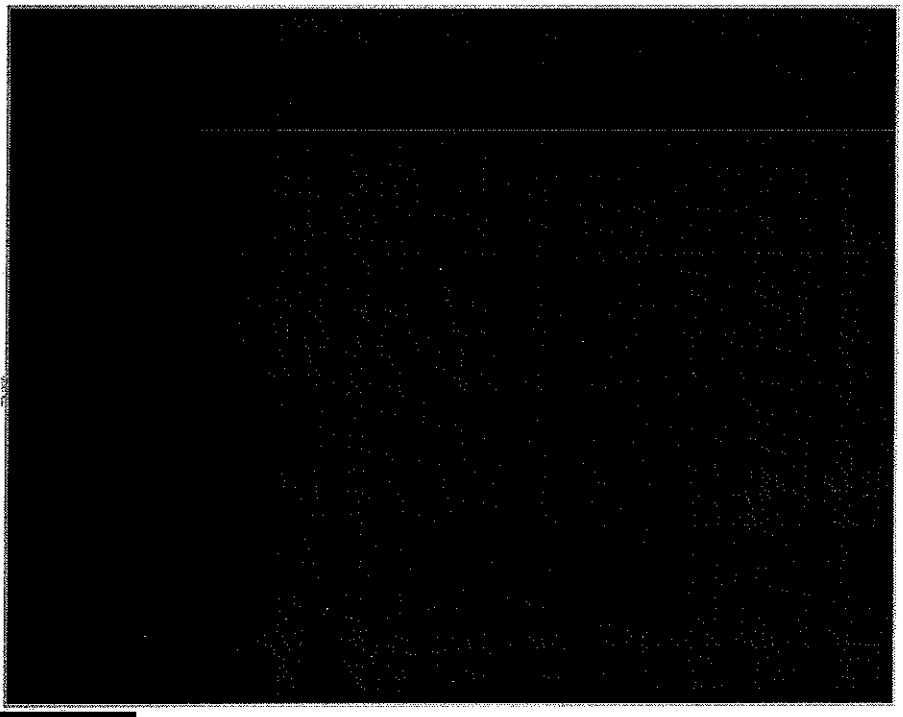
Table 7: Alternative Design Criteria 3

Flexible Cell Design Criteria	Comparison
1. Design Machines for Flexibility.	Similar to the BOSE proposed cell. Separate stations per major product, however flexible enough to allow for new product assembly.
2. Design Cell Layout for Flexibility	Similar to the BOSE proposed cell. [redacted]
3. Look at the Total Plant Layout	Follows BOSES's BPS ideals and will incorporate a Kaizen station for improvement.
4. Eliminate Dams within the Cell	There are essentially no dams within this cell. The operator has a clear path when walking to each station. Hot melts and other larger fixtures have a specific place within the cell which will reduce any possible dam situation
5. Look at Material Flow in and out of the Line	There is a designated spot for material drop-off and delivery. Roller conveyors and specialty racks are also used in this cell. There will be a kanban system in place for material replenishment.
6. Design Line around Operators	Similar to the BOSE proposed cell. All tools, raw material and specific fixtures will be available to the operator at an appropriate reach (hung from ceiling)
7. SMED	This cell design does follow fairly closely to SMED. Operator(s) have the specific tools and fixtures they need and nothing more as well as more specific set of instructions. (new MP)
8. Organize Job Rotation	Similar to BOSE proposed cell.
9. Standardize Work/Motion	Similar to BOSE proposed cell.

[redacted]

[redacted]

[redacted]



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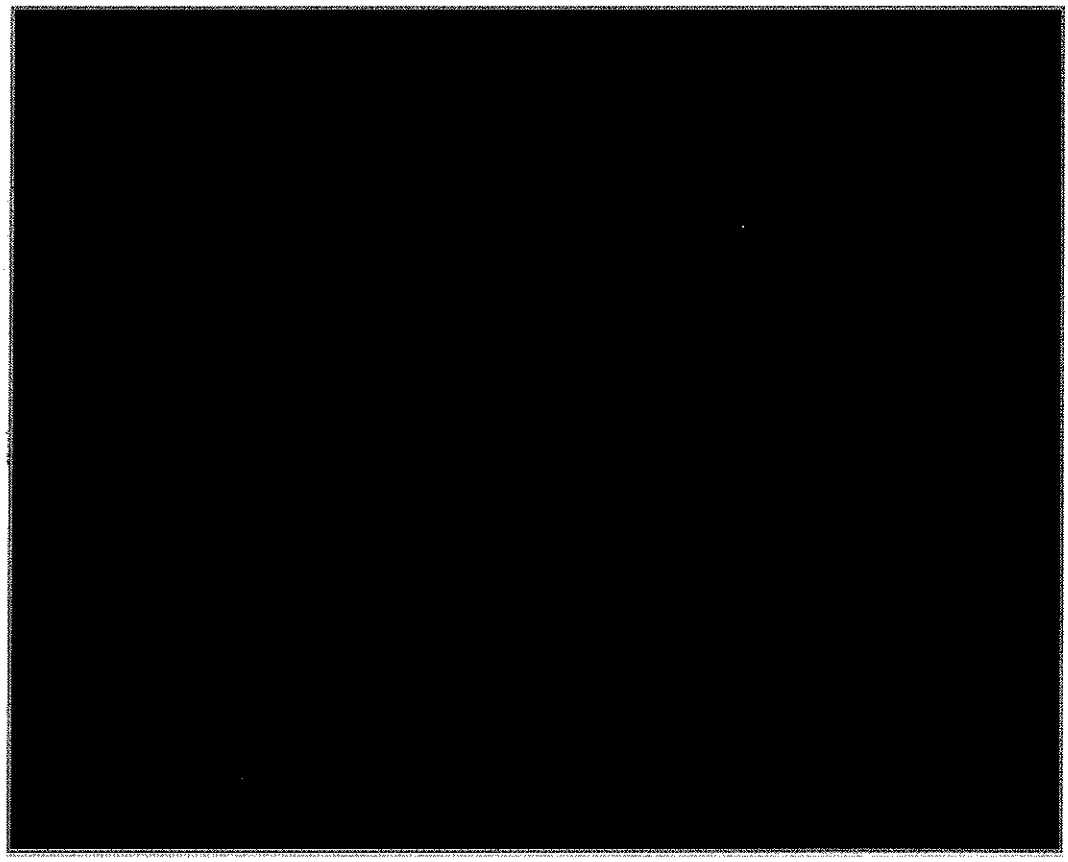

4.4 Implementation

The implementation of the new final line cell was in large part based on the kaizen event. Different implementation options were considered based upon the questions we wanted the cell to answer and their strengths and weaknesses. In order to help organize the process and the project in general, an A3 was created which outlined and summarized the entire project including the implementation. The actual implementation of the final design came about after multiple improvements of the design that was decided upon after the kaizen event.

[redacted]

[redacted][2] [redacted]

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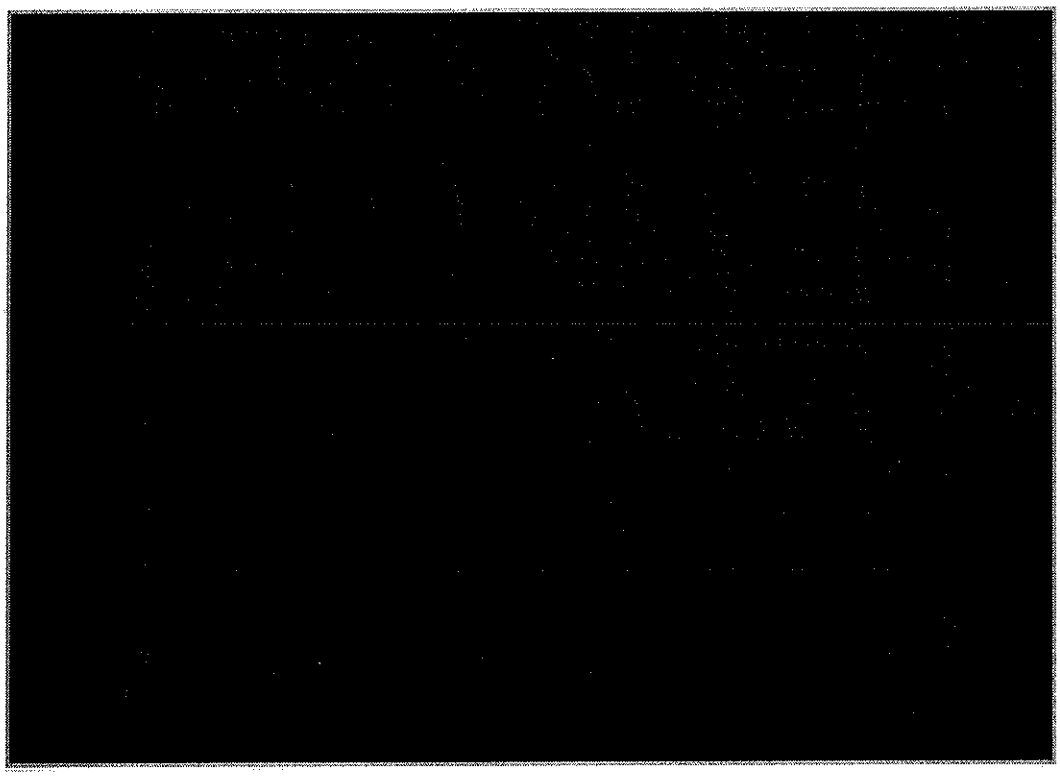
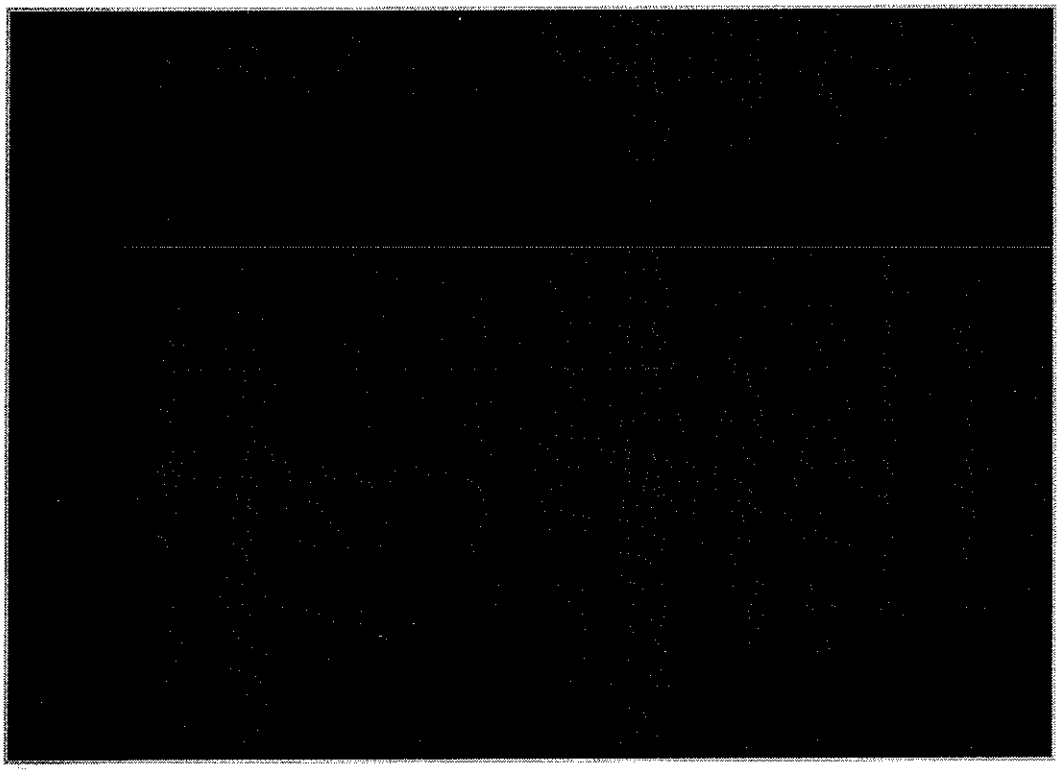
2 [redacted]





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4.4.3 Group Roles within BOSE

Embracing a task as exacting and demanding as the development of a cell design based on a conveyor and batch delivery system requires the use of many different people and their specialized fields. These fields can consist of anything from quality, production and material.

Specific to the final line cell, the implementation team involved approximately twelve Bose employees. The facilitators and overall lead of the project consisted of Industrial Engineers both from corporate headquarters and the Park Place facility. Important to the consistency of every cell on the manufacturing floor was the Bose Production System engineer. He helped train and address any lean issues related to the transition between designs. The next responsibilities dealt primarily with the actual construction of products and the coordination between supplier and customer. These roles included Operations, Planning and Production. The production role mainly resided with the actual operators in the cell. Since they knew the product inside and out it was imperative to include them in any change made to the process. Lastly the implementation process consisted of the use of the Material coordinators and Quality and Test engineers. They helped organize how material and other items would be brought to and from the cell.

4.5Design Evaluation

The design evaluation focused primarily on the comparison between the original Final Line and the Final Line cell. We assessed the costs, overall improvements and process flow which resulted in data specific to what we wanted to achieve; a lean cell.

Table 8 lists the criteria used to evaluate the Final Line cell in comparison to the original Final Line:

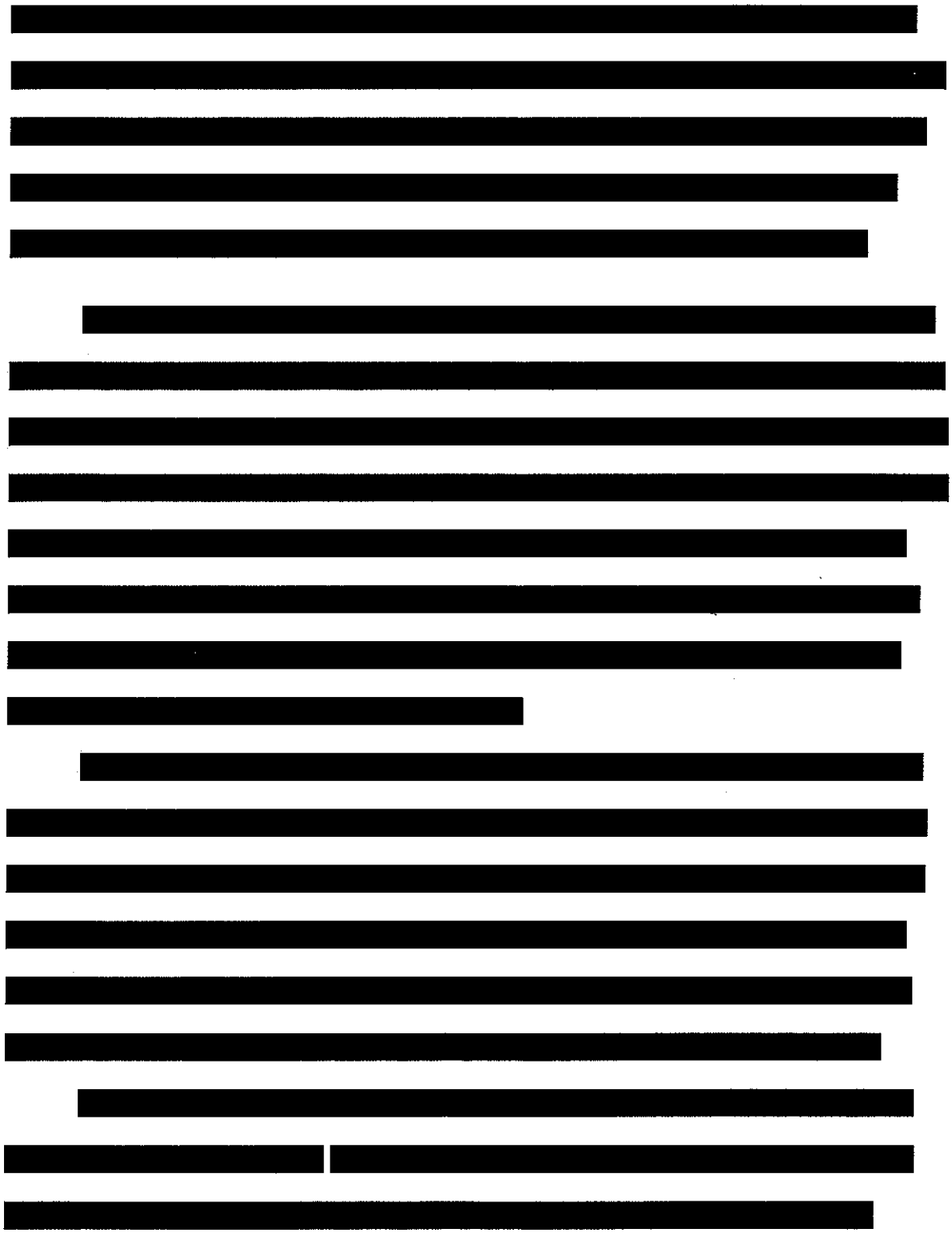
Table 9: Design Evaluation Criteria

Questions	Is the cell more time efficient than the previous set-up?	Is the cell more cost efficient than the previous set-up?	Will this cell be useful to Bose in the future?
Ways to measure the answer to the questions	Takt Time	Floor Space	Floor Plan/layout of plant
	Lead Time	Labor Minutes per Unit	Planned to still be used in the future
	Changeover Time		

4.5.1 Initial Cost & Savings

The cost and savings for the new final line cell are important to consider when assessing the value of the project. These numbers are best estimates and do not take into account the entire benefit of developing a new cell. The primary justification for the new Final Line was to create a cell environment best suited for natural and continuous improvement over time. There are many indirect benefits that are not reflected within savings. For a relatively low cost the new Final Line generates significant value within the first year.

[redacted]



[redacted]

[redacted]

Table 10: Cost and Improvements

[redacted]

[redacted]

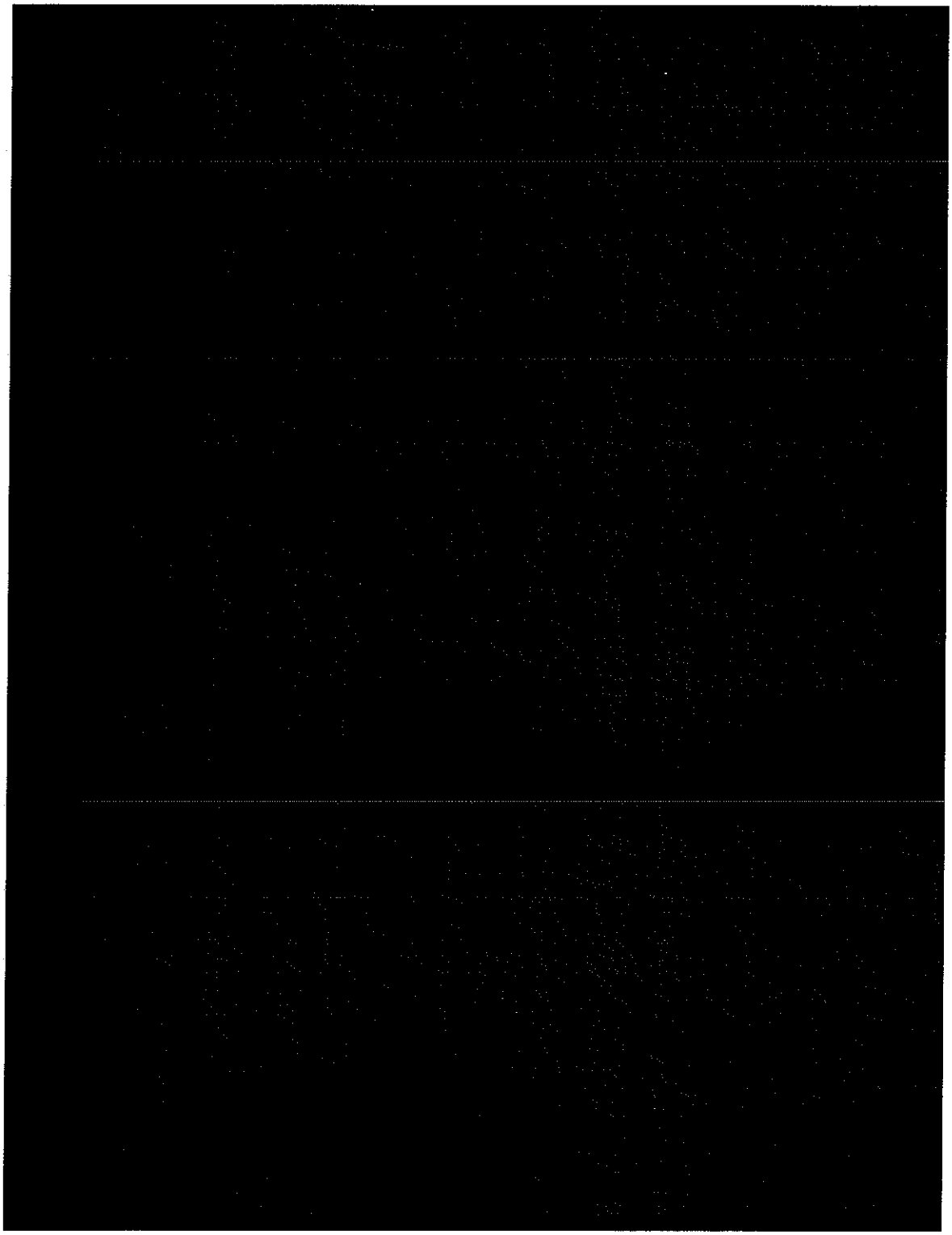
[redacted]

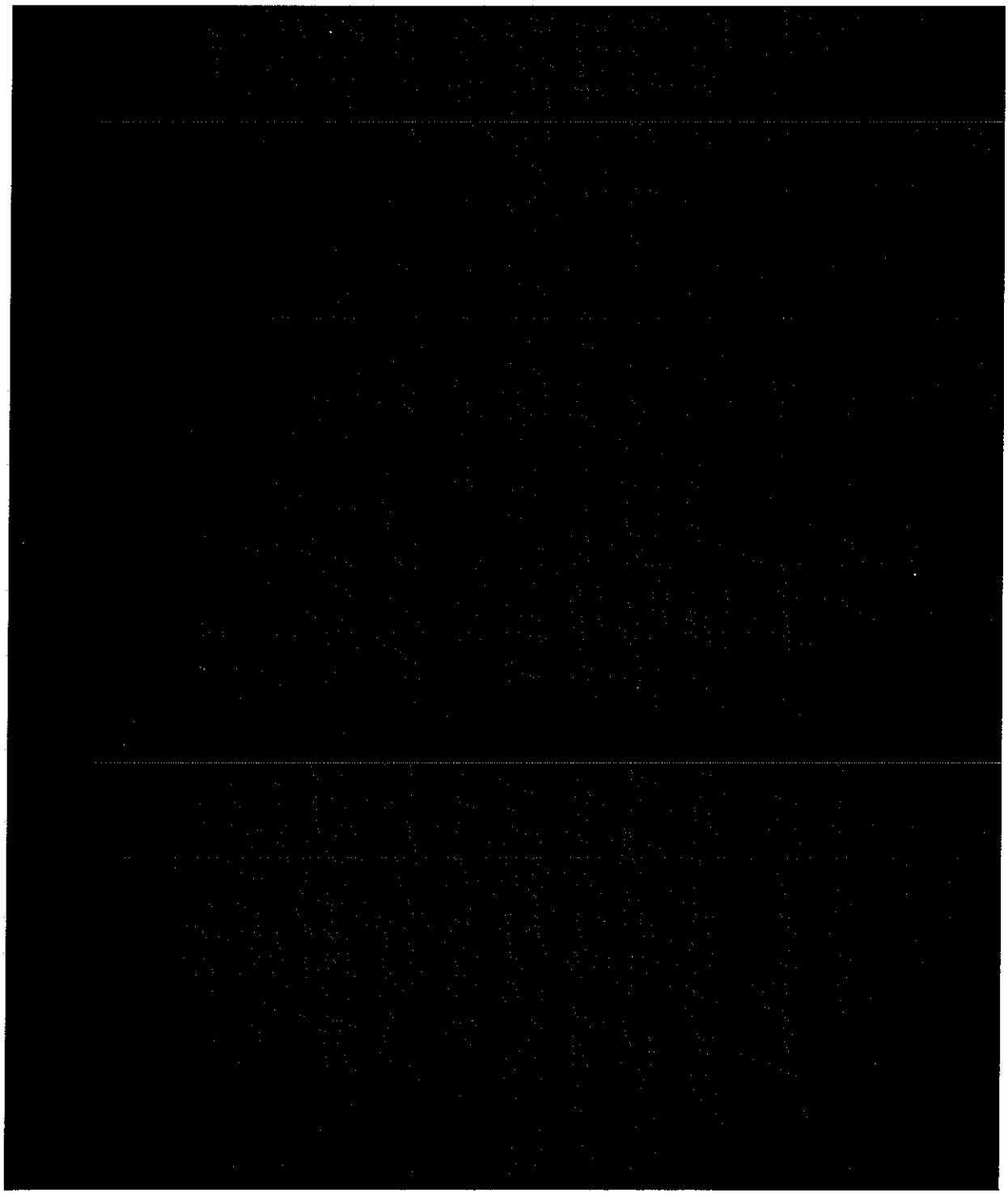
4.6 Constraints

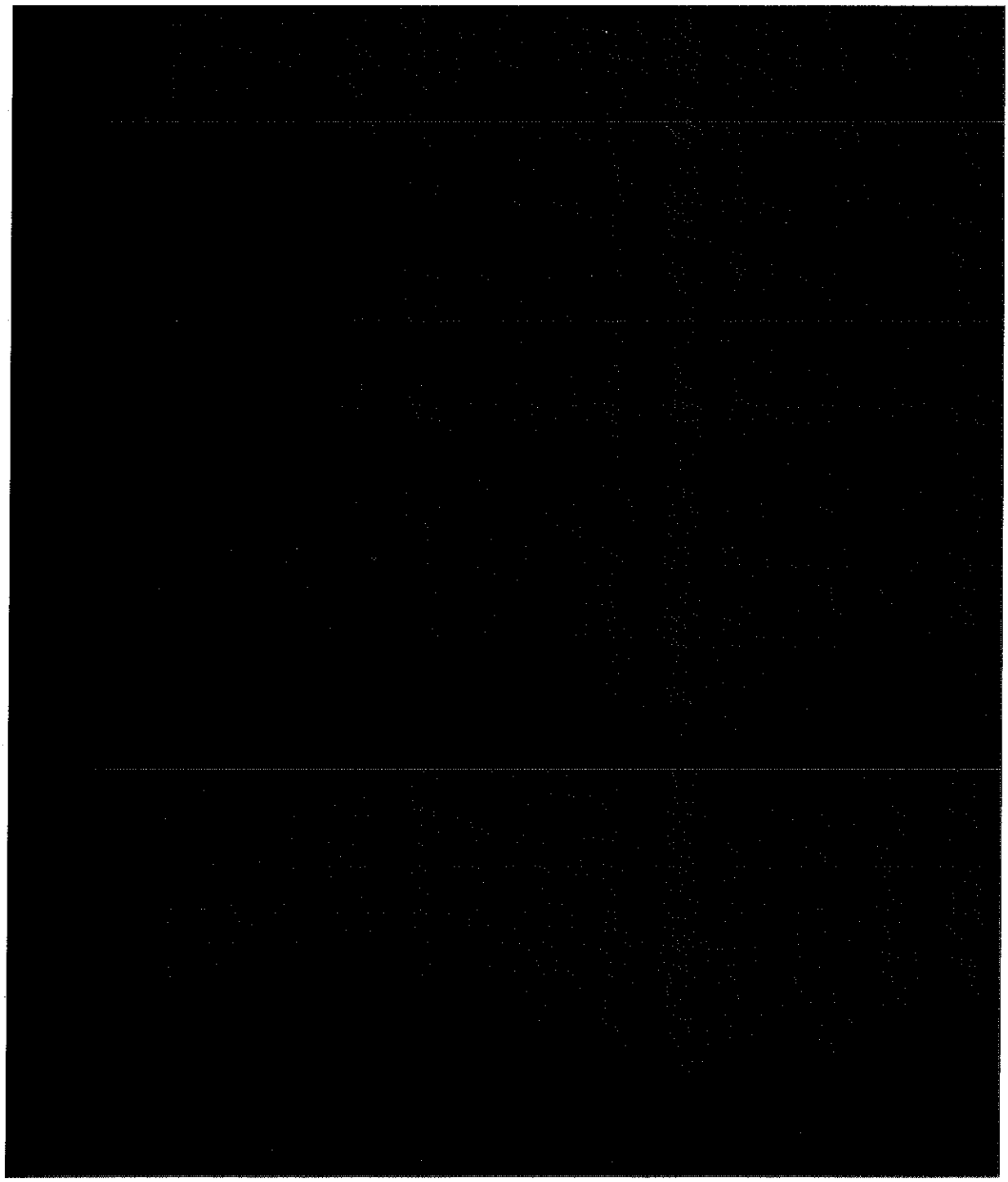
Working through the design and implementation phases it has been necessary to work with a number of variables that have shaped the outcome of the project. While some of these constraints were known from the beginning, others have come to light along the way. Being responsive to change has been an important ability in working on this project.

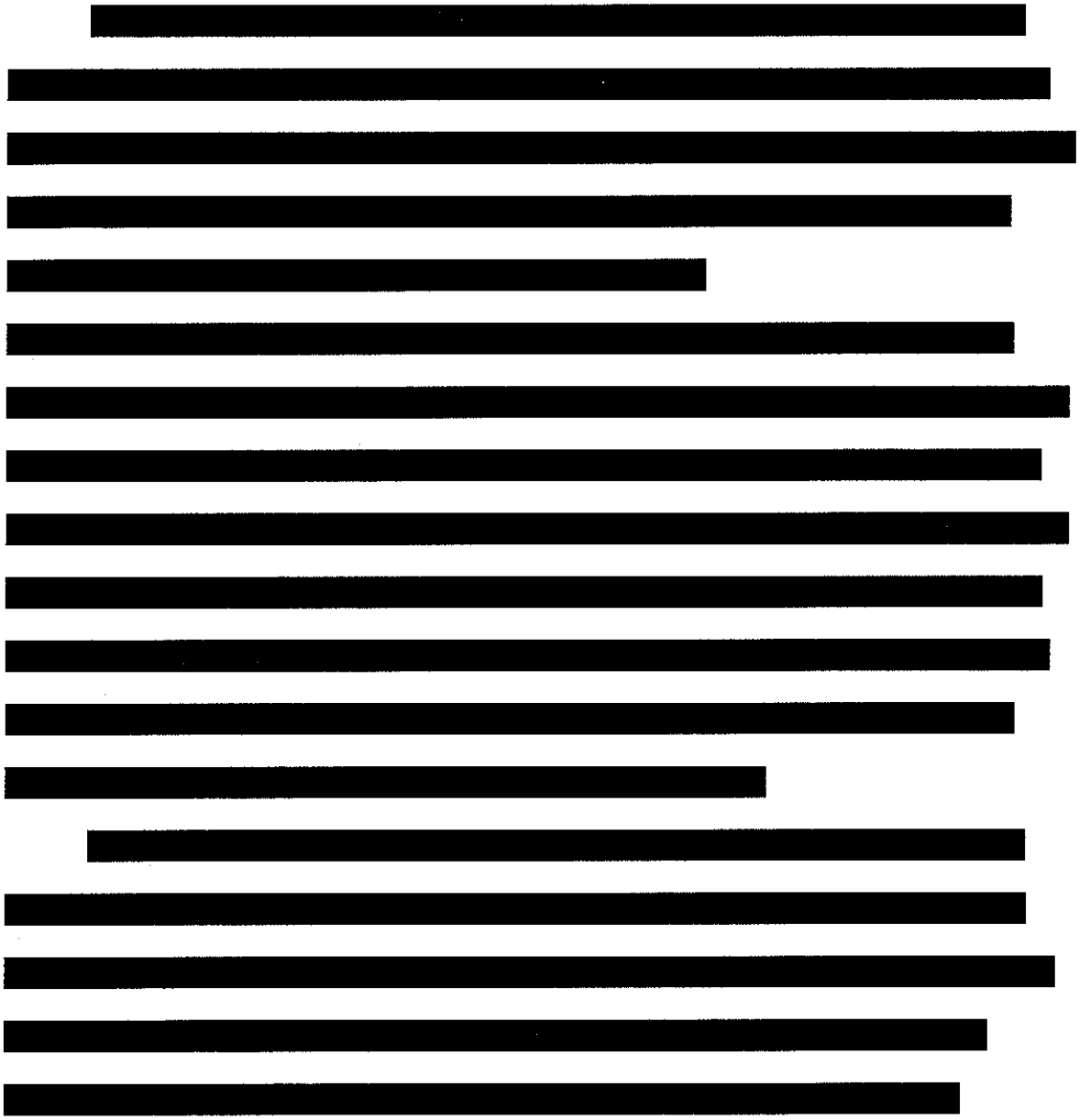
The scope of the project involved managing limitations to the design of the cell. One of the major criteria for the new cell was reducing the number of operators. With the original design requiring up to nine operators on a product, the time to build the product was much quicker than the demand. Based on labor minutes per unit (LMPU) calculations it was determined that between one and two operators was optimal to best align with the product's estimated TAKT times. As demand can often be unpredictable, having the capacity to deal with spikes was a necessary capability. The design of the cell had to be able to adjust to accommodate additional operators if the need arose.

Another consideration in designing the cell was ensuring that the layout was best fitted for the location. The location of the cell was determined primarily by available space and presentation. Material handling is dependent upon this location and the cell must be set up accordingly. [redacted]









Chapter 5: Conclusions

The Park Place Bose manufacturing plant in Framingham, MA has converted to lean manufacturing cells over the past 2 years and implemented the Bose Production System. The Final Line posed some unique challenges. [redacted] The goal of this project was to create a Final Line cell that was in line with BPS standards. The line produces several large, low volume products and is used by R&D to assemble new products. As a result the Final line cell had to be highly flexible while accounting for the constraints and limitations of the material and operators.

Initial measurements were taken and the processes for each product were analyzed. This data was then used during a Bose Kaizen Blitz Workshop. In this workshop Bose professionals, from a variety of departments, worked alongside the WPI team to address the challenges of the Final Line to apply BPS principles. The final result of the workshop was a cellular design for the Final Line. Space was made available and the equipment was moved in the new cell configuration. Adjustments were made throughout the testing phase of implementation to better accommodate the movement of operators within the cell. This set a precedence of continuous improvement within the Final Line cell.

[redacted]

The Final Line saw many improvements throughout the implementation process; however BPS calls for continuous improvement. In line with all other BPS cells, the final line should have kaizen cards and perform 5S +1 audits. The material flow in and out of the cell

must also be addressed. Currently there is excess material handling. If possible material should be purchased in quantities and containers that will allow for easier delivery and use in the cell.

[redacted]

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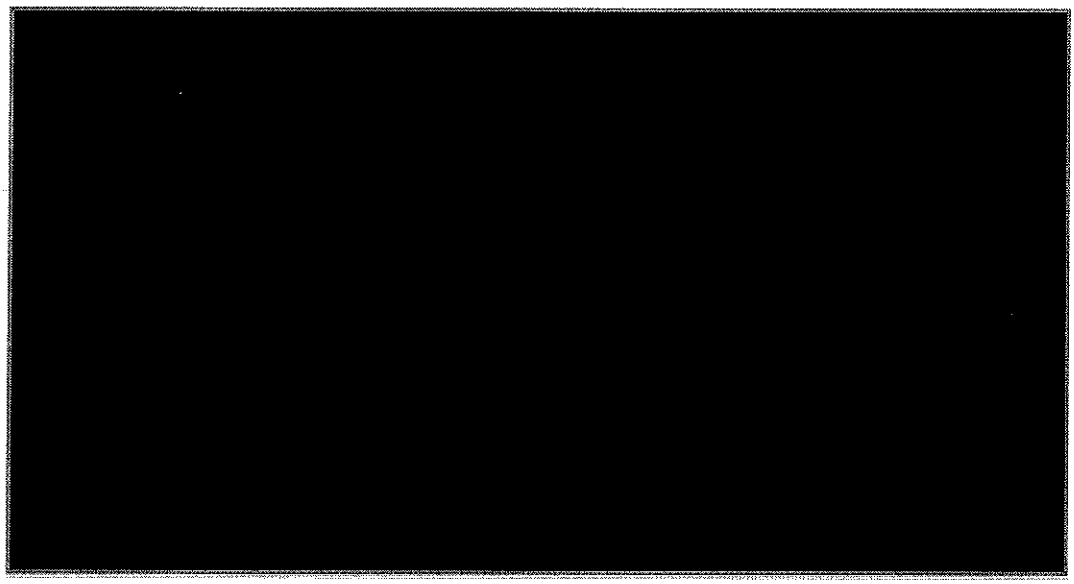
Appendix



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