ASSEMBLY LINE KITTING: FOAM MOLD MATERIAL SUBSTITUTE

A Senior Project submitted

In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science in Industrial Engineering

the Faculty of California Polytechnic State University,

San Luis Obispo

by

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December 2016

Approved by: Dr. Daniel J. Waldorf

Date of Submission: 12/15/16

ABSTRACT

Assembly Line Kitting: Foam Mold Material Substitute

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Kitting is considered an incredibly innovative and effective solution intended to aid operators within a mixed model assembly line. However, it is a non-value added procedure and one that customers may not be willing to pay for. With this project, the goal is to examine opportunities to employ lean principles and provide a solution that further eliminates non-value added procedures, while also producing the potential for a flexible, mixed model assembly line.

To achieve the aforementioned purpose, the production of foam molds, located within industrial totes and sent to the assembly line, was found to be a major waste within the kitting process. Foam molds are crucial to the creation of a kit as they provide clear presentation of components to assemblers line side, allow components to be held securely and easily, and enable facilitated access and standardized organization when picking parts. A foam mold material substitute is a potential solution to this problem as it allows for the elimination of the separate production loop and a streamlined, in-house process intended to present assembly components for consumption line side. Of the material prototypes ranked using Analytic Hierarchy Process, Beaded Foam (an uncompressed molding foam) provides the best alternative as it does not dry, does not crumble, can be formed infinitely, abides by the three R's, and holds its shape before and after pressure.

Included within the report is a description of the material demonstration (concerning metal assembly components), a comparison between the current-state and design of the future-state for kitting stations, and an economic analysis comparison between the new material, Beaded Foam, and the current material, polyurethane/polyethylene. The economic justification for Beaded Foam leads to projected savings, to the total annual cost, of about $66,000 for a single kitting station. As there may be as many as sixty or more kitting stations in a full-scale, mixed model assembly line, these savings may be multiplied.

ACKNOWLEDGMENTS

I would like to thank my advisor Daniel Waldorf, and those that provided additional feedback: Karla Carichner, Sam Aborne, and John Juell.

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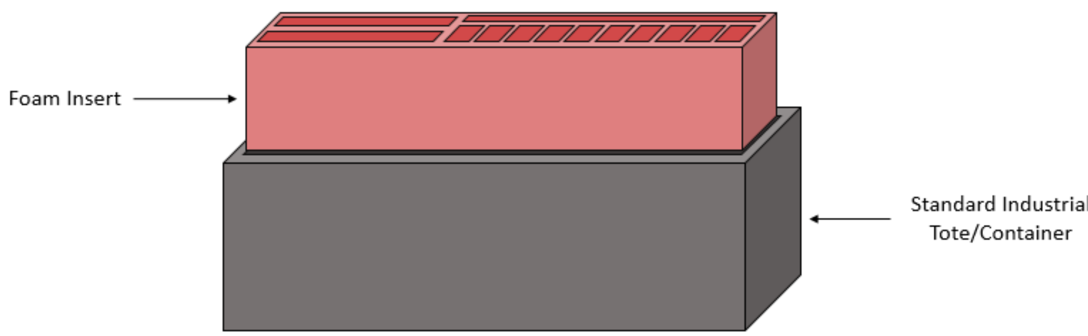
I. Introduction

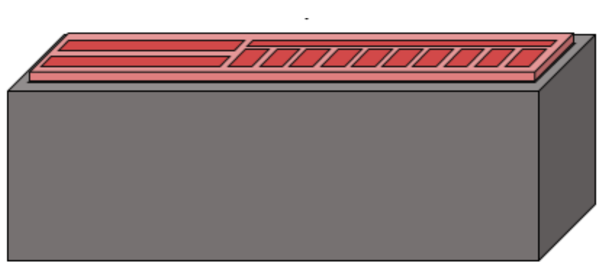
Manufacturing has come a long way since that fateful day, December 1st, 1913, when Henry Ford introduced the world to his creation: a moving assembly line, a machine that built the machine, installed to mass produce an automobile. His idea brought the production of an entire vehicle from approximately twelve hours to a brisk two hours. Since then, the manufacturing industry has scrambled to find innovative and profound improvements to assembly lines surpassing those of just automobiles.

The subject of this report seeks to address the creation of a new material to facilitate material flow within assembly line processes and, specifically within that realm, the process of assembly line kitting in the automotive industry. The process of assembly line kitting has been made thoroughly easier by the innovative creation and use of foam molds within container kits (a.k.a. shadow boards) - helping to secure component parts and act as a visual check, among other benefits. However, these foam molds and the creation of them have since become very expensive resulting in the generation of many non-value added procedures costing material handling departments money and time, while also further impeding faster part feeding during assembly.

To provide an illustration of the aforementioned problem, the current state designs of kitting processes involving containers, especially those requiring any type of foam mold insert, is delineated in the following diagrams:



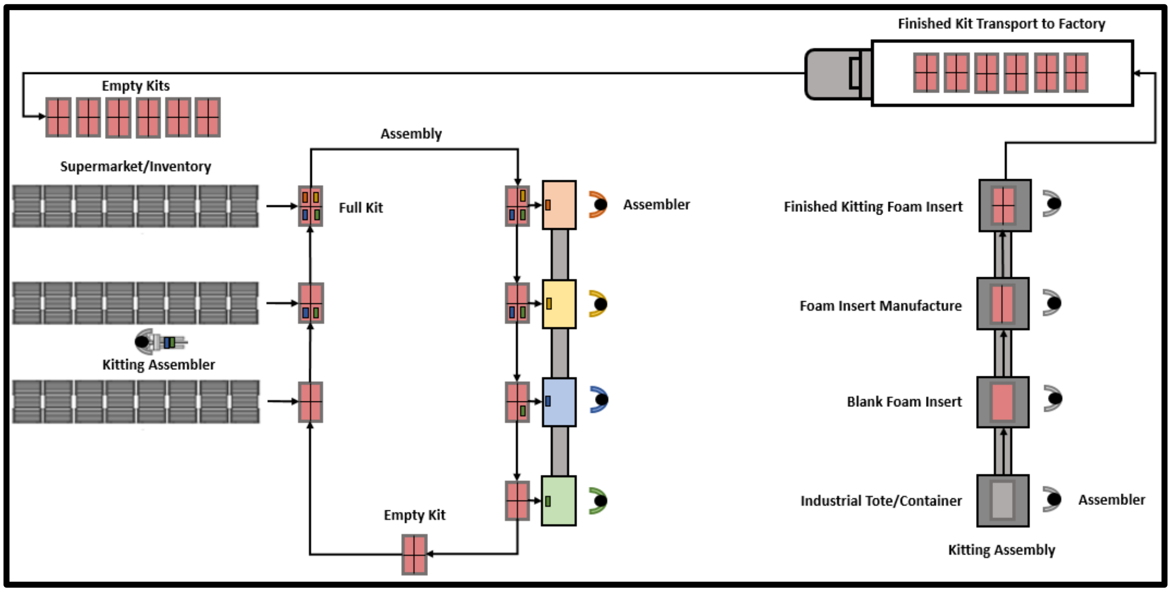
**View of Kit Breakdown - Fig.1*



**View of Kit Presented Line Side - Fig.2*

The current state of the process and manufacture of these foam molds as well as their involvement within the assembly line will be detailed and analyzed more thoroughly later on in this report, however, Figure 3 provides additional, high-level insight into how the foam molds/kitting containers fit within the larger manufacturing spectrum. As seen in Figure 3, there

is a separate production loop for the foam molds from a specified supplier, and this is in addition to that of the kitting of components to the consumption of the kits line side within the manufacturing facility. Later on, in the report, the representation of the future state and proposed solution, will show the elimination of this separate production loop and instead an entire kitting assembly operation being sustained within the manufacturing facility.



**Layout of Current Kitting Process and Kitting Foam Insert Manufacture Loops - Fig.3*

Kitting as a line feeding technique within the assembly process is already a non-value added procedure. The secondary loop, in Figure 4, for the supply of customized foam molds required in kits further amplifies the non-value added activities and adds to the overall waste found in facilities. These kits are usually specific to a certain "pitch" or set of assembly stations, which usually means that the space utilized in the foam molds is limited to the particular components required for assembly. Foam molds are utilized within kits to allow clear presentation of components to assemblers lineside. They also allow components to be held securely and easily, enabling assemblers facilitated access and organization when picking parts. The foam molds are specifically designed with cutouts tailored to the particular components. This lends itself to many different drawbacks, which will be thoroughly analyzed later on in the report and briefly described by the following:

- Kits are pitch specific; non-transferrable between different pitches along the assembly line.
- Kits become obsolete when in-house Engineering departments issues product design changes or elimination of particular components
- Foam molds experience a considerable amount of "wear and tear" resulting in short life cycles.
- Foam molds must be designed and prototyped which result in large investments of time and money; this causes kit implementation on the assembly line to take anywhere from weeks to months beginning after the time of design.

With these drawbacks in mind, the scope of this project may be defined by the following four categories:

- Final Design/Potential Prototype: This will include the material final design, analysis regarding specifically the functionality, reliability, sustainability and manufacturability of the material. The design will also be shown to meet all such goals. Alongside the design, a prototype will be constructed to help clearly visualize the performance of the material.
- Market Analysis and Customer Specification: Consideration must be included as to the market demand for such a material and its potential applications - even those found outside the scope of kitting. Attributing customer specifications to the design and analyzing the investment compared to the profitability.
- Manufacturing Plausibility and Sustainability: An analysis of the manufacturing processes and constraints involved with production of this material. In addition, the sustainability of such processes and the long term effects on production (i.e. equipment).
- Economic Justification: Analyzing the return on investment and other economic justifications involved with the purchase of the material for use in assembly processes. Comparisons with the current state, foam material will be included.

In addition to the four categories mentioned, the scope of this project also includes only those assembly components made of metal and that are ESD (Electrostatic Discharge) safe. This project also applies to factories that utilize kitting as the primary method of material supply to assembly line and maintain mass customization with “make-to-order” or “assemble-to-order” product lines.

The problem statement of the report and proposed solution will be compared and analyzed alongside the current state. After an analysis of the current state, with a thorough view utilizing flow diagrams and value stream analysis, the new material design will be produced and analyzed using the same methods, in addition to, tests including but not limited to Analytic Hierarchal Process. In regards to the plausibility of manufacturing, the processes included will be delineated as well as labor and the various costs of materials.

It is critical to note that due to the limitations of materials expertise and focus on industrial and manufacturing engineering concepts certain considerations (i.e. material structure, etc.) will not be included in this report. Many of these important, yet contextually peripheral, considerations will be necessary should research and development of this project continue in the future.

The remainder of the report is structured by the following: first, a background and researched context to the terms and ideas involved in this report - including kitting, just-in-time, just-in-sequence and batching, as well as a brief history of assembly lines and their development. Subsequently, an explanation of the proposed material design and corresponding requirements, followed by a discussion of the methodologies used. And finally, this report will conclude with the results of experimentation, final thoughts and conclusions.

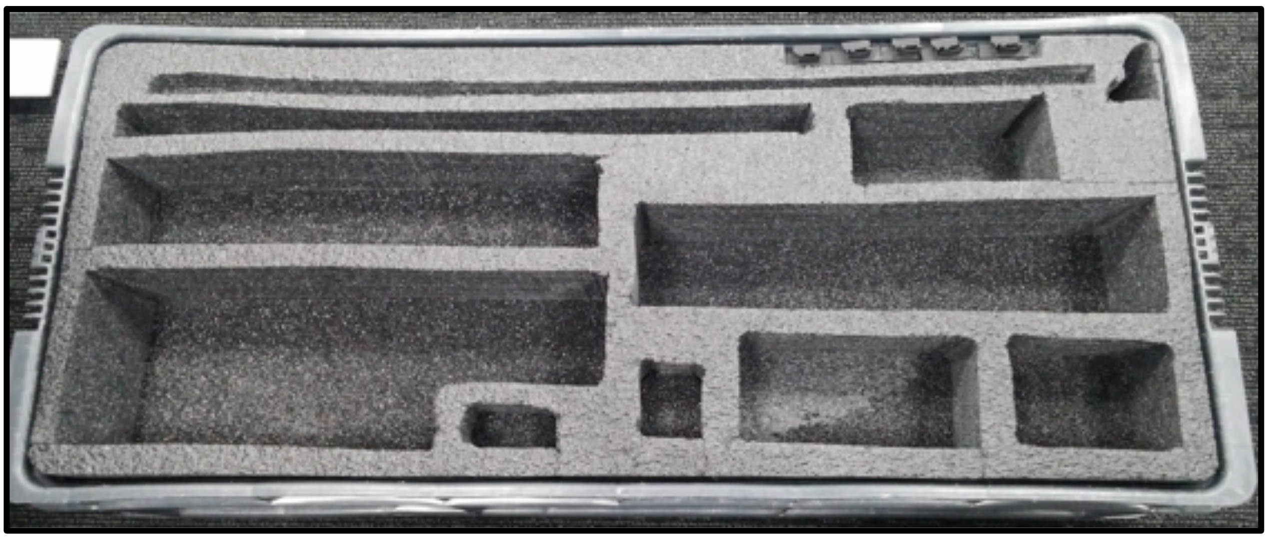
II. Background & Literature Review

To better understand and further illustrate the problem statement and introduction of this report it is necessary to understand the current state entities and process in detail. The following lists and figures help to better visualize the kit structure and foam mold, as well as, the flow diagram of the current production loops.

Current State Materials:
The current state materials may be any of the following:

- Polyurethane
- Polyethylene
- Charcoal Ester

Current State Kit:
To better grasp the actual kit, which is made up of an industrial tote and foam mold, Figure - 4 shows the current state model:



**View of Actual Kit – Foam Mold & Industrial Tote – Figure 4*

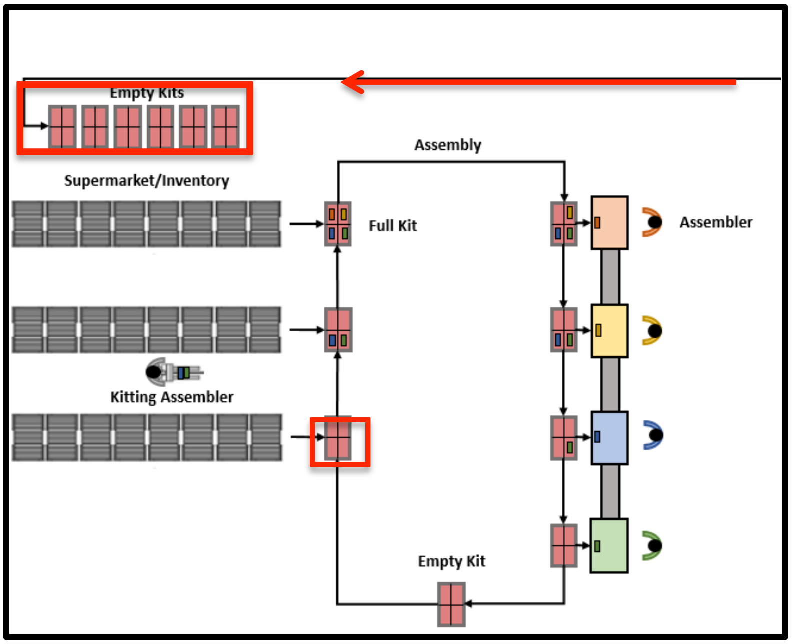
The figure shows a standard 31" x 14" x 12" industrial tote/container that has a charcoal ester foam mold placed within it. It is important to note that the foam supplier specializes in many different foam applications along with many different foam types. Generally, a foam supplier will fabricate a foam mold such as the one seen in Figure - 4 for a manufacturing application upon request. As many foam suppliers are craftsmen and make each foam mold by hand, the finished products maintain a high level of variability and must be manipulated and custom fit to slide into the designated tote.

Revisiting kit value, these foam molds provide several benefits for the assembly line operator:

- Foam inserts allow clear presentation of components to assemblers line side
- Allow components to be held securely and easily, enabling facilitated access and organization when picking parts
- Allow for an optimized and standardized picking process

Current State Assembly Line Production Loop:
The following figures show the current state of the assembly line production loop in detail.

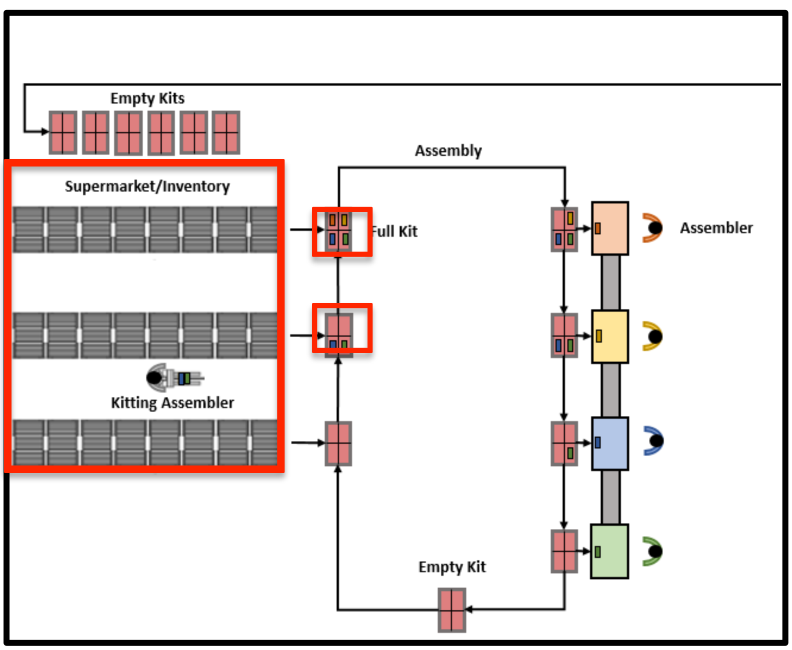
Assembly Line Production Loop: **Step One**



Step One involves empty kits that enter into the kitting station. These kits have been consumed line side and return to the kitting station supermarket to be replenished.

**Assembly Line Production Loop: Step One – Figure 5*

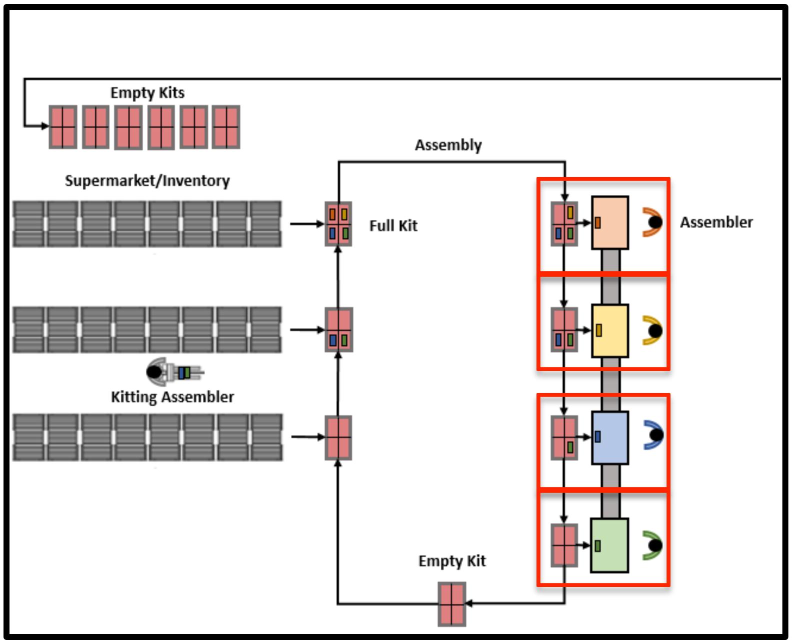
Assembly Line Production Loop: **Step Two**



In **Step Two,** the kits are replenished with various assembly components required for the corresponding assembly line pitch. The kits are passed from operator to operator and gradually completed and sent off to the first station (pitch) in the assembly process. A section of the assembly line may contain many assigned pitches.

**Assembly Line Production Loop: Step Two – Figure 6*

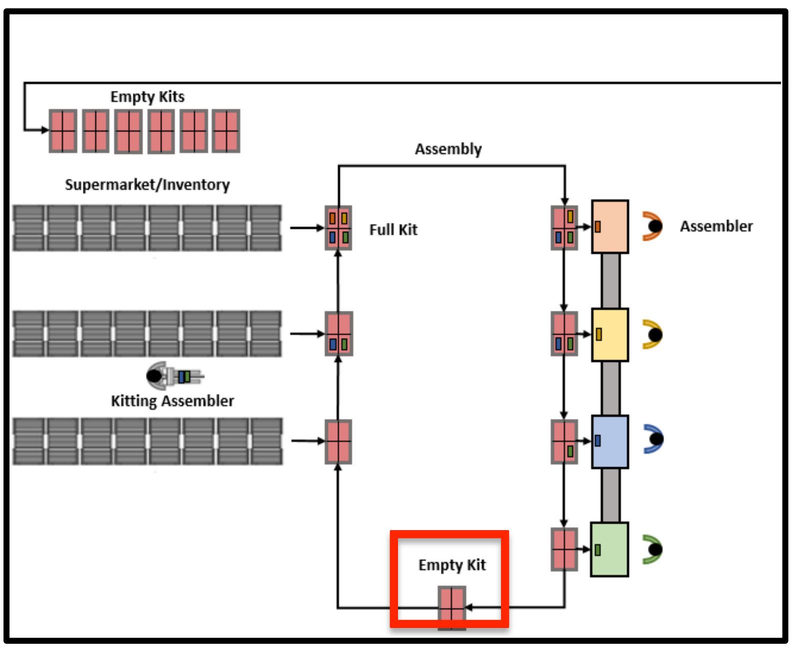
Assembly Line Production Loop: **Step Three**



In **Step Three**, the components are gradually consumed from pitch to pitch along the assembly line. Once empty, the kit is staged for transport to the kitting station.

**Assembly Line Production Loop: Step Three – Figure 7*

Assembly Line Production Loop: **Step Four**

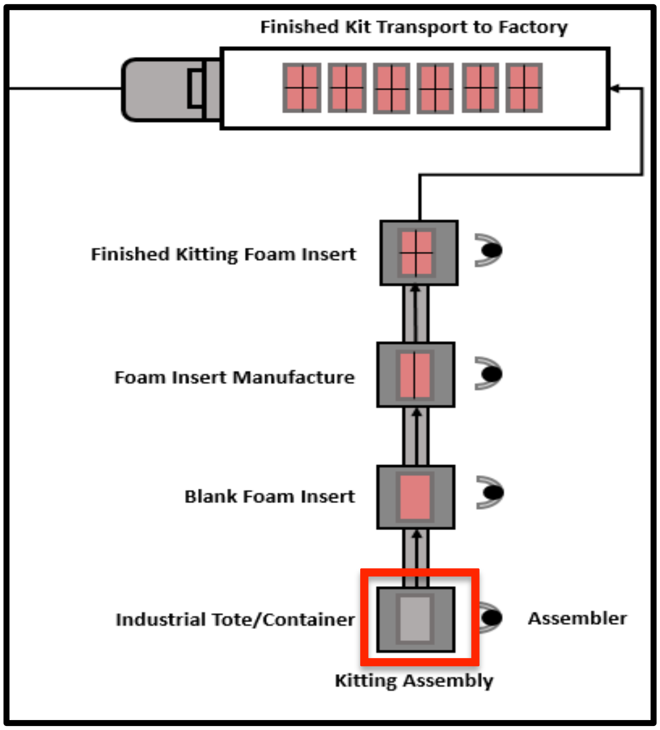


Step Four, the empty kit is transported once more to the kitting station to be replenished within the supermarket. The process repeats.

**Assembly Line Production Loop: Step Four – Figure 8*

Current State Kitting Production Loop:
The following figures show the current state of the kitting production loop in detail.

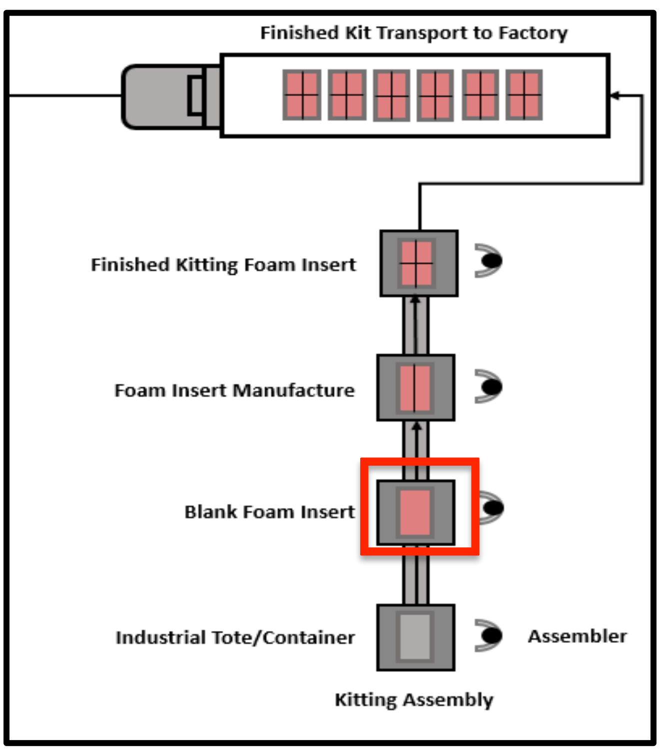
<u>Kitting Production Loop: **Step One**</u>



In **Step One** the kitting production loop begins with the foam supplier. A preliminary evaluation of the provided tote and assembly components is performed. This is done to determine how the assembly components should be oriented. Generally, an engineering department will provide a CAD of the proposed kit organization to aid this initial process.

**Kitting Production Loop: Step One – Figure 9*

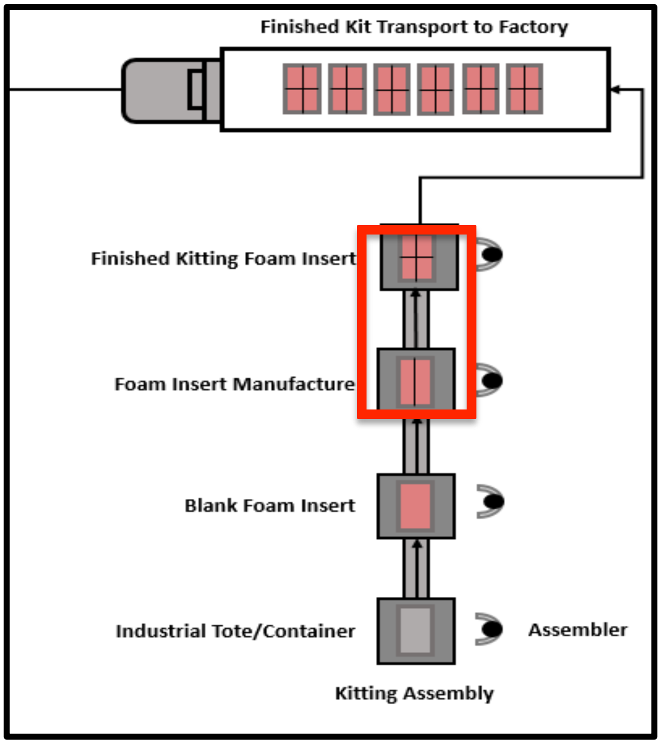
<u>Kitting Production Loop: **Step Two**</u>



Step Two involves a foam blank with a material classification of either polyurethane, polyethylene or charcoal ester.

**Kitting Production Loop: Step Two – Figure 10*

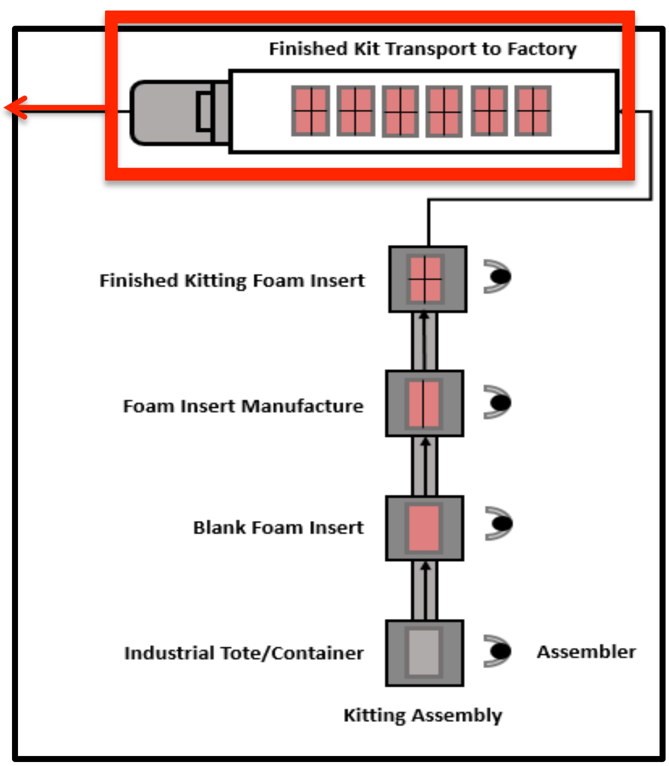
Kitting Production Loop: **Step Three**



In **Step Three**, the craftsmen begin fabricating the foam mold. The designated compartments are all cut out of the foam block and customized per the kit design. Additional manipulations are made to fit the foam mold to the tote.

**Kitting Production Loop: Step Three – Figure 11*

Kitting Production Loop: **Step Four**

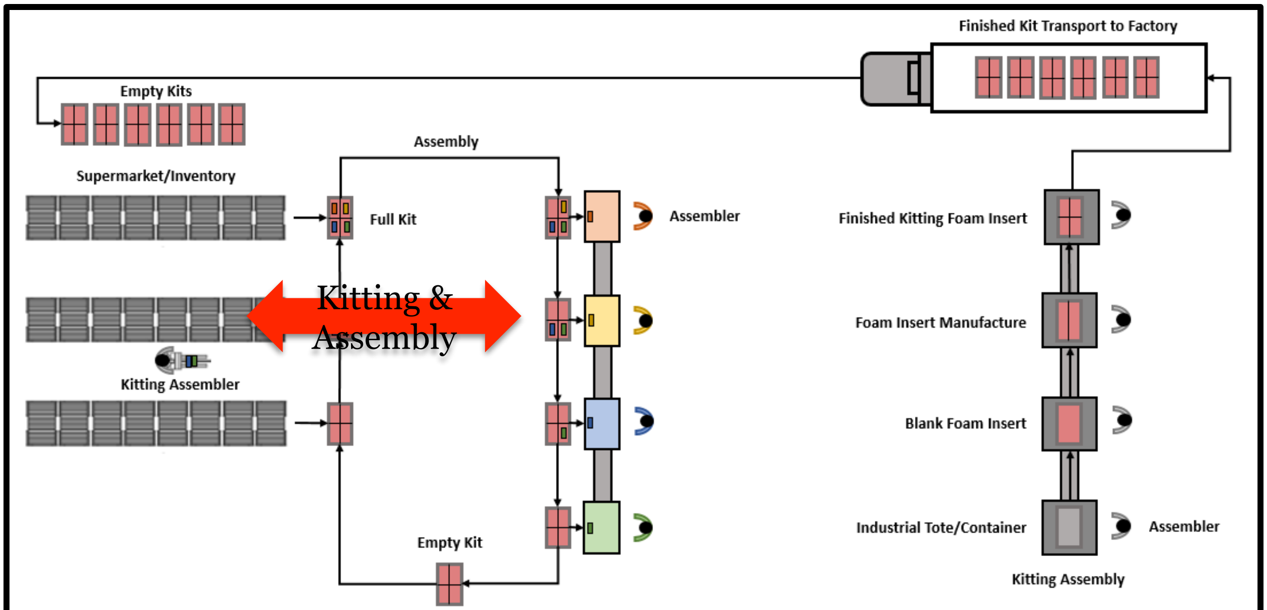


In **Step Four**, the finished foam molds are shipped to the factory for use within the kitting station and circulation to the assembly line.

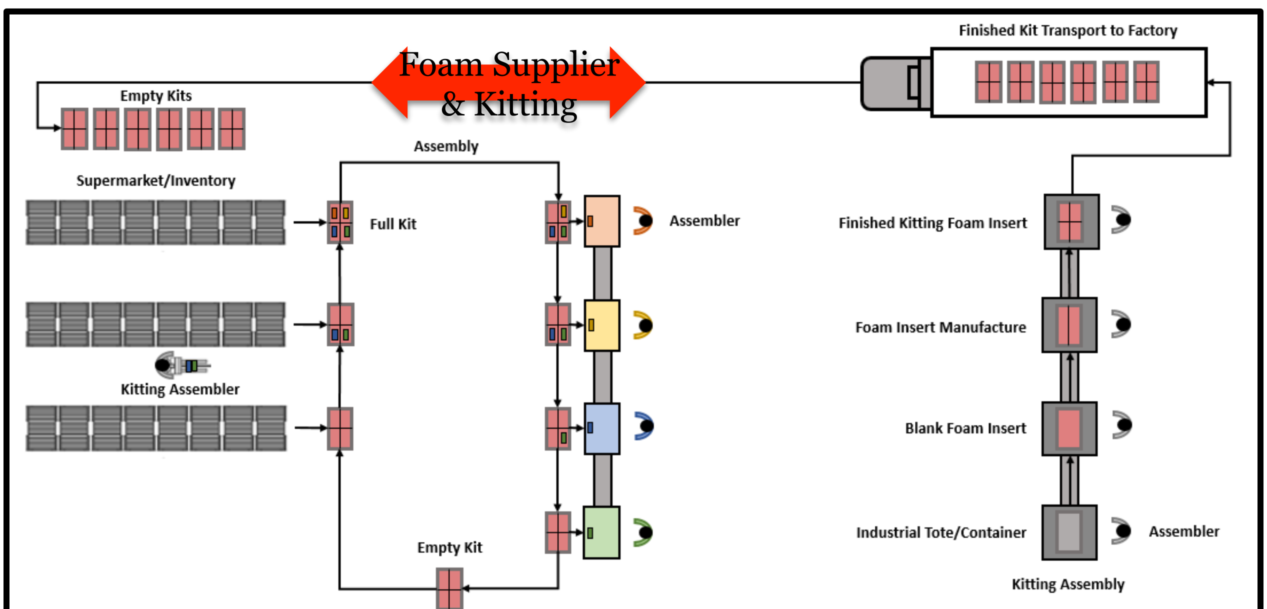
**Kitting Production Loop: Step Four – Figure 12*

Current State (High-Level View) Production Loop Comparison:

Below are two high-level representations that show the two separate production loops. Both processes are consolidated and placed alongside each other. The first production loop goes from the kitting station to the assembly line. The second spans the kitting station to the foam supplier. In the pursuit of lean processes within the manufacturing setting, the second production loop, foam supplier to kitting station, is a major waste. It is crucial to note that the kitting process is a non-value added procedure and one that the customer may not be willing to pay for. The elimination of the second production loop would result in the potential for a more flexible, mixed model assembly line.



**Kitting Station to Assembly Line High Level – Figure 13*



**Kitting Station to Foam Supplier High Level – Figure 14*

Literature Review:
The consolidation of the following topics and associated research is necessary to gain the proper context for the possible proposed solution that this report attempts to address. It should be noted that of the research conducted, a large portion only addresses the choice of which [assembly line] feeding policy should be chosen within a particular application. In addition to the aforementioned decision, there are these, and other studies, that address the advantages and disadvantages of kitting; among those, being the cost, material handling and timesavings effects on cycle time and lean systems. When addressing the actual components of kitting, such as how to further refine the separate production/batching/sequencing loop required for kits or the materials utilized, these have not been addressed in case studies or patents to date.

Definitions:

- *Component:* A fabricated or purchased part that cannot be subdivided into distinct constituent parts.
- *Subassembly:* The aggregation of two or more components and/or other subassemblies through an assembly process.

**Both "Component" and "Subassembly" definitions are supplied by the Bozer and McGinnis study "Kitting versus line stocking: A conceptual framework and a descriptive model".*

- *Kitting*: Process in which related, yet individually separate, parts or components are grouped, packaged, and supplied as one unit or "kit". Thus, with the action of kitting, there are limited to no inventories stored line side and instead parts are temporarily stored (until point of consumption or use) in containers delivered to assembly stations.
- *Line Stocking*: Process in which a part or component is stored line side in bulk. In other words, continuous supply where no repackaging activity is performed.

Kitting:
Description:
[7] The proper introduction to kitting can be found in a study conducted and documented by Yavuz A. Bozer and Leon F. McGinnis. As theirs is one of the first academic papers to address this topic, the Bozer and McGinnis study provides the framework for the various aspects of kitting, while also offering many of the foundational definitions this report will rely on. As aforementioned, a definition of kitting is supplied by the following, '... a specific collection of components and/or subassemblies that together (i.e. in the same container) support one or more assembly operations for a given product or shop order.' (Bozer and McGinnis 1992, p. 3). As with most assembly line part-presentation techniques, kitting has a variety of schemes utilized. For instance, in mixed-model assembly, different assembly objects generally require different kit contents. Hence, each kit is prepared for a specific assembly object. Within this realm, kits can either be classified as "stationary", where each kit supports one assembly station, or "traveling", where the kit moves with the assembly object along an assembly line and contains parts for several assembly stations (Bozer and McGinnis 1992). Beyond these classifications, it is important to note the following common cases found in assembly plants as described in a case study performed by Vujosevic, Ramirez, Hausman-Cohen, and Venkataraman (p. 1-2) [9]:

- *Central Stockroom, ERP-Driven Kitting*: Generally, Production Control will release kits to the central stockroom, or related area, when generated by the ERP system. In most

cases, PC relies heavily on the ERP system in order to make sure that enough inventory is readily available in the stockroom.

- *Point-Of-Use, ERP-Driven Kitting*: This process is fairly similar to the "Central Stockroom, ERP-Driven Kitting" process. The main difference is that inventories are located in various warehouses or storage areas within close proximity to the assembly line. These storage areas can be committed to specific customers, assembly lines, or to the entire shop floor and located through the entire plant.
- *In-House, Supermarket Based Kitting*: "Supermarkets" are placed throughout the shop floor and components are received and stored in these locations. Kanban cards are used as signals to replenish the supermarkets and dedicated material handlers are responsible for the transition of these Kanban cards into replenishment orders, which are then sent to the central stockroom. It is assumed that the assembly line operator performs kitting processes.
- *Supplier-Controlled, Supermarket Based Kitting*: Both the ERP-based procurement and central stockroom are eliminated. Instead, suppliers who can supply the majority of components are used. In addition, part attrition and consumption are managed through an MES system.
- *Outsourced Kitting*: This process, as its name suggests, calls for the outsourcing of kitting and part storage - pushing all responsibility to outside suppliers. Outsourcing is fairly appealing as it pushes the associated waste to the supplier, this, as well as, the responsibility of component storage/kitting and improved cash flow, among other benefits.

Advantages & Disadvantages:
In regards to the benefits of kitting, Hanson and Brolin (2013, p. 11-12) perhaps best summarized four aspects that can objectively serve as advantages credited to the material supply method. The first involves man-hour consumption. Not only do part numbers not need to be presented all at once, but the parts that are presented, are easy to locate and consume thus resulting in the reduction of man-hours line side. The balance is seen, however, when the reduction in man-hour consumption of assemblers was more than cancelled out by the increase in man hours required for preparing and delivering the kits. The second advantage maintains that kitting benefits product quality and assembly, as the use of kits to present parts at the assembly stations should support the assembler, making it easier to achieve high product quality (Sellers and Nof 1986, Johansson 1991, Bozer and McGinnis 1992, Caputo and Pelagagge 2011). (Hanson and Brolin 2013, p. 1). This achieved through the idea that simplified part presentation allows an assembler to focus on assembly tasks instead of searching for which parts to pick. The third comes in the form of flexibility, in which, kitting can serve to facilitate and yet under certain conditions, unfortunately limit. Kitting has been known to increase flexibility when there is a large number of variants in parts or production volume fluctuates. Finally, the fourth advantage has to do with inventory space requirements and levels. Naturally, along the assembly line, inventory levels are greatly reduced as well as the space required to hold such levels and this results in less congestion in those critical areas. The downside, as will be addressed in the section pertaining to the disadvantages, is that these inventory levels and space requirements will move elsewhere to kitting preparation stations.

[5] Another summary of the advantages of kitting, as provided by Hanson and Medbo (2013, pg. 1), maintains that "...kitting has been reported to be associated with a number of potential advantages, such as space efficient parts presentation (Hua and Johnson 2010; Medbo 2003; Bozer and McGinnis 1992), improved assembly quality (Bozer and McGinnis 1992; Johansson 1991; Sellers and Nof 1986), shorter learning curve times (Johansson 1991), a more holistic understanding of the assembly work (Medbo 1999) and less time spent by the assembler fetching parts (Hua and Johnson 2010; Johansson 1991; Ding and Puvitharan 1990)." In addition to all of these, there a couple of other advantages found in the Ramirez, Hausman-Cohen and Venkataraman study (p. 1) which include: reduced work-in-process, reduced lead times and reduced "part damage" due to excess handling [9].

[2] As expected, there are disadvantages kitting. In a thesis written by M. Alper Corakci, the many disadvantages of kitting are concisely referenced and summarized:

- Kit preparation requires a considerable amount of time and effort which further adds to the non-value added activity or waste. (Bozer and McGinnis, 1992, p. 5-6)
- Kitting increases overall storage space requirements. This is especially true if kits are prepared in advance. (Bozer and McGinnis, 1992, p. 5-6)
- When common parts are located in different kits, an assignment of the parts available needs to be allocated to each particular kit. (Bozer and McGinnis, 1992, p. 5-6)
- Should there be a temporary shortage of parts, kitting efficiency decreases. (Bozer and McGinnis, 1992, p. 5-6)
- In the occasion that a part in a kit is misplaced or defective, spare parts must be kept within assembly stations. This is required to avoid disruptions in production. (Bozer and McGinnis, 1992, p. 5-6)
- There are components that fail during the assembly process. Due to this issue, kits cannot accommodate such components. (Bozer and McGinnis, 1992, p. 5-6)
- Certain components are not suitable to being kitted as they experience an increased amount of handling. Thus, when handled often, the component becomes more prone to damage. (Johansson and Johansson, 2006)

It should also be noted that kitting can also constrain flexibility when unique kits are used for portions of the assembly line, especially when those kits maintain fixed positions for specific parts. These disadvantages highlight the idea that there is a need for more innovative improvements to the line feeding method. Again, as much as kitting helps an assembly line achieve its purpose, there are serious drawbacks associated with it, which is ultimately the premise of this report.

Kitting vs. Other Part-Feeding Techniques - When to Use Kitting:

The advantages and disadvantages of kitting have always been known and accessible, however the understanding of when and where kitting should be utilized remains in somewhat of an unknown. According to Hanson and Medbo (2010, p. 12) when analyzing four separate cases of kitting within automotive manual assembly lines, kitting maintains large time savings when "fetching" parts if all components are included in the kit. [8] Supporting this claim, Satoglu and Ucan (2015, p. 2) reference the Battini, Faccio, Persona, and Sgarbossa study in which there is a comparison of three, part-feeding techniques and the decisions made when choosing the best option for a particular system. The authors all concluded that the three factors that play into the

decision are the number of components, lot size, and the distance between the warehouse and workstation. Included in this, is the idea referenced by Satoglu and Ucan (2015, p. 2), found in the Hua and Johnson study, which suggests that if the products being made contain few common parts, kitting is generally the best alternative. Satoglu and Ucan found that after clustering component parts into kits, these three areas experienced significant reduction in time spent: the time spent by operators verifying parts availability, the time the production planner spent allocated to controlling the production fulfillment requirements, and "material feeding" time. The Satoglu and Ucan study provide a concise evaluation of when to use kitting and the components needed for the technique.

Assembly Line:

Description:

[12] To understand kitting and its use within manufacturing, one must first understand the history of the assembly line. In Wilson and Mckinlay's article, among their concluding remarks, the idea is brought up that Highland Park, Ford's first factory, maintained "...ancillary systems such as factory logistics being refined to reflect the needs of the assembly line and, importantly, to throw any unexploited potential into sharp relief. That is, administrative and ancillary systems did not just buttress the assembly line but were used to facilitate, perhaps even force its development." (2010, p. 775). If the assembly line is to be looked at in this way, a machine or product of sorts, then its continued evolution is expected if not absolutely necessary. In addition, this excerpt stresses the idea that the assembly line can be looked at as a "barebones" foundational operation on which all other systems mutually rely. So it should seem that the streamlining/leaning out of non-value added activities that support the purported assembly line is heavily implied.

[4] In a study conducted by Golz, Gujjula, Günther, Rinderer, and Ziegler (2011, p. 1), the history of assembly lines is explained in another, similar way and is summarized with the idea that originally, beginning with Henry Ford, all assembly lines were intended for specialized, mechanical products such as automotives. Most of these production systems were designed to be single model/single objective or meant to manage one particular product. The study continues introducing the topic by claiming that the development of more versatile tools and the introduction of automation propelled the assembly line to be robust enough to handle a random mix of different models at the same time. Thus, the assembly line has indeed experienced exponential growth and development, sustaining and standardizing solutions that were once considered novel. It is within this realm that one is able to see the impact of kitting and the provided room for innovation.

Assembly Line Types:

[6] In regards to the different types of assembly lines, there's a dedicated set of criteria available to classify them. As described in the Khorasanian, Hejazi, and Moslehi study (2013, p. 1), their research suggests that assembly lines can have any of four criterion that renders them unique: 1). Straight or U-Shaped, 2). Single or Multi/Mixed Model, 3). One-Sided or Two-Sided, and finally, 4). Single Objective or Multi Objective. Depending on the specific application of the assembly line, there are any number of combinations that can be chosen to help achieve the desired purpose while also accommodating factory layouts and desired throughput efficiencies.

Given the aspects of assembly lines, it is important to highlight the importance of kitting within this realm. As it is in these different assembly lines, particularly those mainly classified as mixed model, that kitting has helped to benefit operators and material handlers alike. As aforementioned in the “Kitting” section, given a particular set of conditions found lineside, kitting is often recommended and utilized to facilitate lean and just-in-time production.

<u>Batching & Sequencing:</u>

Description:
In a study performed by Zhu, Hu, Koren, Marin, and Huang (2007, p. 1), a concise description of sequencing is analysis and planning also allows for an organisation to decide which select tasks are to be worked on immediately and which tasks are to be worked on later. An example of sequencing can be seen in the precedence graph below, in which a Ten-Task Assembly is modeled.

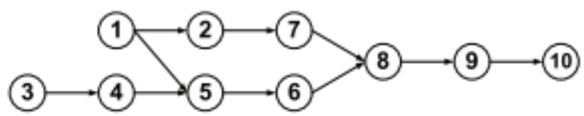


Fig. 1. Precedence Graph of a Ten-Task Assembly (From [3], pp.5)

[8] Interestingly, another definition of sequencing, provided in a study performed by Sali and Sahin (2016, p. 2), relates sequencing to kitting and maintains the thought that the it is a “particular form of stationary kit” where the variants of a particular component are carried within the kit. The study continues on and maintains that because each assembled end product requires specific variants requested by the customer, all sequenced parts and kits are supplied to the line in a specific order that corresponds to the particular production schedule generated by the customer orders received.

Advantages:
[13] In the same study by Zhu, Hu, Koren, Marin, and Huang (2007, p. 1), the benefits of sequencing are referenced in three distinct ways: Correctly sequenced parts allow for a balanced line, limited capital investment in equipment, and all-around improved product quality.
[11] Summarized in another way, in regards to batching, a study done by Wang, Li, Arinez, and Biller (2010, p. 1) discusses the main idea of flexible manufacturing systems and the improved product quality and reduced costs experienced when implementing batch production. Sequencing and batching are not only found in mixed model assembly but are the factors that drive and facilitate it. In this way, mixed model assembly is broken down into further detail.

<u>Just-In-Time:</u>

Description:
[8] [3] Focusing on Just-In-Time, as described by Sali and Sahin (2016, p. 1) “automotive part assembly plants are characterized by high end-products diversity and synchronous assembly based on customer order sequence. In such production systems, end product diversity stems from the combination of different components associated with different end product configurations.”

Sali and Sahin continue in more detail arriving at the idea that component diversity largely contributes to the “increase of internal logistic processes”. That, ultimately, manufacturing “practitioners” continuously search for innovative solutions intended to improve the material feeding process and desire to do so while minimizing cost.

Now that a proper background and context for this project has been established, the next section will continue the discussion with a description of the design of the substitute material, the material design requirements, material selection, and future state design of the kitting station.

III. Design

This section covers a variety of topics ranging from material selection criteria and analysis, to the design of the future state production loop, between the kitting station and assembly line.

Material Selection Criteria:
Before providing a list of potential materials that may act as a substitute for the current state materials [polyurethane, polyethylene, and charcoal ester], it is important to develop a primary list of material selection criteria. This will help focus the research conducted and strongly refine the material choices. It is also important to understand the setting in which this material is projected to reside. Being that the primary application of the material will be in a manufacturing setting, it must take into account such aspects having to do with price, flexibility, durability, reliability, and damage to assembly components – these however are considerations taken into account with the project scope.

The following list contains the developed primary design requirements and maintains that the selected material:

- Does Not Crumble
- Does Not Dry Out
- Abides by the 3 R's (Reuse, Recycle, Reduce)
- Can Be Formed Infinitely
- Holds Its Shape w/o Container (Before/After Pressure)

The five criteria listed above encompass the primary characteristics of the proposed, new material. Beginning with the first criterion, the new material must not crumble to avoid extra maintenance and damage to assembly components. Ultimately, the material must be one entity. The next criterion involves that of drying. As many of these foam molds must be reused, it is imperative that they do not dry out allowing for recyclability and accessibility. The next criterion covers the sustainability and ability to be recycled, reused, and capacity to reduce overall waste within the factory. The next two criteria involve the material structure and how often the material can be made into a "blank slate" as well as hold its shape after being contained. These criteria make up the foundation for the characteristics of the new material. The list below describes peripheral considerations. Even though many of the considerations are fairly important, they are also embedded and supported within the scope of the project, providing a preliminary screening of the vast list of potential materials.

Design Requirements Peripheral Considerations:

- Inexpensive
- Lightweight
- Durable
- Flexible
- Texture & Properties
- Recyclable
- Reusable
- Reduces (Overall Waste)
- Withstands Temperature Fluctuations

- Environmentally Friendly

Material Choices:
Given the aforementioned material selection criteria, the following is a list of the potential materials considered:

- Slime (a mixture of glue and borax)
- Clay
- Kinetic Sand (sand treated with a hydro-phobic chemical)
- Beaded Foam (uncompressed molding foam)
- Memory Foam
- Floam (a mixture containing elements similar to Foam and Slime materials)

These proposed materials all maintain strong attributes that would largely contribute to a proper current state material substitute. However, a few hypotheses must be made. At first glance, Slime, Floam, and Memory Foam contain major negative attributes that would result in rejection from a manufacturing facility. These include characteristics such as strong surface tension (not allowing multiple components to be inserted within), high maintenance (leaves residue and hard to clean), and low viscosity (therefore needs a container/tote and may not be tilted). Despite their setbacks, these materials will still be considered alongside the rest, to provide comparisons and context in regards to the primary material selection criteria. These materials are compared, in-depth, using Analytic Hierarchy Process.

Analytic Hierarchy Process:
Analytic Hierarchy Process is a useful tool to utilize when deciding between multiple choices with various criteria. It is a structured matrix that combines mathematics and psychology to help better consolidate and analyze complex decisions. At its core, AHP works to develop a set of governing priorities for various discretions as well as the criteria by which to judge such alternatives. Generally the criteria, developed by the biases of the decision maker, are measured on different scales (typically with a ranking ranging with values from 1-9) and especially those biases that remain intangible and for which no scales still do not exist.

The following tables represent the Analytic Hierarchy Process and demonstrate the decision-making behind the determined new material. Below in Table -1, the five primary criteria are listed and weighted against one another. This is done to determine the criterion with the highest priority in regards to the decision maker. When filling out the matrix, a ranking value ranging from 1-9 is chosen and assigned to a cell. For instance, the criterion of “Does Not Crumble”, when compared to the criterion of “Does Not Dry Out”, is a major priority and weighted heavily. In the “Average” column, a ratio is developed based on the weights given for each criterion. So the “Does Not Crumble” and “3 R’s” criteria maintain the strongest ratios and represent the biases of the decision maker.

Criteria						
	Does Not Crumble	Does Not Dry Out	3 R's	Can Be Formed (Infinitely)	Holds Shape w/o Container	Average
Does Not Crumble	1.00	7.00	3.00	3.00	5.00	0.43
Does Not Dry Out	0.14	1.00	0.14	0.14	0.14	0.03
3 R's	0.33	7.00	1.00	3.00	5.00	0.28
Can Be Formed (Infinitely)	0.33	7.00	0.33	1.00	3.00	0.16
Holds Shape w/o Container	0.20	7.00	0.20	0.33	1.00	0.10
Sum	2.01	29.00	4.68	7.48	14.14	

**Five Primary Criteria – AHP – Table 1*

After the weights of the criteria are established, a matrix is made for each of the materials with respect to each of the five primary criteria. Shown in Table -2, the six material choices are weighted against each other and multiplied with the "Does Not Crumble" ratio to determine the weighted average. This is done with the remaining four criteria (these tables may be referenced in the Appendix).

Criteria	Material Comparison - "Does Not Crumble"						
	Slime	Clay	Kinetic Sand	Beaded Foam	Memory Foam	Floam	Average
Slime	1.00	5.00	7.00	0.33	0.20	0.33	0.13
Clay	0.20	1.00	5.00	2.00	0.14	0.33	0.09
Kinetic Sand	0.14	0.20	1.00	0.11	0.14	0.20	0.03
Beaded Foam	3.00	0.50	9.00	1.00	0.14	5.00	0.17
Memory Foam	5.00	7.00	7.00	7.00	1.00	8.00	0.47
Floam	3.00	3.00	5.00	0.20	0.13	1.00	0.12
Sum	12.34	16.70	34.00	10.64	1.75	14.87	

**Material Comparison – "Does Not Crumble" – AHP – Table 2*

Once the six materials are weighted against the five primary criteria, the weighted averages are compiled into a final matrix to be scored. This matrix determines an average of the compiled averages and computes an overall score. The highest overall score selects the choice, or in this case, material, that abides by the priorities and criteria decided upon respectively.

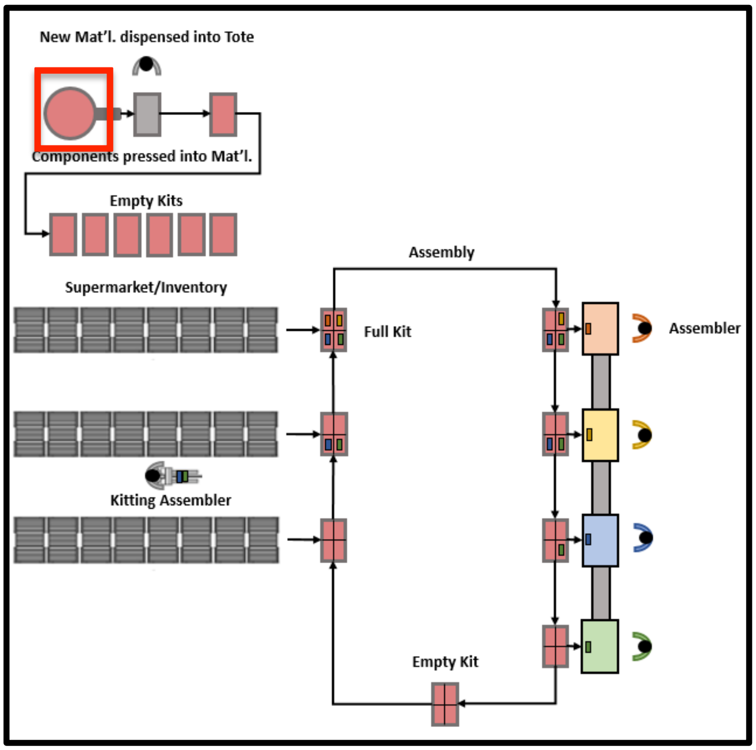
Weight of Criteria	0.43	0.03	0.28	0.16	0.10	
	Does Not Crumble	Does Not Dry Out	3 R's	Can Be Formed (Infinitely)	Holds Shape w/o Container	Overall Score
Slime	0.13	0.22	0.16	0.13	0.05	0.13
Clay	0.09	0.03	0.03	0.13	0.17	0.08
Kinetic Sand	0.03	0.11	0.13	0.17	0.13	0.09
Beaded Foam	0.17	0.20	0.48	0.40	0.30	0.31
Memory Foam	0.47	0.30	0.11	0.04	0.31	0.28
Floam	0.12	0.14	0.09	0.13	0.04	0.11
Recommended Material:		0.31	Beaded Foam			

**Overall AHP Score – Beaded Foam – Table 3*

In this case, the recommended material was that of Beaded Foam. The AHP confirmed the original hypotheses that a material such as Beaded Foam would be the prime choice for this particular application. Beaded Foam, as mentioned earlier and further specified in the "Methods" section, is an uncompressed molding foam that is a mix of borax and other substrates. The material can be formed infinitely and while providing proper insulation and structural properties.

Future State Production Loop:
Following the material selection criteria and Analytical Hierarchy Process, a representation of the future state of the production loop between the kitting station and assembly line must be shown. It is important to note that the separate production loop, between the kitting station and foam supplier, is eliminated and the staging of the material is now received in the factory's warehouse and delivered, upon request, similarly to other raw materials. This only takes place in the beginning phase of implementation as the current state foam molds are replaced with the future state foam blocks. The following four steps delineate the process in detail:

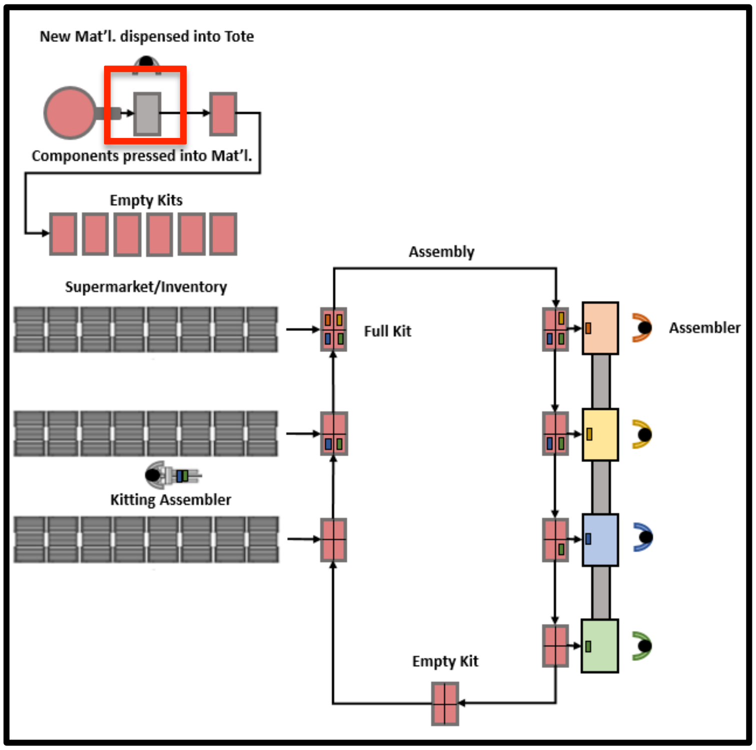
<u>Future State Production Loop: **Step One**</u>



In **Step One**, with the beginning of implementation of the new material, a kitting operator will dispense the material and prepare it for placing within a tote/container. The material may either be stored in bulk or pre-cut into blocks that fit within the industrial container.

**Future State Production Loop: Step One – Figure 15*

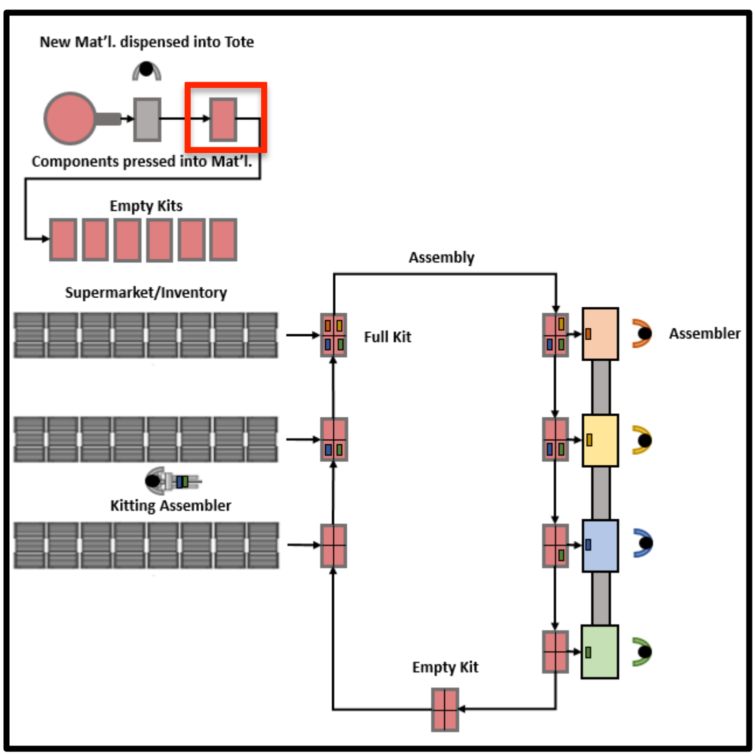
Future State Production Loop: **Step Two**



Step Two, the proper sized tote/container will be staged near the material and ready. A standard industrial tote will measure 31" x 14" x 12". Depending on the assembly components being held, the tote size will vary.

**Future State Production Loop: Step Two – Figure 16*

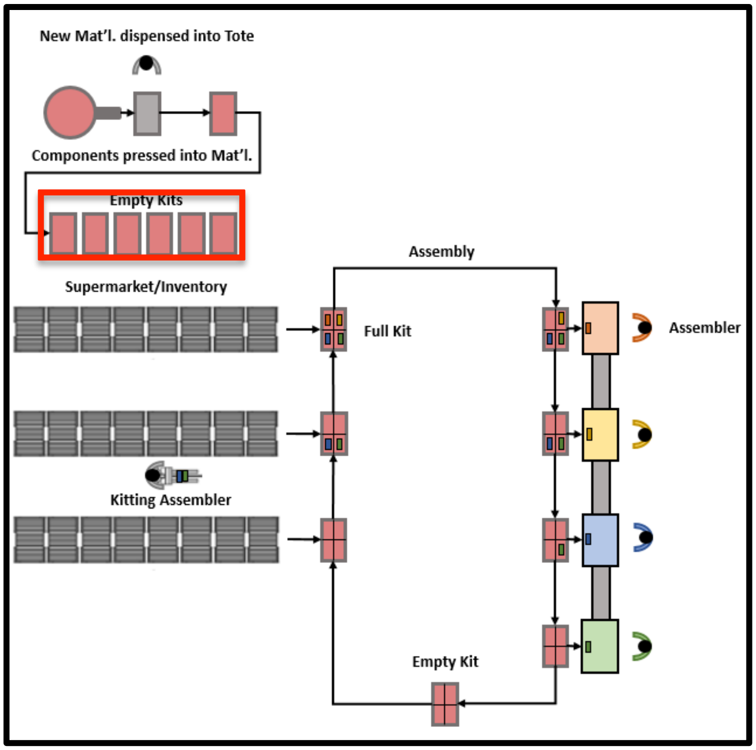
Future State Production Loop: **Step Three**



In **Step Three**, the operator will place the block of material into the tote making sure that the material is flat on the surface and fully contained within. This only needs to be performed once, as the material immediately takes the shape of the tote and can be manipulated accordingly if needed.

**Future State Production Loop: Step Three – Figure 17*

Future State Production Loop: **Step Four**



Step Four, requires that the kits be staged and ready for assembly components within the kitting supermarket. As this is the beginning of implementation, this process only takes place once. Once all old foam molds have been replaced with the new material and the imprints have been set, the circulation of kits moves in a loop involving only the assembly line where parts are consumed and the kitting station supermarket.

**Future State Production Loop: Step Four – Figure 18*

The following section is a description of the methods of testing performed to continue the discussion and analysis of the new, selected material.

IV. Methods

This section discusses the different methods used to test the selected material, Beaded Foam. These tests include material demonstration and an examination of performance – i.e. a simulation of how the new material might react to similar factory conditions.

Material Demonstration/Testing:
The first test is a visualization of how the material interacts and performs. It is important as it expands on the design phase and various criteria involved. Therefore this test is crucial in understanding how the proposed steps in the future state [kitting station] production loop might look. The demonstration breaks down the actions a kitting operator might perform during the first phases of implementation for the new material. The five steps are as follows:

<u>Material Demonstration/Testing: **Step One**</u>

In **Step One** of the material demonstration, as shown on the left, a block of beaded foam is taken and immediately ready for placement within a tote/container. However, it is important to note that before being placed in an industrial container, the material does not require any preliminary preparations and/or manipulations. In addition, the material may be in any orientation or shape before use.

**Material Demonstration/Testing: Step One – Figure 19*

Material Demonstration/Testing: **Step Two**

In **Step Two**, an industrial tote or container is needed for the appropriate application. In regards to the applications of this project, the size of the container is essential and must tailor to the components that will be held within it and later sent to the assigned assembly line pitch.

**Material Demonstration/Testing: Step Two – Figure 20*

Material Demonstration/Testing: **Step Three**

**Material Demonstration/Testing: Step Three – Figure 21*

**Material Demonstration/Testing: Step Three – Figure 22*

Moving on to **Step Three**, the block of foam is taken and pressed into the industrial container. The material is kneaded resulting in a process that involves very few actions to achieve the shape seen on the right in Figure – 22.

Material Demonstration/Testing: **Step Four**

**Material Demonstration/Testing: Step Four – Figure 23*

**Material Demonstration/Testing: Step Four – Figure 24*

Step Four demonstrates the ease with which a component may be placed and pressed into the material. The component sits firmly within the material and does not move during turbulence.

Material Demonstration/Testing: **Step Five**

In the final step, **Step Five**, the component is removed from the material and an imprint is left. This step in the process mimics the act of an operator consuming an assembly component line side and the empty kit being sent back to the kitting station to be stocked once more. The material is projected to keep its shape, including the imprint, and better conforms to the component with continuous use.

**Material Demonstration/Testing: Step Five – Figure 25*

Other Methods of Material Testing:
The next tests demonstrate the durability and reliability of the material prototype. The extent of crumbling and compression was explored as both conditions provide insight into the endurance of the material, especially within the context of the assembly line and the demanding, harsh environment experienced.

<u>Crumbling Test:</u>
The test of material crumbling involves a simulation of the actions of picking and placing experienced during consumption and replenishment procedures. These actions are continuous and highly repetitious – being experienced constantly in the loop between the kitting station and assembly line. The instance of crumbling may be observed in the following situations:

- Time pressure on the assembly line/kitting operator resulting in quick or hurried part consumption/replenishment
- Sharp or distinguished part features
- The difference in assembly line pitch regulations regarding the requirement of safety gloves – studying whether the material sticks to an operators gloves or bare hands

Crumbling may adversely affect operations on the assembly line as the possibility of the material sticking to an assembly component may result in a nonconformance or malfunction to the overall product.

During the crumbling test, an assembly component, such as the one seen in Figure -23, is taken and, with varying degrees of speed and force, is picked and then placed within the material. In the interval between picking and placing, the part is fully inspected for any signs of material residue and/or crumbling. If crumbling is experienced, a “Yes” response is recorded for the designated trial, while a “No” response is recorded if no crumbling occurs. There were 200 trials/instances of picking and placing performed with a hundred of those trials being performed with safety glove and the other hundred trials being performed with bare hands.

<u>Compression Test:</u>
The test of material compression involves a simulation of the independent actions of the material itself. For instance, the effects of a dense, metal component on the material and whether or not the material structure begins to give way or “sag”. Generally a part may sit in the kit anywhere from ten to thirty minutes after being replenished/placed within the foam mold and sent line side.

The compression test includes the following steps:

- A dense assembly component, such as the one seen in Figure -23, is placed in the center of the material
- Once placed, the setup is left for six hours with measurements taking place every hour to record material “sag”
- The experiment is repeated for ten trials

The “sag” of the material is recorded with a standard ruler. The initial component position is marked and each hourly measurement is recorded against the initial position. The component is left for six hours to provide a thorough study on the long-term effects of its mass on the material structure.

V. Results and Discussion

This section covers a variety of results and discussion points including: material test results, design limitations, environmental and social considerations, and an in-depth look at the economic justifications of forecasted implementation.

Material Testing Results:
The testing of the material proved to be very revealing and created many tangible observations and conclusions about Beaded Foam.

Material Demonstration Results:
The material demonstration confirmed several of the hypotheses surrounding the performance of Beaded Foam. The future-state material demonstrated an ability to meet all primary design criteria. This was proven through the preliminary material manipulation. When constantly interacting with the material, the structure allowed for an infinite combination of formations. This was achieved without drying out and without crumbling. It also showed a capacity to be reused, recycled and possibly reduced. Finally, the material held its shape without the container and before and after pressure.

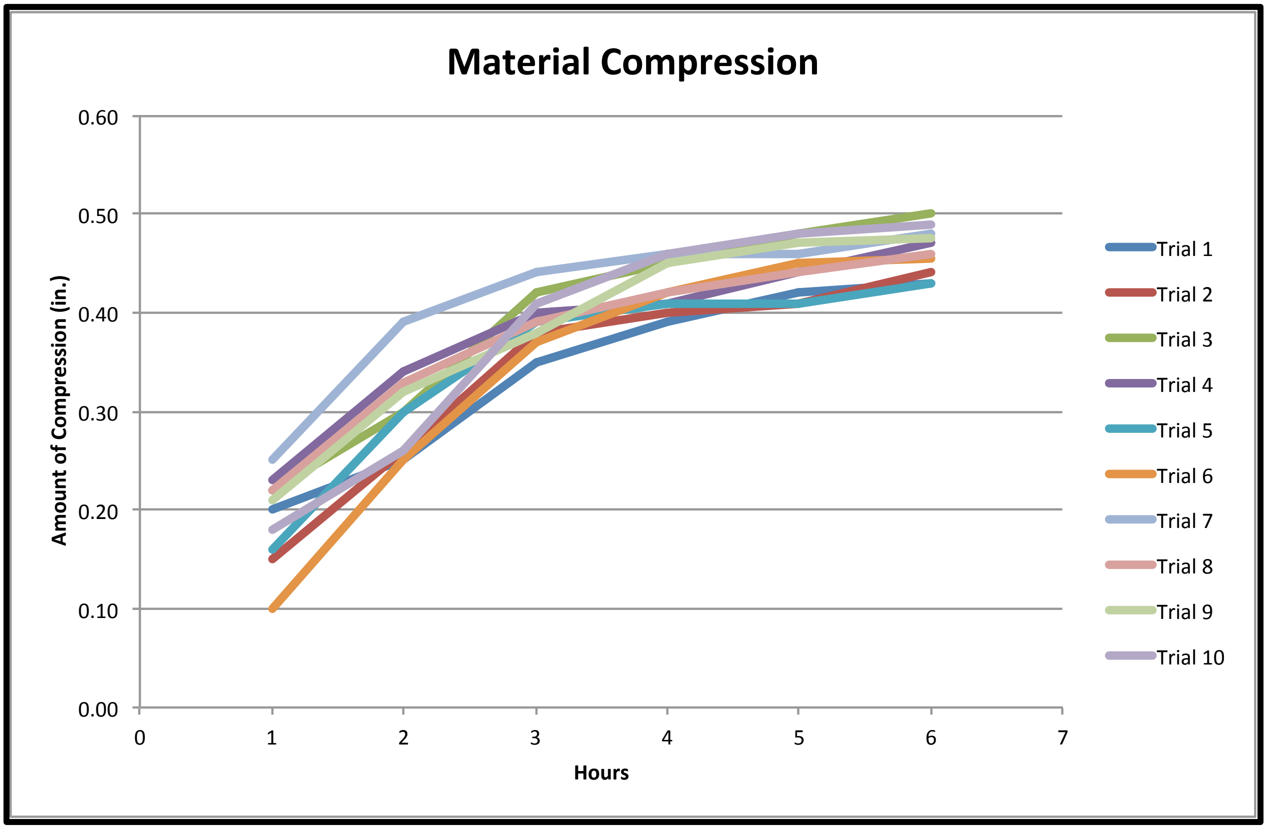
Moving on to the simulation steps, the material performed quite well allowing for facilitated trials of the procedure. The material is fairly malleable; the process of flattening/conforming within the tote is performed with ease and can be done rapidly. In addition, the component, when pressed into the Beaded Foam, remains steadfast with little to no movement when shaken or tilted. When the component is taken out of the material, the imprint left is clear and maintains its shape infinitely. Overall, the demonstration showed many positive attributes and confirmed the design criteria used to select the material prototype.

Material Crumbling Test:
The crumbling test demonstrated positive results as well. The trial number, 200, was fairly revealing and led to the following results:

- 15 of the 200 trials reported a "Yes" response to crumbling – about 7.5% likelihood
- Of the 15 instances of crumbling, none occurred on the actual component, therefore no material was left once picked
- Of the 15 instances of crumbling reported, 12 occurred when using bare hands to pick the component – about 80%

These results allow for interesting observations. It appears as though the material becomes more compact the as the action of replenishment, or placing, occurs. This leads to less crumbling as the process continues, resulting in a logarithmic distribution where the material is more likely to break up in the beginning of use. It is also important to note that the material is more likely to crumble when handled with bare hands as opposed to safety gloves. It appears as though the presence of moisture causes the adhesive substance holding the material together to stick to the texture of skin rather than that of a glove.

Material Compression Test:
The compression test confirmed the hypotheses developed surrounding the purported assumptions on whether the material structure would give way or "sag". The following graph shows the distribution:



**Material Compression – Figure 26*

The results reveal a fair amount of information. To begin, the material reaches a maximum "sag"/compression limit of 0.5 inches. The graph shows a logarithmic distribution, where the most compression happens in the beginning of half of the six hour long trial. This would lead to the assumption that as soon as a component is placed in the tote, the material will experience a substantial amount of its total compression within the first hour. However, seeing as the compression reaches a projected limit of 0.5 inches, the difference will be negligible since the cycle time is about 10-30 minutes. A more detailed look at the data table and specific values is included in the Appendix.

Design Considerations and Limitations:

There were many reflections regarding the design of this experiment, the material, and limitations encountered during experimentation.

Of the two major limitations, the first limitation experienced had to do with the material's malleability and rigidity. While the Beaded Foam is incredibly malleable, when placed in a tote and contained, the material's structure becomes a bit denser. This implies that pushing and placing a component into the material is less facilitated than previously hypothesized. This leads to a confirmation of the scope, as it refines the application to assembly components made of

metal, which are ideal for their density and obvious rigid structure. However, when dealing with all other components (i.e. made of plastic, rubber, etc.) an imprint may be quickly made with a "dummy" rigid rod or other instrument to allow for an imprint tailored to the delicate component. It is assumed that this would take the same time in the beginning phases of implementation as the metal components, as once the imprint was made, the more fragile component would be placed with ease. Again, this process only takes place once, when the new kit design is dispatched and the foam mold is created, in-house.

The second limitation experienced related to the material and its ability to prevent from drying out. While this was more or less true, when the material was left to sit for hours or days, the material would stiffen slightly. Once the material was taken out of the tote and manipulated and formed once more, the material would become as malleable as it was initially. This isn't a major problem, however, as it turns out that the stiffness provides a solid structure for the components housed within. It also prevents against crumbling – experienced in the beginning of implementation with the creation of the foam molds.

Overall, the design of this project has held up quite well to the objectives set throughout the introduction. In addition, while there are limitations, there are proper countermeasures that may prevent immediate and initial problems that arise. It is important to note, however, that this material is still a prototype and much more testing would likely need to be done, as well as, observations of its circulation within an assembly line.

Environmental & Social Impacts:
The environmental impact of this project, and more specifically the material, is projected to be fairly straightforward and positive. The biggest impact that this material can have on the environment is its recyclability and reusability. Reviewing the current state materials [polyurethane, polyethylene, and charcoal ester] for a moment reveals that foam molds made from them must be replaced and disposed. Once a foam mold with the current state materials is obsolete, worn down, or reduced, they are also non-universal to the factory and no longer needed, resulting in fair amount of waste due to the costs associated with disposal and replacement. The proposed future state material is projected to be highly reusable and recyclable. This is mainly due to the material's ability to be reshaped and reformed, resulting in a "blank slate" or foam block, in this case. This allows the material applications to be universal factory-wide. It is also estimated to cut down on shipping and emissions involved with current transportation methods.

In regards to the social impact, material handling environments, as well as those managing kitting stations, may experience a sense of flexibility and creativity, as there is a larger degree of freedom. This can especially be seen reflected through a reduced amount of planning, logistics, and disposal required for a non-value added procedure.

VI. Economic Analysis

Following the results and discussion aforementioned, it is important to discuss the economic implications of implementation. While the new material and the solution proposed allow for advantages that include the flexibility of material feeding to the assembly line/facility and the elimination of various non-value added procedures, economic justification is needed to provide a more tangible and calculated assessment of the results. There are, however, further assumptions needed to give context to the following economic justification. These include:

- Material Storage: the new material does not require storage within the kitting station; therefore there is no need to dedicate any special consideration to allocated space requirements. Bulk storage of the material should be considered in the same way as other raw materials accepted within the factory and stored accordingly - within the warehouses. When the new material is needed, it will be delivered to the kitting station in the same manner as other assembly components and raw materials.
- Transition/Implementation: when transitioning to the new material, specifically replacing the polyurethane/ethylene/charcoal ester foam molds, the changeover and setup times are assumed to be the same as those associated with the current state materials aforementioned. Ultimately, there is a strong comparison between the installation of the current state and future state foam molds within the tote and, thus, it can be concluded that the actions involved (manipulation, press, and placement) are the same for both.
- Operator Training: Many of the preliminary guidelines and instructions required for [kitting] operators involved with the installation of these materials are non-complex. Therefore kitting operator training times and costs associated with the future state material are also considered the same as those for the current state material.

These assumptions are included as they isolate the kitting operation with respect to the rest of the assembly line, operations within, and the factory as a whole. However, this doesn't imply that these overall costs are neglected; they are just assumed to be the same for both current and future state materials when implemented respectively.

The economic considerations can be summarized through a conceptual, modeled equation. To gain perspective into what costs are required, it is important to consider both the material and labor inputs of the kitting station. For instance, there are the costs of the raw material. Then, included within those, are the production (i.e. cutting, machining, etc.), labor and/or customization costs. These costs take place outside of the kitting station. When looking at the costs within the kitting station, labor is the primary consideration. This results in an equation that addresses the "Total Annual Cost" of a single kitting station. The reason only one kitting station is being analyzed versus a factory's entire kitting system is that many kitting stations are specialized to their assigned pitches, so the costs may not be the same from one station to the next. However, the following equation as well as, Table - 4 and Table - 5, allow for those specialized and unique kitting station costs to be considered as inputs.

Conceptual Modeled Equation (for a single Kitting Station):
Total Annual Cost = Product Costs + Raw Material Costs + Labor Costs

Economic Justification: **Polyurethane**

Additional Preliminary Assumptions:

- Current State
- Labor (per Kitting Station): is assumed to be the same with Polyurethane as it is with Beaded Foam. However, these inputs may be different from one kitting station to the next. For instance, certain kitting stations supply to a large row of assembly line pitches, thus requiring many more than the assumed "3 Operators". The following tables were included to provide a model with customizable inputs intended to take into account many diverse situations. In addition the number of operators, some factories operate with three shifts (8 Hours) or a lower hourly wage, again, these may be customized accordingly. Below are the assumed Labor statistics in reference to this particular project.
  - 3 Operators
  - 2 Shifts – 12 Hours
  - $18/Hour

Products, Coproducts and Byproducts			
Name of Material	Price, $/kg	Annual Amount, kg/y	Annual value of product,
Prototype #1 & #2	$1,000.00	12.247	$12,247.00
			$-
			$-
Total annual value of products =			**$12,247.00**

Raw Materials			
Name of Material	Price, $/kg	Annual Amount, kg/y	Annual raw materials cost,
Polyurethane	$200.00	272	$54,400.00
			$-
			$-
Total annual cost of raw materials =			**$54,400.00**

Material Annual Amount			
# of Existing Totes	Mass of Foam (kg)	# of Times Foam	Annual Amount (kg/y)
50	1.36	4	**272**

Operating Labor			
Number of operators per	Shifts per day	Operator rate, $/h	Annual operating labor
3	2	$18.00	**$338,256.00**
Enter appropriate value for batch operation.			

Total Annual Cost:	**$404,903.00**

**Economic Justification: Polyurethane – Table 4*

Products, Coproducts and Byproducts:

As seen in Table - 4, the product costs show two prototype costs – Prototype #1 and Prototype #2 (Two are made on average). These prototypes incur a large cost as they are mainly produced by craftsmen and tailored to the shape of the components and the tote that will contain the resulting foam mold. The prototypes only need to be made once and this condition is reflected in the "Annual Amount".

Raw Materials:
Polyurethane, by the pound, costs double that of beaded foam. In addition, this includes the cost of production (i.e. manufactured by hand at most foam suppliers) and labor hours. These costs can range greatly with different suppliers. However, the input seen in Table - # is the average, bulk retail price.

Material Annual Amount:
This section calculates the amount of material, per pound/kg, needed annually. The first consideration is the number of existing totes, or, how many totes are in the loop between the kitting station and the assembly line pitch. The second consideration is that of the mass of the block of material. For polyurethane, the average mass is about three pounds for a block of material that measures 31" x 14" x 12" (the size of a standard industrial container). Finally, the third consideration takes into account the number of times these foam molds are replaced due to natural "wear and tear". In a standard factory, foam molds will be replaced anywhere from two to four times a year.

Economic Justification: **Beaded Foam**

Additional Preliminary Assumptions:
- Future State
- Labor (per Kitting Station): (reference assumptions included in the "Economic Justification: Polyurethane" - Additional Preliminary Assumptions)
    - 3 Operators
    - 2 Shifts – 12 Hours
    - $18/Hour

Raw Materials			
Name of Material	Price, $/kg	Annual Amount, kg/y	Annual raw materials cost,
Polyurethane	$30.00	22.5	$675.00
			$-
			$-
Total annual cost of raw materials =			**$675.00**

Material Annual Amount			
# of Existing Totes	Mass of Foam (kg)	# of Times Foam	Annual Amount (kg/y)
50	0.45	1	**22.5**

Operating Labor			
Number of operators per	Shifts per day	Operator rate, $/h	Annual operating labor
3	2	$18.00	**$338,256.00**
Enter appropriate value for batch operation.			

Total Annual Cost:	**$338,931.00**

**Economic Justification: Beaded Foam – Table 5*

Products, Coproducts and Byproducts:
In regards to beaded foam, there are no prototyping costs, therefore no product costs. This is mainly because of the idea that the beaded foam will be bought in pre-formed blocks measuring

the correct size for a standard industrial tote. There is no need for preliminary manufacturing as compared with polyurethane.

Raw Materials:
Beaded Foam, by the pound, costs half of polyurethane. This input represents the average, bulk retail price.

Material Annual Amount:
This section, compared with polyurethane, contains two different inputs for the material mass per pound/kg and the number of times the material is replaced per year. The mass of beaded foam is half that of polyurethane, especially considering the same 31” x 14” x 12” size for a standard industrial tote. In addition, the number of times the foam molds must be replaced throughout the year ranges from zero to two times considering the durability of the material.

Cost Comparison:

The costs for polyurethane and beaded foam are summarized, once more, below:

- Polyurethane: **$404,903**
- Beaded Foam: **$338,931**

This results in a total projected savings of: **$65,972**

While this number may seem negligible, it is important to remember that this cost may be saved for a single kitting station. In a full-scale, automotive factory there can be as many as sixty or more kitting stations for the Final Assembly line alone. So these potential savings may be multiplied, for a resulting substantial amount, factory-wide for the entire kitting system.

Sensitivity Analysis: **Polyurethane**

Sensitivity analysis, with two input variables, was performed to account for different ranges of both the price per kilogram of material and annual amount of material for a single kitting station. These two factors account for the two inputs that affect the total annual amount most. Below, in Table - #, the total annual cost of Polyurethane is explored in regards to a range of $50 to $350 per kilogram block of material. Concurrently, the annual amount of material per year is manipulated, ranging from 68 to 476 kilograms (or number of times replaced: 1-7 times per year).

ANNUAL AMOUNT OF MATERIAL (kg/y) - Polyurethane

PRICES PER BLOCK ($/kg)	$404,903.00	68	136	204	272	340	408	476
	$ 50.00	$353,903.00	$357,303.00	$360,703.00	$364,103.00	$367,503.00	$370,903.00	$374,303.00
	$ 100.00	$357,303.00	$364,103.00	$370,903.00	$377,703.00	$384,503.00	$391,303.00	$398,103.00
	$ 150.00	$360,703.00	$370,903.00	$381,103.00	$391,303.00	$401,503.00	$411,703.00	$421,903.00
	$ 200.00	$364,103.00	$377,703.00	$391,303.00	$404,903.00	$418,503.00	$432,103.00	$445,703.00
	$ 250.00	$367,503.00	$384,503.00	$401,503.00	$418,503.00	$435,503.00	$452,503.00	$469,503.00
	$ 300.00	$370,903.00	$391,303.00	$411,703.00	$432,103.00	$452,503.00	$472,903.00	$493,303.00
	$ 350.00	$374,303.00	$398,103.00	$421,903.00	$445,703.00	$469,503.00	$493,303.00	$517,103.00

**Sensitivity Analysis: Polyurethane – Table 6*

The values reflect conditional rules; hence the different shades within each cell and corresponding total annual cost. If the cell is yellow, then the value fell below the average total annual cost of $404,903 for Polyurethane. However, the value is still yellow and not green, which implies that while the value falls within a desirable range, it is still higher than that of the total annual cost of Beaded Foam. If the cell is red, then the value was above the average total annual cost and therefore an undesirable value.

Sensitivity Analysis: **Beaded Foam**

The sensitivity analysis setup for beaded foam was the same as it was for Polyurethane. The Table -# below measures different ranges of price per kilogram of material against the annual amount of material. The difference between the two tables may be seen in the "Annual Amount of Material" section of Beaded Foam. This is mainly due to the assumption of beaded foam being projected to be replaced about zero to two times a year. The range reflects the annual amount from 22.5 kilograms to 157.5 kilograms (or number of times replaced: 1-7 times per year).

		ANNUAL AMOUNT OF MATERIAL (kg/y) - Beaded Foam						
PRICES PER BLOCK ($/kg)	**$338,931.00**	**22.5**	**45**	**67.5**	**90**	**112.5**	**135**	**157.5**
	$ 10.00	$338,481.00	$338,706.00	$338,931.00	$339,156.00	$339,381.00	$339,606.00	$339,831.00
	$ 20.00	$338,706.00	$339,156.00	$339,606.00	$340,056.00	$340,506.00	$340,956.00	$341,406.00
	$ 30.00	$338,931.00	$339,606.00	$340,281.00	$340,956.00	$341,631.00	$342,306.00	$342,981.00
	$ 40.00	$339,156.00	$340,056.00	$340,956.00	$341,856.00	$342,756.00	$343,656.00	$344,556.00
	$ 50.00	$339,381.00	$340,506.00	$341,631.00	$342,756.00	$343,881.00	$345,006.00	$346,131.00
	$ 60.00	$339,606.00	$340,956.00	$342,306.00	$343,656.00	$345,006.00	$346,356.00	$347,706.00
	$ 70.00	$339,831.00	$341,406.00	$342,981.00	$344,556.00	$346,131.00	$347,706.00	$349,281.00
	$ 80.00	$340,056.00	$341,856.00	$343,656.00	$345,456.00	$347,256.00	$349,056.00	$350,856.00
	$ 90.00	$340,281.00	$342,306.00	$344,331.00	$346,356.00	$348,381.00	$350,406.00	$352,431.00
	$ 100.00	$340,506.00	$342,756.00	$345,006.00	$347,256.00	$349,506.00	$351,756.00	$354,006.00

**Sensitivity Analysis: Beaded Foam – Table 7*

These values abide by the same conditional rules as seen above, with the Polyurethane sensitivity analysis. If the cell is yellow, the same rules apply with the value having fallen below average, however, not below the total annual cost of $338,931 for Beaded Foam. If the cell is green, then the total annual cost was below that of Beaded Foam and thus an acceptable and desirable total annual cost.

The next section of this report captures the final thoughts and conclusions of the project, as well as, provides a summary of the findings, a set of conclusions and results, and future considerations for further study.

VII. Conclusions

As kitting is a non-value added procedure and greatly limits the flexibility of assembly line operations, it is necessary to apply lean principles to a process that greatly impedes faster part feeding. A major waste, which further amplifies the problems aforementioned, is the creation of foam molds that provide many benefits for operators line side. The future state material, beaded foam (an uncompressed molding foam) was subjected to design, testing, and analysis to determine a proper material substitute for the current state of kitting processes. This solution is recommended for those applications that maintain mixed model assembly with kitting as the primary material feeding technique. While the long-term effects of this solution cannot support any significant conclusions, the short-term effects analyzed provide promising results and additional research. Such results show that beaded foam may save a single kitting station about $66,000, while also allowing for the elimination of a separate production loop needed to produce the current state foam molds. The following, in addition to the material savings achieved, is a summary of the conclusions and objectives met for this project:

- Final Design/Potential Prototype: A future state material was found and an optimized material design developed. As aforementioned, the design was subjected to various design, testing and analysis techniques.
- Market Analysis and Customer Specification: A set of five primary, material selection, criteria was developed with priorities reflective of the market analysis and customer specifications. This aided in the selection of a substitute material intended to replace that of the current state. In addition, the criteria address the concerns and characteristics common to harsh and rigorous manufacturing environments.
- Manufacturing Plausibility and Sustainability: The manufacturing plausibility and sustainability of the selected, future state was confirmed, however and in addition, benefits were shown to directly impact those requirements related to the manufacturing facility [kitting stations and assembly line(s)]. These benefits include: improved internal material handling (less material "touches" and faster material feeding), a significant reduction in the lead time required for kit changes, an increase in factory flexibility and agility in regards to the required response to changing operations and designs found on the assembly line, and substantial savings in inventory space requirements for line side operations, kitting stations and warehouses.
- Economic Justification: The economic justification, included within this project, explicitly covered that of material savings. However, the economic justification may be expanded to continuous costs related, but not limited, to logistics (i.e. shipping, storage, etc.). This is possible as the separate production loop, between the kitting station and foam supplier is eliminated and as such, so are those costs related to all relevant, external operations, resulting in an expenditure required only once with the beginning of implementation.

Future work regarding the prototyping, testing, and implementation of Beaded Foam is necessary. There is also room for certain considerations such as more in-depth material research, cost of parts and damage analysis within material handling, and an analysis on Foreign Object Damage with respect to assembly components.

REFERENCES

[1] Bozer, Yavuz A., and Leon F. McGinnis. "Kitting versus Line Stocking: A Conceptual Framework and a Descriptive Model." *International Journal Cf Production Economics,* 28 (1992): 1-19. *Elsevier*. Web. 16 Aug. 2016

[2] Corakci, M. Alper. "An Evaluation of Kitting Systems in Lean Production." Thesis. University College of Boras, 2008. 2008. Web. 1 Sept. 2016.

[3] Faccio, Maurizio. "The Impact of Production Mix Variations and Models Varieties on the Parts-feeding Policy Selection in a JIT Assembly System. "*The International Journal of Advanced Manufacturing Technology Int J Adv Manuf Technol* 72.1-4 (2014): 543-60. *Web Of Science*. Web. 14 July 2016.

[4] Golz, Jenny, Rico Gujjula, Hans-Otto Günther, Stefan Rinderer, and Marcus Ziegler. "Part Feeding at High-variant Mixed-model Assembly Lines. "*Flexible Services and Manufacturing Journal Flex Serv Manuf J* 24.2 (2011): 119-41. *Springer*. Web. 14 July 2016.

[5] Hanson, Robin, and Lars Medbo. "Kitting and Time Efficiency in Manual Assembly." *International Journal of Production Research* (2010): 1-22.*HAL*. Web. 6 July 2016.

[6] Khorasanian, Danial, Seyyed Reza Hejazi, and Ghasem Moslehi. "Two-sided Assembly Line Balancing considering the Relationships between Tasks. "*ScienceDirect* 66.4 (2013): 1096-105. Dec. 2013. Web. 12 July 2016.

[7] Robin Hanson and Anna Brolin. "A Comparison of Kitting and Continuous Supply in In-plant Materials Supply." *International Journal of Production Research* 51 (2013): 979-92. *Engineering Village*. Web. 21 June 2016.

[8] Sali, Mustapha, and Evren Sahin. "Line Feeding Optimization for Just in Time Assembly Lines: An Application to the Automotive Industry." *International Journal of Production Economics* 174 (2016): 54-67. *ELSEVIER*. Web. 13 July 2016.

[9] Satoglu, Sule Itir, and Kirac Ucan. "Redesigning the Material Supply System of the Automotive Suppliers Based on Lean Principles and An Application. "*IEEE*. N.p., 5 Mar. 2015. Web. 11 July 2016.

[10] Vujosevic, Ranko, Jose A. Ramirez, Larry Hausman-Cohen, and Srinivasan Venkataraman. "Lean Kitting: A Case Study." (n.d.): n. pag. Optelco. Web. 30 Aug. 2016.

[11] Wang, Junwen, Jingshan Li, Jorge Arinez, and Stephan Biller. "Product Sequencing With Respect to Quality in Flexible Manufacturing Systems With Batch Operations." *IEEE*

Transactions on Automation Science and Engineering IEEE Trans. Automat. Sci. Eng. 7.4 (2010): 776-90. *IEEE*. Web. 13 July 2016.

[12] Wilson, James M., and Alan Mckinlay. "Rethinking the Assembly Line: Organisation, Performance and Productivity in Ford Motor Company, C. 1908–27." *Business History* 52.5 (2010): 760-78. *America: History and Life [EBSCO]*. Web. 12 July 2016.

[13] Zhu, Xiaowei, S. Jack Hu, Yoram Koren, Samuel P. Marin, and Ningjian Huang. "Sequence Planning to Minimize Complexity in Mixed-Model Assembly Lines." *2007 IEEE International Symposium on Assembly and Manufacturing* (2007): 251-58. *IEEE*. Web. 13 July 2016.

APPENDIX

AHP – Material Comparison "Does Not Dry Out"

Criteria	Material Comparison - "Does Not Dry Out"						
	Slime	Clay	Kinetic Sand	Beaded Foam	Memory Foam	Floam	Average
Slime	1.00	7.00	1.00	3.00	1.00	1.00	0.22
Clay	0.14	1.00	0.20	0.14	0.14	0.14	0.03
Kinetic Sand	1.00	5.00	1.00	0.33	0.33	0.33	0.11
Beaded Foam	0.33	7.00	3.00	1.00	0.33	5.00	0.20
Memory Foam	1.00	7.00	3.00	3.00	1.00	5.00	0.30
Floam	1.00	7.00	3.00	0.20	0.20	1.00	0.14
Sum	4.48	34.00	11.20	7.68	3.01	12.48	

AHP – Material Comparison – "3 R's"

Criteria	Material Comparison - "3 R's"						
	Slime	Clay	Kinetic Sand	Beaded Foam	Memory Foam	Floam	Average
Slime	1.00	3.00	3.00	0.11	5.00	1.00	0.16
Clay	0.33	1.00	0.20	0.11	0.20	0.14	0.03
Kinetic Sand	0.33	5.00	1.00	0.14	3.00	3.00	0.13
Beaded Foam	9.00	9.00	7.00	1.00	3.00	7.00	0.48
Memory Foam	0.20	5.00	0.33	0.33	1.00	3.00	0.11
Floam	1.00	7.00	0.33	0.14	0.33	1.00	0.09
Sum	11.87	30.00	11.87	1.84	12.53	15.14	

AHP – Material Comparison – "Can Be Formed (Infinitely)"

Criteria	Material Comparison - "Can Be Formed (Infinitely)"						
	Slime	Clay	Kinetic Sand	Beaded Foam	Memory Foam	Floam	Average
Slime	1.00	1.00	1.00	0.33	3.00	1.00	**0.13**
Clay	1.00	1.00	1.00	0.33	3.00	1.00	**0.13**
Kinetic Sand	1.00	1.00	1.00	0.33	3.00	3.00	**0.17**
Beaded Foam	3.00	3.00	3.00	1.00	9.00	3.00	**0.40**
Memory Foam	0.33	0.33	0.33	0.11	1.00	0.33	**0.04**
Floam	1.00	1.00	0.33	1.00	0.33	1.00	**0.13**
Sum	**7.33**	**7.33**	**6.67**	**3.11**	**19.33**	**9.33**	

AHP – Material Comparison – "Holds Shape w/o Container (Before/After Pressure)

Criteria	Material Comparison - "Holds Shape w/o Container (before/after pressure)"						
	Slime	Clay	Kinetic Sand	Beaded Foam	Memory Foam	Floam	Average
Slime	1.00	0.33	0.20	0.14	0.33	1.00	**0.05**
Clay	3.00	1.00	3.00	1.00	0.20	3.00	**0.17**
Kinetic Sand	5.00	0.33	1.00	0.20	0.33	5.00	**0.13**
Beaded Foam	7.00	1.00	5.00	1.00	1.00	7.00	**0.30**
Memory Foam	3.00	5.00	3.00	1.00	1.00	5.00	**0.31**
Floam	1.00	0.33	0.20	0.14	0.20	1.00	**0.04**
Sum	**20.00**	**8.00**	**12.40**	**3.49**	**3.07**	**22.00**	

Material Compression Data Table

Material Compression						
	Hour 1	**Hour 2**	**Hour 3**	**Hour 4**	**Hour 5**	**Hour 6**
Trial 1	0.20	0.25	0.35	0.39	0.42	0.43
Trial 2	0.15	0.26	0.38	0.40	0.41	0.44
Trial 3	0.22	0.30	0.42	0.45	0.48	0.50
Trial 4	0.23	0.34	0.40	0.41	0.44	0.47
Trial 5	0.16	0.30	0.39	0.41	0.41	0.43
Trial 6	0.10	0.25	0.37	0.42	0.45	0.46
Trial 7	0.25	0.39	0.44	0.46	0.46	0.48
Trial 8	0.22	0.33	0.39	0.42	0.44	0.46
Trial 9	0.21	0.32	0.38	0.45	0.47	0.48
Trial 10	0.18	0.26	0.41	0.46	0.48	0.49