Design and Analysis of Packaging Methods at PepsiCo Frito-Lay

A Major Qualifying Project Report submitted to the Faculty of

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Abstract

The objective of this MQP was to design a solution to address the ergonomic issues and increase sanitation during transportation of a key production line component known as a 'former'.

The rationale was to reduce time during production line changeover and minimize wear and tear on food packaging equipment.

Some of the methods included axiomatic design, value stream mapping, and SolidWorks 3D modeling software to design the cart, as well operator feedback sessions to receive criticism on the cart iterations.

Our results included a re-designed transportation cart being prototyped as well as comments about implementing and airlift.

In conclusion, we designed an improvement to streamline a design for the company and save about 8% of time on the changeover, yielding about $150,000 annually.

Acknowledgement

The team would like to thank the following individuals and organizations for contributing to the overall success of our project:

The employees at the company PepsiCo, including Anthony Stolo, our project "liaison" to the company, who provided all the company information and resources we needed to write this paper and complete the project. Wayne Grenier, an additional asset in visualizing understanding the technicalities of the production lines. Finally, all the operators spoken to at our feedback sessions, who provided invaluable insight and criticism that aided our overall success.

Finally, we would like to thank Worcester Polytechnic Institute, for giving us the opportunity to utilize as well as challenge all of our undergraduate knowledge in this culminating project. In particular, the support of our project advisors, including Professor Walter Towner, Professor Torbjorn Bergstrom, and Professor Helen Vassallo, for providing excellent feedback, direction and motivation to complete this project. They pushed us beyond the limits of our classroom experiences to apply our knowledge in this off-campus project, as well as teach us new skills that will extend outside of our undergraduate experience into our real-world employment. We cannot thank them enough for their time and guidance throughout this project.

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Executive Summary

This major qualifying project (MQP) was completed in a chip packaging department in Killingly, CT with the purpose to address handling issues encountered when installing, removing and transporting the ‘formers’. Formers are a special type of funnel within the packaging machines that shape the film plastic into consumer bags for chips. The formers are interchangeable within the packaging line and with every change in chip bag size or seasoning change, the formers must be removed and sanitized. The formers can weigh up to seventy pounds and production workers have to lift them over their heads to place them into the packaging machine. By reducing necessary replacement time of the formers, the intended outcome is a measurable reduction of down-time on the production line.

The team used axiomatic design to complete a hierarchical decomposition of the problem. The problem statement was broken into two main objectives each with the following functional requirements to complete the project: increase sanitation of the former during transportation and decrease ergonomic stress on the employees. Utilizing a designated transport device, operators would avoid carrying or dragging the formers during the production line changeover and reduce accidental damage. By implementing a solution to reduce necessary weight and over the head height for operators to lift, the hope is to reduce strains on the operator and avoid accidents.

The operators in the packaging department currently have seven different types of carts that can be used to transport film. The capacity of these carts varies, but the operators encounter difficulties with all of them. For the smaller chip sizes, some of these formers can fit on one of the carts but they are not secured and there is a possibility of the formers getting damaged. For the bigger formers, none of the film carts can hold them and thus the operators move them in

unconventional ways, creating sanitation concerns during transportation. Additionally, these ways of transportation cause the operators to put unnecessary stress on their bodies as well as possible damage to packaging equipment. Given that the formers must be placed above the operator's head on the packaging line, the operators must lift the formers outside of the ergonomic green zone. This movement is rare, but in an ideal situation, the operators would not have to do it. The team made two deliverables form this; there is a prototype of a redesigned transportation cart and designs for an airlift (Figure 1).

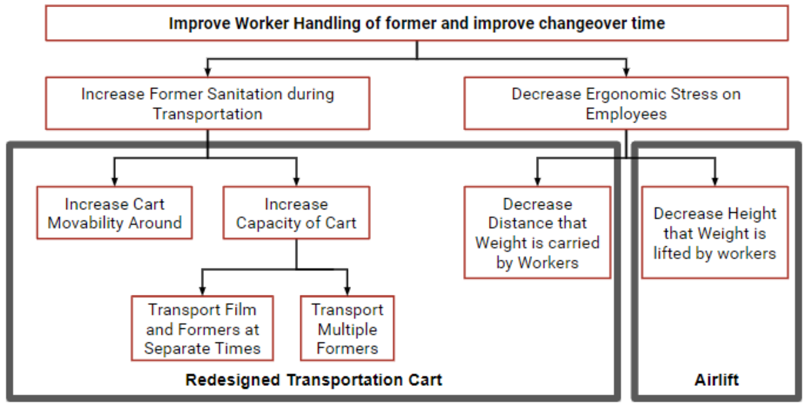

Figure 1: Objectives and Deliverables

Three cart concepts each satisfying the objectives but varying slightly by design were designed in SolidWorks and went through multiple iterations with the advising professors. The team presented the three updated cart designs to the packaging operators who would be using them to get their feedback which could be incorporated into the design. The operators had various perspectives on the carts with many favoring the cart that was ultimately sent to the company to be prototyped. The current state-of-the-art cart and the new prototype of the cart were compared (Figure 2 and Figure 3).

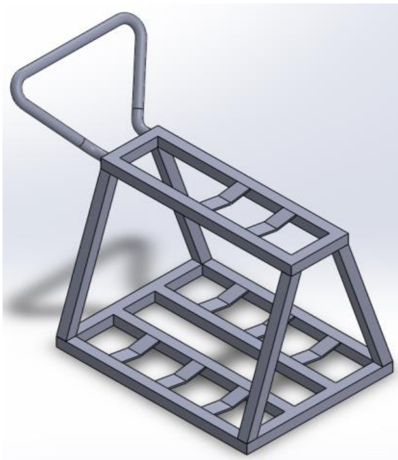

Figure 2: Current Cart (SolidWorks)

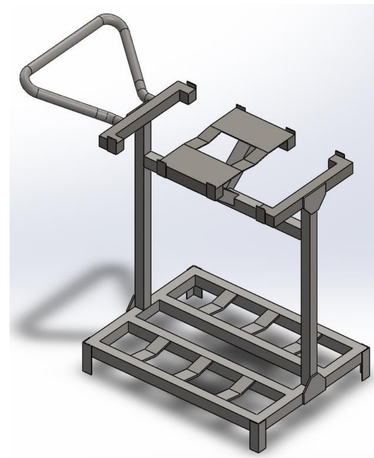

Figure 3: MQP Redesigned Cart (SolidWorks)

A major difference between the two was the capacity, as the previous cart was meant to hold three rolls of film and modified to hold one small former; the redesigned cart is also designed to hold three rolls of film, but it additionally has a spot to hold the two formers on the top. With the redesigned cart, the formers can be loaded form either side of the cart and the film can be stacked above capacity if required, similar to the previous cart.

Stress analysis through SolidWorks was completed on the cart to ensure that it would handle the different stress that the workers put on the cart. The weak points were identified, and structural bracing was applied to the cart to strengthen those areas. In addition to sudden impacts, the analysis showed where the cart might deform from strain and if these points require maintenance throughout the carts use during a fiscal year.

The team utilized fishbone diagrams for root-cause analysis to ensure that the objectives were addressing the problem and that the deliverables would satisfy these objectives. By measuring process time, the team created a value stream map of the current state and future state of a line changeover, when film and the former must be replaced due to changing chip size, or seasoning. The team estimated that the new cart would save about 30 seconds during a changeover. This reduction in time during the changeover is shown in process maps (Figure 4 and Figure 5).

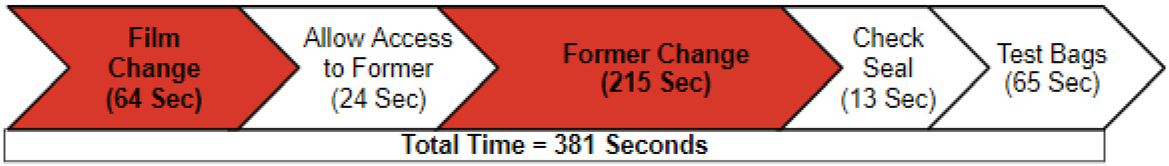

Figure 4: Current Process Map

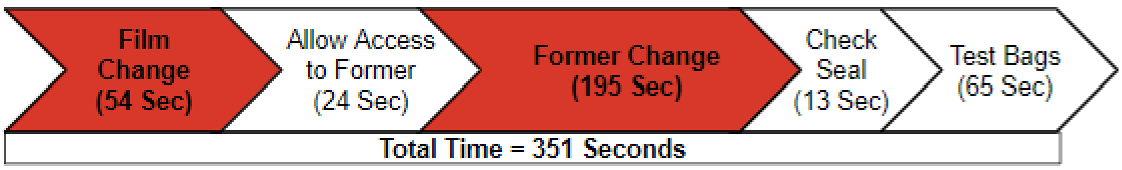

Figure 5: Future Process Map with Redesigned Cart

The change shows a ten second reduction during the film change and 20 seconds during the former change. Through spaghetti diagrams, the operators would only need to take about half of the trips to the sanitation area as the capacity of the cart is doubled compared to what the operator could previously load the carts. This will allow the operators to have more time near the production lines, thus have quicker responses to any line needs.

Although the operators will have a quicker response time during the production line, the reduced line downtime was used to create a conservative financial analysis (Figure 6).

This outcome of the financial analysis showed a savings in $100,000 for the first year and then $150,000 annually for each subsequent year following cart implementation.

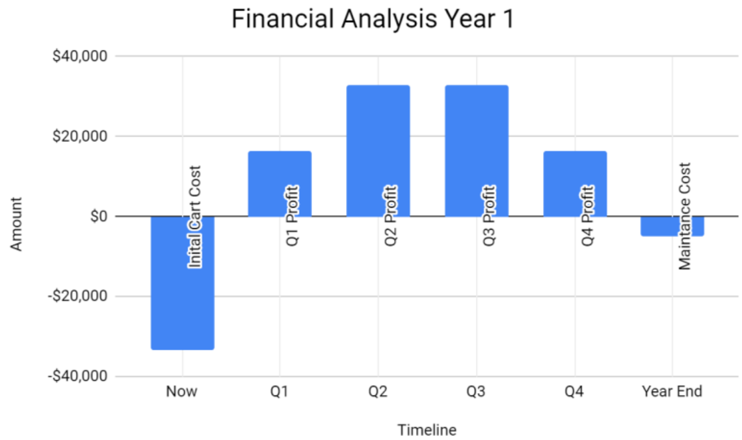

Figure 6: Projected Year 1 Financial Analysis

The team acknowledged that there are alternate materials that the cart could be designed with, instead the stainless steel that the company's fabricators were limited to. Aluminum was a strong candidate, as it is similar to strength of steel, but lighter and doesn't cost significantly more. But while looking into these other materials, the team needed to look into other requirements of the cart besides strength, and stainless steel was eventually chosen because it fulfilled those requirements.

Overall, the team created a redesigned transportation cart to address a majority of the project's problems. The team rudimentary addressed the overhead lifting concerns of the cart which was planned to be met by an airlift. Upon project completion, the team had the deliverable of the prototype designs for the transportation cart completed for the company and defined the parameters for the airlift, a potential future project.

Chapter 1 - Introduction

1.1 Problem Statement

This project was completed in the packaging department at PepsiCo Frito Lay in Killingly, CT, with the purpose to address handling issues encountered when installing, removing and transporting the 'formers'. Formers are a special type of funnel within the packaging machines that shape the film plastic into consumer bags for chips. The formers are interchangeable within the packaging line and correspond with the different sizes of chip bags. With every change in chip bag size or seasoning change, the formers have to be removed and sanitized. The formers can weigh up to seventy pounds and production workers have to lift them over their heads to place them into the packaging machine. By reducing replacement time of the formers, the intended outcome is a measurable reduction of down-time on the production line.

1.2 Customer Needs

Anthony Stolo, operations manager of the corn packaging at Killingly, CT, acted as our sponsor and our liaison of our client PepsiCo. Through conversations with Mr. Stolo, the team identified the customer needs based on the sanitation, ergonomic and other concerns encountered with the formers (Table 1).

Customer Needs

• Ergonomic stress on the operators
  ○ Formers are lifted overhead
• Sanitary concerns (due to cart unavailability and size constraints)
  ○ Former is food contact surface
• Prolong the former life
  ○ Formers made of aluminum
• New tool must be faster and easier to use
  ○ Net zero time

Table 1: Customer Needs

Additionally, the integration of the new product must be seamless with the current formers and packaging machines. No matter 'helpful' or 'healthy' the team's suggestion is, the operators will not use it unless it is faster and better. There will be a learning curve for any new implementation, which should be taken into account. These customer needs would serve as the foundation of our objectives for the project, expanded upon in the next section.

1.3 Objective One: Sanitation during Transportation

The first objective is to increase sanitation of the former during transportation. Utilizing a designated transport device, operators would avoid carrying or dragging the formers during the production line changeover, and reduce accidental damage.

1.4 Objective Two: Ergonomics during Changeover

The second objective is to decrease ergonomic stress on the employees. By implementing a solution to reduce necessary weight and over the head height for operators to lift, the hope is to reduce strains on the operator and avoid accidents.

Chapter 2 - Background/Literature Review

2.1 History of PepsiCo

In 1965, with its merger with Frito Lay, PepsiCo became an internationally renowned food and beverage company, owning over twenty-two brands under its portfolio (Lays Chips, Gatorade, Quaker Oats, just a few examples) that generate a revenue of over $63 billion annually, as of 2017 (About - PepsiCo, 2017). Frito-Lay is the convenience foods business sector of PepsiCo, generating over $12 billion annually in itself for the umbrella corporation. In 1932, the Frito-Lay idea was the brainchild of C.E. Doolin and his purchase of the Fritos recipe and subsequent selling of the product from his car. That same year, Herman W. Lay would form the H.W. Lay & Company, becoming one of the largest snack companies in the Southeast United States. By 1961, Lay would merge his company with the Frito Company to become Frito-Lay (Global Divisions - PepsiCo, 2017).

2.1.1 Packaging Department in Killingly, CT

The focus of this Major Qualifying Project was to assist in the operation of the packaging department and support equipment of the PepsiCo Frito-Lay manufacturing plant located in Killingly, CT. At this site, Doritos, Tostitos, Smartfood, and Fritos are produced from potato or corn through multiple stages such as cutting, sorting, frying and seasoning, packaging, and finally shipping; the products produced are shipped across the northeast region of the United States. The Killingly Plant runs 24/7 over three shifts, but closes for seasonal holidays such as Thanksgiving, Christmas, and July 4th. The plant has sixty-seven packaging lines: six Smartfood packaging lines, thirteen non-automatic corn packaging lines, and forty-eight automatic lines for corn and potato chips. There are three main companies that manufacture the packaging machines used on the packaging floor.

The company's 'busy' season is during the summer as sales increase due to customers hosting parties and buying snacks for those occasions. In addition, smaller bags sell better during the school year and bigger bags during the sports season during the fall and winter. In fact, Killingly is one of the few Frito-Lay locations that still produces large, family bags during the winter, as its location best supports New England sports fans stocking parties (Stolo, 2018).

2.2 Details Regarding Formers

Formers are a removable part of the packaging line, changed based different bags on the production schedule. Tony Stolo, the operations manager for corn packaging at the Killingly location, estimated there are 115-120 formers on the packaging floor; with each packaging line having at least one spare former (Figure 7).

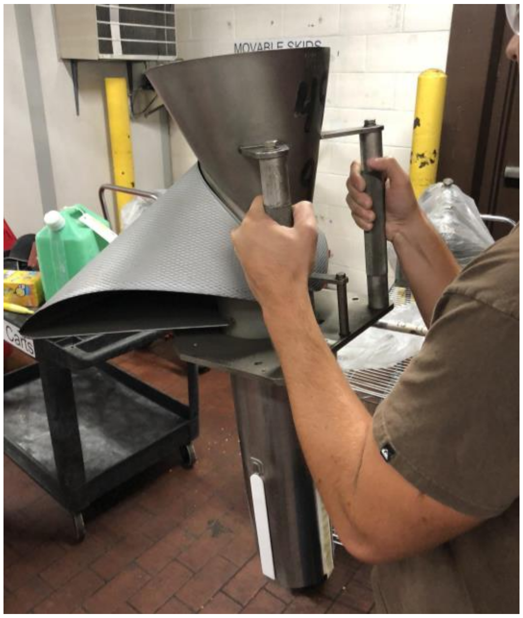

Figure 7: Image of Typical Former (Dave Bovich in photo, MQP member)

The name former is actually the name of one of the companies that makes them, but the name has become synonymous with this piece of equipment. There are three main companies that supply formers to the Killingly plant. The average former costs five thousand dollars and can last up to ten years with proper handling and care (Stolo, 2018). The formers are based on the bag size; Figure 8 shows a labeled former and Table 2 is measured ranges of the formers.

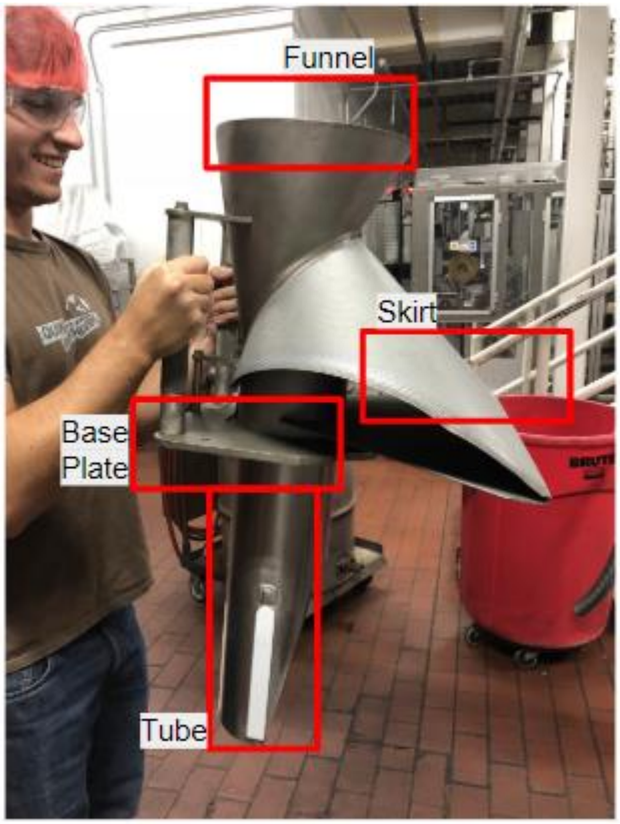

Figure 8: Former with Reference Labels (Dave Bovich in photo, MQP member)

The base plate sizes are independent of bag size and secure the former to the packaging machine. The funnel, tube and skirt size depend on the bag size. The skirt forms the film from the roll into a circle, which is the size of the tube. The chips fall from above into the funnel and into the tube. From there, an automated sealer seals the top of that bag, which is cut so the bottom of the next bag is already sealed. Dimensions of measured formers are found below (Table 2).

Size of Former	**1 oz Bag**	**18 oz Bag**	**Measured Ranges**
Weight	26.5 lbs.	38.5 lbs.	20-70 lbs.*
Bottom Diameter	5.5 inches	12 inches	5.5-12 inches
Skirt Width	12.5 inches	26 inches	12.5-26 inches
Skirt Depth	12.5 inches	26 inches	12.5-26 inches
Height of Tube (from bottom of base plate)	14.25 inches	18 inches	11.5-18 inches
Wall Thickness of Tube	0.075 inches	0.075 inches	0.075 inches
Height of Funnel (from top of base plate)	14.25 inches	14.5 inches	14.5inches*
Base Plate Height	1 inch	0.5 inch	0.5 - 1 inch
Base Plate Width	13 inches	12 inches	12-13 inches
Base Plate Length	9 inches	10 inches	8-12 inches

*Table 2: Dimensions of formers * indicated that the range was an estimate from company*

2.3 Details Regarding Film

The rolls of film used on the packaging lines are determined by the chip bag size and customer. The graphics on the film varies on the customer and product, as PepsiCo sells store brand chips as well as their brand names. Typically, the film will be utilized on the packaging lines for no more than 2 hours before needing to be replaced. Figure 9 shows a roll of film and Table 3 has the specific dimensions labeled for reference.

Figure 9: Film Roll with Reference Labels

The width of the film is constant for each bag size; the larger bags have a larger width, but a shorter length so all film rolls are of similar weight. The diameter of the film core was constant, but the radius from the core outwards varied depending on bag size. These dimensions are shown in Table 3 for three different sizes of bags.

Size & Type	1-ounce Dorito	16-ounce Dorito	18-ounce Tostitos
Width	12 inches	19 inches	23.5 inches
Outer Diameter	12.5 inches	10 inches	10.5 inches
Inner Diameter	3 inches	3 inches	3 inches

Table 3: Dimensions of Film Types

2.4 Axiomatic Design

Axiomatic design is a hierarchical decomposition method that translates the customer needs into functional requirements and design parameters to fulfill the goals of the design. The aim of axiomatic design is to reduce non production iterations during the design process, and also calculate the probability of successful design parameters that fulfill the functional requirements of the project (Suh 1990). The axiomatic design method follows a four-part domain mapping system; customer, functional, physical, and process domain (Figure 10).

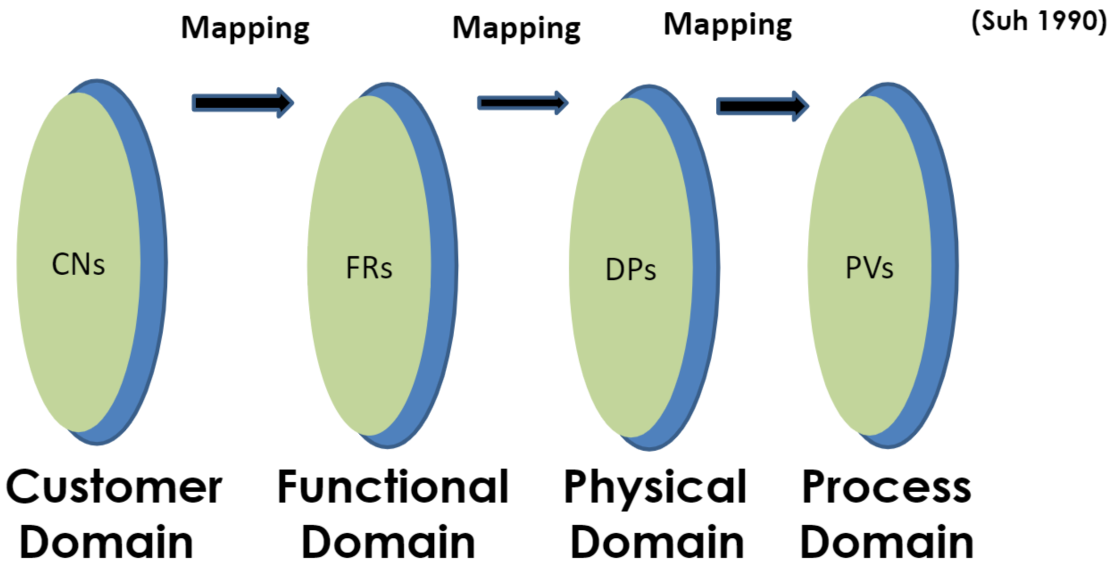

Figure 10: The Four Domains of the Axiomatic Design (Arcidiacono & Brown 2013)

The relation between the domains is as follows; the customer domain focuses on the customer's direct needs, the functional domain tackles a solution that solves the customer's parameters, the physical domain are the parameters of the design, and the process domain is the means of producing this solution (Arcidiacono & Brown 2013). Together, these aspects are critical for an axiomatic designer to focus on whilst brainstorming their solution. When proceeding with axiomatic design, there are two design axioms to fulfil. Axiom one maintains the independence of the functional elements of the design, and axiom two limits the information of the design. (Suh 1990). Due to the hierarchy base of axiomatic design, each domain has one highest-level domain, which is then decomposed into next-level domains.

Chapter 3 - Rationale

3.1 Axiomatic Design Decomposition

For the work with PepsiCo, a design matrix was used to qualify the first Axiom of the axiomatic design: maintain the independence of the functional elements of the design. As seen below in Table 4, the focus was on FR0, which addressed the handling of the formers and the necessary time for removal and installation. From this, the functional requirements are split into two FRs, one focusing on sanitation problems when handling the formers and the other targeting the ergonomic stress impacting the workers. FR1 and FR2 are broken down further into subsets that cover the needs of the customer, PepsiCo.

FR0: Improve worker handling of formers and improve changeover time			
	FR1: Increase former sanitation		
		FR1.1: Increase cart movability around	
		FR1.2: Increase capacity of cart	
			FR1.2.1: Transport multiple formers
			FR1.2.2: Transport film and formers at separate times
	FR2: Decrease ergonomic stress on employees		
		FR2.1: Decrease height that weight is lifted by workers	
		FR2.2: Decrease distance that weight is carried by workers	

Table 4: Functional Domains of Axiomatic Design

From each of the functional requirements, a matching physical domain was created. Each physical domain was defined as a system to meet the functional requirements. The physical domains are shown below in Table 5.

DP0: System to improve worker handling of formers and improve changeover time
DP1: System to increase former sanitation
DP1.1: System to increase cart movability around
DP1.2: System to increase capacity of cart
DP1.2.1: System to transport multiple formers
DP1.2.2: System to transport film and formers at separate times
DP2: System to decrease ergonomic stress on employees
DP2.1: System to decrease height that weight is lifted by workers
DP2.2: System to decrease distance that weight is carried by workers

Table 5: Physical Domains of Axiomatic Design

Each functional domain has a physical domain that is mutually exclusive and independent of the others. The connection between the FR's and DPs can be visualized through the design matrix created using Acclaro software (Figure 11).

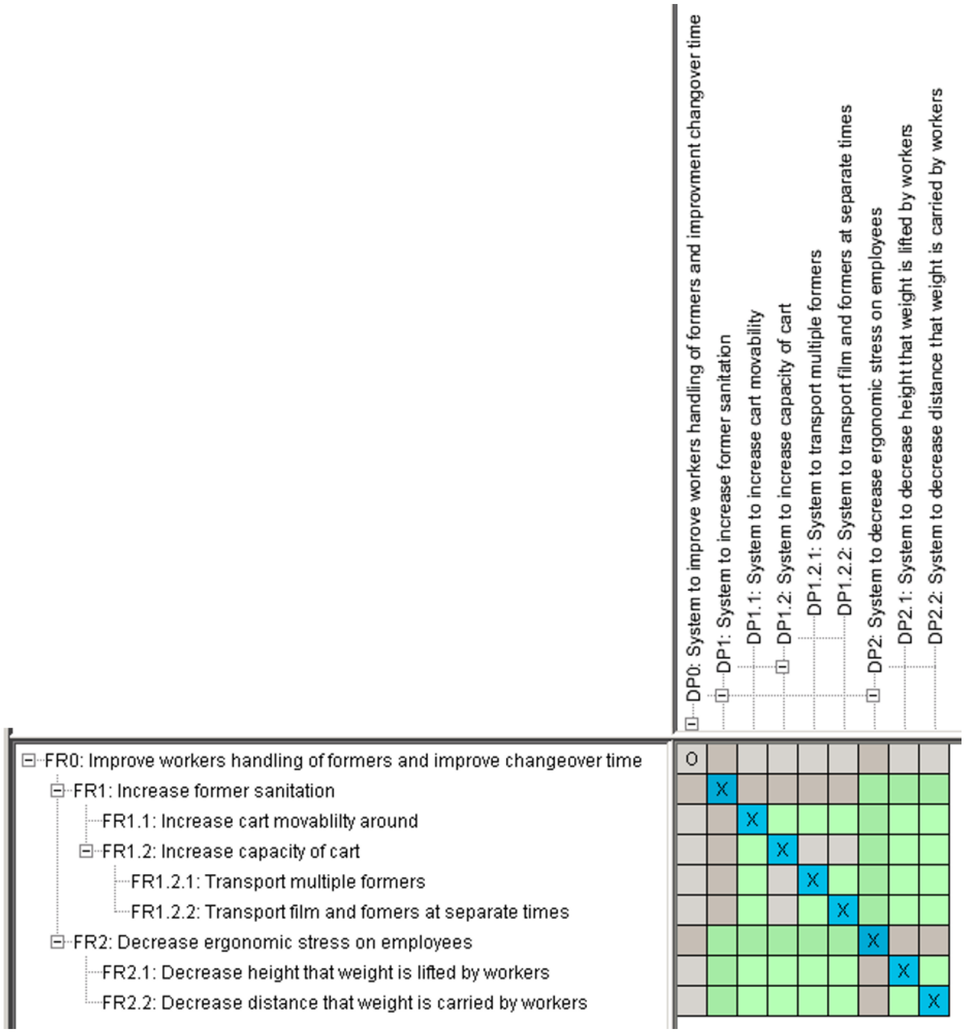

Figure 11: Packaging at PepsiCo axiomatic design matrix (Acclaro)

The project has two parts in the axiomatic design, former sanitation and ergonomic stress on the operators. In order to meet the customer needs and functional requirements that were presented to the requirement, two deliverables were planned. There was a transportation device and a lift assistive device; the transportation device fulfilled the facilitation of former sanitation and the distance portion of the ergonomic stress, while the lift assist device fulfilled the decrease of ergonomic stress on employees. Since each functional domain is only dependent on one physical domain, they act independently. The independent factor is shown by the diagonal of functional domains corresponding to one physical domain. This means that anything in the system can be changed without affecting the entire system.

3.2 Rationale of Objective 1: Sanitation during Transportation

3.2.1 Rationale of Focus on Cart to Aid in Sanitation

As a food contact surface, the formers require periodic cleaning and must be transported by the operators to the washing stations. The operators have inefficient options to do so. The carts they use for transport are meant for the film, and if they are not available, operators resort to carrying or even dragging the formers on the factory floor.

A system that would carry formers or film, depending on which, resulted in reduced hazards, decreased likelihood of damaging or contaminating formers, as well as increasing production and reducing changeover times.

3.2.2 Current State of Cart

Currently in order to move formers from the packaging machines to the sanitation station, these formers were either carried by hand, placed precariously onto the carts, or even dragged on the factory floor. During this process, with their current methods of transportation, the formers could easily be damaged or contaminated.

To avoid relying on other operators to lift the heavier formers together, there are available carts for operators to independently transport multiple formers. The cart can hold two formers across the top, but it is not a secure placement (Figure 12).

Figure 12: Wire frame cart currently used to hold and transport formers

The team counted seven different types of carts on the packaging floor, of which three can hold and transport formers. Unfortunately, since the carts are not a secure way to transport the larger sized formers, the operators each use their own method of transportation.

3.2.3 State of the Art Cart

The best cart that PepsiCo has at the moment is one that holds either five rolls of film or one small former, according to the operation manager. Currently, the closest PepsiCo has to a former cart can be seen in Figure 13. Many features of this cart were preferred, primarily its stainless-steel material and the durability of the wheels capable of withstanding use on the factory floor.

Figure 13: Current Cart design utilized on the Packaging floor (Ben Seitz in photo, MQP member)

The primary function of this cart was to transport packaging film rolls of varying diameters to each packaging station. It was originally created to hold three rolls of film but was modified to hold one small former. This cart cannot hold the larger formers, as the bottom tube diameter is too wide for the top crossbars. The operators use the cart so it transports five rolls of film: two on the bottom of the cart with one stacked on top, one on the top of the cart and one perpendicular to the direction of movement that lays across the handle.

3.3 Rationale of Objective 2: Ergonomics during Changeover

3.3.1 Defining Ergonomic Parameters

While there is an expectation of physical labor for the operators, the possibility of over exertion, pains and strains should be kept to a minimum. In food manufacturing overall, overexertion and bodily reaction accounts for 42.5 injuries per 10,000 full-time workers of which

11.7 are in lifting and lowering, and 8.7 are in a repetitive motion. (Bureau of Labor Statistics, 2018). In order to prevent these injuries, the "green zone" which is defined as the ideal area for employees to lift objects. This "green zone" is defined by the weight, the distance away from the body, and the height lifted up and down (Figure 14).

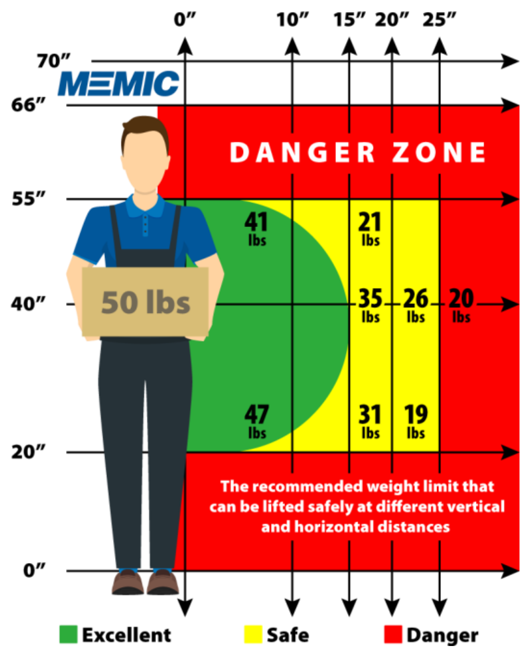

Figure 14: The Worker Green Zone (Brown, 2017)

3.3.2 Rationale of Cart to Improve Ergonomics

Any designated device to transport formers will improve the operator's ergonomics. Although some operators currently use the one cart to transport smaller sized formers, the larger formers are heavy and do not have a transportation device. This cart that has a designation to transport formers will assist in the distance that the operators have to carry the formers. In comparison to the current state, the operators will no longer be dragging the formers or bending over after a former falls off the carts, which will both limit the ergonomic strain on the operator.

3.3.3 Rationale of Airlift Device to Improve Ergonomics

All formers need to be placed overhead on the packaging line, therefore placing the former is outside of the green zone. This presents possible dangers for the operator's health and safety as well as the formers if they are dropped. Since operators range in height and physical strength, the replacement of formers can be more difficult.

3.3.4 State of the Art for Airlift

There is no airlift device in use for aiding the operators in lifting the formers. Currently, the Killingly site uses an airlift machine to lift labels for their bags. The machine uses compressed air to operate a piston that relieves the weight of the labels. All the operator has to do is push a button, lift the assisted labeler and set it in place, and the reverse for lowering it. This device proved of interest to the vertical challenge of the former because of its simplicity, and was also a suggestion from one of the operations managers, as a functional design could be retrofitted by PepsiCo for every packaging machine.

Chapter 4 - Methods

4.1 Iterations Plan-Do-Check-Act

The team utilized "Plan-Do-Check-Act" to design and redesign the cart and airlift and was used as follows: "plan" for the changes or creation of the designs, "do" meant to make changes to the SolidWorks assembly, "check" was evaluating possible capacity and internal team ideas, and finally "act" by reviewing with external criticism (Figure 15). For the most part, reviewing the iterations was done by the MQP team, advising professors, operators, as well as the sponsor.

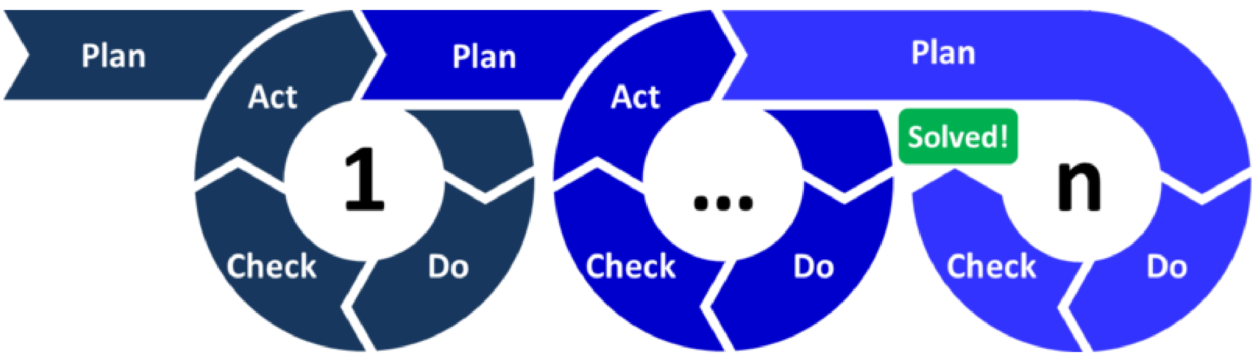

Figure 15: Plan-Do-Check-Act (Roser 2016)

The only way that the team's project would create a long-term implementation would be if the product created a faster, more efficient way of doing their current job. The solutions will not be used if it is too complicated or does not improve current production. Due to the learning curve of a new product, there may be hesitation to change to a new device. The team knew that there would be multiple iterations to insure the implemented design would only contribute positively to the overall process time.

4.2 Method of Objective 1: Sanitation during Transportation

4.2.1 Parameters for Designing the Cart to Aid in Sanitation

The main parameter for designing a cart to aid sanitation is that is must have dual functionality to transport formers and film, as there is not extra space on the factory floor for an additional cart. The cart should hold at least four rolls of film as well as include a designated section for the formers. As stated before, the operators won't use the cart unless it improves process flow and changeover time. In discussions with the supply chain leader and the operator manager, they said that the handle height of the current cart is accommodating for operators of all heights, the wheels must be durable on the factory floor, and the stainless steel was capable of sustaining years of wear and tear. These parameters would be guidelines for designing the new cart.

4.2.2 Fishbone Diagram of Sanitation Issues

In determining the root-cause of the sanitation issue, the team created a fishbone diagram. The 'head' of the fish is the problem one is looking to analyze, and the skeleton is all of the effects of the problem. It is broken down so that there are 'first level root causes' that are bigger 'bones' as they are areas of problems. This fishbone diagram has the problem as sanitation issues and the next-level hierarchy as the different areas that caused sanitation issues. Then, within each area, specific causes were identified. After completion, the team agreed with the operators that a cart that could hold formers would solve the sanitation issues.

4.2.3 Iterations of the Cart

Using ideas and concepts from discussions with Tony Stolo, the MQP team designed three base model carts in SolidWorks, a computer aided design program. The design of the cart was modeled off the state-of-the-art cart that PepsiCo is currently using. According to the operator manager, the state-of-the-art cart was the most favored cart used by the operators, and held up to five rolls of film. Measurements of the base model cart (Figure 16) were taken to dimension our designs.

Figure 16: State-of-the-Art Cart currently in use

The iterations of each of the three carts changed based on the team's understanding of the factory floor and customer needs increased and feedback from the WPI advisors and packaging operators. For the operator feedback, a graduate team of students from OIE 555 Lean

Manufacturing completed the sessions with the MQP team. The OIE 555 group was able to bring new thoughts and an additional set of ears for the feedback sessions to find more about the root cause.

4.2.4 Value Stream Map of Changeover Process

The value stream map allowed the team to map the movement of an operator during a line changeover. A major goal of the value stream map is to identify value-added and non-value-added time (Nash, M. A., & Poling, S. R.). Value-added time is a step that adds value to the end product; non-value-added time is a step that does not add value to the end product. This allowed the team to identify waste and ensure that the new cart would eliminate some waste of movement and transportation. Focusing in the scope of the changeover, the team created a current state map and a future state map. To create a value stream map, the process is followed through and each step is identified and visually shown using the symbols (Figure 17).

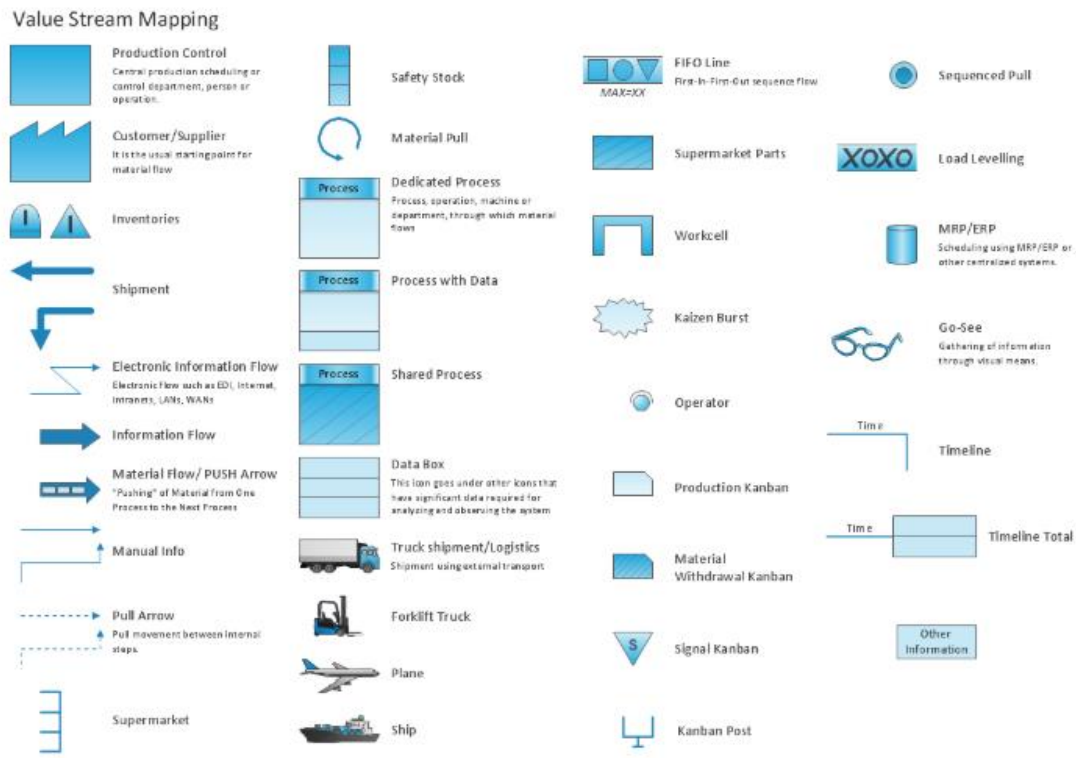

Figure 17: Value Stream Map Symbols (Value Stream Mapping Symbols)

These symbols allow the process to be visually shown, with the passage of time progressing across the bottom, and whether it was non-value-added time or value-added time.

4.2.5 Stress Analysis of Cart

By designing the cart with fabricated stainless steel, similar to the current state above, it was safe to assume the cart was structurally sound, as the previous cart could take a beating. Even with two formers and multiple formers loaded on the cart, the entire cart would only experience a couple hundred pounds of force overall. However, the team utilized SolidWorks force study software to analyze points of highest stress concentrations on the design structure.

These points would help the company determine what aspects of the cart would need maintenance after long periods of use and fatigue on the steel.

4.2.6 Financial Analysis of Cart

To determine the value our cart adds to the process the team created a financial analysis over a projected year following the implementation of our product. This financial analysis is a projection which is based upon the packaging operator's efficiency and the cost of the carts being fabricated or purchased using the company's margin of profit and the lowest unit price of the chips advertised on Amazon. This was done for both potato chip and corn chip products.

This financial analysis is important as it outlines how our cart will add value to the packaging process. The product will only be implemented if it has the potential to make or save the company money. Due to the initial cost of any new product, there is always hesitation in implementing a new product because the cost of the initial investment might seem too high; however, if the long-term investment is justified, the product should be implemented.

4.2.7 Additional Design Considerations

While limited by the constraint that the company could fabricate the cart on site with stainless steel, the team considered alternate material methods, such as aluminum. Aluminum, while not as strong, is cheaper than stainless steel, and is about one third the weight with a similar level of corrosion resistance (Reshift Media, 2018). However, aluminum is more difficult to weld, which is the manufacturing method the company would use, so they might need to outsource the fabrication.

Other materials such as polymers are even lighter and easier to process materials, but would be less practical, as polymers are susceptible to fatigue under lighter loads. Due to the frequent use of these carts during the shifts, the carts would distort or even fail, thus requiring more maintenance or even replacement. The cart could also use a mix of materials, for example, the main supports of the design made of stronger stainless steel and the remainder of aluminum or some other lightweight, cheaper material. Another consideration would be using nylon or similar materials for securing the formers or film. Again, this would introduce manufacturing issues with mixing materials and complicating the process, especially if the company intends to make multiple carts.

4.3 Method of Objective 2: Ergonomics during Changeover

4.3.1 Parameters for Designing the Cart to Aid in Ergonomics

The main parameter for designing a cart to aid ergonomic issues is the cart needs to be close to the operators during the changeover and able to place objects easily on the cart. In order for the cart to be close to the operators, the cart must be small enough to fit between two packaging lines. For the objects to be easily placed on the cart, the operators should keep the formers and film within the green zone. By creating a cart that holds formers, the operators will be able to stay in the green zone while transporting a former. Additionally, the wheels on the cart must roll smooth across the factory floor and the handle height must work for all operators.

4.3.2 Parameters for Designing the Airlift to Aid in Ergonomics

With designing the airlift, the idea of an air piston to manage the majority of the weight seemed appropriate. The goal of the design was to keep the former within the operator's green zone, between shoulders and knees, as it was taken from the cart and placed into the lift, so the lift needed to reach that height. With a push of the button, the piston must take most of the weight and the operator would "guide" it vertically. The former would rest in a claw mechanism that would provide any unwanted translation while being lifted.

4.3.3 Fishbone Diagram for Ergonomics

To determine the root cause of the ergonomic issues, the team used a fishbone diagram. The problem was ergonomic issues and next-level causes were identified as areas that can cause the problem of operator ergonomic issues. From there, another level of causes was found to ensure that the team was solving the real cause of the problem. After completion, the team agreed that the cart and the airlift device would solve the root-cause of operator ergonomic issues.

4.3.4 Iterations of the Airlift

The team based the concept of an airlift assist device off the label maker that the company currently uses. First the team created many potential designs for the airlift, but many of them were not feasible, due to limited space around the packaging machine.

4.3.5 Spaghetti Diagram of Operator during Changeover

The spaghetti diagram is a method used to track movement and transportation of items or people over a finite amount of time. Chiefly, this type of diagram is utilized to track distances traveled throughout a process, but can additionally serve as a step-by-step breakdown of an operation.

The team used a spaghetti diagram to identify the steps an operator takes during the line changeover. The team found the current state of the changeover process and identified the waste in the process. The rationale for creating a current state spaghetti diagram was to ensure that the implemented devices would assist in removing the waste in the process. Then the team created a future state spaghetti diagram if the cart and airlift were implemented. From there, a comparison could be found to see the amount of operator wasted movement and transportation that was used with the two suggested devices.

4.3.6 Strength of Materials Analysis of Airlift

The team analyzed the possibility of an operator losing their footing on the factory floor and reaching for the airlift as a brace to catch their fall. From this incident, two possible scenarios were considered: would the airlift fail and shear itself or would it be ripped out of the ceiling before failure? The team analyzed the forces and stresses the operator would produce and determine the maximum surface stress on the part. In addition, research was done on methods to secure the airlift to the ceiling above the packaging machine.

4.3.7 Financial Analysis of Airlift

Similar to the cart, financial analysis will need to be completed before the product is implemented. This will ensure that the company knows the long-term financials of the product. Given the airlift is assisting in keeping the operators in the green zone, the main outcome will be operator pains and strains decreasing. Although that may not seem like a direct connection to company bottom line, it would improve worker satisfaction. In turn, increased worker satisfaction can create a happier environment which is more productive.

Chapter 5 - Results

5.1 Results from Objective 1: Sanitation during Transportation

5.1.1 Prototype of New Cart to Aid in Sanitation

A redesigned cart was the best solution to handling the transportation and sanitation issues of the former (Figure 18). The new cart provides dual functionality for use of film and formers at separate times; it has capacity for four rolls of film and a dedicated section for two formers of any size. This enables the operators to place the formers on this cart for easier transportation from the production line to the washing stations.

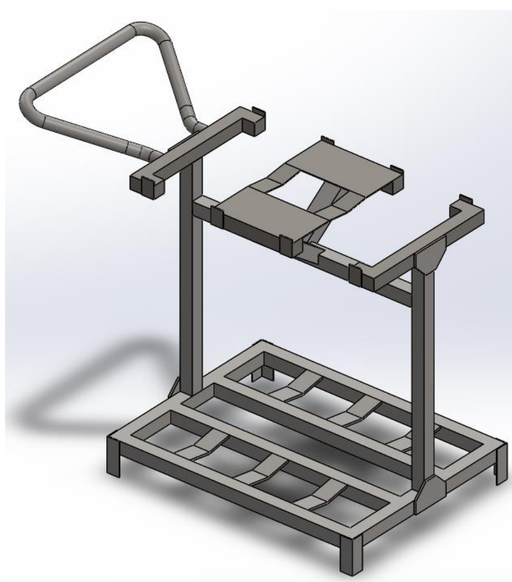

Figure 18: Prototype of Cart (SolidWorks)

This cart has the film stacked the same way as the current state-of-the-art cart that the company has, but with an additional rack on top and stoppers to secure in transport. The cart has designated with the concept of poke-yoke so it can be easily loaded from either side.

5.1.2 Fishbone Diagram for Sanitation Issues

Via root-cause-analysis the sanitation issues within the scope of our project have been narrowed down to the causes illustrated (Figure 19).

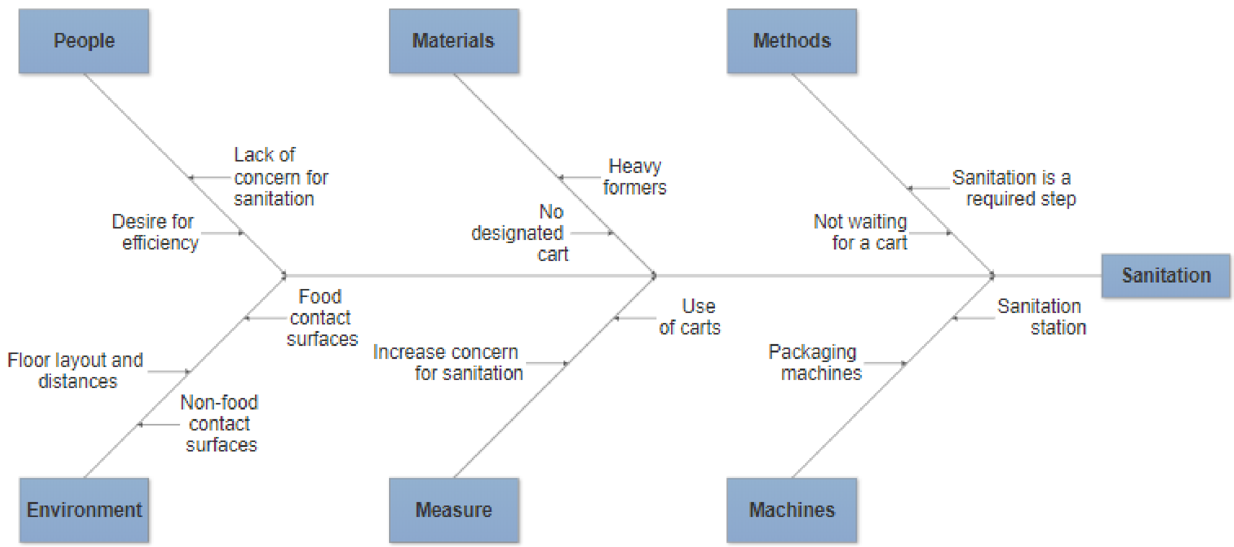

Figure 19: Sanitation Fishbone Diagram (SmartDraw)

The sanitation issues presented through the transportation process are mainly attributed to the people, the environment, and the materials. The operators value efficiency above all else; thus, the precautions and recommended steps for sanitation sometimes fall to the wayside. Employees look to get the lines up and running as fast as possible therefore, on occasion, the formers are placed on areas which are convenient to the employee and do not fit the classification of being a food contact surface. The mix between contact surfaces and nonfood contact surfaces attribute to the environmental causes of the sanitation issues on the factory floor. Additionally, the floor layout, specifically the distances of some lines to the sanitation station, adds inconvenience to the workers and as stated before is not ideal for them to follow proper procedures and protocols. The materials, being the formers, when combined with the aforementioned causes are the primary reasons why the sanitation issues exist.

5.1.3 Iterations of Cart Designs

5.1.3.1 Base Model

Since the current start-of-the-art cart had many features that functioned well on the factory floor, we kept those constant in our design (handle height, wheels, material, Figure 20).

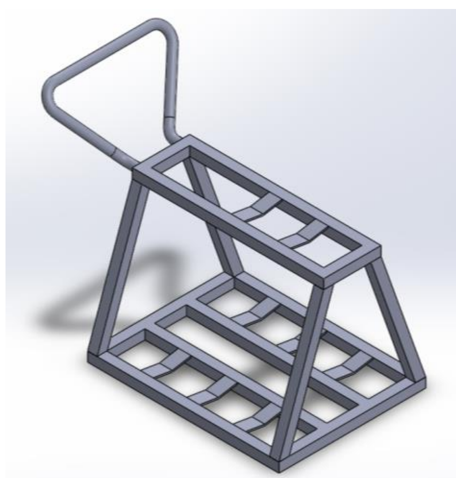

Figure 20: Base Model of Cart Design (SolidWorks)

While designing, it was kept in mind that we wanted a cart with a dedicated former storage location that could be accessible within the green zone by operators, whilst keeping it secure during transportation.

The cart designs were labeled A, B, and C so the team could keep track of them and not have numerical numbers. The iterations of each design were then numbers (e.g. A.1 is the first design of variation A and A.2 is the second design of variation A).

5.1.3.2 Design A

Design A had two changes compared to the base cart: the length is 14.5 inches longer to create a designated location for the formers, and the top section was widened so that two rolls of film can sit parallel to each other (Figure 21).

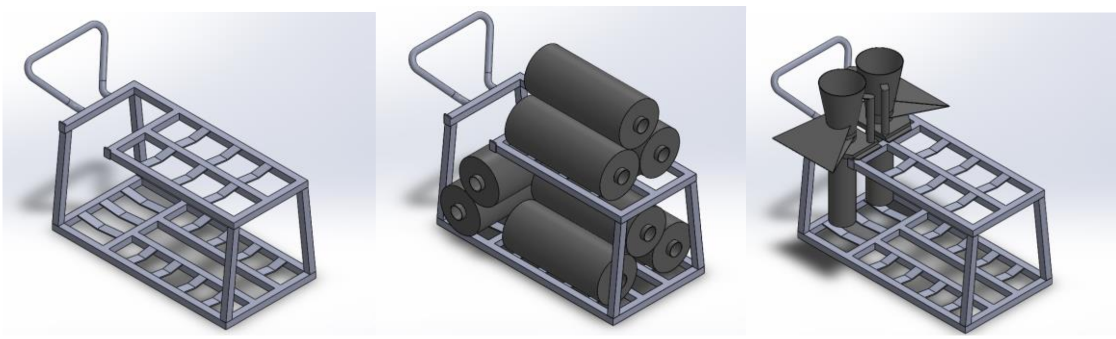

Figure 21: Design A Cart Model (SolidWorks)

The team expected the disadvantage to this cart design to be the increase in length, especially since the former handles must be in the middle to fit two formers at once, which would not be easy. The advantage of this cart design was that it can hold eight rolls of film.

5.1.3.3 Design B

Design B had the same dimensions of the base model cart on the bottom, but the top section is wider to create a designated space for formers and increase film capacity. To ensure the former stays in place, the design has a 0.5-inch lip that will keep the former from sliding off of the cart (Figure 22).

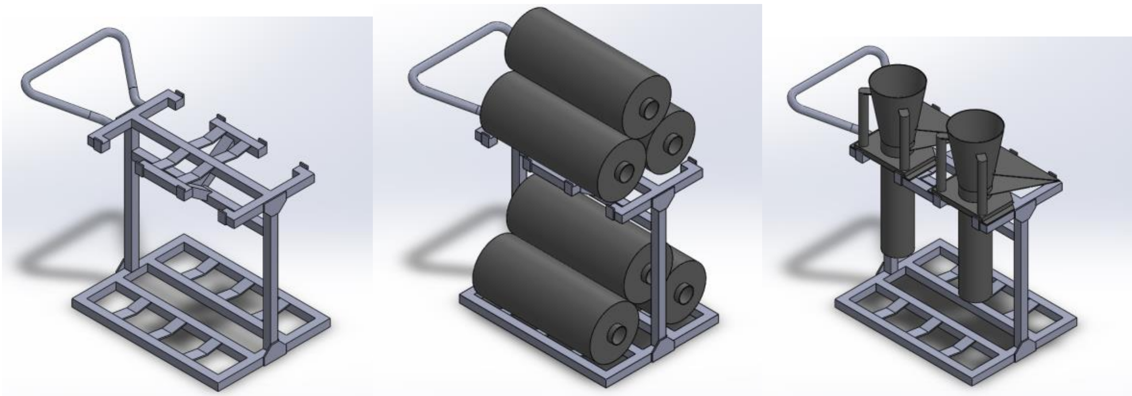

Figure 22: Design B Cart Model (SolidWorks)

The team expected that the operators may dislike the design as it is visually different. But the team found the advantage that each former can be accessed independently, and the former skirt sits over the cart. Additionally, the formers in this cart have a concept of poke-yoke as they can be loaded in any order and side of the cart.

5.1.3.4 Design C

Design C has all of the same exterior dimensions as design B (Figure 23). The difference from design B is that the top has the film being place in the opposite direction and the section for formers can only be accessed from one side.

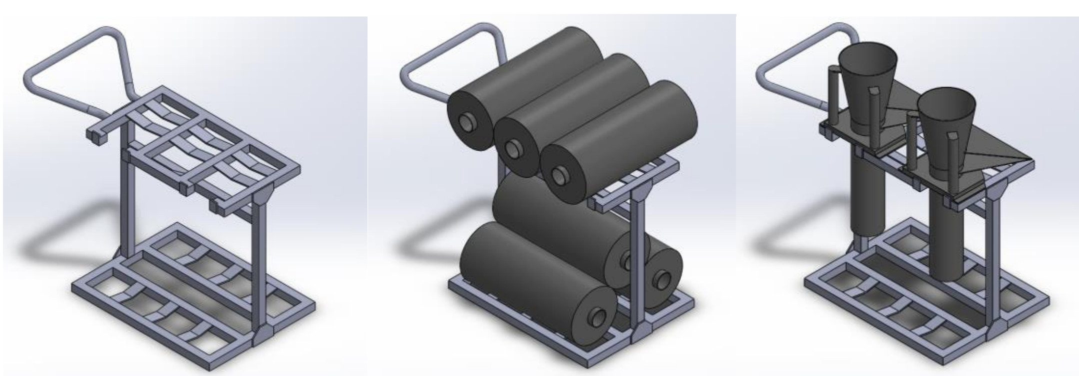

Figure 23: Design C Cart Model (SolidWorks)

The team expected that design B would be favored over design C by the operators since the film has a higher chance of rolling off and larger film roll will hang off the edge.

5.1.3.5 Professor Feedback

The original designs had many additional supports than the designs shown above. After showing the WPI advisors' the designs they called it "bomb proof" as the design had too many unnecessary supports (Figure 24).

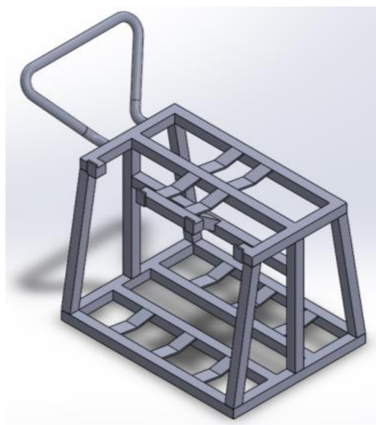

Figure 24: Design B, iteration 2 (SolidWorks)

The team took those additional supports out and completed stress and strain calculations to ensure the new design would still function as expected.

5.1.3.6 PepsiCo Operator Feedback

At Killingly, the operators reported to their shifts early, twice a week, for pre-shift meetings. A graduate group of OIE 555 Lean Manufacturing students assisted in presenting the three designs to the operators. The group had the focus on lean and the long-term effects of the cart; given each cart varied in capacity and maneuverability, different wastes resulted.

The feedback from all three of the operator sessions was summarized. For all carts, the operators said: the wheels are the biggest issue, horizontal stoppers will tear with film, film holders need to be recessed down, and the space on top won't allow two rolls side by side without one rolling off (Figure 25).

Design A	Design B	Design C
Pros: • Film can stay on cart with formers	Pros: • Film can be stacked • Would be used to store/wash formers • Good for changeovers	Pros: • Good for small rolls, but not versatile for all lines
Cons: • Too big for some areas & too big to be pushed • Former skirt sticks out • Only work in big bags, not in small bags	Cons: • Maybe too big for areas around small bags	Cons: • Maybe too big for areas around small bags

Figure 25: Cart Feedback by Design

The operators also mentioned new design suggestions for the team to take into consideration. These suggestions were not consistent between all operators (Table 6).

New Design Suggestions from Operators
• Two different carts, one for film and a separate dedicated one for formers that our three designs would function as • Create different designs for big and small bag sizes • One cart per line and the same cart throughout every line so that the cart stays with the respective line and is not taken; • Guard in front of the wheels so they are protected

Table 6: New Design Suggestions from PepsiCo Operators

The team was able to take a number of the comments and considerations in creating the first prototype.

5.1.3.7 Finalized Prototype Design

After reviewing operator feedback, the team went back to the design with the cart iteration B. The team made minimal changes to the design in order to accommodate for some of the concerns that were presented to them by the operators who will be using our cart. One of the major takeaways from the meeting with the operators was that they wanted a cart that would make the changeover of the formers easier for them. The cart did not need to hold as many rolls of film as it could, so we redesigned the top section of the cart to hold one roll of film. We kept the number of slots for the formers the same at four (Figure 26).

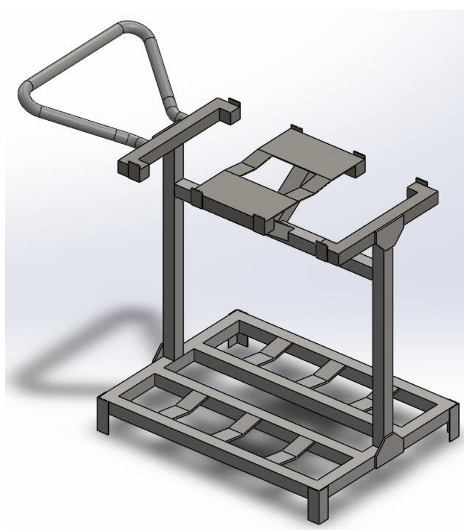

Figure 26: Final Prototype Design (SolidWorks)

The prototype accomplishes the needs outlined by the operators, without adding any unnecessary design elements that do not add to the usability of the cart. With the use of design strengthening elements, like the support plates on the vertical support legs, we are able to increase the strength of the cart without adding too much weight to the overall design.

5.1.4 Value Stream Map

The value stream map was created to compare the current state of the carts that PepsiCo uses and the future state with our designed cart. The team observed a changeover, to include both former and film, and timed each phase of this process to get a baseline of the current state. A value stream map was created, this depiction of the current state shows that the total time of the changeover is 381 seconds (Figure 27).

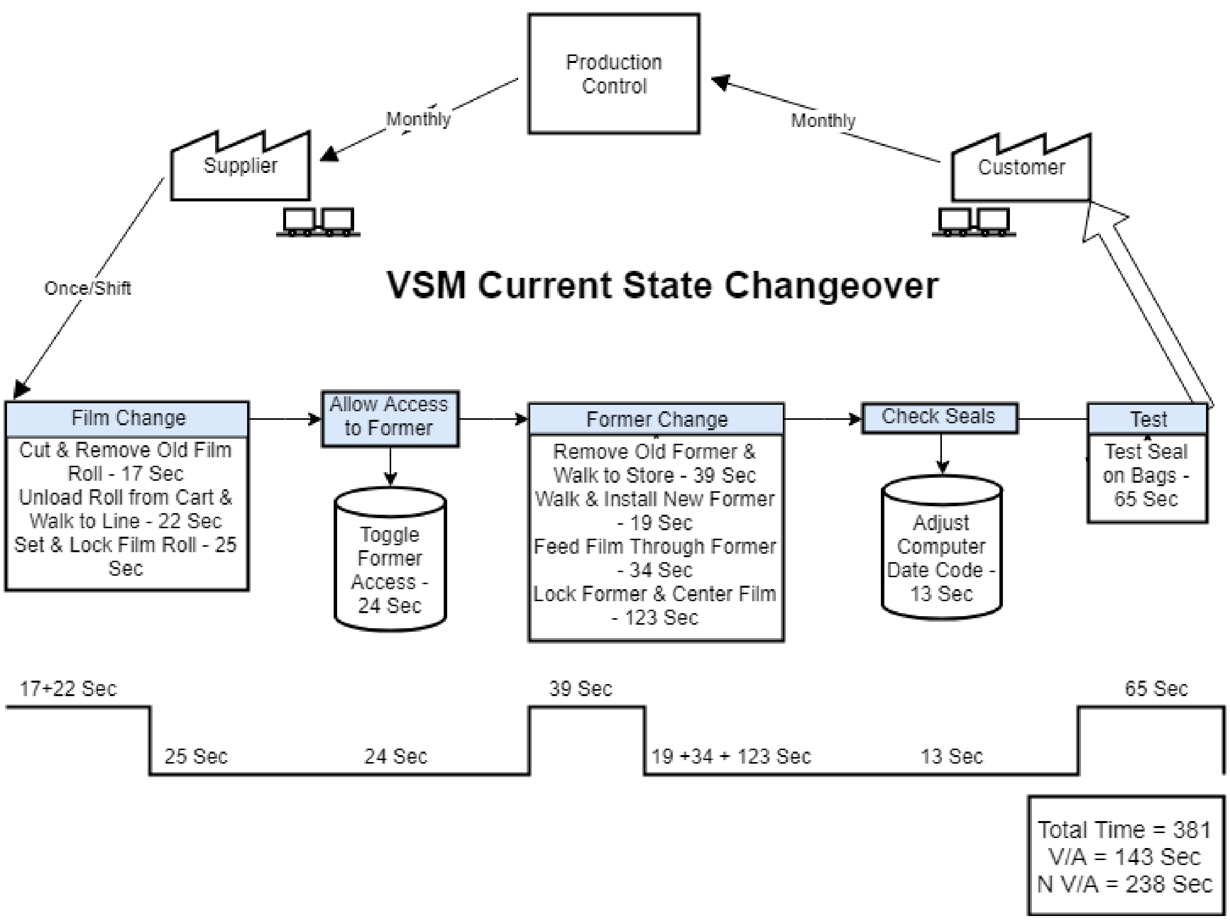

Figure 27: Value Stream Map of Current State of Changeover (Draw.io)

The current state of the changeover allowed the team to extrapolate a future state using the team's cart. With the added mobility and characteristics of the new cart, it would allow operators to have more freedom of movement between lines. The size of the cart coupled with the capacity for both formers and film would limit the operator's movements to the front of the line. As observed in the current state change over process, the new former and film roll are typically stored at the front of the line which creates excessive movement for the operator, thus adding non-value time. The team estimated that the time savings would be about 10 seconds in by having the cart near the film changeover and twenty seconds time saving in the former changeover as the operators currently have to walk further to place the formers than the film. However, our cart would allow the operator to transport all change over materials to a position in direct proximity to the point where the operator needs them (Figure 28).

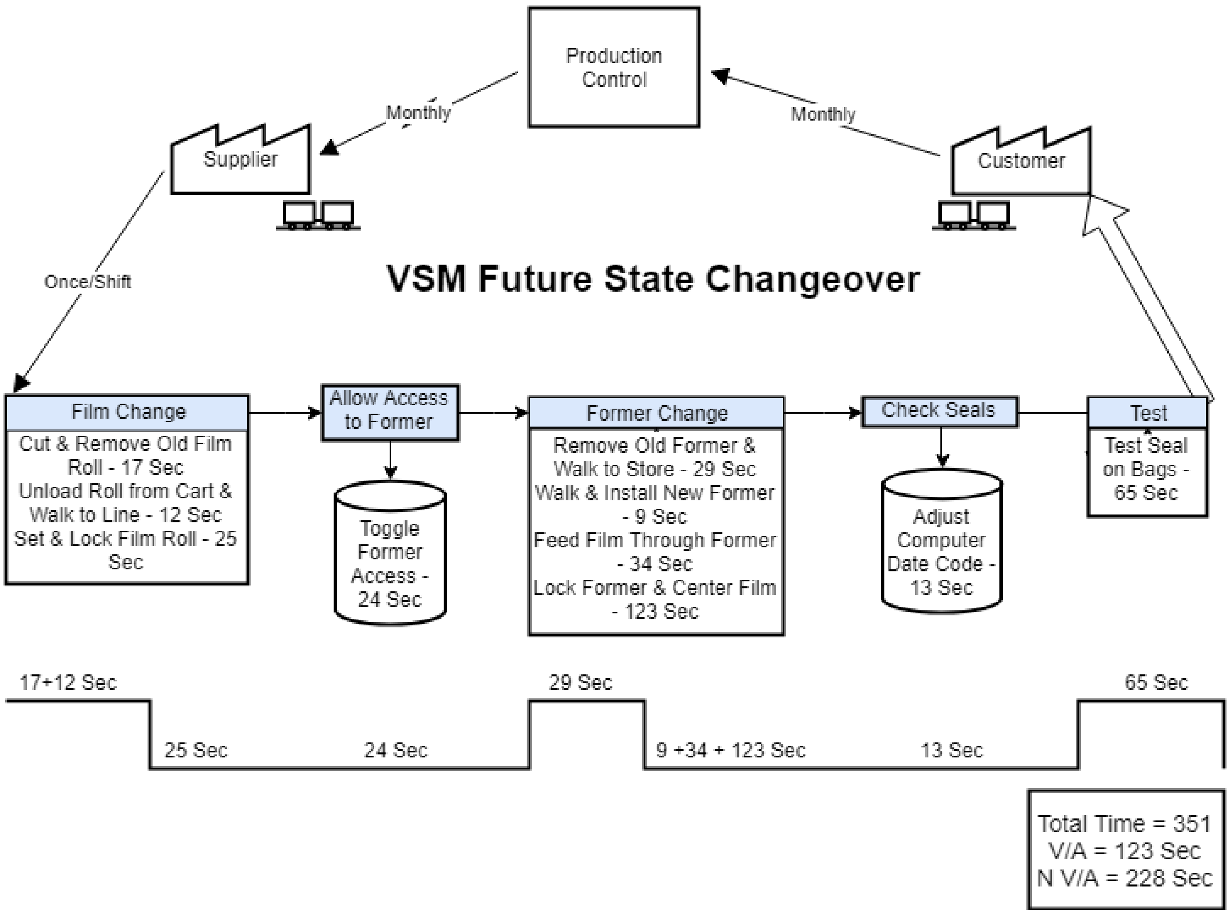

Figure 28: Value Stream Map of Future State of Changeover (Draw.io)

The value stream map shows that there would be 30 seconds, about 8% saved in comparison to the current state during a line changeover. The total time is now 351 seconds, notably the process is comprised of only 123 seconds of value-added time. This is due to the fact that the changeover process does not add value to the product as the customer is only paying for the product to be packaged; which per bag, is not dependent upon the need to have different formers and film rolls, but is based upon the size and seasoning of the style chip. That difference makes the changeover process a majority non value-added time.

5.1.5 Stress Analysis Results for Cart

The team ran a study using SolidWorks 3D modeling software to see how the cart would withstand a weight force applied to the top section of the cart. The two main engineering principles that the team focused on were the strain and the displacement values that came of as a result of a 100 lb. force. The result of the study can be seen in Figure 29.

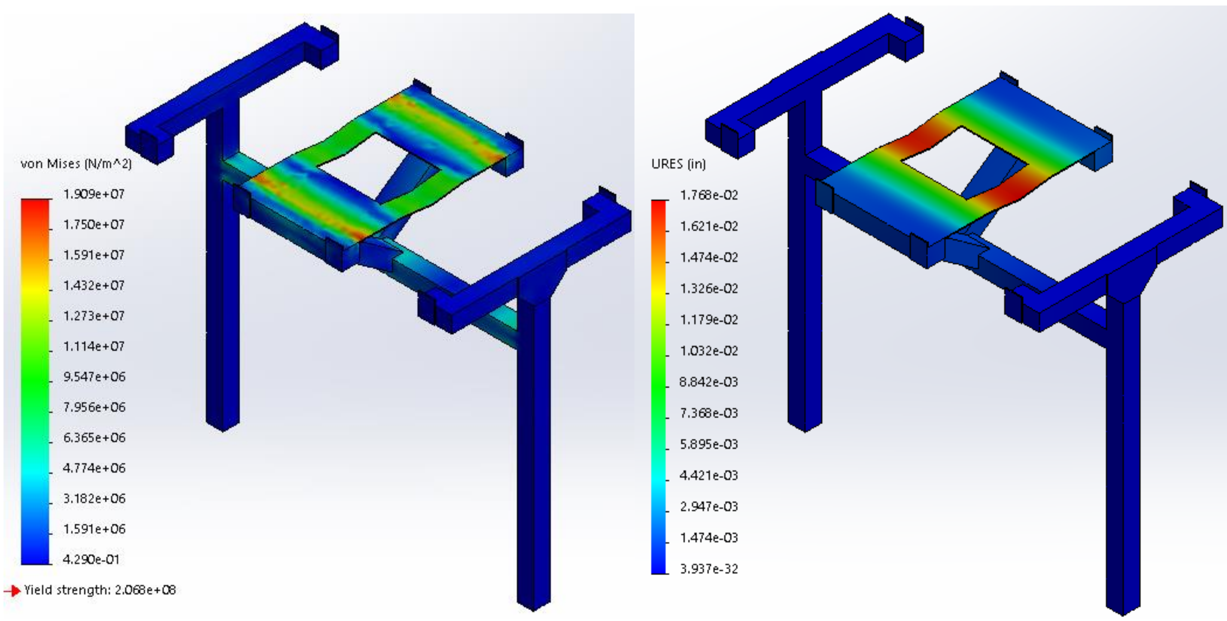

Figure 29: Strain and Displacement Study on Cart with 100 lb. Force (SolidWorks)

The strain and displacement of the cart with the 100 lb. force are both very small values. The maximum strain is experienced on the top section of the cart and has a value of around 6/100,000 which is negligible when determining how much weight the cart can hold before failure. The highest displacement on the cart is a little under 1/50 of an inch, which is practically invisible to the naked eye. The design of the cart is more than capable of handling the weight of the formers.

5.1.6 Financial Results of Cart

The financial analysis evaluated the implementation of a cart at every packaging line, in both potato and corn chips (Table 7). The quantity of product in pounds per day differs between the types of chips, and due to the larger quantity of corn chips being produced the projected ‘additional income with cart per year’ is larger for corn chips. The company margin of profit was chosen as the lowest in the past 3 years and the most recent (PepsiCo Profit Margin, 2018). This margin of profit was used to find how much money the company was making compared to the cost.

	Potato Chips	Corn Chips
Pounds of Chips Per Day	28,800 lbs. / day	76,800 lbs. / day
Improvement in Cycle Time	30 seconds	
Average Changeovers Per Day	3 changeovers / day	
Operator Efficiency	81%	
Saved Time per Day	73 seconds / day	
Increase in Pounds Per Day	580 lbs. / day	1,600 lbs. / day
Cost of Chips Per Pound (Amazon, 2018)	$4.00 / lbs.	$3.10 / lbs.
Company Margin of Profit (PepsiCo Profit Margin, 2018)	7.66%	
Company Income per Pound	$0.31 / lbs.	$0.24 / lbs.
Additional Income with Cart Per Day	$180 / day	$370 / day
Additional Income with Cart Per Quarter	~16,000 / quarter	~$33,000 / quarter

Table 7: Financial Analysis of Potato and Corn chips with the Designed Cart

The implementation of our cart design is projected to save $16,000 in potato chip production per quarter and $33,000 in corn chip production per quarter, for a total of $49,000 additional income per quarter.

The final portion of the financial analysis takes into consideration the cost to fabricate and maintain 67 carts. The team estimated a cost of $500 per cart and then a $5,000 maintenance fee at year one to fix any issues that may arise and a $1,000 maintenance fee for each year after for smaller replacements such as wheels. Given that Killingly's lines are running at full production in quarter 2 and quarter 3 more than in quarters 1 and 4, the team estimated that there would only be half of the savings in the slower quarters (Figure 30).

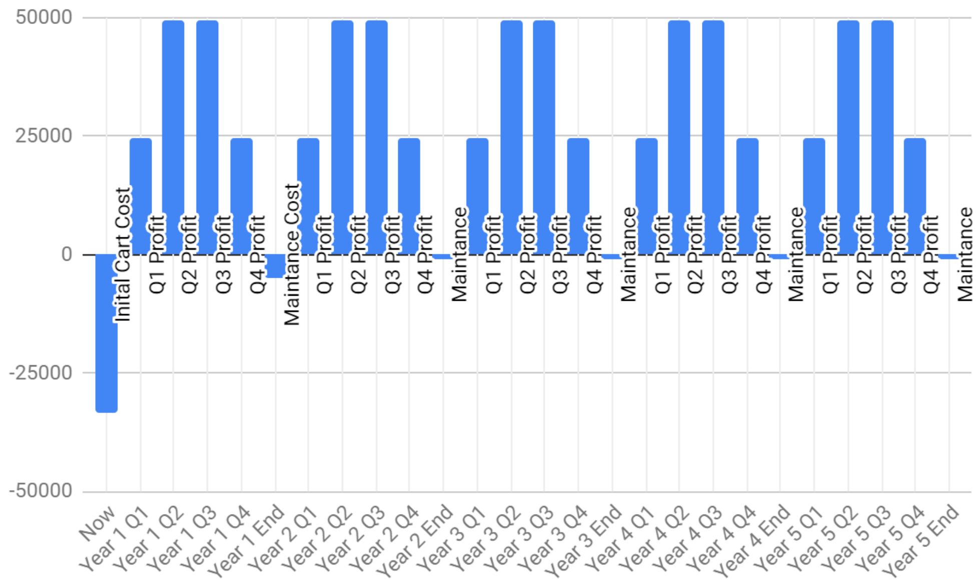

Figure 30: Projected Five Year Financial Analysis

The five-year financial analysis shows a potential increase in $700,000 of profit as the first year would be increase in $100,000 and each following year $150,000. In looking closer at the first year of implementation, the product does in fact "pay for itself" by cutting down on the change over time and therefore saving the company money within the first year (Figure 31).

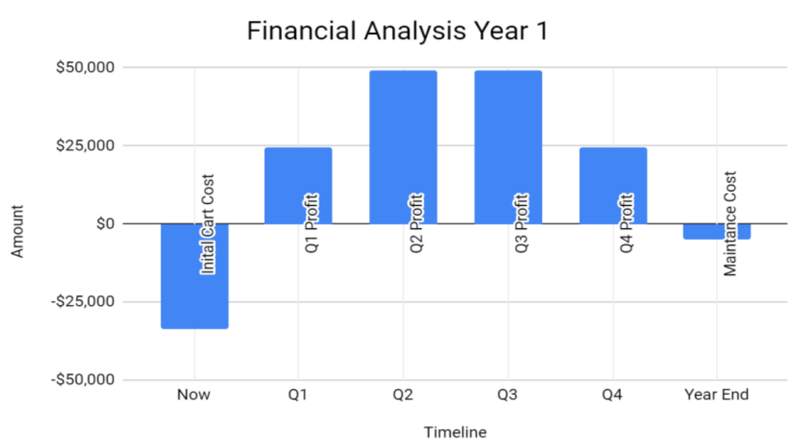

Figure 31: Projected Cart Financial Analysis of First Year

Given that the first-year increase in profit with implementation could be about $110,000, the company can spend more for the carts and not be financially constrained. Given that the current cart has lasted over 20 years (Stolo, 2018), the new carts using similar materials would allow the savings to be invested in further increasing the cart's longevity. Overall, the projected financial analysis boasts an approximate $700,000 in savings annually should the company choose to implement our design.

The financial analysis completed above was done as if PepsiCo changed their operator's schedules with the direct changes in cart implementation. In reality, our team recognizes that PepsiCo will not make that change at this time and labor, waste, and throughput would not change. Instead, the biggest change with the implementation will be employee morale and will allow the operators to spend more time on the line instead of away from it, which will allow them to be able to fix potential issues earlier. In the long term, this change may positively affect waste and throughput but for the short-term it will improve operator efficiency of the line.

5.2 Results of Objective 2: Ergonomics during changeover

5.2.1 Designing the Cart to be Ergonomic

The cart maintained key features from the original model: handle height, wheel type, material used. Our final iteration allowed the cart to hold formers on top for transport, but also allowed operators to keep a roll of film on top while the lines are in normal operation for easier access than reaching down to the lower film rolls stored on the cart. Overall, the cart is only slightly taller and longer than the original model, as this would maximize maneuverability on the floor.

5.2.2 Designing the Airlift: The Final Design

Our sponsor suggested to us that to improve the ergonomics of the vertical motion of removing the former, some kind of lift device could be implemented. He suggested utilizing the air pistons similar to those found in a labeling machine on the factory floor (image could not be included due to proprietary reasons). The hope was that the former could be placed in a claw-like chassis, the operator activates the piston which reduces the weight to allow the operator to lightly push the former overhead with the ease of a single hand. Due to the nature of our project being limited to three terms, designing the airlift completely didn't fit within the scope of the project. Detailed further below, the team did some basic calculations to see if implementing the airlift device into the ceiling would be safe for the operators in normal operation or in an accident.

5.2.3 Iterations of Airlift Design

Unlike the cart, the airlift would be a permanent addition to the bagging machine lines. As stated before, not all packaging lines have the same space around the machine. There is minimal overhead clearance between the machine and ceiling, and minimal clearance on the sides of the machines. In addition, nothing could be placed too close to the laser density device near the top of the machine. This device was required to be sensitive enough to detect foreign objects entering the bagging machine, so no vibrations or physical objects could be placed near the device, possibly causing interference.

5.2.4 Fishbone Diagram on Ergonomics

Through root-cause-analysis we broke down the ergonomic issues made present by the current processing methods. The causes are presented in the fishbone diagram (Figure 32).

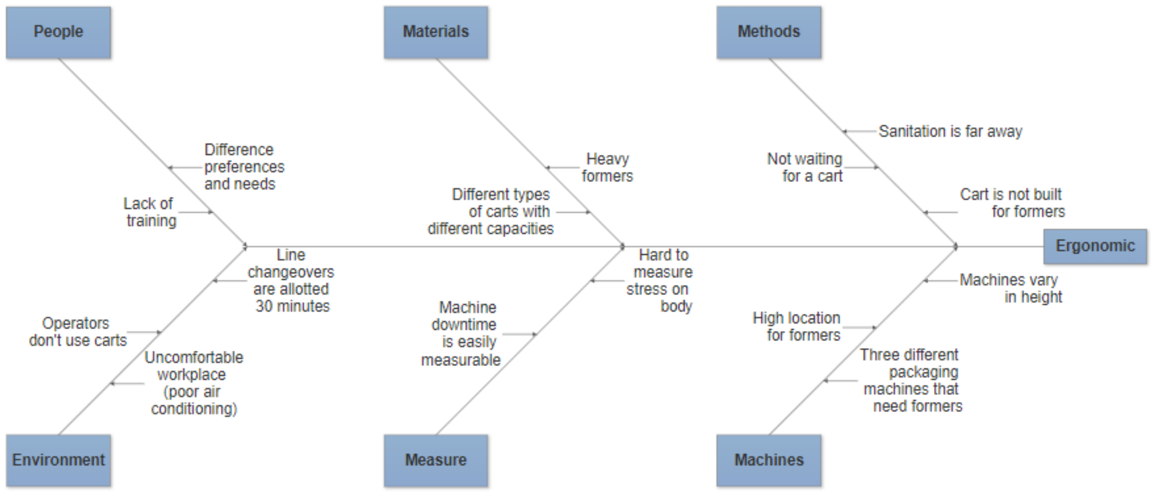

Figure 32: Ergonomic Fishbone Diagram (SmartDraw)

The major contributing factors to the ergonomic issues are people, materials, and machines. All of the personnel working the line are of different heights and physical builds and therefore issues are presented for those whom have to lift the former above their heads. Major issues are also presented with the materials and machines utilized within the packaging process. The formers themselves are both heavy and cumbersome; coupling that with the different types of machines and ranging heights the formers have to be lifted to prevent obvious ergonomic issues. This breakdown of the ergonomic issues allowed the team to focus on the major contributing factors to this issue, being the people, materials, and machines.

5.2.5 Spaghetti Diagram

The team utilized spaghetti diagrams to depict operator movement during a line changeover and sanitation of the formers. Figure 33 depicts the current state which has noticeably more trips to the former sanitation area when compared to the projected future state

(Figure 34) should the company choose to implement our cart. This is because the current state carts have no designated section for the formers and thus the operator is limited to one former per trip to the sanitation area. However, if our product is introduced, the number of trips to the sanitation area is reduced in half due to the capacity of our cart design holding two formers at once.

Fewer trips to the sanitation area reduces non-value-added time in the form of resource transfer time, which could otherwise be added on to other operations within the packaging area that add value to the product. Furthermore, the new cart would increase operator efficiency by getting the same amount of work done in less time and steps.

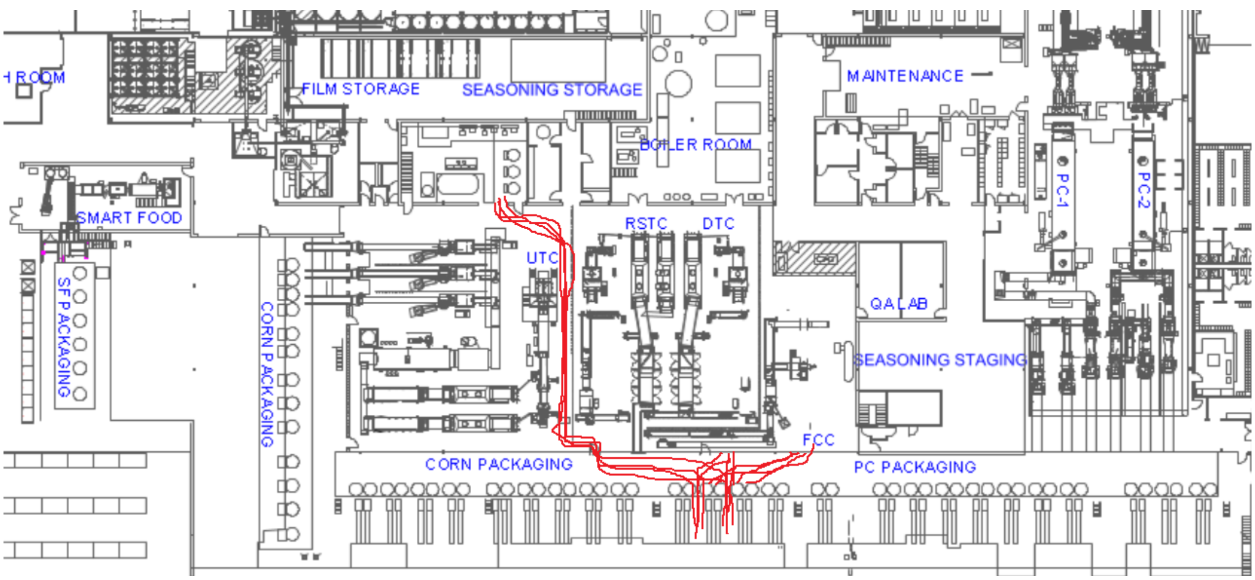

Figure 33: Spaghetti diagram of former sanitation in current state process

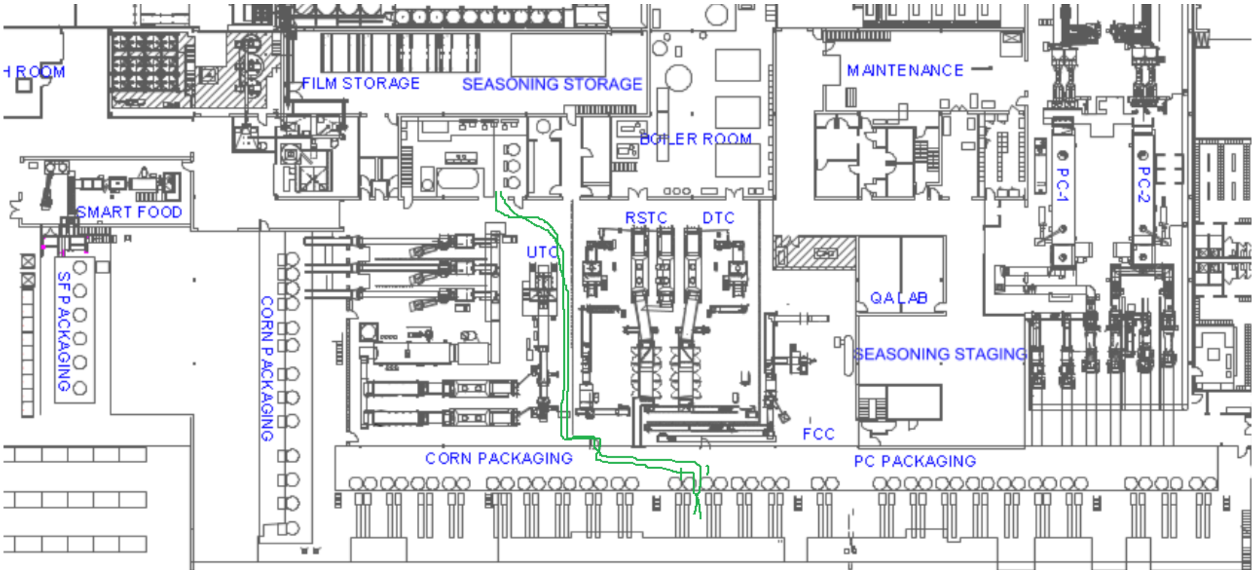

Figure 34: Spaghetti diagram of former sanitation future state process

Given that the current cart and the redesigned cart have the same capacity of film, the process for film would remain the same. The only difference is that certain carts can only hold one roll of film while upon implementation, each line would have storage for two rolls of film and two formers at once, making it ideal for a line changeover.

5.2.6 Stress Analysis

To test the security of the airlift to the factory ceiling, a strength of materials analysis was done on the fasteners placed into the ceiling concrete. As mentioned in the methods, a situation was considered where if a 250 lb. operator was to grab the airlift, would the device itself fail or would it be ripped from the ceiling? Further calculations can be found in the Appendix.

From the calculations done by the team, the combined force of the operator and the airlifts weights would only cause a stress of 21.4 Kilopascals (force per square meter), which pales in comparison to steel's point of failure 505 Megapascals, a magnitude of four thousand times greater! This is to be expected, since stainless steel AISI 304 is extremely tough and would need more force than the weight of a man to cause any failure. From these calculations it was concluded that failure, if any, would occur in the supports of the airlift to the concrete ceiling.

Concrete sleeve anchors would be best suited to secure the airlift. Common ceiling concrete is rated at 2000 PSI and according to the specifications sheet on the website Hilti, a sleeve anchor can support 310 lbs. of tensile force. With the combined weight of the operator (250 lb.) and a theoretical airlift of 10 lb., four of these fasteners would be able to secure the airlift and an operator without ripping from the ceiling. The specifications for the sleeve anchors used in the design are as follows (Hilti Inc. 2018). For the design to be implemented, the company would need to be concerned with how the airlift is mounted to the ceiling (Figure 35).

Table 3 - Stainless steel sleeve anchor allowable loads[1]

Nominal anchor diameter	Nominal embedment		f'_c = 2,000 psi				f'_c = 4,000 psi				Hollow C-90 concrete block[2]			
			Tension		Shear		Tension		Shear		Tension		Shear	
	in.	(mm)	lb	(kN)	lb	(kN)	lb	(kN)	lb	(kN)	lb	(kN)	lb	(kN)
1/4	1-1/8	(29)	235	(1.0)	450	(2.0)	300	(1.3)	450	(2.0)	200	(0.9)	400	(1.8)
5/16	1-1/4	(32)	310	(1.4)	675	(3.0)	410	(1.8)	675	(3.0)	335	(1.5)	600	(2.7)
3/8	1-1/2	(38)	450	(2.0)	1,000	(4.4)	600	(2.7)	1,000	(4.4)	470	(2.1)	890	(4.0)

Figure 35: Specifications of stainless-steel sleeves sold by Hilti Inc. (Hilti Inc. 2018).

5.2.7 Financial Results of Airlift

Without a final design, the financial analysis of the airlift is less complete than the financial analysis of the cart. The airlift will reduce long term operator ergonomic strain present due to the weight of the film and formers they have to manipulate. Considering second and third order effects, should the company choose to implement an airlift, the change of processes will be safer from an ergonomic standpoint. This will inherently reduce the risk of operator injuries and accidents; thus, saving the company money on injury related insurance claims and replacement fees associated with damaged formers as a result of an accident. The team recommends that prior to implementation of any airlift design a new financial analysis should be completed which takes into consideration the aforementioned situations.

Chapter 6 - Conclusion and Future Recommendations

6.1 Summary

The objective of this MQP was to address the transportation issues while handling chip bag formers. The team identified two objectives that the packaging department had: sanitation and ergonomic difficulties. From there, the team did root-cause analysis using fishbone diagrams. This ensured the team was solving the problem that the customer thought they had.

There was no dedicated transportation device to move the formers from the packaging department to the wash station. The transportation devices used were unstable and could potentially damage the formers.

The team drew up designs about how to create the cart so that it was easy to use and would make transporting the formers safer. After coming up with three possible designs, the team presented them to the operators that would be working with these carts. The operators gave feedback on which cart they liked the most and how they might change it to better suit their needs. The team then collected the data that they had received from the operators and made small changes to the design to incorporate the most common changes to the cart. After designing the prototype, the team sent the design to the company for final review and construction.

The team used stress analysis to make sure the cart was stable, value-stream maps to see the current state and the expected outcome of implementation, spaghetti diagrams to understand the flow of the operators and financial analysis to find the bottom line.

6.2 Future Recommendations

First and foremost, the team recommends implementation of the cart design into the packaging process. It is suggested that this is done with a progression style approach. First creating a singular prototype and assessing its usage and effectiveness based upon operator feedback. Should step one prove to be successful the company should then construct several more carts and introduce them to the different style lines to ensure that the design works for both big and small bags as well as both potato and corn chips. Lastly, if and when all other steps yield positive results the team suggests to the company that a cart is fabricated for each line.

The second recommendation to the company is that they seriously consider the implementation of an airlift designed to raise and lower formers into place on the packaging machine. A team whose goal it is to focus specifically on the manipulation of the former would be able to use our project and paper as both a reference and start point.

6.3 Areas of Learning

The team was able to practice design engineering principles learned over the past four years at WPI. The initial cart design was extremely over engineered, with unnecessary supports that add to the weight and price of the cart. We learned that in the design process the material is key, as material properties can limit design and simplify designs. The team was able to delve into advanced programs in Solid works to further visualize the art to part idea, in how a design looks good but how functional is it?

Efficiency and adding value are the cornerstones of industrial engineering. Through our project the team learned the importance of both factors in the design process. The main role being justification for design implementation. This came in the form of projections related to both finances and general processes. The financial analysis helped to translate our cart design into dollar values added to the company profit margin. Process evaluation tools such as the fishbone diagram, spaghetti diagram, and value stream map facilitate an in depth understanding of how our cart and in turn our project have an impact on the packaging process as a whole. Furthermore, these process summaries are a form of visual articulation which consolidate data and multiple step processes into an easy to read format, each of which presents clear benefits to introducing our project design.

6.4 Overall Conclusion

To assist with operator ergonomic health and packaging sanitation, the team redesigned a transportation car and suggested implementing an airlift to assist in lifting. The team suggested implementing one of the redesigned carts at every production line and keeping the larger film storage carts on the factory floor as well. The redesigned cart has equivalent capacity of the current carts for film, as well as it has two designated sections for formers. The financial analysis of the cart shows that it would save PepsiCo about 150K dollars each year due to the increase on availability of the line operators and decrease in line down time.

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Appendix A – Operator Cart Presentation

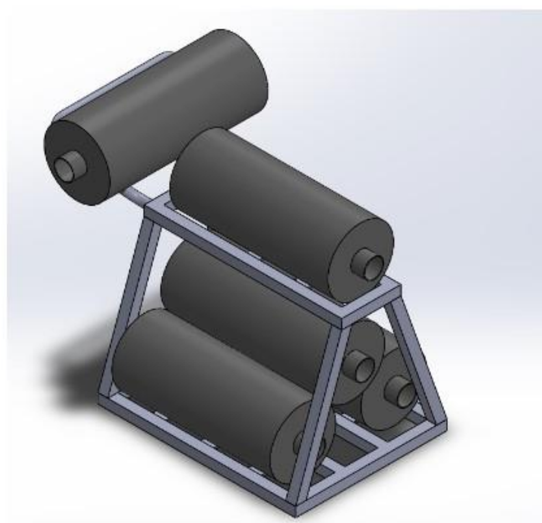
The following slides were presented to the PepsiCo operators at all three shifts during a pre-shift meeting.

Base Model

- Key Features to Sustain
  - Bottom width 23 in
  - Handle height 41 in
  - Wheels (not pictured)
  - Capacity (film)

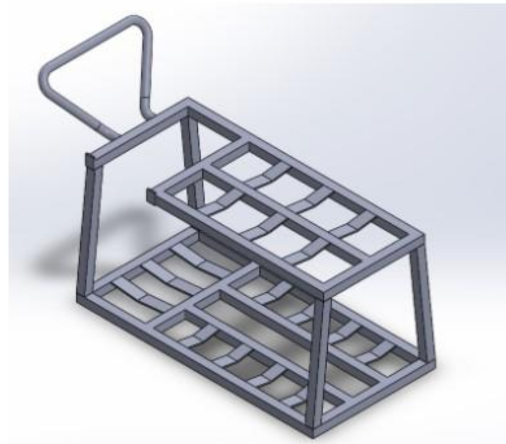
Recommended Film Capacity: 5

Base Model with Film



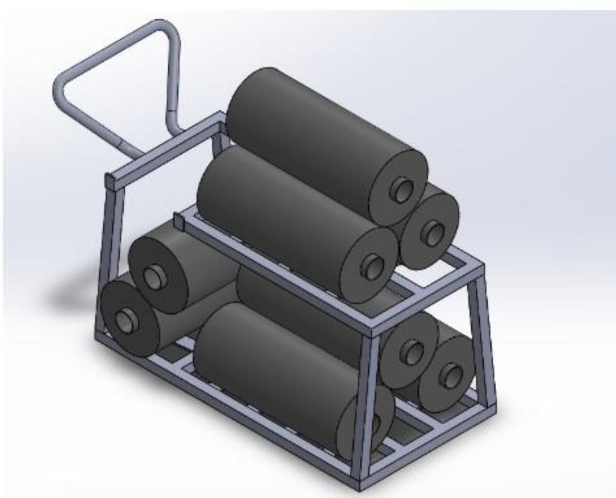
Design A

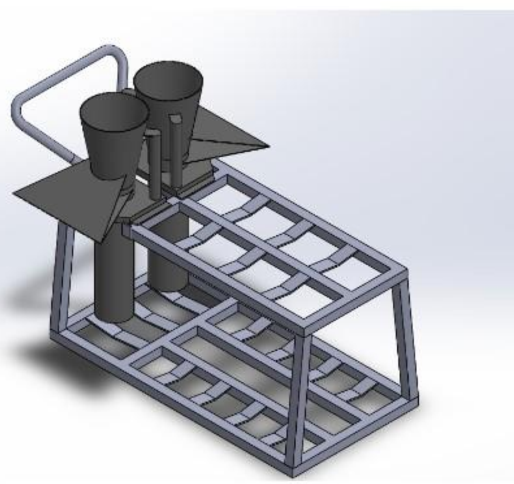
- Modifications
  - Added 10 inches to base length
  - Parallel rows on top to accommodate two rolls of film
  - Added designated location for one or two formers (two is not ideal)
  - Stoppers to limit horizontal movement of formers
- Sustains
  - Width of base
  - Handle height
  - Same Wheels



Design A at Capacity

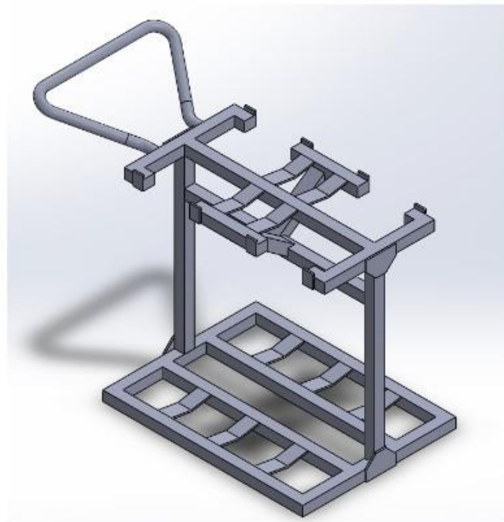
Recommended Film Capacity: 8
Recommended Former Capacity: 2





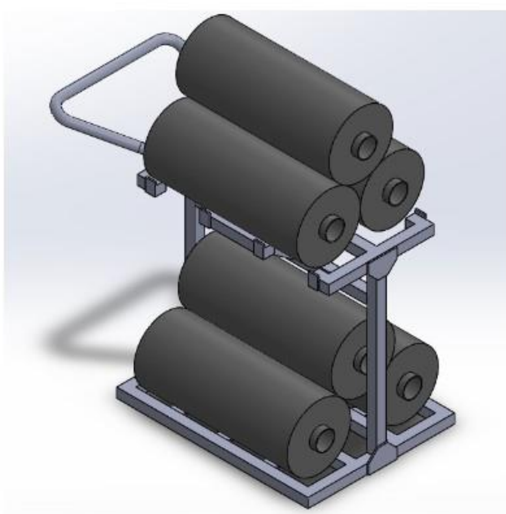
Design B

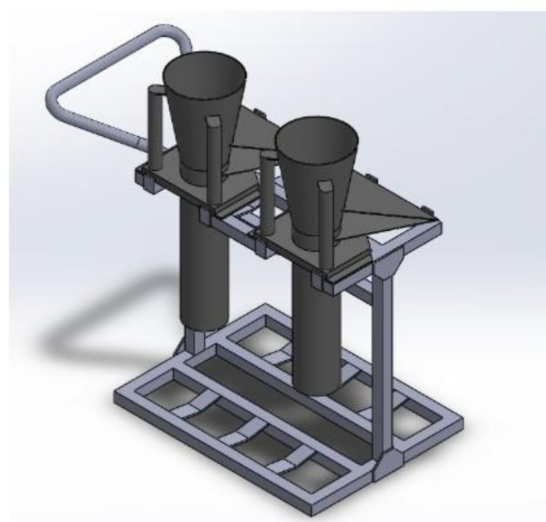
- Modifications
  - Top can hold two formers with access on either side
  - Parallel rows on top to accommodate two rolls of film
  - Stoppers to limit horizontal movement
  - Raise the top rack 6 inches
- Sustains
  - Same length and width as base model
  - Handle height
  - Same Wheels



Design B at Capacity

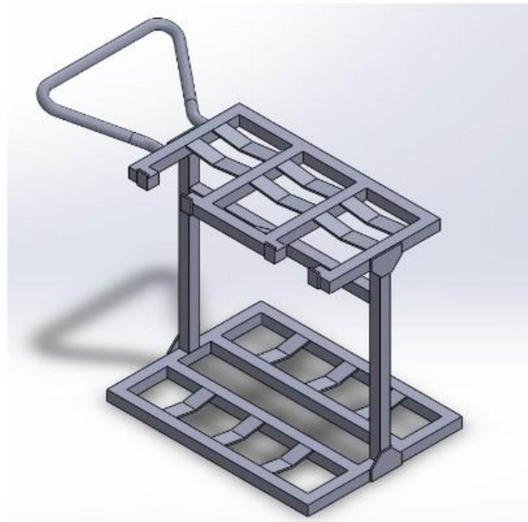
Recommended Film Capacity: 6
Recommended Former Capacity: 2





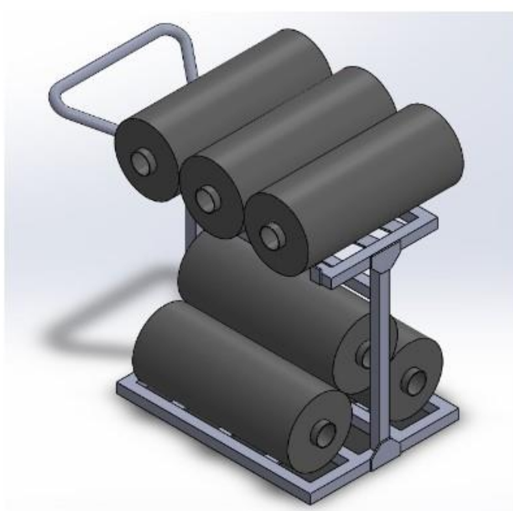
Design C

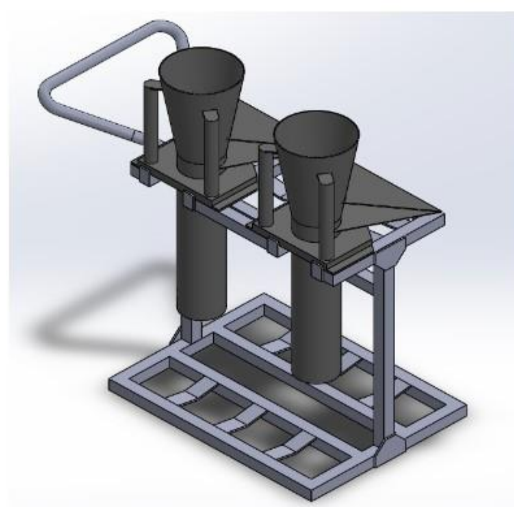
- Modifications
  - Top can hold two formers with access on **one side**
  - Three rows on top to accommodate three rolls of film
  - Stoppers to limit horizontal movement
  - Raise the top rack 6 inches
- Sustains
  - Same length and width as base model
  - Handle height
  - Same Wheels



Design C at Capacity

Recommended Film Capacity: 6
Recommended Former Capacity: 2





Comparison

Current Design	Design A	Design B	Design C
			
Recommended Film Capacity: 5	Recommended Film Capacity: 8	Recommended Film Capacity: 6	Recommended Film Capacity: 6
No Former Capacity	Recommended Former Capacity: 2	Recommended Former Capacity: 2	Recommended Former Capacity: 2

Appendix B – Airlift Calculations

Force= 250 lbs* 32.2 ft/s^2 = **8,050 lbf**	A_1 = 0.359 ft^2 I_1 = 0.25 ft^4	I_{total} = 1.131 ft^4	Max stress = 0.0214 MPa (4.44*10^2 lbf/ft^2)
Moment= Force*length (1ft of arm) = **8,050 lbf*ft**	A_2 = 0.125 ft^2 I_2 = 1.62e-4 ft^4		Yield Strength of AISI 304 = 505 MPa Safety factor = 23528

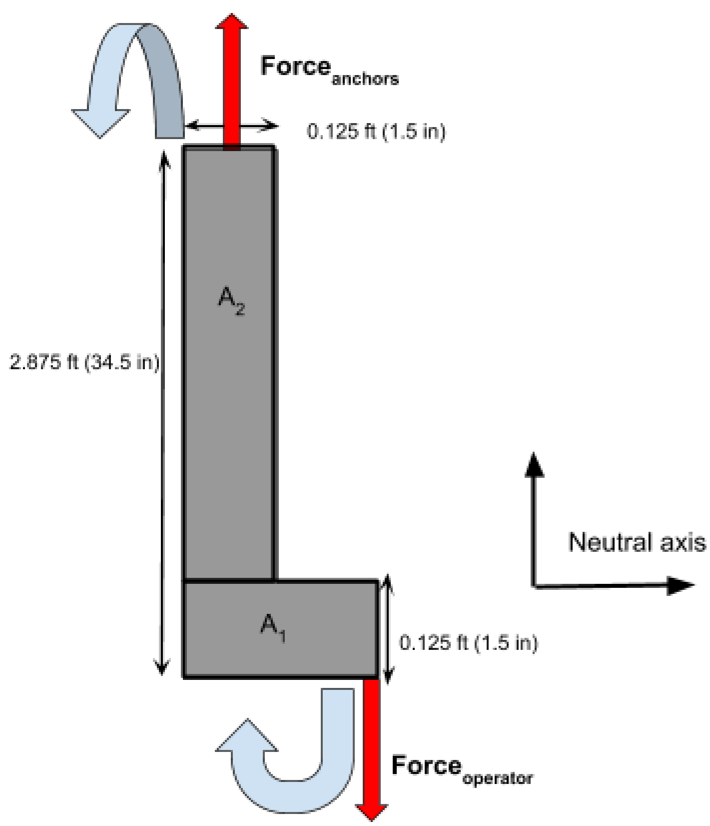


Figure 36: Simple Free Body Diagram of forces on airlift

$$I_{total} = \sum (\bar{I}_i + A_i {d_i}^2) \text{ where:}$$

$\bar{I}_i$ = The moment of inertia of the individual segment about its own centroid axis
A_i = The area of the individual segment
d_i = The vertical distance from the centroid of the segment to the Netrual Axis (NA)

Max surface stress, $\sigma_{max} = \frac{Mc}{I} = \frac{M}{Z}$

Where: *M* = bending moment
c = distance from neutral axis to outer surface where max stress occurs
I = moment of inertia
Z = I/c = section modulus

Figure 37: Maximum surface stress equation (Edge, L. E. 2000)

Appendix C – Detailed Financial Analysis

	Potato Chips	Corn Chips
Current Changeover Cycle Time	381 seconds	
New Changeover Cycle Time	351 seconds	
Improvement in Cycle Time	30 seconds	
Number of Changeovers/ Day	3 changeovers/day	
Time Saving per Day	90 seconds/day	
Operator Efficiency	81%	
Saved Time per Day	72.9 seconds/day	
Pounds of Chips Per Hour	1,200 lbs/hr	3,200 lbs/hr
Pounds of Chips Per Day	28,800 lbs/day	76,800 lbs/day
Due to Time Savings, Increase in Pounds Per Day	390 lbs/day	1,600 lbs/day
Cost of Chips Per Ounce (Amazon)	$0.25/ ounce	$0.19/ounce
Cost of Chips Per Pound (Amazon)	$4.00 / lbs	$3.10 / lbs
Company Margin of Profit	7.66%	
Company Income per Pound	$0.31 / lbs	$0.24 / lbs
Additional Income with Cart Per Day	$180 / day	$370 / day
Additional Income with Cart Per Quarter	$16,000 / quarter	$33,000 / quarter
Additional Income with Cart Per Year	$65,000 / year	$135,000 / year