Final Design Report

Blessed by Bucky

Jake Bever

Adam Mitchell

Millie Rolander

Ben Theobald

1.0 Executive Summary

Dairy Land Inc. -- a rapidly growing online distributor of cheese -- currently uses manual labor in order to transport their inventory bins to the proper shipping location to be distributed, resulting in operator fatigue, strain, numerous back injuries, and high absenteeism coupled with operators making selection errors and damaging product due to mishandling. They are in need of an Automated Retrieval System that will improve the efficiency and safety involved with moving inventory from storage to shipping and allow Dairy Land Inc. to meet their growing demand.

This report will summarize the project itself, goals, objectives, requirements specified by Dairy Land Inc., and the current progress in creating the Automated Retrieval System. The resources available and the utilization of those resources for this project will be specified in an Aggregate Resource Table. Additionally, an Activity Network Diagram and Gantt Chart have been created to illustrate the schedule under which we will be operating in order to ensure the delivery of a fully functioning prototype.

The desired outcomes of the Automated Retrieval System for Dairy Land Inc. include reducing the time it takes to complete an order, eliminating manual labor, and optimizing both storage and transportation of inventory bins. With these key requirements in mind, we began the design process by brainstorming different mechanisms, ideas, and concepts followed by organizing them into feasible design ideas. A pairwise comparison was created in order to establish a corresponding weight to criteria of the design. Then, through two iterations of a Pugh Matrix, we were able to select the optimal design, an AGV, similar to the ones utilized by Amazon. It will move fast and freely among the aisles of the warehouse where it is able to retrieve desired inventory bins and bring them to the appropriate shipping location. As it receives order data, it will make the required to decisions to best fill that order.

Since the AGV moves quicker than manual labor, does not fatigue, optimizes storage location, and chooses the best route for completion, Dairy Land Inc. will be able to meet its increasing demand and become the leading online distributor of cheese. Although there is an increased cost to implement this system, it will result in greater profitability in the long run.

2.0 Project Definition

2.1 Purpose:

The purpose of our project for Dairy Land Inc., a small online retail business in Wisconsin, is to reduce the amount of physical work for employees, reduce operator fatigue, strain, back injuries, and high absenteeism. This will be done by improving material handling with the help of an automated retrieval system (ARS). The need for this automated system arose because the company is experiencing increasing business causing problems in efficiency, ergonomics, and quality. Due to the high demand, they have acquired backlog causing significant delays in shipments to customers as well as operator fatigue and strain. We need to construct an algorithm that allows the ARS to fulfill orders in the least amount of time, to increase efficiency and customer satisfaction. It is important to the customers and employees that we implement an improved system that will satisfy the company's needs and allow Dairy Land Inc. to continually grow.

2.2 Description:

Currently, packers are struggling to keep up with orders so they are carrying excessive amounts of cheese from the inventory storage bins so they have a sufficient supply on hand. These excessive cheese storages are causing congestion throughout the warehouse and further reducing efficiency. Our team will work on restructuring the inventory storage in a more dynamic process to increase utilization and meet the fluctuating demands for cheese by referencing historical data and making predictions of anticipated orders. Implementing this dynamic storage process will help reduce congestion in the warehouse which in turn will lead to an increase in packer efficiency. A major part of implementing the dynamic inventory storage is the use of an automated retrieval system. Team Bucky will be designing an automated retrieval system (ARS) for Dairy Land Inc. that moves inventory bins between stations to improve efficiency, ergonomics, and quality while minimizing order fulfillment time and error rate. The ARS will be programmed to automatically return the cheese bins to the optimal spot based on the fluctuating demands and anticipated orders. This will remove a lot of human error from the system and require less manual labor for employees.

2.3 Risks:

Changing so many variables within the facility comes with some risks and concern. Possible risks involved with the ARS include malfunctions that could ruin inventory or other structures within the plant, breakdowns that would stop Dairy Land Inc. from shipping effectively until fixed, as well as someone walking in the path of the ARS and being struck by the robot.

2.4 Scope:

The scope of this project focuses on implementing a more efficient and effective inventory system, establishing a working prototype of an automated retrieval system. The project is scheduled to start on 9/19/18 and must be presented on 12/5/18 with a required midterm design presentation on 10/17/18. Within these dates, there are milestones set by Team Bucky:

1. Team Formation
2. Project Management Plan
3. Design Parameters and Process Capabilities Plan
4. Alternative Design Concepts
5. Design Proposal
6. Proposal Presentation to the Client
7. Failure Mode and Effects Analysis
8. Final Design Report
9. Prototype Delivery and Presentation

To make sure the team will stay on track we will be allocating our time as shown in the Resource Allocation Plan and Aggregate Resource Table shown below.

Resource Allocation Plan

TASK	RESOURCE NEEDED	TIME NEEDED
Design parameters and process capabilities	· All members reading project details · 1 or 2 members writing and organizing information	· 30 minutes · 15 minutes each at any time
Design concepts and descriptions	· All members discussion	· 2 hours during lab
Mid-term design presentation	· Each member contributes to PowerPoint · Review presentation with TA/Ask questions	· At least 2 hours each outside lab hours · TA Office Hours or by appointment
Project prototyping and testing	· The Whole group works with Lego Mindstorms EV3	· All time during lab for 4 weeks
Design proposal	· Each member works on a separate aspect of the proposal	· At least 2 hours outside of class for FMEA analysis and design report

Aggregate Resource Table

Tasks	Lab Time	Time with TA	Time with Prof	Home Work
Formation	1	0.25	0	0
Ground Rules	2	0	0	0
Learning EV3	3	3	0	0
Project Concept	3	1	2	3
Charter Development	3	1	0	5
Brainstorming	3	1	0	0
Presentation	3	1	2	2
Design Proposal	3	1	0	10
Prototype	9	5	0	15
Test	6	5	0	15
Final Presentation Preparation	3	0	1	5
Final Design Report	0	1	1	10
Resource Demand (Hours)	39	19.25	6	65
Resource Capacity (Hours)	39	39	10	N/A
Resource Allocation (Percent)	100	49.35897436	60	N/A

2.5 Resources:

This leads us to the resources required/provided for the project because time is our most valuable resource. Team Bucky is made up of four students: Adam Mitchell, Millie Rolander, Jake Bever, and Ben Theobald. Due to all members of the teams being full-time students we have to be incredibly efficient with our time to give this project the dedication required to produce a working prototype. We will be focusing most of our time to the three-hour lab session every week as well as necessary time out of class required to meet deadlines. Other resources include a Lego Mindstorm EV3 kit, household items, and any parts or equipment we can find in the class's storage closet.

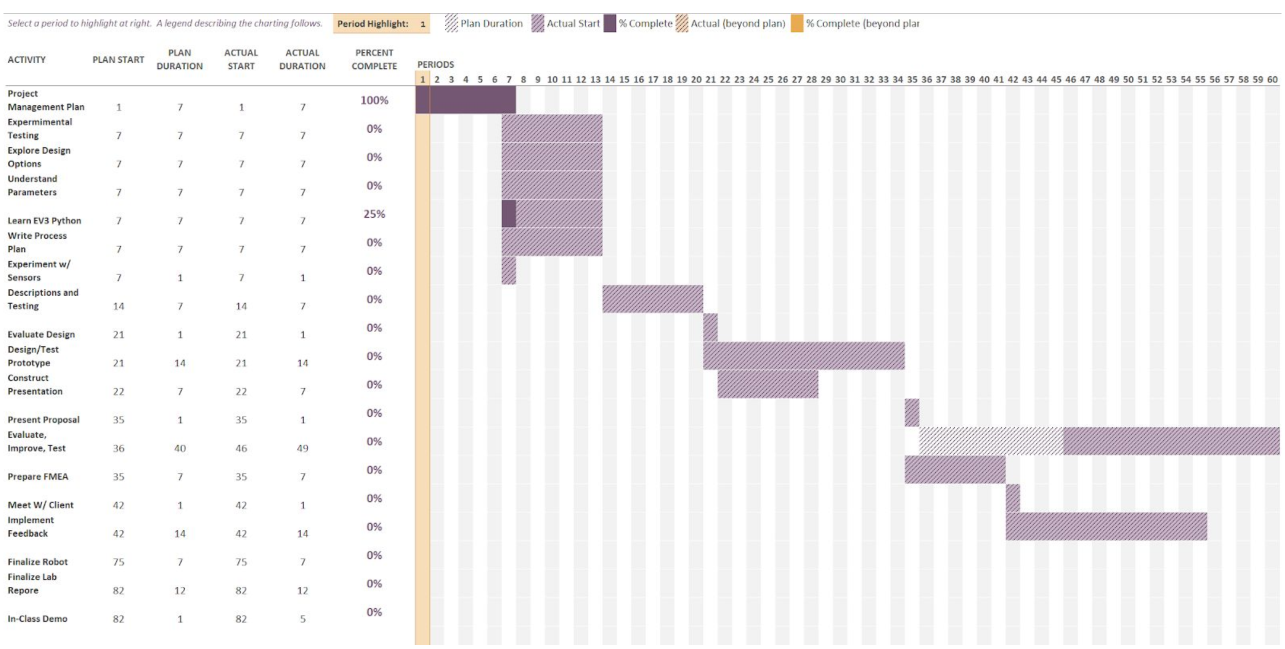
2.6 Deliverables:

The deliverables of the project:

- ○ An automated product retrieval system
- ○ A working prototype programmed to be as efficient as possible
- ○ A demonstration of the prototype to showcase its capabilities
- ○ Presentation on the design process and development
- ○ Final report summarizing product development and research

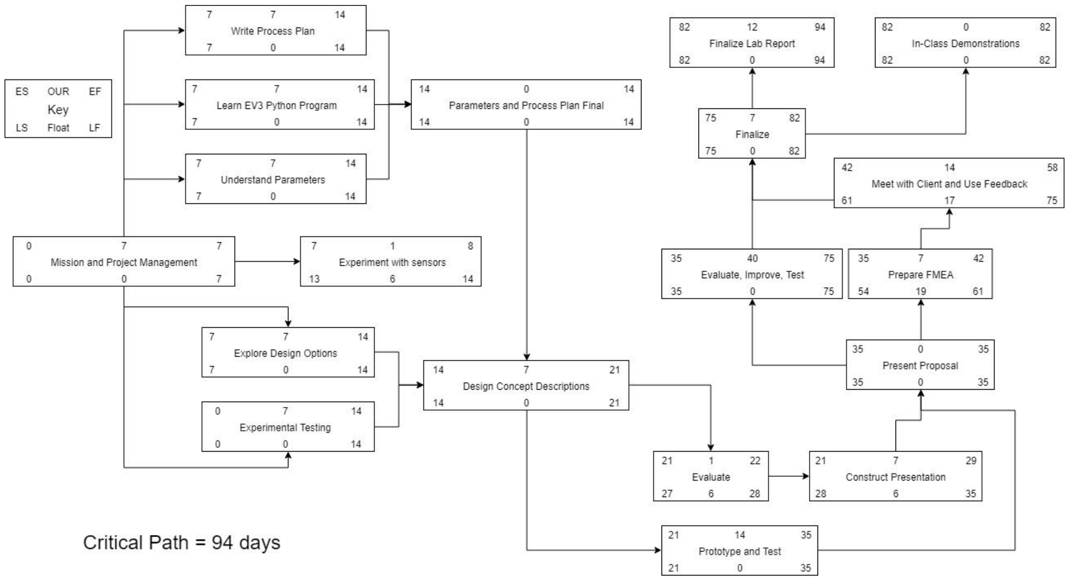
The timeline for the deliverables is organized by the Gantt Chart and the flow of work is shown by the Activity Network Diagram.

Gantt Chart



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project Management Plan	1	7	1	7	100%
Expermimental Testing	7	7	7	7	0%
Explore Design Options	7	7	7	7	0%
Understand Parameters	7	7	7	7	0%
Learn EV3 Python	7	7	7	7	25%
Write Process Plan	7	7	7	7	0%
Experiment w/ Sensors	7	1	7	1	0%
Descriptions and Testing	14	7	14	7	0%
Evaluate Design	21	1	21	1	0%
Design/Test Prototype	21	14	21	14	0%
Construct Presentation	22	7	22	7	0%
Present Proposal	35	1	35	1	0%
Evaluate, Improve, Test	36	40	46	49	0%
Prepare FMEA	35	7	35	7	0%
Meet W/ Client	42	1	42	1	0%
Implement Feedback	42	14	42	14	0%
Finalize Robot	75	7	75	7	0%
Finalize Lab Repore	82	12	82	12	0%
In-Class Demo	82	1	82	5	0%

Activity Network Diagram



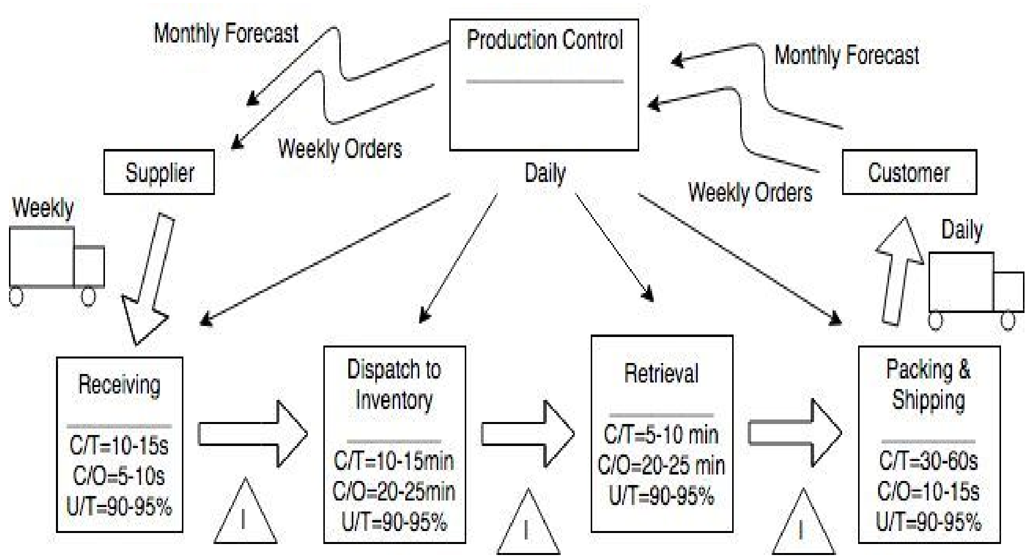
As shown by both the Gantt Chart and Activity Network Diagram, we will be operating on a strict schedule in order to have the final prototype ready to go for the in-class demonstration. From start to finish, there is a critical path of 94 days, meaning all must be complete in that time frame. Many items overlap and have a float value -- meaning the timing of completing that item remains somewhat flexible. If we stick to this schedule, we will be able to deliver a fully functioning prototype, presentation, and final report in the end along with all the deliverables in the process.

3.0 Project Goals and Objectives

3.1 Overview:

Dairy Land Inc. -- a rapidly growing online distributor of cheese -- is seeking an Automated Retrieval System (ARS) to improve the efficiency of their warehouse transportation of cheese from inventory to shipping and back. This is also motivated by a desire to reduce the manual labor involved in these processes as it is resulting in operator fatigue, strain, numerous back injuries, and high absenteeism coupled with operators making selection errors and damaging product due to mishandling. With so many issues negatively impacting the efficiency of their operations, leading to shipment delays and causing congestion, the need to switch to an ARS is absolutely necessary in order to accommodate the constantly increasing demand.

The Value Stream Map below shows the current operations of Dairy Land Incorporated including the receiving, dispatch to inventory, retrieval, and packing and shipping. The map includes weekly deliveries from the supplier as well as daily shipments to customers. Performance measures are displayed beneath each operation, and the goal is to reduce these times as well as the utilization to give the company more of a capacity cushion.

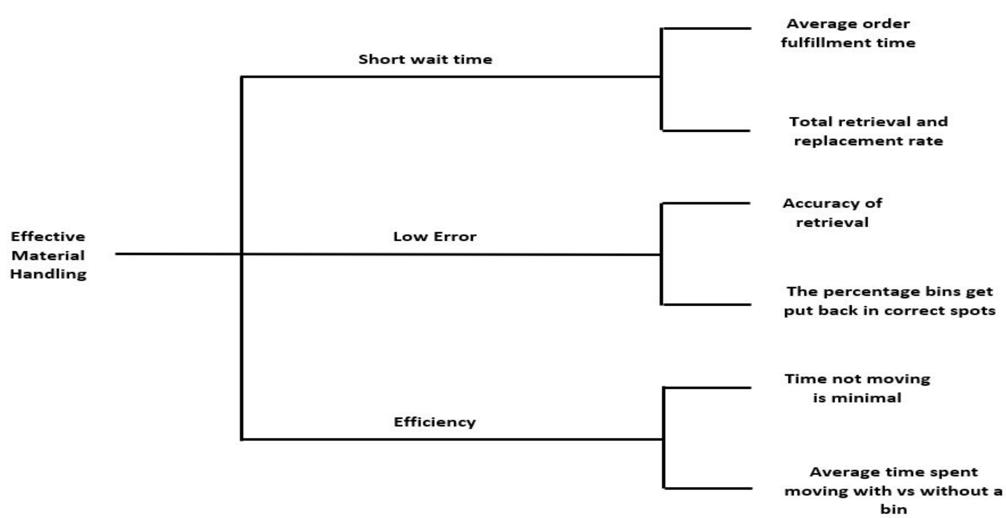


3.2 Customer Specifications:

After reading the project description and speaking with the customer, there are some obvious specifications required in this project we have to work around. We found the customer would like the ARS to transport the cheese inventory bins from storage to the appropriate packing location. After bringing a bin to its packing station, ARS must return the bin to the most efficient, vacant spot using an algorithm based on anticipated orders and product value. This means the inventory will now be based around dynamic storage and the ARS must continuously track the locations of the bins. There will be a total of five bins on six SKU's leaving two empty spaces for the robot to place a bin each time. The bins can only be placed in the locations: B2, B4, D2, D4, F2, and F4. Every time the robot picks a bin, it must bring it to shipping station one, two, or three. These stations are organized based on the geographic regions the cheese is being shipped to. The ARS must initiate changes in the location of the inventory bins, although the process of moving the cheese can be done manually with costs for time and labor.

3.3 Design Evaluation and Criteria:

The overall goal of this project is to increase effective material handling. This is a very general goal that is very hard to quantitatively measure and track. The Critical-To-Quality Tree breaks this broad goal into more measurable categories show below.



As seen in the CTQ tree, effective material handlings can be broken down into three key aspects of the design: short wait time, low error, and overall efficiency. These categories can then be further broken down into concrete measures to analyze whether that goal is being met. To accomplish a short wait time, we plan to minimize the average order fulfillment time by having the AGV operate at high speeds and begin fulfilling orders as soon as they are received. Furthermore, minimizing the total retrieval and replacement time can be accomplished by optimize our software so that the AGV chooses the nearest inventory location to the packer when fulfilling an order. To reach a low error percentage, the AGV must both accurately retrieve the inventory corresponding with the order it is fulfilling and replace the bin in the correct spot which can be accomplished by the AGV continuously updating the location of each type of inventory at all times and its own location on the grid. To achieve maximum efficiency, the AGV must spend the majority of its time moving and with a bin in its storage compartment. This can be accomplished by the minimizing the downtime while inventory is being loaded or unloaded, beginning the succeeding order immediately upon completion of the current order, and if the order is fulfilled prior to the next order being received, it can use predictive analysis based on order history in order to optimize its resting location on the grid. Through programming the robot to meet these expectations, it will succeed in fulfilling the critical, overarching goal of effective material handling.

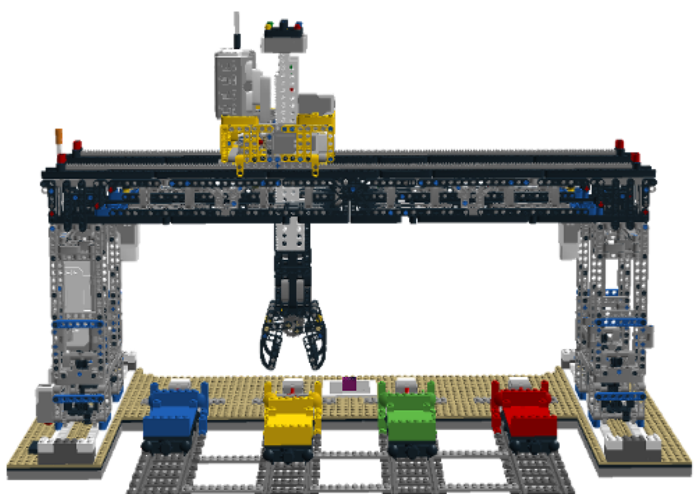
4.0 Design Concepts and Problem Analysis

Brainstorming Results:

For the brainstorming activity, all members of the group wrote down their ideas for possibilities of our prototype for the project. Among the groups, we came up with ideas relating to the overall structure of the prototype, the actual process we would need to consider, the coding behind the machine, and other basic considerations and limitations. In this process, we came up with four alternatives as well as many of our goals for coding and for the system in general. This provided us with the framework and helped us realize we all had similar ideas and goals for the project.

4.1 Design Concepts

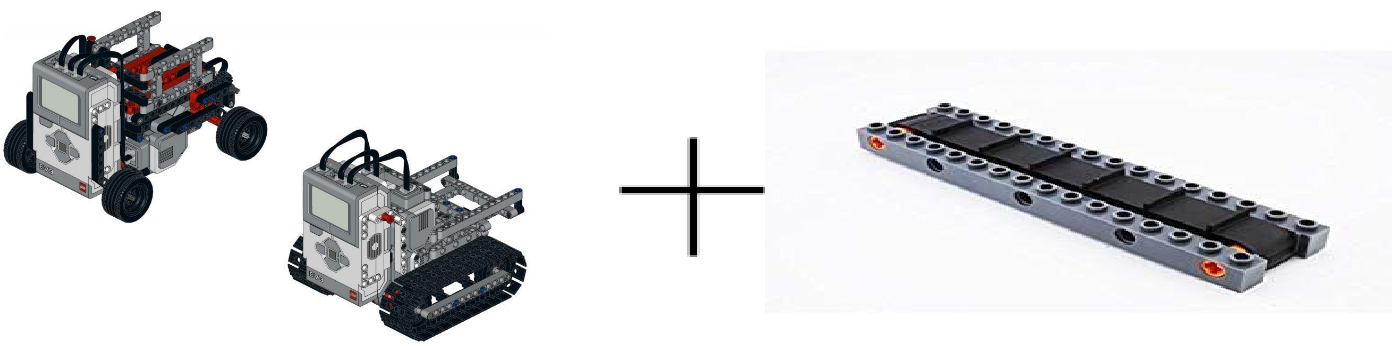
Alternative 1: Crane



An idea for an efficient way of retrieving the bins and cheese blocks for each specific order would be building a crane mechanism. This mechanism would have 4 legs, each built in the corners of the grid. The structure would have the shape of a rectangular prism and would have a sliding device and an attached claw. A benefit of this design is the speed because the device is able to lower the claw and move along the axis simultaneously. It can move above SKUs, hence reducing time by moving diagonally. A disadvantage to this is the feasibility of the construction a large enough structure to compensate for this design and the coding of this device.

This option addresses many components from the Critical to Quality Tree, one being the "time not moving is minimal." Because of this option's constant, 3-dimensional motion, the claw machine would be moving up and down and the sliding mechanism would be moving horizontally and diagonally. This constant motion would also contribute to the "total retrieval and replacement time" because of how quickly it is processing the orders.

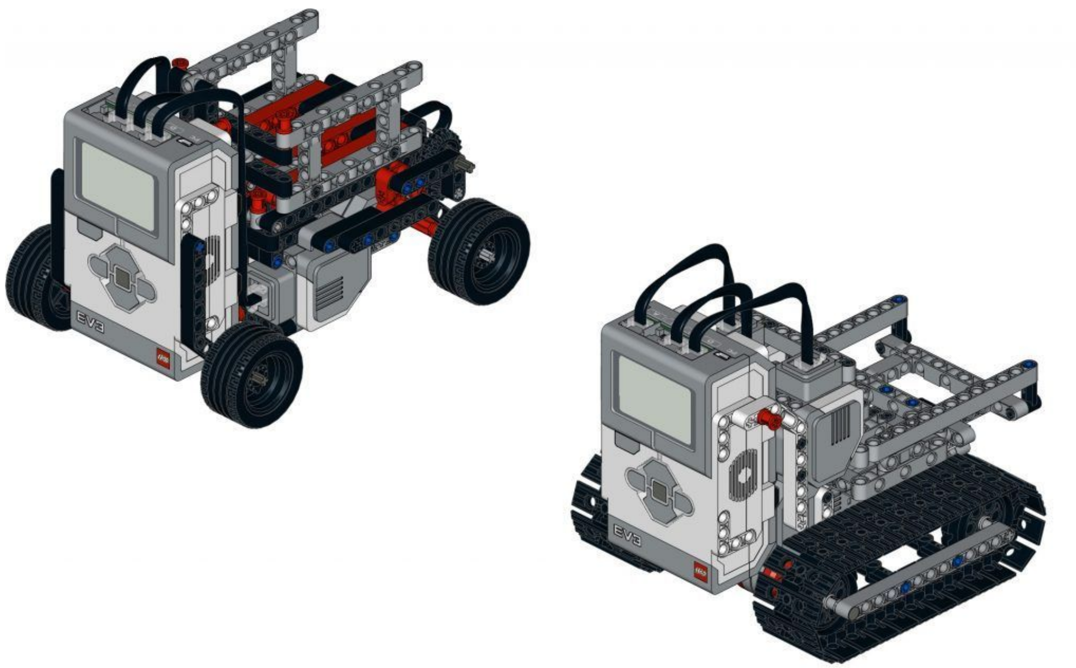
Alternative 2: Automated Guided Vehicle with Conveyor



In order to minimize the total movement of the AGV a conveyor belt could be used to transport blocks of cheese to the assigned packer. Belts would be placed on two sides of the grid, allowing the AGV to drop off cheese directly behind the bin it picked up from. The direction the belt is moving would be determined by which packer the cheese is heading to. This idea is efficient because it minimizes the movement of the AGV and would be very quick. The downside to this is the difficulty of coding two different entities simultaneously as well as the feasibility of its functionality. If the AGV were to be working faster than the conveyor belt, this would result in incorrect cheese blocks in shipments.

This option also succeeds in many of the Critical to Quality Tree ideas. The AGV would excel in the "accuracy of retrieval" because of its dependability. There is nothing risky about this design, and the robot just needs to know how far it is moving in order to go to the correct SKU and bin. The robot also excels in "the percentage bins get put back in correct spots" because as long as the robot is programmed correctly, this should be one hundred percent. Although this alternative does well in these areas, the “time not moving is minimal” is not necessarily true. We have allocated a specific amount of time to stop to ensure the workers are able to load the bin into the storage compartment. This time may be excessive, but it is necessary to reduce orders if there is a worker delay.

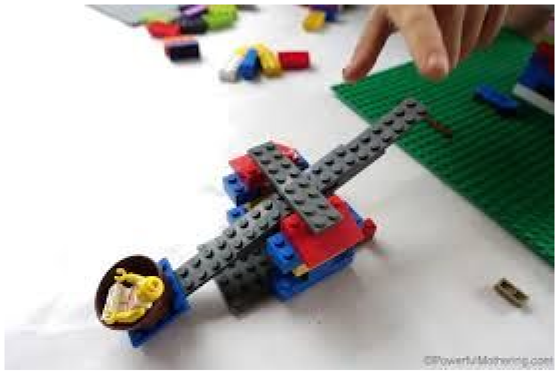
Alternative 3: Automated Guided Vehicle



An Automated Guided Vehicle would be a great method to increase efficiency in the plant due to its consistency, speed, and easily programmed system. This AGV would have a built-in storage compartment for placing the cheese as it travels from SKU to the packing station. It would decrease worker fatigue by doing all the heavy lifting and driving the cheese to the packaging systems. This option is extremely consistent, reliable, and feasible with the only disadvantage being that it can only move horizontally or vertically.

In addressing the components of the CTQ Tree, this alternative will do a good job of one of the aspects. This would improve “average order fulfillment time” because this option has multiple objects working at once to move bins to the packer. However, the “accuracy of retrieval” would suffer. This is because there would be a difficulty coordinating if the conveyor belt had already delivered the bin to the packer. If there was no way of establishing this, the conveyor belt could still be delivering the bin and have to grab another one simultaneously. This would result in a decreased accuracy.

Alternative 4: Projectile



An idea for a retrieval system would be placing catapults next to each SKU. These catapults would be able to launch the cheese blocks to each packing station upon receiving the order of the shipment. This alternative would be extremely quick but would come with many side effects. The projectiles would have the potential to injure employees, damage the product, and not be as accurate. Although this would reduce processing time significantly, the negatives do outweigh the positives.

This option would succeed in the “average order fulfillment time” because of how rapidly the catapults would send off cheese blocks to the packers. However, the catapults would negatively impact just about every other component on the CTQ Tree like “accuracy of retrieval” and “percentage bins get put back in correct spots” because of the unpredictability of the catapults.

4.2 Problem Analysis:

To reiterate, each alternative has its own successes within the Critical to Quality Tree, and some had more failures than others. From the brainstorming activities, we talked through how each alternative would function in real time. We considered every one of those qualities and which alternatives could handle a majority of them. After initially thinking that the AGV along with the conveyor belt would be the most efficient, brainstorming helped us discover the coordination of both systems simultaneously would be extremely challenging.

4.3 Pairwise Comparison:

	E	C	A	AV	D	S	UF	U	Com	L	F
Efficiency	X	E	A	E	E	E	E	E	E	E	F
Cost		X	A	C	D	S	C	C	C	C	F
Accuracy			X	A	A	A	A	A	A	A	F
Aesthetic Value				X	D	S	UF	AV	CO	L	F
Durability					X	S	D	D	D	D	F
Safety						X	S	S	S	S	F
User-Friendliness							X	UF	CO	UF	F
Uniqueness								X	CO	L	F
Compactness									X	L	F
Level of Automation										X	F
Feasibility											X

When discussing different components of the automated retrieval systems, several aspects were considered more important. We considered our own personal goals as well as the client's goals when we were deciding which qualities were more important than others. The qualities discussed are in the above figure, where a pairwise comparison analysis was conducted, resulting in feasibility as the most important feature, followed closely by accuracy, efficiency, and safety. Qualities that had little or no value were aesthetic value and uniqueness. Other factors with middle range importance were level of automation, cost, durability, user-friendliness, and compactness.

4.4 Final Selection:

Pugh Matrix Iteration 1 with AGV + Conveyor as Baseline

Key Criteria	Weight	AGV	AGV Conveyor	Crane	Projectile							Current Baseline Datum
Efficiency	8	-		-	+							B
Cost	5	+		-	+							B
Accuracy	9	S		S	-							B
Aesthetic Value	1	S		+	-							B
Durability	6	-		+	-							B
Safety	7	-		-	-							B
Usability	2	+		-	+							B
Uniqueness	1	-		+	+							B
Compactness	4	+		-	+							B
Level of automation	4	+		S	-							B
Feasibility	10	S		-	-							B
												B
												B
												B
												B
												B
												B
												B
												B
												B

	AGV	AGV Conveyor	Crane	Projectile
Sum of Positives (+)	4	0	3	5
Sum of Negatives (-)	4	0	6	6
Sum of Sames (S)	3	0	2	0
Positiives - Negatives	0	0	-3	-1
Weighted Sum of Positiives (+)	15	0	8	20
Weighted Sum of Negatives (-)	22	0	36	37
Weighted Sum of Sames (S)	20	0	13	0
Weighted Positiives - Weighted Negatives	-7	0	-28	-17

Pugh Matrix Iteration 2 with AGV as Baseline

Key Criteria	Weight	AGV	AGV Conveyor	Crane	Projectile							Current Baseline Datum
Efficiency	8		+	+	+							B
Cost	5		-	-	+							B
Accuracy	9		S	S	-							B
Aesthetic Value	1		S	+	-							B
Durability	6		+	-	-							B
Safety	7		+	-	-							B
Usability	2		-	-	-							B
Uniqueness	1		+	+	+							B
Compactness	4		-	+	+							B
Level of automation	4		-	+	+							B
Feasibility	10		-	-	-							B
												B
												B
												B
												B
												B
												B
												B
												B
												B

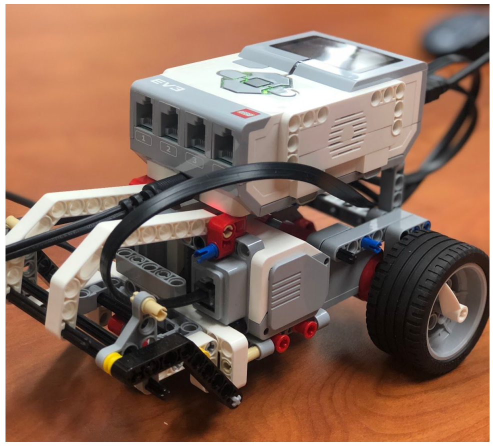
	AGV	AGV Conveyor	Crane	Projectile
Sum of Positives (+)	0	4	5	5
Sum of Negatives (-)	0	5	5	6
Sum of Sames (S)	0	2	1	0
Positiives - Negatives	0	-1	0	-1
Weighted Sum of Positiives (+)	0	22	18	22
Weighted Sum of Negatives (-)	0	25	30	35
Weighted Sum of Sames (S)	0	10	9	0
Weighted Positiives - Weighted Negatives	0	-3	-12	-13

To analyze our alternatives, we created a Pugh matrix using all of the factors previously listed. For our first iteration, we believed that the AGV with the conveyor belt was better in many aspects, and we originally thought this idea was feasible. Upon discussing the functionality of this alternative, we discovered that the programming capabilities were too advanced and that we did not have the proper tools to do what we had originally planned. We changed our idea of what the conveyor belt would be doing, which made this alternative less feasible. Before we made our second iteration, we also realized that the plain AGV would be extremely feasible because we had all the correct materials and coding available. The second iteration revealed that the AGV would be the best option.

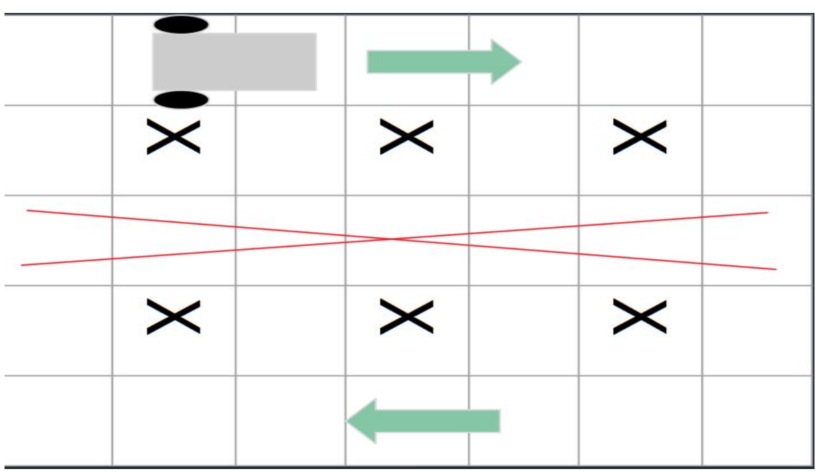
Once we saw the results of this Pugh matrix, we decided to go through and discuss every aspect of this option. We realized that it addressed all of the Critical to Quality Tree aspects and that it performed very well in each factor in our Pugh matrix. We knew this design was simplistic and would give us lots of time to focus on the coding behind it and to make it as efficient as possible. The AGV overall wins in most of the more important factors, so this is why we chose to pursue this alternative. We are confident in our ability to deliver an AGV that greatly improves the efficiency and safety of the inventory process and will allow Dairy Land Inc. to meet their increasing demand.

When it comes to the specific factors we considered for our pairwise comparison, we have already discussed why this was the most feasible option. When it comes to accuracy, the AGV beats all other alternatives. Because the robot will know where to go and will communicate where to go to us, this will be extremely accurate. This differs from the conveyor belt because it would be slightly confusing to have to deal with communication from the conveyor belt as well as the AGV. This would place a lot of responsibility on the user doing exactly as the machine says and responding to these complicated commands.

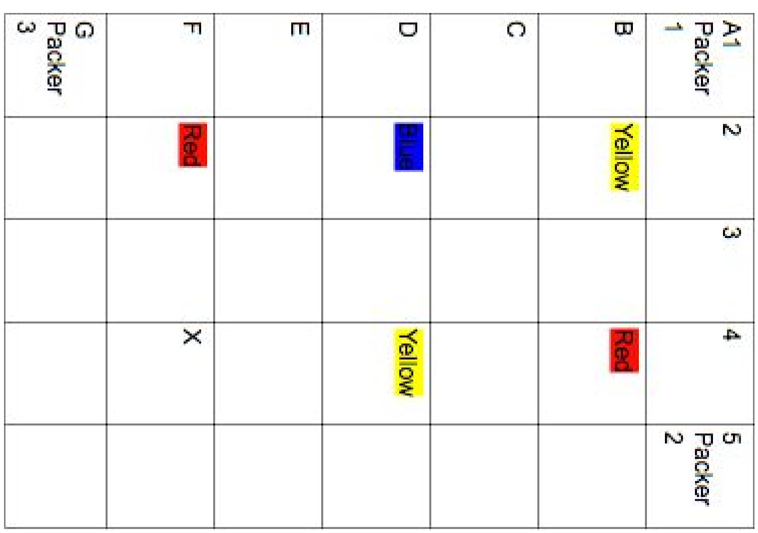
5.0 Design Approach



In designing our prototype, we aimed for a simplistic and basic structure. Using the original Lego robot with four wheels and the EV3 mounted on top as a base, we had minimal remaining steps to finish the final product. The only other component we needed to construct was the storage compartment located on the front of the robot. We built this along with a clamp designed to secure the cheese bin in place within the compartment. Along the way of designing our product, we realized the color sensor was not being used, so we removed that. After testing, we also found that the clamp was causing delays with the orders, so we also decided to remove that as well. The wires attached to the EV3 were also getting in the way, so we had to tape those down to reduce the possibility of the wires obstructing the robot's path. After all of these steps were completed, our robot was complete.



When it came to the operations behind the robot processing orders, we originally planned for the robot to use the middle lane as well as the far left aisle and the far right aisle. After meeting with the client, we were told that the middle lane could not be used and that the robot could instead direct us to which aisle it needed to travel to. The AGV was designed to move backwards and forwards only. If it needed to change aisles, it would tell the user and we would manually move it. Originally when this happened, we placed the AGV at the bottom of the grid at either (0,0) or (5,0). Once we started testing the AGV, we decided placing the AGV directly across from where it was and programming it accordingly would be more efficient. Another revision we made had to do with which SKU would be used when picking up a yellow or red cheese bin, which were the colors that had two bins. The AGV is designed to prioritize bins that are in the same aisle as the packer. We determined that this would take less time than picking up a cheese bin in its current aisle, then asking to be switched to the other aisle. At first, the only speaking from the AGV was telling the user to switch aisles. We ran into trouble when testing the prototype because we were unsure if it was replenishing inventory or dropping cheese off at a packing station. To clarify this, we implemented more communication so that we would be able to tell exactly what to do. This decreased confusion as well as decreased the risk for human error in the warehouse. Overall, the AGV receives orders, processes them, delivers and returns inventory on a first-come-first-serve basis according to the optimized layout created through thorough historical data analysis.



6.0 Project Execution

The biggest challenges faced during this project were associated with programming the AGV. As a group, our prior experience with coding was limited to a single introductory computer science class. We elected the group member who was most confident in their abilities to write the majority of the required code. This member spent the first couple weeks reviewing syntax and programming rules/techniques in order to develop an effective plan to program the AGV. The other group members focused on optimizing bin locations, designing the physical AGV, and completing project deliverables.

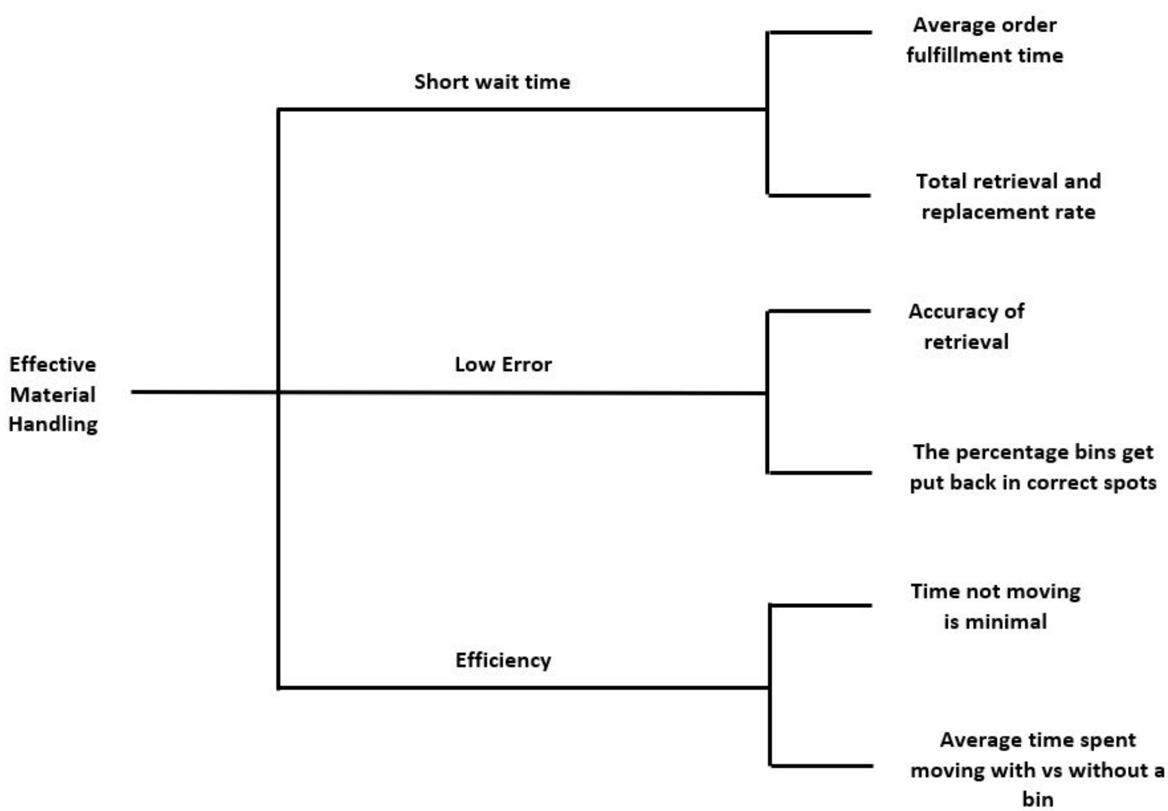
The AGV program was designed with the focus of delivering orders to each packer as quickly as possible, while maintaining a 100% accuracy rate in order fulfillment and correct bin replacement. Because our AGV was only allowed to operate on the two outside aisles of the grid, we worked under the assumption that we could manually move our AGV to the other aisle when necessary, as long as the AGV indicated to the operator that it needed to be moved. To minimize the time the AGV spends bringing a bin back to its inventory location, we prioritized bins that were in the same aisle as the required packer when selecting from which inventory bin each order would be fulfilled from. The next programming hurdle after finding the optimal bin was to actually move to this location on the grid from the current location. The relationship between the AGV's wheel circumference and the distance traveled was used to determine the number of revolutions required to bring the AGV to its destination.

After completing the main functions in the AGV program, we began testing and revising our AGV by running the given test case. It became apparent after our initial trials that our first prototype design needed to remove several unnecessary or obstructing components. The bottleneck of our system occured when the inventory was being loaded/unloaded from the AGV. We concluded that the inventory compartment clamp was not necessary in securing the bins and added to the time to load/unload the inventory bin. With the removal of this component we were able to cut out 2 seconds of time stopped at each destination while the manual action was performed to the inventory; a total of 6 seconds saved from the average cycle time. To further reduce bulk and clutter around the inventory compartment, we taped down the two wires connecting the motors to the outputs so they didn't protrude into the inventory compartment.

7.0 Performance and Test Data

7.1 Elements completed

The design of the AGV and overall cheese handling system was based around creating a more effective material handling operation. Dairy Land Inc. heavily stressed the importance of increasing automation to achieve the goal of reducing worker physical activity and order fulfillment time; as current levels are unsustainable when matched with projections of a future demand increase. As shown by our Critical-to-Quality tree below, effective material handling can be broken down into quantifiable measures. The most important measures include, average order fulfillment time (cycle time), accuracy of retrieval, and percentage of correct bin replacement. After analysing the historical data and running some tests we also thought it was important to measure average inter-arrival time.



The AGV concept is a relatively safe design compared to some other possible material handling designs. The robot's movement is limited to up and down the outside aisles, leaving the middle aisle open for employee movement and inventory reloading. Our team also added auditory warnings to increase the transparency of the the robot-to-human interface. The robot announces its intended action in order reduce error in inventory loading/unloading and to keep employees aware of the autonomous system status. The predictable forward and backward movement combined with auditory warnings of future AGV actions will further reduce the chance of employee injury.

From the initial design, we have been able to improve the robot's efficiency even further by increasing the speed of the motors and the efficiency of routes taken by the AGV. The motors were not set to a high speed to begin with, but after running tests and analyzing the robots capabilities, we were able to determine that an increase in speed would decrease order fulfillment time without imposing too many risks or reducing reliability. We optimized the AGV order fulfillment route by imposing the rule that the robot will always retrieve inventory from a bin of the correct color located in the same aisle as the required packer for that order. This rule minimizes the time the robot spends bringing an inventory bin back to its inventory position after dropping the order at the packer.

7.2 System Status and Performance

Performance measurements for the AGV fall into two main categories: parameters entered into the code and average measurements taken over multiple trials. Some of the important input parameters that are observable on the facility floor include the speed of the robot at 2.5 grid squares per second, and a 5 second delay when switching aisles and loading/unloading the order. These inputs were determined by arbitrarily assigning a value to them, then adjusting them based on observed performance. After the first few trials, we observed that our system bottleneck was the speed at which the employee was able to load/unload inventory from the AGV. As our group members became quicker at this process, we were able to reduce the initial 7 second delay with a 5 second delay. As mentioned earlier, the AGV speed was increased to 2.5 grid squares per second when we realized increasing the speed had little to no negative effects.

Comparing the newly measured statistics to the historical data provided by the company, we were able to determine how the system measurables improved with the new autonomous retrieval system (ARS) design.

Old Statistics

- Average cycle time: 49.64 sec
- Average inter-arrival time: 16.92 sec
- Accuracy of retrieval: 100%
- Percentage of correct bin replacement: 100%

New Statistics

- Average cycle time: 16.33 sec
- Average inter-arrival time: 16.92 sec
- Accuracy of retrieval: 100%
- Percentage of correct bin replacement: 100%

All of the measured statistics from the historical data are the same as the new statistics except average cycle time. There was an impressive decrease in the time it takes the AGV to complete orders compared to the old system of manually retrieving the inventory. The decrease from 49.63 seconds to 16.33 seconds is an improvement of about 67%. Based on our measurables, we can conclude that the ARS system design is drastically more efficient than the previous system while also keeping the a perfect standard for correct order fulfillment and bin replacement. Dairy Land inc. employees will benefit from a large decrease in physical activity while meeting the future rise in demand.

8.0 Opportunities for Improvement

Although the prototype functions as planned, there are still some recommendations that could be used to further improve the product. Our original prototype had a storage compartment with a clamp to close around the bin after it was placed inside the storage compartment. The thought behind this attachment was to avoid inventory from falling out of the compartment. Ultimately, we removed this component from our design because it made it more difficult to place the bin in the compartment in a timely manner. If our design were to be implemented in the facility, we would recommend adding a compartment clamp that autonomously opened and closed to lock the inventory in place. This solution requires no employee interaction and achieves a higher level of safety. Another component to fix on the AGV would be the overall size and bulk. Certain Lego pieces on the robot were not utilized and could be discarded. The wires connecting the motors to the input channels were taped to the robot to free up inventory compartment space, but could be further shortened to minimize excess wire.

When it comes to the overall design and process of this product, there is also some room for improvement. If technology and costs allowed, we would recommend adding a second AGV to this layout. One AGV would be in the far left line and one would be in the right. This system would improve the speed and efficiency of the overall system and would reduce the cycle time because of the current need to switch the robot from one lane to another. Another aspect that would improve the system would be how the robot processes the orders. Currently as orders come in, the robot processes them on a first come, first serve basis. This is easy to program, but not necessarily the most optimal choice. In order to increase efficiency, the robot would process orders as they come in and would choose which one to address based on which required bin is closest. This method would create a quicker cycle time, but would require more resources and testing to coordinate. Another improvement could be adding a button to be pressed by the employee who loads/unloads inventory from the AGV. Once the button is pressed, the employee has completed their action and the robot knows that it is able to leave the current location. The addition of this component would increase human-to-robot interaction transparency.

After the presentation, there are some areas that can still be improved upon. For example, our AGV turns to the side slightly. Fixing this turn would reduce error and increase accuracy, but there is a speed accuracy tradeoff that makes the robot turn although it is extremely fast. During our presentation, it was necessary for the robot to be saying every action that the employees would need to do. To improve the length of time that this takes, it would be helpful to develop a language or light signal that would tell the employees what to do without wasting any time on speaking a full instruction.

8.1 FMEA Analysis

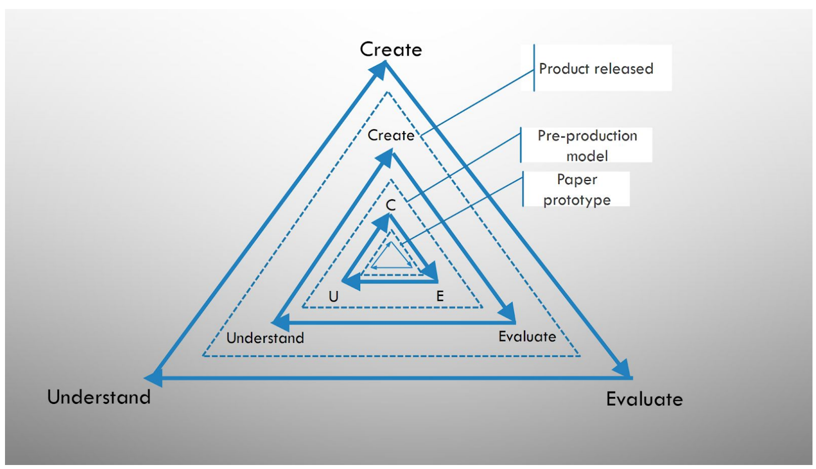
The Failure Mode and Effects Analysis is a method used to identify the failures that may arise in a design process, manufacturing system, or other areas where possible problems should be identified. The risk priority number (RPN) shows how severe the potential failure could be on a scale from 1-1000. The analysis shows two categories that could be a major issue and are mainly due to the inability to detect the problem along with a possibility of a high occurrence. These potential failures are: AGV does not receive order (RPN 420), AGV processes incorrect order (RPN 540). Our recommendations to reduce the severity of these problems include implementing constant shipping receipt checks and passive validity checks to increase the detection of these issues.

Item/Process Step	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Cause(s) of failure	Occurrence	Current Controls	Detection	RPN	Recommended Actions
Order Processing	AVG does not receive order	Customer is dissatisfied	7	Problem with network	6	No current controls	10	420	Constant checks and shipping receipt checks
	AVG processes incorrect order	Customer receives wrong item	6	Order entry data is incorrect	9	No current controls	10	540	Introduce passive validity checks as much as possible
Inventory retrieval	Retrieves the wrong inventory	Delays shipping and slightly disrupts flow of factory	4	Someone placed inventory in wrong place. AVG received the wrong order	7	Proper inventory control	6	168	Current control is adequate
	Employee loads the wrong order onto AVG	Delays shipping and slightly disrupts flow of factory	4	Miscommunication	7	Proper inventory system and inventory checks	6	168	Current control is adequate
	AVG brings order to wrong packer	Delays shipping and slightly disrupts flow of factory	4	Network issue or malfunction	4	Continuous improvement on AVG code and efficiency	2	32	Continuous efficiency efforts
	Moves before inventory is placed on it	Disrupts flow and possibly injures an employee	10	Employees working too slow or machine moving too fast	3	No current controls	1	30	Implement a button on AVG to pause movement so workers can stop it if necessary
	Drives off the grid	Possible injury to employees and damage to equipment	10	One motor malfunctioned	1	Proper maintenance checks and repairs	1	10	Current control is adequate
	Wears down over time	Slight malfunctions and slight speed decrease	4	Common use and wear and tear	3	Proper maintenance checks and repairs	9	108	Current control is adequate
	Inventory falls off robot	Order does not make it to packer and possibly damages product	8	Not loaded properly	7	No current controls	1	56	Add a secure bin or strapping system to AVG

9.0 Summary and Recommendations

Dairy Land Inc. reached out to our team with a project request focusing on improving efficiency, helping with increased demand, and decreasing employee injury rates in their facility. We were able to provide them with a prototype AGV robot and a system to implement which will transition them from manual labor-based work to an innovative, automated workplace focused on continuous improvement. The new and improved system will be a substantial step for the company as a whole as it will increase employee morale and help them achieve an impressive rapport within the industry.

In an analysis of historical trial data, our prototype proved to be an impressive step above the current system employed by Dairy Land Inc. The new system uses an automated guided vehicle to collect inventory and bring the order to the packers for shipment. It will travel up and down the outside aisles, leaving the middle aisle open for employees to safely move about the facility floor.



The progression of the project moved smoothly from start to finish as we used an iterative design process (shown, right) to constantly improve to the point we are at now. The project is now in the hands of Dairy Land Inc. management to take what they have learned and apply the AGV inventory system to their distribution facility. Some recommendations regarding the AGV: adding an automated storage clamp to reduce the chance of inventory falling off the robot and getting damaged, internalizing all wires and cables to prevent corrosion or accidental disconnection, and reducing the overall bulk of the machine. The new inventory system as a whole should be regarded as an opportunity for constant improvement, but some initial improvement opportunities could include adding a second AGV so there will be no need for aisle switches, incorporating a more efficient retrieval system instead of the current FIFO method, and including an employee input button that could notify the AGV to start moving if the inventory is loaded/unloaded in under five seconds.

Finally, we believe it is in Dairy Land Incorporation's best interest to carry out the newly designed inventory retrieval system to make their company more profitable and a more welcoming place to work. We thank you for your trust in Blessed By Bucky and wish you the best in your future growth and success as a company.

10. Bibliography

Lee, John D. “Design Method Overview”. ISyE 349: Human Factors Engineering. UW-Madison. Spring 2018.

Li, Jun-Tao. “Design Optimization of Amazon Robotics .” Science Publishing Group, 30 May 2016, article.sciencepublishinggroup.com/pdf/10.11648.j.acis.20160402.17.pdf.

Industrial and Systems Engineering Junior Design Laboratory

Design Team Project

Fall 2018

Background:

The client for this project is a small (fictitious) on-line retail business in Wisconsin, *Dairy Land Inc.,* which sells and ships Wisconsin cheese through its web site, DairyLandCheese.com. The site retails numerous varieties of cheese, and customers can order quantities of five pound blocks that are shipped throughout the US. Orders are made on-line and product is packaged and shipped from the Dairy Land Cheese warehouse fulfillment center in Madison, WI. The business is rapidly growing, and the client aspires to become the Amazon.com of cheese retail.

The Dairy Land Cheeses warehouse receives products from various cheese suppliers for storage and subsequent shipping to its customers. The warehouse has four main operations, 1) receiving, 2) dispatch to inventory, 3) retrieval and 4) packing and shipping.

The receiving operators unload shipments from various cheese producers off trucks and unpack the individual cheese blocks at the loading dock. After the products are unpacked, they send each down a conveyor to the dispatch to inventory sorting area. The cheese clocks are identified by their variety and dispatchers load them into color coded storage bins grouped by specific product. Each storage bin is transferred by forklift to the refrigerated warehouse, where they are kept until cheese bricks are needed.

The cheese blocks remain in the storage bins until needed, at which point any ordered items are retrieved by a team of packers. The packers read the specific products ordered from an electronic data file displayed on an overhead screen. They walk through the refrigerated warehouse to locate the product's color coded storage bin, pick the quantities requested, carry them back to the shipping area, and pack them into boxes that are sent out for shipping.

Appropriate shipping invoices are prepared, attached to the boxes, and the boxes are transferred to trucks for shipping. Manual materials handlers load the trucks and the orders are shipped and delivered straight to the customer.

Any shortage, breakage or nonconforming items (i.e. errors, defects, etc.) are recorded, and the item(s) are replaced, or the order is modified and shipped as a partial order. Inventory is periodically taken in the warehouse and products are ordered to maintain sufficient quantities. It can be safe to assume that the color-coded storage bins will never run out of cheese. Records are kept for the amount ordered from suppliers, on-hand inventory, orders received, and orders processed. These records are critical for good inventory management.

The Problem:

Due to increasing business, the warehouse has been experiencing challenges in efficiency, ergonomics and quality. Management noticed that rather than retrieving the necessary amounts of products for each order, the packers frequently lifted and carried excessive amounts of cheese from the inventory storage bins in the warehouse to their shipping stations and keeping a supply on hand to keep up with the orders. This has resulted in operator fatigue, strain, numerous back injuries, and high absenteeism. Furthermore, operators are making selection errors and damaging product due to mishandling while carrying cheese orders. With growing orders, packers are unable to keep up and there is a long backlog causing significant delays in shipments to customers. There has also been an increased congestion throughout the warehouse while retrieving inventory and this further reduces the packer efficiency.

Due to these issues, management hopes to structure inventory storage in a more dynamic process to increase utilization of the refrigerated warehouse and meet fluctuating demands for different types of cheese. Dairyland proposes, instead of having the packers go to the inventory storage bins to retrieve the cheese, to implement an automated retrieval system (ARS) that lifts the bins from inventory storage and bring them to directly the packing station, where the packers remove the ordered cheese. After the requested order is selected, the ARS automatically replaces the bin at any vacant location in the inventory area.

The client anticipates that the ARS will consist of an automated guided vehicle (AGV), a robot, or other automation that selects and retrieves bins from the inventory and transports them to the packing/ shipping station. Because space at the packing/shipping stations are very limited, it is necessary to continuously replace the bins after retrievals.

The company has requested proposals from UW-Madison industrial and systems engineering design teams for an automated product retrieval system. In addition to designing the automated system, the client requests every design team demonstrate a working prototype of their design. The prototype displaying the best performance (i.e. throughput, efficiency, reliability) will be selected by the client.

System Constraints:

There are three variety of cheeses (Gouda, Blue Cheese, and Cheddar) that are in color coded inventory bins of Yellow, Blue and Red, respectively. The new design shall accommodate the materials flow illustrated in Figure 1. Five bins are initially located in any of the six SKU storage grid locations shown in Figure 1. You may choose how many inventory bins of each cheese variety you would like to use in your storage grid based on historical demand (e.g. two yellow bins, two red bins, one blue bin). Each inventory bin has a capacity to hold three cheese blocks. The empty grid location is used to make the grid as flexible and dynamic as possible. The white spaces in the grid are for ARS movement and bins cannot be placed there. Bins can only be placed in the B2, B4, D2, D4, F2 and F4 locations. Packing Stations 1,2 and 3 are assigned orders, based on geographic regions that orders are shipped.

The client would like to design a system that retrieves an inventory bin containing the ordered cheese from the warehouse to a packing station and replaces it back to any vacant location in the storage grid (i.e. B2, B4, D2, D4, F2 and F4). When a bin arrives at a packing station, the packer removes a cheese block. Since the packing stations have limited space, **it cannot store inventory bins for fulfilling orders.** Thus, inventory bins must be returned to the storage grid after the packers remove a wheel of cheese. The automated retrieval system chooses an SKU location and returns the bin to the warehouse.

	Inventory Warehouse Grid				
	1	**2**	**3**	**4**	**5**
A	**Packer 1**				**Packer 2**
B		**SKU**		**SKU**	
C					
D		**SKU**		**SKU**	
E					
F		**SKU**		**SKU**	
G	**Packer 3**				

Figure 1. Inventory storage bin locations in the refrigerated warehouse.

The system follows a FIFO (first in, first out) policy, so the ARS must replace the first bin brought to a packing station to make space for the next bin. Management wants to create a dynamic storage grid, **so the system may replace the bin to any vacant location that is the most efficient.** Because the storage grid is dynamic, the system must continuously keep track of locations of each storage bin.

Orders for cheese are coded:

#Yellow, #Blue, #Red, Packer

Only one order item can be coded for a given packer. For example, an order: 1, 0, 0, 1 requests a block of Gouda cheese (Yellow) be transported to Packer 1.

You are asked to automate the retrieval and replacement process between the inventory warehouse and the packing and shipping area. The bins may be moved using an AGV, robot, cartesian picker or any other mechanical means you select. Your simulation is permitted to **manually lift and place** inventory bins into your mechanical system. For example, if using an AGV for retrieval, the vehicle must navigate to the correct inventory location, but you may lift and place the inventory bin into the vehicle.

Occasionally while fulfilling orders, the inventory bins may run out of cheese blocks. The bins are replenished when they are returned to the inventory grid; however, each replenishment will come at a cost of labor and time. For this reason, it is important to incorporate as many inventory bins as possible for fulfilling orders. The ARS should retrieve the inventory bins and transport them to a packing station based on an algorithm that is part of your ARS design, which adjusts the location each bin is returned based on anticipated orders and product value. Historical demand data will be provided by the client for forecast analysis. The format of the historical data is:

Date, Order number, Packer, Product Code (R, Y, or B)

For example:

Date	Order No.	Packer	Product
10-16-17	1	1	R
10-16-17	2	3	R
10-16-17	3	2	Y
10-16-17	4	1	B
10-16-17	5	1	Y

In the above example, Order No. 1 on 10-16-17 consisted of a Red (Cheddar) block shipped by Packer 1,

After you have analyzed the historical order data, you should build policies into your ARS to optimize the locations of each inventory bin. For example, if you find in your data analysis that Packer 1 consistently fills more Red orders during a specific time interval, you may wish to stage Red inventory bins closer to that packer during that time interval.

To help enact your policies for the locations of inventory bins throughout the storage grid, you may manually swap inventory bins from one location to the other instead of having your system physically do this. Your system, however, must initiate any changes in locations of inventory bins and each swap will come at a small labor and time cost.

It is anticipated that occasionally bins are misplaced when they are replaced by the ARS. Large design teams (i.e. 5 students) shall also design a system to handle bin misplacement errors (i.e. the AGV should check for the presence or absence of bins in a location before retrieving or replacing it). A design feature requested for the AGV incorporating a poka-yoke, which is a Japanese term for mechanism to help avoid (yokeru) mistakes (poka). If an error occurs (e.g. a bin is not present), the design should include a process to prevent and correct the error.

Key process performance variables include:

- Average order fulfillment time
- Total retrieval and replacement rate to fulfil orders
- Accuracy of retrieval and replacement within the grid
- Error percentage (retrieval of incorrect inventory bin)

Request for a Proposal

Your team is asked to design, prototype and test an ARS that automatically transports the ordered products from inventory in an efficient manner, while minimizing order fulfilment time and error rate and maximizing accuracy. The objective is to fulfill orders in the least amount of time, while improving current system performance for a reasonable cost.

Each team is asked to design and prototype a model of the ARS using TETRIX and LEGO MINDSTORMS EV3 kits. The bins are represented using one-inch wooden colored cubes. The only limitations in your design approach are your creativity, time, and the parts and components available to you in the TETRIX and LEGO MINDSTORMS lab kits. The prototype cannot be longer than the diameter of a laboratory table (58 inches).

A complete parts list is provided on the course web site. Examples of some previous designs are shown of the course web page. Your design should also minimize costs to fabricate. Resources in the Materials list (pp 1-4) are $100 each, the remaining items are $1,000 each (pp 5 except connector cables, which are still $100 each). External items are $5000 +, and are to be approved in advance by the client.

The factory computer is simulated in the model using an EV3 brick and communicates with the AGV EV3. Your design should consider the flow of information (e.g. as well as the flow of materials. The updating of records such as the new locations of bins, orders received, and orders processed should be considered in your design. In the process, teams will be asked to conduct certain analyses and tests that will support their selected design approach, build and program a prototype, and demonstrate its performance (i.e. output rate, reliability, etc.). You are asked to demonstrate your working model and process an order file that will be provided by the client. Assume that each bin is fully stocked throughout the process (and will never run out of cheese). Designs are permitted to manually load and unload the bins on and off the AGV, robot or other transport system. The design is also permitted to manually reposition the AGV at a packing station, any manual repositioning of the AGV or bins in the inventory area are not permitted and will count towards the system accuracy.

Because some design teams have more members, different requirements are specified:

Five Student Teams: Design and build an automated system that that optimizes the transport of materials in the warehouse with the constraint of pokayoke.

Four Student Teams: Design and build an automated system that optimizes the transport of materials in the warehouse without the constraint of pokayoke.

Some questions for your team to consider:

- How can this process be performed optimally?
- Where can the bins be placed to ensure faster order fulfillment.
- What is the time limiting element of the system? How much can this time be reduced without sacrificing accuracy?
- What types of errors can your system make and how will they be detected and corrected?
- What features will your design include to assure reliability?
- Have you taken into consideration the safety requirements? What would happen if a person walks into the path of the automated system?

- How will your system transport the bins and what procedures will be designed for loading and unloading the products?
- How will you test and verify that your design performs to expectations?

Project Milestones:

1. Team Formation
2. Project Management Plan
3. Design parameters and process capabilities plan
4. Alternative design concepts
5. Design proposal
6. Proposal presentation to client
7. Failure mode and effects analysis
8. Final design report
9. Prototype delivery and presentation