ISyE 350: Junior Design Laboratory
Final Design Report
Team Skaberne

Dairy Land Cheeses Inc.
December 18, 2016
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I. Executive Summary

Dairly Land Cheeses Inc., a leader in cheese sales and distribution, has been experiencing a bottleneck in operations. Since the company recently improved their retrieval process from inventory to order shipment, cheese can be transported through retrieval at a faster rate, which should allow the company to maintain a higher demand. However, inventory is not being replenished quickly enough. Thus, a new transport device must be fabricated to ensure cheese is quickly and safely transported from receiving to inventory at a faster rate that meets the increase in demand.

In order to solve this problem, Dairy Land Cheeses has reached out to the ISyE 350 Junior Design Course at the University of Wisconsin - Madison. Using the client's requirements and description of the cheese retrieval process, the team of five students must determine the most effective way to to improve the current process. The students are available to help the client for one semester. In order to solve the problem of inventory shortage, the team of 350 students executed a complete design process.

The following report will provide an overview of the the problem, goals, and objectives of the project as help shaped by the client. Next, the concepts and design approach will be discussed in detail; the team's brainstorming process, different prototype alternatives, and tools such as Critical to Quality Diagrams, Value Stream Maps and Gantt Charts used by project managers and engineers to ensure the project requirements are met and the problem solved will be displayed.

We chose our final design after an analysis of several different prototypes: a conveyor system, automated guided vehicle, pivoting robot with ramp, and three slides from dispatch. After much consideration, it was decided the best option to pursue entails implementing a singular convey from receiving to the center point of the distribution center with a sorter that sends the cheese down three slides to their three respective inventories. Because of minimal cost, safety, efficiency and minimal timing to transfer cheese with this prototype, the team collectively felt this alternative was best suited the client's needs. The report displays the process used to fabricate the prototype, including resources used and revisions made.

Lastly the performance of the system will be determined by looking at test data and observations, followed by opportunities for improvement and recommendations we have for the client moving forward. The complete process undergone will be displayed in the following report to ensure Dairy Land Cheeses understands our prototype and ensure it is implemented.

II. Project Definition

A. Background

Dairy Land Cheese’s Inc. is one of the fastest growing cheese distributors in the United States. Dairy Land Cheese’s online cheese retail business retrieves local cheese products from suppliers, stores them, and then resells them to customers. The company ships five pound blocks of Wisconsin cheese throughout the country. The company's warehouse has three main operations: receiving, dispatch and inventory, and retrieval to shipping. [3]

The following process is in place for the transportation of cheese from receiving to shipping, through the three main operations:

1. *Receiving*- Trucks will deliver the cheese blocks to the warehouse. From here, the cheese bricks are individually placed onto the unloading dock. The bricks of cheese are then individually sent down the conveyor belt, unsorted, to the center of the distribution center.
2. *Dispatch to Inventory*- After reaching the end of the conveyor, cheese blocks are sorted and sent down one of three slides to their respective inventories. Dispatchers then load them into their corresponding storage bins. From there, the storage bins are transported by forklift to the refrigerated warehouse where they are stored in inventory until needed.
3. *Retrieval to Shipping*- The retrieval process involves packers reading order requests off a screen. It has been recently improved to increase efficiency through the implementation of an automated system. The packers then walk through inventory storage to collect the desired cheese bricks and return to their workstations where they pack the cheese and send it on a conveyor to shipping.

B. Purpose

Dairy Land Cheeses Inc. is currently experiencing a rapid increase in demand. In response, the company recently did a project within the retrieval portion of the warehouse to improve efficiency of cheese transportation from inventory to shipping. They replaced the manual material handling system described above with an automated system that retrieves products from the storage areas based on an optimized computer algorithm. With this improvement, the company hopes to satisfy the increasing demand and deliver cheese most efficiently.

With improvements made in the cheese retrieval operation from inventory, it is now more efficient transporting cheese from inventory to shipping, however this has created a bottleneck when transporting cheese from the receiving to inventory. The bottleneck disrupts flow within the distribution center, in addition it restricts the rate at which cheese can be supplied to customers. Additionally, the pressure to keep up with the increase in demand has caused major ergonomic concerns within the storage department. The amount of time off due to work related injuries at Dairy Land Cheeses is high benchmarked to other leaders in the cheese industry. This can be attributed to the fact that employees do not currently have automated assistance to lift the large order quantities. Therefore, we need to design a user-friendly system that will optimize our transportation of cheese from dispatch to inventory.

C. Importance

Management has determined that action must be taken in order to eliminate the bottleneck in the storage department. [1] Team Skaberne will create an automated system to ensure that the flow of cheese through the distribution center is smooth. The bottleneck within the storage department is project to be eliminated by the end of the 2016 business year. All time off due to work related lifting injuries will be eliminated and the increase in demand will be satisfied.

D. Project Schedule

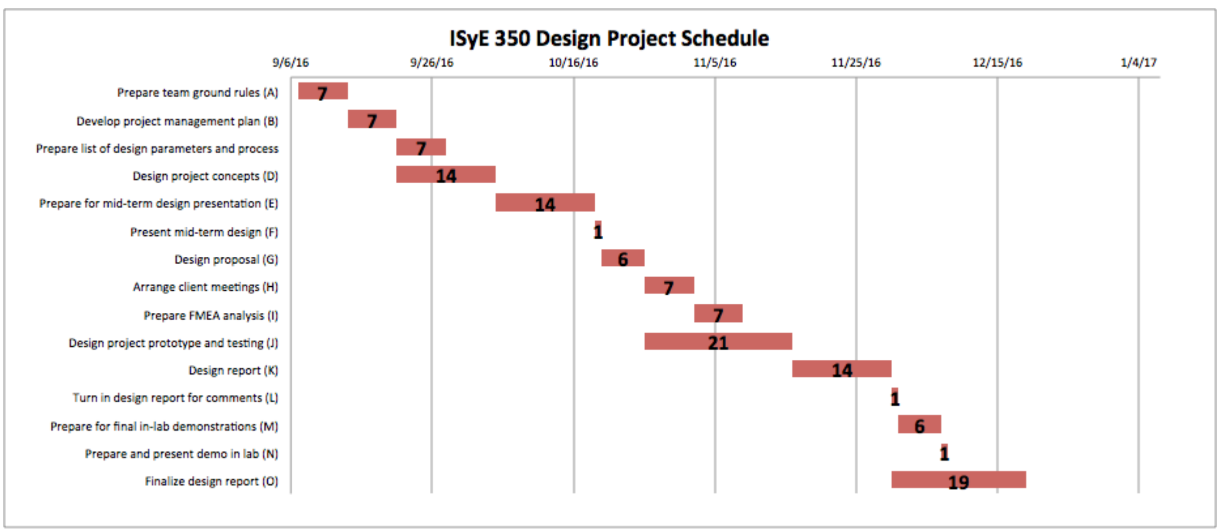

Figure 1. Gantt Chart

The Gantt Chart provides a good representation of when we expect to start and finish various tasks. [3] We clearly see that some tasks take longer than others and must be started accordingly in order to stay on track. As a team, we must be willing to accommodate and alter the Gantt chart because some elements are out of our control.

Another tool will used to enable our team to keep our project on track is to create and activity Network Diagram. [3] Looking at the Activity Network Diagram below, it can be seen that many of the tasks are in sequential order, with a few parallel and coupled tasks. We could decrease our project time if we were to spend less time on task D and J, however we want to ensure everything we are doing is not rushed and are providing the best quality to the customer. We are confident that allowing cushion room in our timing will ensure this quality.

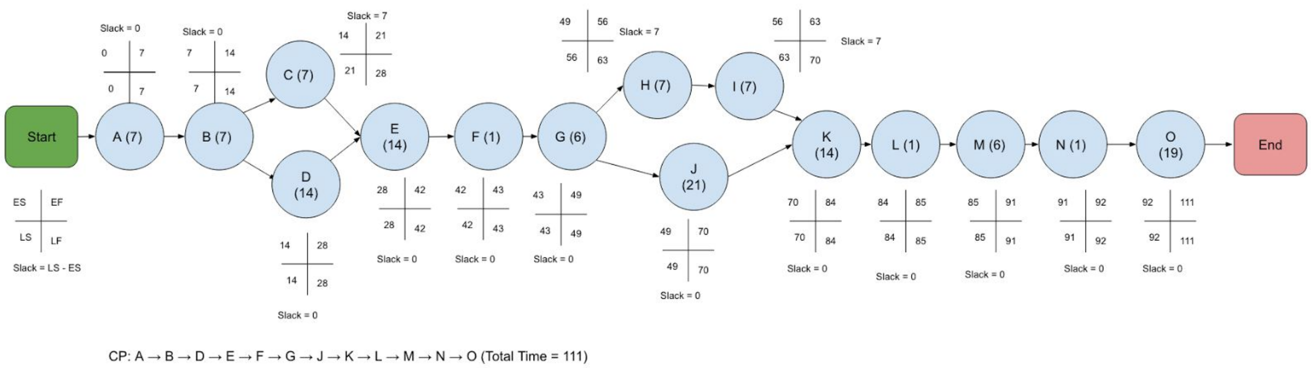

Figure 2. Activity Network Diagram

E. Resources and Allocation

Our project team is made up of five Industrial Engineering students from the Junior Design Laboratory at UW- Madison. As a team, we have the fall semester to collaborate and build a working prototype. Each week we will meet in discussion and lab for 4 hours to work on the project, but will also need communication effectively and set up time outside of class to finish any other tasks.

The client is also available with specifications on project requirements and feedback on any questions that we can think up. He is easily accessible through scheduled client meeting, email, and during select worktimes.

To build the prototype, the materials we have at our disposal include all the parts in the TETRIX and LEGO MINDSTORMS. To test the prototype we build, we also have a mock shop floor in our lab room to test the product and make any adjustments as we work through the project schedule.

In order to ensure our project and personal time is managed effectively, we have created a resource allocation plan to indicate our assignment of resources.

Tasks	Resources (hours)		
	Lab Time	Meeting Time	Personal Time
Team Ground Rules	3	0	0
Design Project Mission Statement and Management Plan Assignment	3	0.5	2
Design Parameters and Process Capabilities Plan	3	2	0
Design Concepts and Descriptions	3	3	0
Mid-Semester Powerpoint Presentation	3	6	5
Design Proposal	3	12	10
Design Report	18	10	12
Resource Demand	36	33.5	29
Resource Capacity	36	40	35
Capacity Utilization	100.00%	83.75%	82.86%

Table 1. Resource Allocation

F. Revisions

One major project revision that we came across in the scope of our project was a change in the information provided to us in respect to the arrival of the cheese. Originally, we were told that we would not know the order in which each individual package of cheese would arrive. Thus, it was our responsibility to use the light sensor to determine which variety of cheese each package was and use that collected data to sort the cheese to its proper destination. Later on, the client informed us that we would be given a list of the order of each individual packages arrival, providing us with the variety of each individual cheese. This way, we will not have to rely on the accuracy of the light sensor to determine the cheese's variety. Since we know the order, we do not have to collect that data, we can just enter it directly into our sorting code and the cheese will be sorted accordingly. This will ensure cheese is sorted more accurately and that the customer is receiving the correct order.

III. Project Goals and Objectives

A. Goals

The goals of the project is to develop a delivery system that can increase the productivity of the cheese distribution process from receiving to inventory by eliminating errors and reducing lead time for the customer, henceforth leading to cost savings. In addition, in order to eliminate injuries and ensure employees can use the device safely, we are implementing an ergonomically friendly work environment. Looking to achieve zero workplace accidents, yet produce a fast and efficient system.

B. Scope of the Project

The process we are improving starts at the receiving dock. The workers will unload the cheese and with the help of a transport device, cheese will be delivered to one of the three storage areas. Each storage will be specific to a certain type of cheese

Due to the small scale of the project and resource constraints, we will be unable to build a full size prototype and implement in in a shop. However, we are able to use almost any materials we can get our hands on. Our clients was provided us with two kits that can be used for fabrication: TETRIX and LEGO MINDSTORMS. A 1:60 scale model of the warehouse will be used, while the prototype will be 4ft by 4ft. [1]

Although our prototype does not have a designated budget, we need to ensure cost are minimized. The resources listed in the Mindstorms Elements Inventory (pp 75-76) are $100 each, while the remaining items are $1,000 each (pp 77-80). Eternal items (not included with our current materials) are $5000 +, and need to be approved by the client before use.

There are 3 storage areas we will be looking to transport cheese too using our robot prototype. Each cheese will correspond to a different color block.

Electronic Order Codes

Storage Area	Color	Cheese Variety
1	Red	Gouda
2	Blue	Blue Cheese
3	Yellow	Cheddar

A request is generated and transmitted to the retrieval system using the specific code as follows:

Order Number, Units for Storage 1, Units for Storage 2, Units for Storage 3.

C. Value Stream Map

In order to ensure our team understood the client's request and cheese process correctly, a value stream map was constructed using Visio. The VSM is a vital tool that many industrial engineers use to see where “value” can be added, but also to see where bottlenecks are and where improvements can be made. [3]

The main focus of the VSM is the customer. The customer should be the center of any company, to ensure they are providing the highest quality product and delivery the product in an efficient matter. As it can be seen from below, we split the process into five main steps: Receiving, Unpacking, Inventory, Retrieval and Packaging, and Shipping.

First, the customer places an order. This order is then received by the warehouse, where inventory levels will be continually monitored, and it is determined when and if cheese needs to be ordered from the supplier. Next, the cheese is unpacking and placed in inventory. This is the process, which we as a team, need to build a prototype for. Here, we also used three different colors of triangles to represent the need for inventory separation.

During the inventory stage, the cheese is put through a quality check. Alongside this step, inventory levels are continuously updated and communicated with the ordering team. Finishing up the process, the cheese is then retrieved and packed, then lastly is shipped out the door to the customer. In the end, we have put on a check mark to indicate quality check where the inventory records are stored and sent to the suppliers for future consideration.

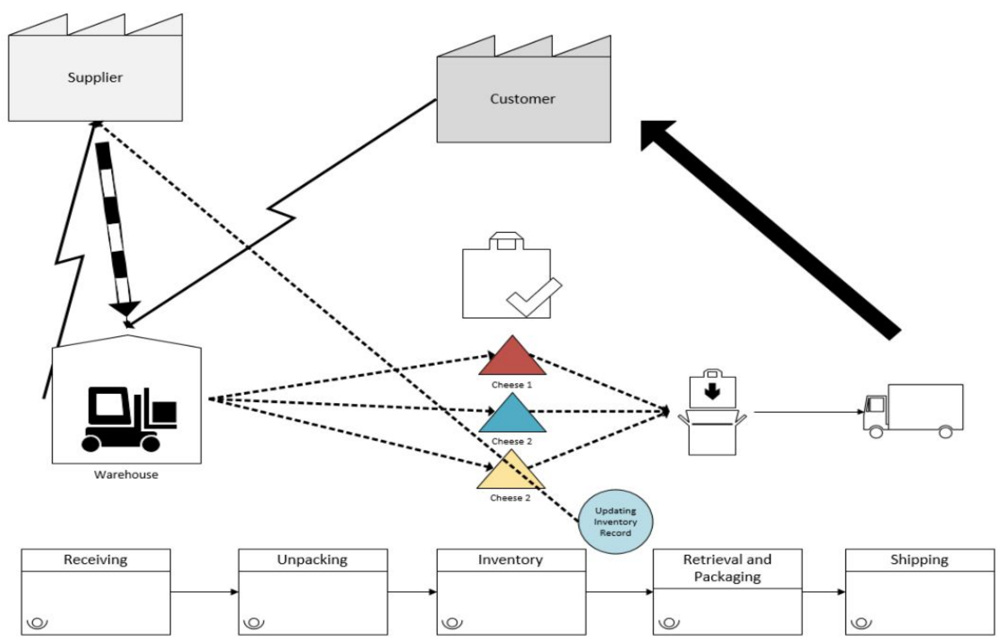

Figure 3 Value Stream Map

D. Critical Needs

As mentioned above in the VSM, we want customer satisfaction to be the number one focus of our project. If the cheese delivery process, from beginning to end, has minimal bottlenecks and is safe, the customer will in return be receiving the highest quality cheese in a short amount of time.

We want to ensure that the client's request is met, that is their no starvation in inventory levels. Need to build a device that will be fast and safe, to transport cheese from receiving to inventory.

Next, another key focus we need to consider in this project is safety. Although this project is only going to be a prototype on a small scale, we want our to ensure our prototype is safe for employees, but also the cheese.

Lastly, to ensure that our customer is receiving a quality product on time, and the client's needs are met, our team needs to take into account communication across the cheese factory. This communication can be within employees and the different steps within the VSM map. For example inventory levels need to be communicated within different areas throughout the plant.

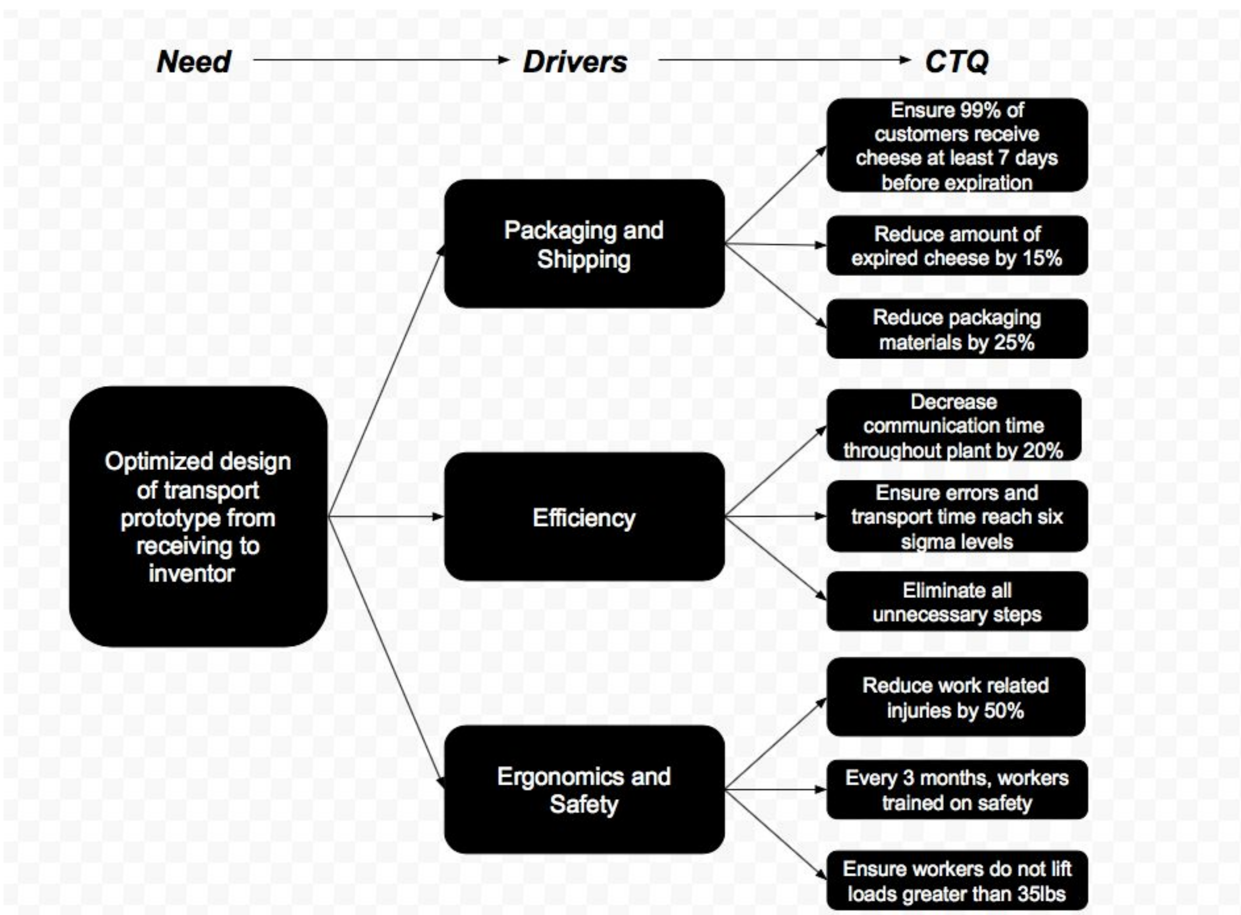

Figure 4 CTQ Diagram

Above is the CTQ diagram. CTQ stands for Critical to Quality. [3] This diagram goes along side to side with the critical needs I talked about in the previous paragraph. As a team, we want to build a prototype that will take into account packaging and shipping, efficiency and ergonomics and safety. Within each of the drivers, we as a team have came up with both quantitative and qualitative CTQs. There are many CTQs listed, however there are a few that we feel we need to prioritize.

With consistent safety training, employees will reduce the amount of injuries at Dairy Land Cheeses and the number of lawsuits or injury files. Customer Satisfaction. This is the main reason why we want 99% of customers to receive our product on time. Although we do not have a large control over delays in shipping, due to our shipping being a 3rd party customer, we can ship fast and early.

The last key CTQ goal to mention is reaching a Six Sigma level. This entails 3.4 DPMO. A defective product would be considered as damaged cheese, an order mix up, or a delay in the shipment of cheese. As industrial engineers, this is something we strive to achieve and we hope our new prototype we build will help us get to this level.

E. Test Plan to Meet CTQs

As Industrial Engineers, one of the biggest things we focus on is continuous improvement. With this project, our goal is to ensure throughout our design process, we are building the most optimal prototype possible. To ensure we are meeting our critical needs and the clients design parameters, we have created a test plan to ensure all these factors are met.

The test plan to meet the CTQs has 3 main factors that need to be considered: Feasibility, Proof-of-Concept and Usability. When looking at the CTQs and goal of the project, we need to ensure our ideas and calculations are possible in both our prototype and if the project were real. Proof-of-Concept, goes along with feasibility, and ensures both our test plan and designs are being thought out and realistic. Lastly, usability needs to be taken into account in order for our client to utilize our prototype with as little ease as possible and make sure the workers using it can accomplish the process at hand.

The test plan we have determined as a team has been to test 100 blocks of cheese once our prototype is complete. This test will allow us to calculate some the CTQs we have determined as a team. Some of these factors we plan to look and collect data on with regards to this test include: retrieval time, transportation time, percentage of cheese damaged, robot errors and lead time. Because of the time constraints of the project, we may not have to take these results and change our prototype accordingly.

F. Limitations

Our test plan aims to help improve our prototype, but there are also limitations that we need to consider as a team. First, our prototype is on such a small scale, that we will not be sure if it will actually work in a real size facility. Second, the resources are finite. The resources we are taking into account include time, materials and money. Lastly, we need to take into account that we will not be dealing with real cheese and real customers. We will not be able to determine if the cheese is damaged or 'hear' if any customers have complained about our product.

As with any task, there will always be interruptions or unexpected events that could affect our testing. If our team does not build a prototype fast enough, we will run out of time before we can test real blocks of cheese. The prototype could also become defective and not function optimally enough to perform testing.

IV. Design Concepts and Problem Analysis

A. Brainstorming

Our group began by brainstorming over 50 design ideas. These ranged from small characteristics we thought we would want to incorporate (i.e. "360 degree turn", "durable material") to overall system designs such as AGV and pivoting robot. After the initial idea brainstorming, we knew there were certain concepts we wanted to focus on. It was important to us that our design allowed the cheese to be sorted immediately and sent to inventory simultaneously and in bulk.

With our most important ideas in mind, we came up with 11 designs organized into an affinity diagram. The smaller ideas that each design encompassed were listed underneath. After multi-voting within our group, the four design alternatives we chose to move forward with in our analysis were a conveyor system, a pivoting robot with a ramp, AGV or automated guided vehicle, and three slides beginning from dispatch.

B. Pugh Matrix

In order to thoroughly analyze the strengths of our design options, we came up with a list of design criteria and weighted them against each other. The table below shows the design criteria with their respective weights and the number of times the characteristic won out during the pairwise ranking we performed.

Option	Tally	Weight (Tally +1)
Brand Recognition	0	1
Building Time	2	3
Output	7	8
Risk of Failure	5	6
Design Parameters Met	8	9
Capital Cost	3	4
Complexity of Assembly	2	3
Customer Satisfaction	6	7
Process Time per Unit	3	4
Safety	9	10

Table 2. Design Criteria

Safety was ranked the most important criteria in our analysis followed by meeting design parameters, output, and customer satisfaction. We placed brand recognition at the bottom, then complexity of assembly and building time just above that as our least important criteria. They are characteristics we would like to incorporate if possible but are less necessary than those that are higher ranked.

After determining the weights of our criteria, we performed the first iteration of our Pugh matrix. [3] We used the three slides from dispatch alternative and compared it to conveyor, pivoting robot with ramp, AGV, and wheel of cheese in terms of our desired characteristics. Some of the most notable areas of this iteration included all other options performing worse than the baseline in terms of risk of breaking parts and process time. This iteration resulted in the weighted positives minus the weighted negatives of all options being negative numbers besides that of the baseline which totaled zero. This confirmed that the three slides from dispatch was superior to the other options in this iteration.

Key Criteria	Weight	Conveyer	Pivoting Robot with Ramp	AGV	Three slides from dispatch	Wheel of Cheese	Current Baseline Datum
Brand Recognition	1	-	+	S	S	-	Three Slides
Building Time	3	-	-	+	S	-	Three Slides
Output	8	+	-	-	S	S	Three Slides
Risk of Breaking Parts	6	-	-	-	S	-	Three Slides
Design Parameters Met	9	S	S	S	S	S	Three Slides
Capital Cost	4	S	-	-	S	S	Three Slides
Complexity of Assembly	3	-	-	S	S	-	Three Slides
Customer Satisfaction	7	S	S	S	S	S	Three Slides
Process Time	4	-	-	-	S	-	Three Slides
Safety	10	S	-	-	S	-	Three Slides
Sum of Positives (+)		1	1	1	0	0	
Sum of Negatives (-)		5	7	5	0	6	
Sum of Sames (S)		4	2	4	10	4	
Positiives - Negatives		-4	-6	-4	0	-6	
Weighted Sum of Positiives (+)		8	1	3	0	0	
Weighted Sum of Negatives (-)		17	38	32	0	27	
Weighted Sum of Sames (S)		30	16	20	55	28	
Weighted Positiives - Weighted Negatives		-9	-37	-29	0	-27	

Table 3. Pugh Matrix - 1st Iteration

We then made adjustments to the current options and compared the three slides baseline to three conveyors from dispatch, pivoting robot to three slides in center, three AGV, and three slides from a rotating shelf. The most important note in this iteration was the areas in which the three conveyors from dispatch, a design very similar to the baseline, performed worse than the three slides from dispatch. The three conveyors would take longer to building as a result of their more complex assembly needs and would have a higher risk of parts breaking. Additionally, they would have a higher capital costs as energy costs would be incurred. Based on this second iteration, where three slides from dispatch exceeded all other options again, we are confident in our decision to move forward with this alternative.

Key Criteria	Weight	Three Conveyers from Dispatch	Pivoting Robot to three slides in center	3 AGV	Three slides from dispatch	Three slide from rotating shelf	Current Baseline Datum
Brand Recognition	1	S	S	-	S	S	Three Slides
Building Time	3	-	-	-	S	-	Three Slides
Output	8	+	S	-	S	S	Three Slides
Risk of Breaking Parts	6	-	-	-	S	-	Three Slides
Design Parameters Met	9	S	S	S	S	S	Three Slides
Capital Cost	4	-	-	-	S	S	Three Slides
Complexity of Assembly	3	-	-	S	S	-	Three Slides
Customer Satisfaction	7	S	S	S	S	S	Three Slides
Process Time	4	+	+	-	S	-	Three Slides
Safety	10	-	-	-	S	-	Three Slides
Sum of Positives (+)		2	1	0	0	0	
Sum of Negatives (-)		5	5	7	0	5	
Sum of Sames (S)		3	4	3	10	5	
Positiives - Negatives		-3	-4	-7	0	-5	
Weighted Sum of Positiives (+)		12	4	0	0	0	
Weighted Sum of Negatives (-)		26	26	36	0	26	
Weighted Sum of Sames (S)		17	25	19	55	29	
Weighted Positiives - Weighted Negatives		-14	-22	-36	0	-26	

Table 4. Pugh Matrix - 2nd Iteration

C. Designs

Conveyor System

The first alternative we considered was a conveyor system. The system consisted of 3 conveyors starting from dispatch that would carry each type of cheese to their respective inventory locations as shown in Figure 5. The beginning of the conveyor would be equipped with a light sensor to sort the different types of cheeses immediately. The conveyor system was strong in its output and process time. The figure below lays out how the cheese would be transported from receiving to inventory through this system. While we felt this was a strong design, ultimately it was not feasible to build in terms of materials and time constraints.

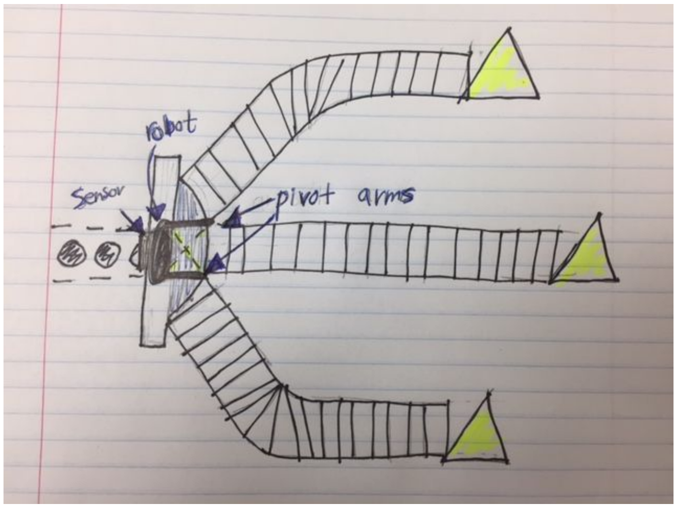

Figure 5. Conveyor System Sketch

Figure 6. Conveyor System Process Map

Automated Guided Vehicle

The second alternative analyzed was an automated guided vehicle or AGV. This design would utilize the robot we built in class to transport cheeses from dispatch to inventory. It would also incorporate a light sensor and be able to move cheeses in bulk to their correct inventory locations. The AGV had a quick building time but slower process times and lower output. It was also deemed less safe than other alternatives as its motion is not as controlled.

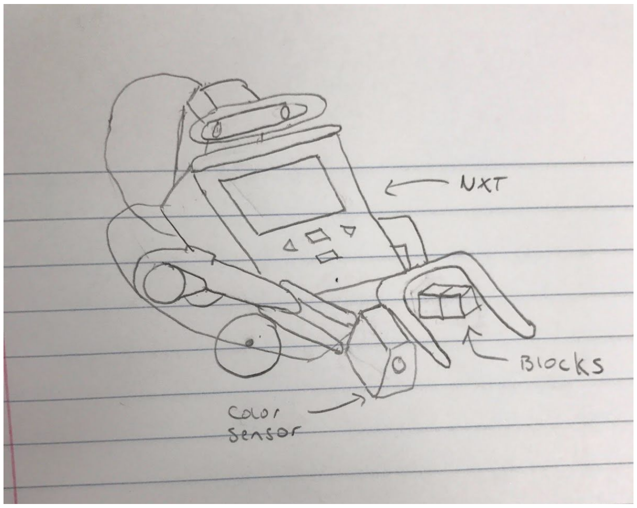

Figure 7. AGV Sketch

Figure 8. AGV Process Map

Pivoting Robot with Ramp

The third alternative evaluated was a pivoting robot with a ramp attached to it. Unlike other options, this design would not sort cheeses immediately and would instead incorporate a revolving shelf where blocks would eventually be pushed down the slide into inventory one by one. We quickly ruled out this design when it performed below the baseline in nearly all categories during our first Pugh matrix iteration.

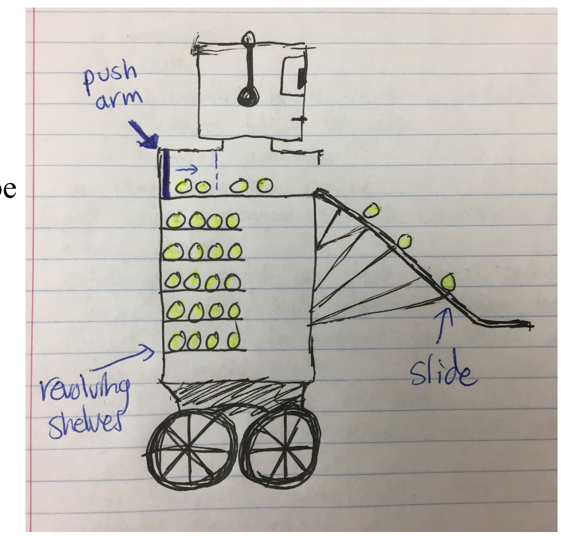

Figure 9. Pivoting Robot with Ramp Sketch

Figure 10. Pivoting Robot with Ramp Process Map

Three Slides from Dispatch

The final alternative analyzed, and the design we ultimately chose, was a system of three slides starting from dispatch. This design was similar in concept to the three conveyor system but outperformed it in multiple areas. In order to make this alternative efficient, the blocks of cheese would be raised up to a mezzanine area but a robot where they would be sorted by a light sensor before sliding to their inventory locations. This is efficient because there is only a short distance for the robot to travel, minimal steps in the process, and minimal labor requirements. This design will also be more energy efficient and cost efficient than the conveyor system.

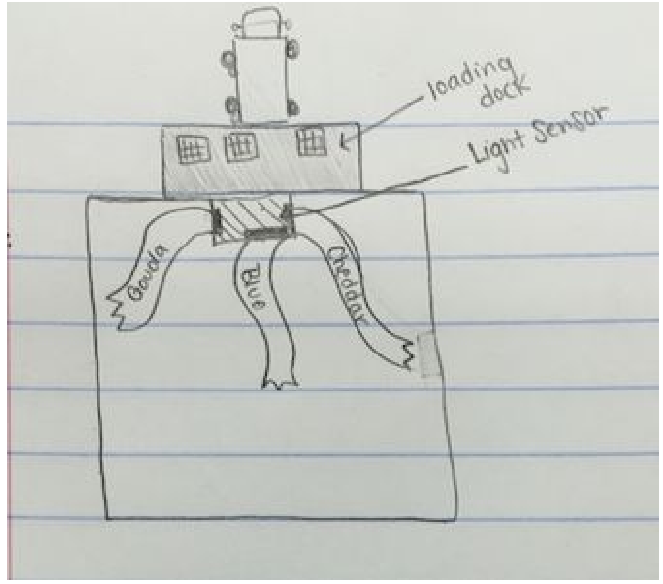

Figure 11. Three slides from dispatch sketch

Figure 12. Three Slides from Dispatch Process Map

V. Design Approach

A. Approach

After taking into consideration the feasibility of approach, our team chose to modify the three slides from dispatch design. We determined that the vertical lift would be too difficult for the facility to manufacture and execute under the given constraints. Additionally, the feasibility of a basement storage area was not likely. A new design approach would need to be drafted in order to eliminate the basement and vertical lift. Our team again brainstormed how the design could be improved to meet the certain requirements. The solution to combat the vertical lift problem deviated into a angled conveyor that would transport blocks of cheese from the loading area to the elevated sorting mechanism. Since the conveyor has a low coefficient of friction, pads were added to portions of the conveyor to allow for the ascent of the block of cheese. With this new design, the need for a basement would be eliminated since cheese would travel vertically. The new design can be seen in the following sketches.

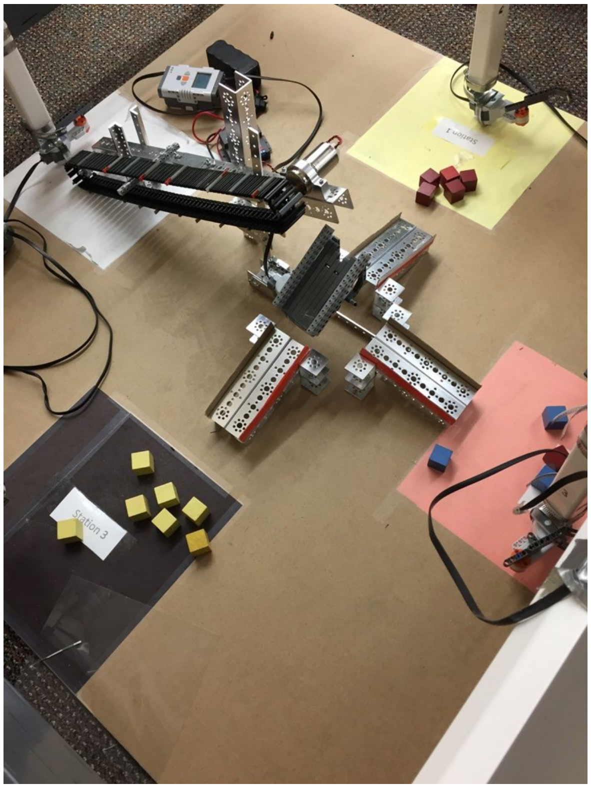

Figure 13. Side View of Final Design

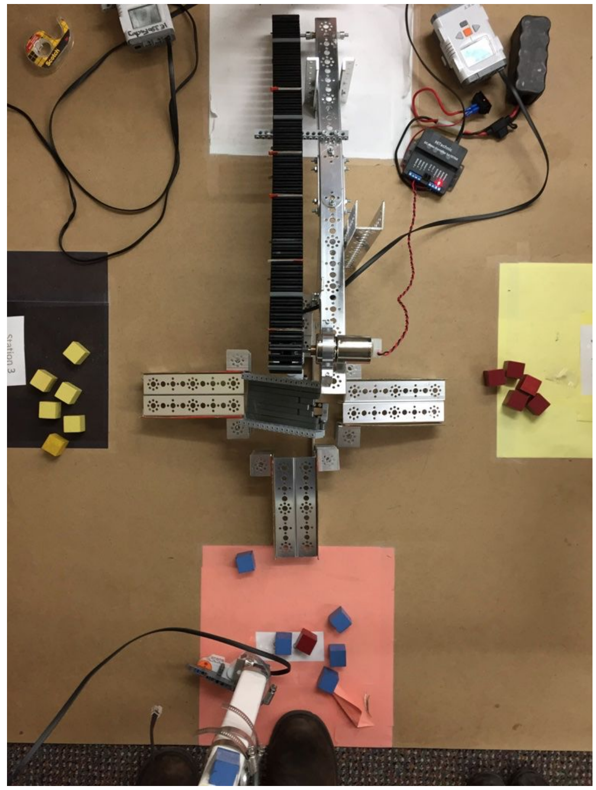

Figure 14. Bird's Eye View of Final Design

B. High End Design Elements

A high end modification our team made to the original design was in the sorting mechanism. Originally, the blocks were to be sorted using a two arms that would direct the blocks down certain slides. Since this design would be difficult to execute and inefficient we set out to redesign the sorting mechanism. Since the conveyor was already created, we needed to use the conveyor components as a constraint. Eventually, we came up with the design of a mechanism that would rotate 270 degrees to guide the block of cheese from the conveyor to the particular slide in which it is to be sorted. The sorting mechanism would be angled as such to keep the momentum from the conveyor going to allow for the blocks of cheese to go down the slide. The sorting mechanism also needed to be coded correctly to ensure no errors were made in the process.

C. Implementation

After careful execution, a prototype was designed and implemented. To build the conveyor, we used the conveyor building material given to us in the Tetrix kit. Metal rods were used as the support structure for the conveyor. A motor was used to power the conveyor and make it move vertically. Wheels and gears were used to help the conveyor to move smoothly. The final design for the conveyor can be viewed in the following pictures.

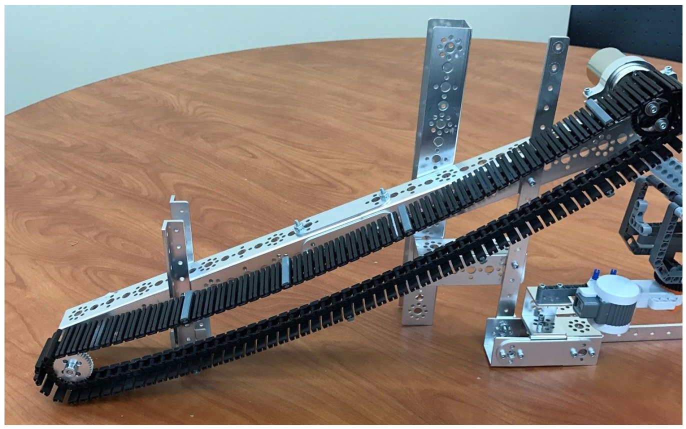

Figure 15 Conveyer System Used to Transport Cheese

In building the sorting mechanism, we used the legos from the Tetrix kit. The legos were then attached to the tetrix motor to guide the slide to move to the correct slide. The final design for the sorting mechanism can be viewed in the following photos. Our team also had to a code the sorter to ensure it was reaching the right inventory location. [2]

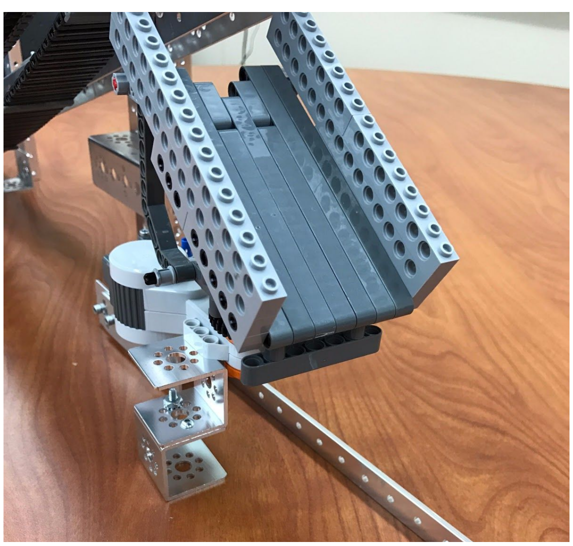

Figure 16 Front View of Sorting Mechanism

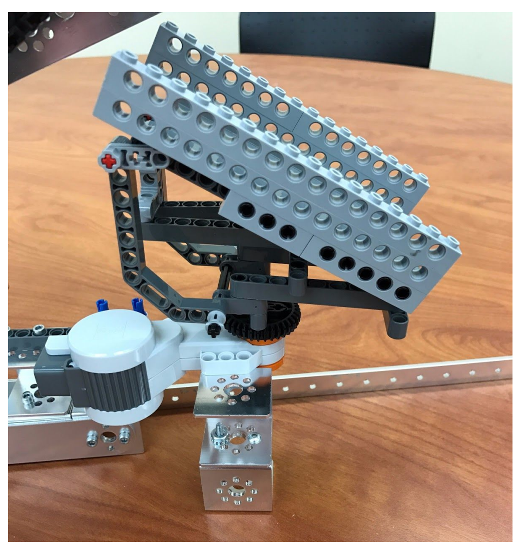

Figure 17 Additional View of Sorting Mechanism

Slides were built using metal rods. Cardboard was then attached to the sides of the slides to create a guard railing so the blocks of cheese would not fall off the slides. The slides were the propped up using metal blocks. The final prototype is the following.

VI. Project Execution

A. Challenges and obstacles

During the coding section, one of the major obstacles that we have encountered is the unresponsiveness of the device in the programming part. After consulting with the TA, we have found that there are some issues with the setting of our laptop, thus we request a new laptop from the TA to work on. Another obstacle that we have faced during our lab session is to set the proper parameter and values with for our motor programming. In order to ensure the block to be transferred stably, we have attempted several tries and eventually tested out the proper speed values in the program. With our selected speed value, we also tried to adjust the angle of the conveyor correspondingly.Besides angle adjustment, we also add some cardboard cut pieces along the conveyors so as to make sure the blocks not fall out during transportation. Moreover, building the system that connect the conveyors with the controllers is also challenging for us. The wiring and connections setting up did not work out smoothly in the beginning, so we requested a new set of wires and have done some trials to identify the problematic part.

Figure 18 Displays the wheel used for the conveyer

In trying to execute our final design, we ran into challenges with both the building of our prototype. The initial conveyor was too long the first time we placed it in the distribution center. The end extended past the center point of the floor and would have required the slides to be positioned so that the blocks would slide back in the opposite direction towards their respective inventory locations. This was unproductive and meant we were using too many resources on the conveyor. First, we tried to correct this by increasing the angle of the conveyor so that the end point was in the center. However, this higher angle was too much for the blocks to easily go up the conveyor. We resorted to rebuilding the conveyor by taking it apart and placing a shorter metal rod connected to the track. After this revision, our conveyor reached the desired center location.

Another complication we ran into with our prototype was the height of the starting point of the conveyor. As a five person group, we need to ensure that we do not need to lift the blocks of cheese more than approximately 0.5 inches at the beginning of our demonstration. The wheels on our first conveyor, displayed on the left of the photo, were very large and caused us to have raise the blocks much higher than allowed. Once we discovered that the size of the wheel did not inhibit the ability of the conveyor to turn, we took off the large wheels and replaced them with smaller ones, on the right, which corrected our height issue.

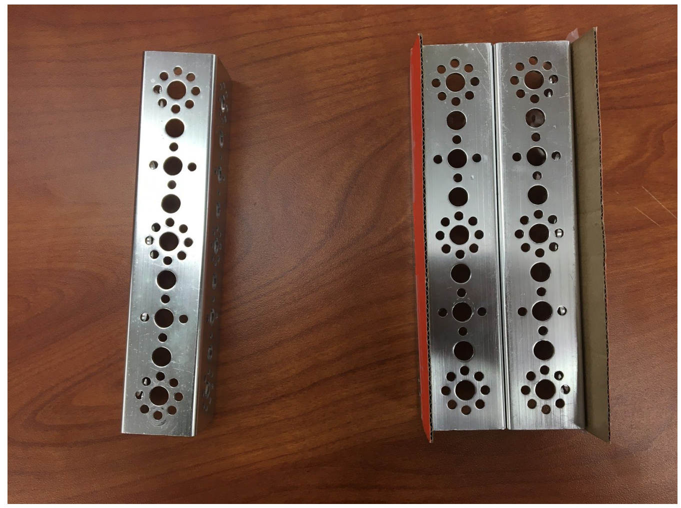

Figure 19 Slides Used for Cheese Transport to Inventory

Our original plan involved using a singular metal rod, as displayed on the left side of the picture, with reinforced cardboard sides for each slide to inventory. Before implementing this however, we realized that the base of our sorting mechanism was too wide to ensure that the blocks would land on the rod after being sent to their correct inventory location. We wanted to keep the wide surface area of the sorting machine to avoid blocks missing it after dropping off the conveyor, so decided to change the slides to meet the width of the sorting platform. Therefore, we made the slides two metal rods, on the right, placed side by side and held together with sturdy tape.

The last big challenge we had when designing the conveyer system, was getting the motor to run. This involved trial and error with the set-up with the motor. The first problem we came across, was just understand how to orient all the tools and determine where everything fit in. After finding an online guide, the motor was set up exactly as shown. After looking at each component, it was determined the the actually battery was not charged fully. Charging and changing the battery was an easy fix to the problem.

Two more problems were discovered with the battery. After tinkering with the switch, battery and motor, our TA helped us determine that the circuit in the battery got blown, meaning there was no current running from the battery to the motor. A new circuit was inserted, yet the motor and conveyor were still not running. Luckily it was easy to determine the issue; the wires were not screwed into the motor controller fully. With a few quick turns of the screwdriver, the battery, motor and conveyor were all working effectively.

B. Project implementation

To ensure our project stays on the schedule, we managed to set up some milestones every time met. In reality, the design team has performed exceptionally and thus they are ahead of the schedule by several weeks. On the other hand, the coding team fell a little bit behind due to the technical issues of the laptop. So our team member adjusted their schedules accordingly. From the Gantt chart, the design team is observed to be on the right side of the graph. Therefore, we will have extra time to review and work on the design.

As mentioned above, the Gantt chart was a very useful tool to help us stay on track with the project, and as a team, we were even ahead of it sometimes when it came to design construction. Most of the time was spent determining how we were going to make the conveyor apparatus, and the device we would use to sort the cheese accordingly.

The project is on time and a demonstration of our prototype will be presented to the client on Wednesday December 7th. Before this session, we need to run our system several times to alleviate any errors and make any additional revisions to our design. With limited time to test our system, we must effectively use the limited time that we have as a team.

C. Revisions

Revisions were ongoing during our project. As mentioned above, our design continuously changed throughout both the brainstorming and building portions of the plan. We consulted with our client at multiple different times, which is not displayed in our Gantt Chart. This was a scheduling change we made as we realized we needed more than a one week period to get our design questions answered. Additionally, our project testing went longer than anticipated and had to be accounted for when planning how to meet our deadline.

VII. Performance and Test Data

After fabricating the prototype and going through the engineering design process, our team came to the testing stage. This stage is vital to ensure the product our clients receives meets their requirements, operations and functions effectively but most of all that it is safe for the employees to use or be around. Throughout the fabrication of our project, we have been altering our design to ensure it would operate effectively at the end and the end part of the testing is to ensure our efforts have been shown.

In order to test the operation of blocks of cheese, we first game up with a test plan. For the test plan, our goal was to really not only quantify our system performance, but see if its characteristic met the CTQs that our team created at the beginning of the design process. The test plan was very simple and we wanted to run 70 blocks of cheese through our system. During these different test runs of the different blocks of cheese we would be collecting data on the following information: transport time (how long cheese takes to get from receiving to its respective inventory location), the number of cheese blocks damaged (ex. Block falls off conveyer or does not reach inventory location) and lastly if the cheese was defective (meaning it was put in the wrong inventory location).

In order to collect data, there were two team members with stopwatches and excel up on their computers. They would alternate timing and recordings of errors for the various cheese blocks. The time would start when the cheese was put on the conveyer and would end when it reached its inventory location. Another team member was in charge of placing the cheese on the conveyor.

After performing the 70 tests runs and analyzing the data, the distribution of the transport time of the blocks can be seen below. The interarrival time was 6 seconds because we coded our program like this to ensure the cheese blocks would never overlap.The average time of transportation was 6.77 seconds for the cheese and the range was quite large (around 3 seconds). It is a little concerning for this time to have such large variation, due to the fact that cheese was placed at slightly different locations on the conveyer. The transport time was also affected by if the cheese hit the walls of the sorter or the slides. In the future, our team would try to reduce the variation by standardizing the process even more and ensuring the cheese follows the same path every single time.

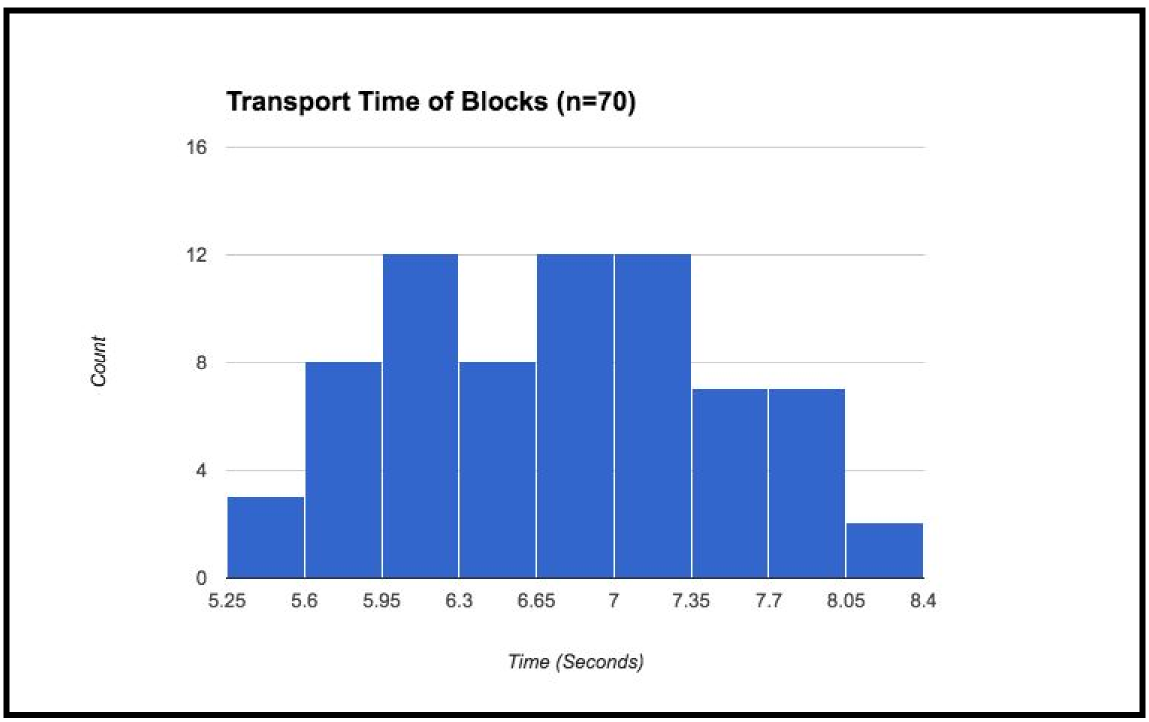

Figure 20 Transport time of the n=70 blocks of cheese tested

Out of the 70 blocks of cheese that we tested, 4 pieces of cheese, or 5.7% of the blocks were damaged. All of the blocks that were damaged did not fall off the conveyer, instead did not make it down the slides completely. This error was due to the fact that the sorter did not line up the the slides perfectly sometimes. This problem would be easy to fix in the future by making the sorter more stable. Overall 2 blocks of cheese, or 2.8%, were defective, meaning the block reached the wrong inventory location. This error was caused by human error and coding. The blocks were placed on the conveyer too late or at the wrong time, so the sorter was facing the wrong inventory location corresponding to the color of the block. The error was fixed and when the test run was performed in class none of the blocks reached the wrong inventory location.

Analyzing the test results and looking at the functionality of the transport system we have created, it is clear that our system meets the client's requirements and will perform. At the beginning of the project we created specific CTQs for our project and I wanted to note what the current status of these CTQs is. (Note: The CTQ Diagram is Table 2 in Design Concepts & Analysis). There were 3 areas our team wanted to focus on: packaging/transport, efficiency/accuracy, and ergonomics/safety.

Packaging/Transport	**Efficiency/Accuracy**	**Ergonomics/Safety**
Quicker Material Handling	4 Damaged Cheeses	Minimal Lifting and Handling
Less Opportunity for Errors	2 Defects	Railings on Slides
	Simple & Precise Design	Supports on Conveyors

Figure 21 Final Status of CTQs

The first section, packaging/transport is hard to quantify but our system is very simple meaning there are few opportunities for errors. This allows employees to follow a very standardized process. Due to minimal employee interaction with our system, that with eliminate human errors.

The second indicator is efficiency and accuracy. This information can really be reflected in the tests that we ran. As stated earlier our system had an average transport time of 6.77 seconds. During our test run 4 blocks were damaged and 2 were defective. The percentages for these measures were not as low as we want, but we only have 70 test runs and minimal time to ensure that our system was reaching six sigma levels.

Lastly, looking at ergonomics and safety, our system ensures employee safety is of utmost importance. There are railings on the slides so the cheese does not fly off and there are supports on the conveyer so the cheese does not fall back on the conveyer. In the future, inserting railings on the side of the conveyer would be ideal, but also making the railings taller on the slides. One last thing to note is that our system just requires the lifting/handling of the cheese at the very beginning when it is placed on the conveyer. After this beginning step, the operator does not interact with the machine until it needs to be moved from inventory.

VIII. Opportunities for Improvement

Although we have put much thought into our work and are confident in the quality of our design, there are still areas in which the final product can be improved upon. First, we figured that if the prototype was life-sized, the torque required to rotate the large sorter would be very large and thus would require unnecessary amounts of power and energy. Therefore, we decided it would be beneficial to decrease the length and weight of the sorter so that it would rotate easier. This would require us to lengthen our slides to reach the sorter, but this is not a difficult task.

We also experienced some difficulty with our cheese blocks slipping. We did the best we could with the materials we had access to, but we were not able to completely fix the problem. One way we could prevent block slippage on the conveyor could be adding specific slots in the conveyor that would keep the cheese secured in place. Or we could perform tests to discover material combinations that produce the optimal friction levels needed for the cheese to slide down the slides smoothly. We could also play with varying friction levels so that we would have more friction on the bottom of the slide and less on the top so that the cheese slows down before crashing full speed into the inventory storage area.

There are a couple other potential improvements that would help us with error prevention. Please see our FMEA chart for full analysis. [3] According to our FMEA, we should be concerned about the handling of the cheese to ensure that it does not get squished or the package does not get ripped. This can happen quite easily if the cheese is not handled with care and can ruin the product completely, leading to customer dissatisfaction. We decided we could prevent this by making sure that all employees are trained properly and that the machine has cushioning to lessen the force of impact as the cheese moves through the system. We also should be concerned about cheese being distributed to the wrong inventory storage area. We decided that we could fix this by assigning clearly assigned intervals for each block of cheeses arrival and having a detection system that automatically stops the system if there is more than one block of cheese within the interval. That way, a worker can fix the problem before it progresses. We also thought that we could put a cage at the end of the sorter to prevent cheese from dropping where we don't want it to drop. The cage will remain closed until the sorter is aimed directly at an inventory area. This way we do not lose cheese in the weird transition time when the sorter is rotating between inventory areas.

Item/ Process Step	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Cause(s) of Failure	Occurance	Current Controls	Detection	RPN	Recommended Actions
Cheese Recieved from Delivery Trucks in Known Order	cheese squished	Customer Dissatisfied or Dairy Land Chesses has a loss	7	poorly handled	10	no current controls	7	**490**	Train employees to handle cheese properly
	cheese gets hot and spoils	Loss of product	4	temperature not regulated in truck or not moving cheese quickly	7	refridgerated trucks; warehouse kept at low temp; multiple laborers ensure that truck is unloaded promptly	7	**196**	Monitor speed of cheese transfer to ensure cheese is exposed to minial temperature change
	cheese gets misplaced/lost	Customer may not recieve order	7	poorly handled	6	inventory checked at multiple points such as when truck is loaded and unloaded; cheese is moved methodollically	5	**210**	Current control is adequate
Workers Transfer Cheese to Vertical Conveyor	order messed up	Customer recieves the wrong order and is dissatisfied	7	Computer problem or error in retrieval process	4	cheese loaded one at a time; workers are given ample breaks as to retain focus	6	**168**	Implement error prevention system such as machine beeps when it detects cheese place on conveyer in order different than that provided
	cheese gets misplaced/lost	Cusomter may not recieve order	7	Instructions not clear	4	inventory checked at multiple points such as when truck is loaded and unloaded; cheese is moved methodollically	6	**168**	Current control is adequate
	worker strains back from bending and lifting	Expensive lawsuit and/or work takes paid time off work	10	Lack of proper training and supervising	3	proper lifting techiques are taught to the employers prior to working; ample breaks to avoid fatigue	1	**30**	Current control is adequate
	worker drops cheese (messes up interarrival time)	Loss and customer may not receive order	7	Lack of proper training	10	machine can be stopped so that the cheese can be placed on its appropriate spot in order on the conveyor as to not mess with timing or the cheese arrival interval	5	**350**	Current control is adequate
Sloped Conveyer Moves Cheese up to the Mezzanine Sorting Area	cheese slips	timing messed up, cheese not distributed properly	4	slope too steep, conveyor not tight	10	we have ridges on our conveyer that function to grab the cheese and provide a ledge that slipping cheese cannot slip passed	3	**120**	Replace ridges with compartments that workers can place cheese in
	conveyor snaps	Customer will not receive order	10	Stress	1	We hopefully have utilized materials in the construction of our conveyor that are reliable and strong enough to avoid breakage. We also will perform routine maintenance to proactively prevent issues due to wear and tear.	4	**40**	Current control is adequate
	battery dies	Customer may not recieve order	7	Lack of regular check	4	Routine mainatenence and battery checks	4	**112**	Current control is adequate
	something gets jammed	timing messed up, cheese not distributed properly	4	Conveyor misfunction	5	When training employees, stress the importance of keeping the work station clear of clutter	4	**80**	Increase systematic monitoring
Cheese is Distributed Based on Type to Corresponding Slide	cheese delivered to the wrong slide	Customer order delayed	7	previous problem causing change in arrival time	8	No current controls	7	**392**	Routine inventory check
	cheese directed to area between slides (misses slide)	Loss of product	4	previous problem causing change in arrival time	8	The time that the rotating sorter is directed between inventory storage areas is minimal compared to the time that it is directed at any storage area. This way, cheese is not completely lost, jsut misplace. The better of two evils.	7	**224**	Add a gateway at the mouth of the sorter so that cheese can only leave when sorter is facing an inventory area
	robot code fails	Cheese got sent to the wrong destination	6	Insufficient testing on code	3	No current controls	5	**90**	Routine system testing
Cheese Follows Slide to Inventory Storage Area	cheese falls off the slide	Loss of product	4	borders are not stable enough	9	We have ridges on our conveyer that function to prevent cheese slippage. We also have borders on our slides and conveyer that keep the cheese from falling of the edge	8	**288**	current control is adequate
	cheese gets stuck on slide due to friction	delay of arrival or product jam	4	slide not steep enough, or too much friction	9	We hope the slope is steep enough, we also have employees keeping an eye on the production so they can help make stuck cheese loose again.	8	**288**	Decrease friction through the manipulation of slide tempt and addition of slick coating on the slide
	packaging rips	Damaged Goods	4	too much friction, cheese not handled carefully	5	Slide routinely dusted to keep friction low and checked for places that might cause high friction and catch	7	**140**	current control is adequate

Figure 22 FMEA Analysis

IX. Summary and Recommendations

Overall, our design has proven to be effective and accurate during testing and demonstration. Since this prototype is built using legos and other cheap materials, the actual implementation of creating this prototype is not realistic under the current design. In moving forward, modifications must be made to the system to create a life-size prototype.

First, we recommend the engineers evaluate the structural support of the conveyor. Although the conveyor was sturdy in our prototype, different loads may affect the structural support in a real life prototype. In addition to the structural support of the conveyor, we recommend a guardrail system along the conveyor to ensure that cheese does not fall off the conveyor. This reduces any potential damaged goods and/or injury to any employees who may be passing by.

A second recommendation is to create an automated loading system. The system depends on the timing of the operator. This timed system may work in the short run with well trained operators, but may not feasible or effective in a real life situation. An automated system to remove the operator completely would be not only the most accurate solution, but also, the most cost efficient. Another benefit of the automated system is that it would reduce the overall wait time in between orders. The automated system could operate under a much quicker loading time constraint since it does not depend on human operator.

Our third recommendation is to modify the sorting mechanism. The sorting mechanism is large and requires large structural support and energy input. The sorting mechanism should be made smaller and more efficient. The sorting mechanism should be placed closer to the conveyor to ensure boxes are not damaged in the transition from the conveyor to the sorting mechanism. In addition, the length and slope of the sorting mechanism should be reduced. Actual boxes of cheese could be damaged by during the drop present in the current model. To ensure maximum customer satisfaction, we highly recommend modifying the sorting mechanism.

Finally, we recommend changing the slide system. The slides should be created so that minimal force should be put on the boxes of cheese during the transition from the sorting mechanism to the slides. A stopping mechanism should be placed at the end of the slide to ensure that the boxes of cheese comes in a reasonable speed and are not damaged. This can be achieved through either an automated catching mechanism or other cheaper alternatives, such such as stopping material placed on the slide.

If all of these recommendations are completed by the design team, the prototype can be transitioned into a final product. With proper implementation, our design can provide a inventory storing mechanism that is both efficient, cost effective, and ergonomically safe. As a design team, we are confident that our design will solve Dairy Land Cheeses' inventory bottleneck problem with certain modifications.

X. Bibliography and Appendices

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