Automatic Lego Sorting Machine

Final Proposal

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Project Sponsor: David Willy

DISCLAIMER

Table of Contents

1 BACKGROUND

1.1 Introduction

The goal of the design team is to design and build a machine that is capable of sorting Legos based on block type. This machine needs to have the capacity to sort a wide variety of Legos while maintaining a high level of sorting accuracy. David Willy, the project sponsor, has a collection of Legos that is too big to justify sorting manually. The team is tasked with designing, creating, and testing a device in order to fix this problem. The objectives of this project include: Sorting a small number of Legos manually to help design a sorting process, researching sensors capable of recognizing Lego types, prototyping a sorting machine using sensors and other mechanical components, integrating all subsystems to make the system capable of sorting all Lego types, system testing, and delivery to the client. Upon completion of this project, the sponsor will have a way to sort Legos that greatly reduces the time and involvement of the user.

1.2 Project Description

The project focuses on a portable machine that accurately sorts Legos by brick type thereby removing the tedium of sorting Legos by hand. This industry standard problem is solved with sensors, mechanical equipment, and image recognition software. The Lego sorting machine transfers Legos from an input container to a camera via conveyor belts which detects what type of Lego is present. Based on what Lego the camera detects, the software will instruct a bin system to ready itself for its respective Lego as the Lego is transferred to it via another conveyor belt. The Lego will then fall into a bin which has been designed to contain that specific type of Lego. The machine will then repeat this process for the remaining Legos until the system is empty or something goes wrong where it will then give an audible signal and shut off.

Scope of the Work:

To design, build, test, and iterate where needed on an Automatic Lego Sorting Machine that sorts by Lego piece type for all classic pieces (brick, plate, rail, etc.) and some specialized pieces that make sense to design for. The system must not require human interaction after Legos are loaded into the machine and until they can be stored after sorting.

Expected Milestones During the Project:

1. Sort a representative sample of Lego pieces by hand to get the big picture of this

2. Research Sensors and sorting techniques that could be used in this design space

3. Prototype Sensor application and individual sorting techniques

4. System Integration of all subsystems required to completely sort the Lego collection

5. Full system testing and iteration as required

6. Final Delivery to the client

Requirements:

Can use standard wall power (120VAC, 60 Hz)

Must be safe enough that a child can run the system

Must sort automatically

Cannot exceed $500, unless further fundraising can be obtained

May be judged by a room full of kids (or adult kids)

1.3 Original System

This project involved the design of a completely new Lego sorting machine. There was no original system when this project began.

2 REQUIREMENTS

This section will detail the different types of requirements that were created at the start of and during the project. Specifically, this section will walkthrough customer requirements, engineering requirement, and the house of quality.

2.1 Customer Requirements (CRs)

Before the design process could be started, it was necessary to begin with customer requirements so that the design aligned with what the customer envisioned. The customer requirements were given by David Willy and are as follows: overall system portability, quick start time, structure must not be made of Legos, withstands impacts/mild abuse, intuitive operation, high sorting accuracy, large input volume, must sort a large variety of Legos, must not have sharp edges, enclosed system to prevent pinch points, smooth surfaces: free of burrs, must have an emergency stop, and must use outlet power. Each customer requirement is listed within the house of quality and was given a subjective rank between 1 and 10 that dictates how significant the customer believes the requirement is. The ranks were put in a column named customer importance. The ranks were also given a relative weight which is a single rank divided by the sum of all the ranks which was converted to a percentage value. This allows one to see the importance that each customer requirement has based on the all the other requirements. These values were put into a column named Relative Weight. There is also a column named Weight Chart that shows the relative weights visually. Below is a portion of the house of quality that lists all the customer requirements, customer importance, as well as the weight chart discussed earlier.

Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit)
1		7%	8	9	Overall System Portability
2		7%	8	9	Quick Start Time
3		4%	5	9	Structure Must not be made of Legos
4		8%	9	9	Withstands Impacts/ Mild Abuse
5		8%	10	9	Intuitive Operation
6		6%	7	9	High Sorting Accuracy
7		6%	7	9	Large Input Volume
8		7%	8	9	Must Sort a Large Variety of Legos
9		8%	10	9	Must Not Have Sharp Edges
10		6%	7	9	Enclosed System to Prevent Pinch Points
11		8%	9	9	Smooth Surfaces: Free of burrs
12		6%	7	3	Must Have an Emergency Stop
13		8%	10	9	Outlet Power
14		5%	6	9	Quiet
15		7%	8	9	Fused

Figure 2.1: Customer Requirements (House of Quality)

Figure 2.1 represents a succinct list of customer requirements that were explicitly and implicitly gathered from the client. The list of customer requirements implies system that can be transported easily, has a large Lego capacity and sports intuitive operation having minimum interaction time. The structure must not be made of Legos, should be durable, safe, and should run on standard wall power. Furthermore, the system should sort a wide variety of Legos with high accuracy and should have a quick start time.

2.2 Engineering Requirements (ERs)

After the customer requirements were listed within the house of quality, an equal number of correlating engineering requirements that specified objective quantifiable parameters were created. The correlations between the customer and engineering requirements were shown with number of symbols that represent strong, moderate, weak, and blank for no correlation. Each engineering requirement was also correlated to every other engineering requirement having a direction of improvement which is shown by symbols that represent positive, negative, or no correlation. Also, each engineering requirement was given a direction of improvement which were also represented with symbols designated a direction of improvement as a maximum, target, or minimum value. A part of the house of quality is shown that lists the engineering requirements (Figure 2.2). A legend is also shown that explains all the symbols (Figure 2.3).

Direction of Improvement	▼	▼	◇	▲	▼	▲	▼	▲	◇	◇	▼	◇	◇	▼	◇
Engineering Requirements / Customer Requirements (Explicit and Implicit)	Weight (<50 lbs)	Cycle Time (<=5 sec)	Material (exclude Legos)	Rigidity (ksi)	Steps (Minimize)	Sorting Competence (95% Correctly Sorted)	Volume(<= 1 ft^3)	Types (>15)	Minimum Filet Radius (0.002 in)	Minimum Clearance (0.1 in)	Roughness (in)	Twist Type (Unitless)	Voltage, Current (120V, 15A)	Noise (< 80 Db)	Fused (#)

Figure 2.2: Engineering Requirements

The list above displays all of the engineering requirements. They are: weight (<50 lbs.), cycle time (≤5 sec), material (exclude Legos), rigidity (ksi), steps (#), sorting competence (95% correctly sorted), volume (1ft^3), types (>15), minimum filet radius (0.002 in), minimum clearance (0.1 in), roughness (in), Voltage and Current (120V, 15A), Noise (< 80 Db), Fused (#). Weight represents the weight of the entire structure, cycle time is the time it takes for a Lego to be sorted, material is a requirement that forbids the use of Legos as a structural element, rigidity is the amount of pressure the entire structure can withstand, step is the number interactions that a human has with the system, sorting competence is the system's ability to correctly sort Legos, volume exhibits the systems Lego holding capacity, types is the number of different Legos the system can recognize, minimum filet radius prevents sharp edges that are a safety concern, minimum clearance is a requirement that specifies a certain space around moving parts so appendages are not damaged, roughness indicates that there should be no burrs on the surfaces of the system, Voltage and Current establishes the type of electricity that the system will be running on. Noise is a restraint on the loudness of the machine. Fused is there to ensure that the machine will have an electrically fused system.

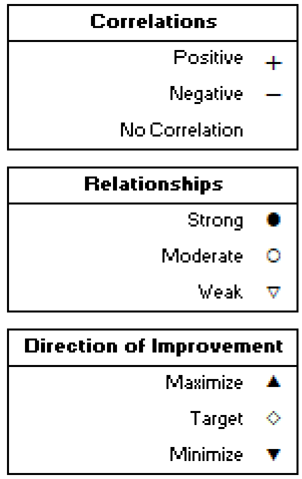


Figure 2.3: House of Quality Legend

2.3 House of Quality (HoQ)

The house of quality is a means of listing customer requirements, giving weights to those requirements, and comparing them to engineering requirements. The engineering requirements are correlated amongst themselves with a direction of improvement for each engineering requirement. There is also a customer competitive assessment section which is a form of benchmarking. This allows us to rank competitor products on how well they satisfy customer requirements. The ranks are subjective and on a scale from 1-5. There is also a graph in this section that shows the ranks visually. Appendix 2 represents the main portion of the HoQ which is explained within the figure itself, the customer competitive assessment and the technical competitor assessment are listed as Appendix 3 and Appendix 4 respectively.

The technical competitive assessment ranks how well each product satisfies a technical requirement on a scale from 1-5. This is also shown visually with a graph. Figure shows the technical competitive assessment section from the house of quality. The rest of the house of quality was previously explained. The house of quality is helpful for understanding for every customer requirement influenced everything else. It is a useful technique for keeping all the data together and allows the team to have a board overarching understanding of the project and what is required for it.

3 DESIGN SPACE RESEARCH

The Lego Sorting Team conducted design space research by first finding five or more relevant sources that pertained to everyone's technical aspects. Each team member then described the books and articles from their research in the literature review. Following the literature, the team researched other Lego sorting competitors. In benchmarking, the competitor's overall design, accuracy, method of sorting, structures, and the number of sortable bricks were examined. Then competitor's subsystems were examined, focusing on their Lego conveyance, Lego recognition, and software methods used. By examining the competitors, the Team generated a Black Box Model and Functional Model to find reoccurring concepts to base models from.

3.1 Literature Review

3.1.1 Eric Pisciotta

Eric Pisciotta will be responsible for designing and implementing all electronic hardware for the project. This includes choosing power supplies, motors, servos, and building any wiring harnesses or circuits. The textbook Electric Circuits by Nilsson and Riedel [1] explains simple DC circuits and AC to DC converters, which covers the majority of the electronics that will need to be designed in house.

Another important part of research covers personal computer power supplies. The power supply chosen for the project has been recycled from an old computer tower, so Pisciotta found a web page titled Everything You Need to Know About Power Supplies [2]. This webpage contains an in depth write up on the power supply chosen including pinouts, power input plugs, efficiency, voltage stability, and cooling. This will help Pisciotta determine where to pull power from, how to ensure the supply will not overheat once installed, and verify that the supply can meet the demands of the components drawing power from it.

In addition to electronics, Pisciotta will aide in the mechanical aspects of the project as well. Shigley's Mechanical Engineering Design [3] will be used to aid in the design of any gearboxes, shafts, belts, and pulleys that may be needed to transmit mechanical energy throughout the system. This textbook thoroughly explains many considerations that need to be taken with respect to applications and part design. Additionally, useful equations are given in regard to many mechanical components so that premature failure can be avoided.

Transporting Legos through the system is another mechanical aspect of the project that Pisciotta will help design. A useful article titled: Which way to convey [4] discusses methods of getting items on and off of a conveyor belt, as well as merging belts. Some of these methods will likely be employed when putting Legos on a conveyor belt, and moving them to their appropriate destination.

Pisciotta also found a valuable article titled: In-line sorting of irregular potatoes by using automated computer-based machine vision system [5]. This article describes the use of computer imaging to categorize potatoes based on appearance to sort out irregular ones that are less likely to sell. Important information regarding camera position and lighting are thoroughly explained, which will be useful for imaging Legos. Additionally, a rough algorithm flowchart is given that describes how the computer processes the images of the potatoes. A similar algorithm will likely be necessary for determining Lego type.

3.1.2 Austin Shorr

Austin Shorr's technical aspect for this project is primarily the Mechanical side of our Lego Sorting Machine. Some of the mechanical features he may have to research, design, and construct include the following. The first system will be an inlet for the Legos, this design will have to take into account the large volume of Legos placed into the system at once, and control the outlet flow for the next system. The next potential system that requires mechanical expertise is a conveyor belt. This design must move the Legos from the holding inlet to the imaging system in a way that will cause the least errors for the imagining system, by moving the Legos in an equidistant single file line. The third inevitable system is the bucket system. This system needs to take the information for the program that recognized the Lego and move it to the proper holding cell for that type of brick. There are multiple was to go about designing all of these mechanical systems. The concepts for which may be seen later in Concept Generation, but first we need sources related to this technical aspect as well as to references inspire our future ideas for this project.

SolidWorks 2014 for Designers by Sham Tickoo [6] will be incredibly valuable. This will be shown when making the visual model for the end of Concept Selection in category 5.2. Additionally, this resource will be helpful when designing moving parts for the design because chapter 20 is entirely devoted to motion study. The rest of the book covers the basics of sketching, creating features of all kinds including but not limited to; extrudes, cuts, and surface modeling. The book also covers how to combine a large number of part and put them together in an assembly so that a motion study can be performed.

Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines by Robert L. Norton [7] is the kinematics book recommended by Dr. Tester to design moving systems. The use of this resource will be designing the four bar mechanism for the conveyor belt that will be incorporated into the design. The bulk of the knowledge will come from chapter eleven, but in order to understand this chapter there will be other chapters that require a rereading. One such examples are chapters six and seven. Chapter 6 covers how to analyze each individual bar in the system and calculate multiple types of velocities, while chapter seven does nearly the exact same thing but with acceleration as its focus.

Alongside the kinematics book Dr. Tester also provided an Atlas that contained four bar paths. The book is called "ANALYSIS of the FOUR- BAR LINKAGE, Its Application to the Synthesis of Mechanisms" and it was written by John A. Hrones and George L. Nelson [8] from THE MASSACHUSETTS INSTITUTE of TECHNOLOGY. This atlas will work in tandem with the Kinematics book as previously mentioned to further educate decision making and calculations when designing a four bar system. This book has thousands of potential paths for to consider. There are two main ways to pick a premade path. The first is by having set four bar linkage lengths that will be using then look for the best possible path with those linkages that must be used. The second type is by finding a path that seems the best for your situation and find out what linkage lengths are required to get said optimal path.

The article Conveyor belt side curtains [9] covers the idea of creating “A skirt board and mounting plate for sealing the side edges of a conveyor belt to prevent spillage of material being transported.” this concept of a skirt board, which consists of ribs spaced in parallel with an electrometric sheet formed to surfaces. These surfaces can be interlinked with a metal mounting plate that has regularly spaced slots. The mounting plate will be separately mounted in parallel from the side edges from the conveyor belt. If the dispenser releases the material at a different rate than the conveyor belt, then the material would cause bulk and eventually overflow. A visual representation is given in the illustration denoted as Figure 3.1. This figure shows the top image as the front view of the belt side curtains, while the bottom image is the top view. This design concept could be useful for our conveyor belt. This design could be modified to help with the potential problem of having Legos spilling off of the conveyor belt. It may also be used as a more defined path for the unrecognized and imaged Legos.

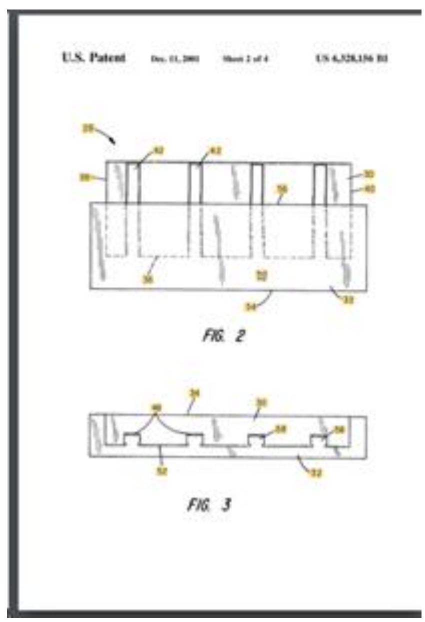


Figure 3.1: Conveyor belt side curtains

In the abstract of “A Bragg grating-tuned fiber laser strain sensor system” [10] the team claims that they can create a fiber laser sensor. This laser integrates a Bragg gating sensor, which is a tunable erbium doped fiber laser. This laser uses a broadband mirror as well as an intracore Bragg gating reflector in a side-pump arrangement. A strain sensor measures the wavelength frequency. This is used in addition to a passive wavelength demodulation system or WDS for short. The WDS allows the system to have a self-contained strain sensor, which permits the device to provide "interrupt-immune sensing of static and dynamic strains with a bandwidth of 13.0 kHz.". To put all of that in the simplest terms possible. This Laser can detect when something intersects its path. These are commonly known as a laser trip wire. The reason this system could benefit us is we could place a similar laser tripwire to detect interference, that would slowly stop the conveyor belt to allow the imaging system to take a clear picture and send it to the program to allow enough time to determine what type of Lego the image contains.

In the article: Measuring of feature for photo interpretation [11], the authors claim to have developed a method and created an apparatus capable of determining height, width, length, and orientation of imaged objects. This image will be taken by an oblique panoramic camera that uses a calibrated reticle magnifying eyepiece. This "eyepiece also has a reference mark and indicia about the eyepiece for measuring the orientation from true north of the longitudinal axis of the feature image" [11]. The measurements are then processed through their program to determine the actual dimensions of the object. This invention was manufactured for the government to determine dimensions and features of buildings, and bridges, as well as other structures. Figure 3.1 "is a schematic cross-sectional elevation view of an object as viewed by a camera at an elevation above the earth" [11]. This means that the design could only call for one imaging system, which would not only cost less but will most likely make it easier to create a program that only takes one image into account that multiple. The fewer cameras connected to the image recognition program the less information the program will have to interpret. Therefore, taking less time to determine where to sort the imaged Lego, meaning the sorting machine can sort more Legos at a faster rate.

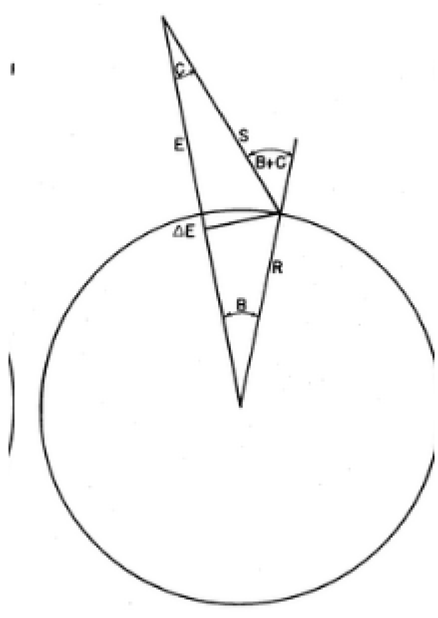


Figure 3.2: Measuring of Feature for Photo Interpretatio

3.1.3 Tristian Vigueria

Tristian is responsible for software potion of the project. This includes all Raspberry Pi related parts of the project including all parts that are connected to the Raspberry Pi. Programming the Raspberry Pi will include dealing with the AI that will ultimately run the entire system and making sure that all the motors, cameras, LED lights, etc. are in working order and in concordance with each other. Tristian has seven relevant sources that will be useful in the design of the project. Four of them are textbooks, and three of them are articles.

The textbooks are as follows: Practical Electronics for Inventors [12], Programming Arduino: Getting Started with Sketches [13], Programming Arduino Next Steps: Going Further with Sketches [14], Programming the Raspberry Pi: Getting Started with Python [15]. The articles are: Portable smart sorting and grading machine for fruits using computer vision [16], Object Sorting System Using Robotic Arm [17], and Object Sorting System in MATLAB using Robotic Arm [18]. All these resources add something that will aid in the overall design of the project. Practical Electronics for Inventors [12] will guide the team on all electronic related endeavors including soldering, wiring, fuses, etc. Programming Arduino: Getting Started with Sketches [13] will help in programming in Arduino should the team decide to switch to that microcontroller instead of the Raspberry Pi. The same rationale applies to Programming Arduino Next Steps: Going Further with Sketches [14]. Programming the Raspberry Pi: Getting Started with Python [15] will be instrumental to completing the software portion of the project as the Lego team plans on using a Raspberry Pi to recognize Legos and run all the electrical components of the system.

Portable smart sorting and grading machine for fruits [16] using computer vision discusses a system that sorts several different fruits based on size and color. The system consists of a low cost, portable, upgradable, computer guided sorting machine that uses cameras to detect the shape and color of a fruit. The system does not use conveyor belts, correctly identifies the size of fruits 98% of the time and has always correctly identified fruit color correctly. This source will help the Lego team because it has useful information on compactness of design and uses computer algorithms to recognize fruit shapes which is the same principle which will be used to recognize Lego shapes [16]. The next article, Object Sorting System Using Robotic Arm [17] describes a sorting system which is composed of a camera to examine whatever it is sorting, an Arduino microcontroller which runs the electrical components such as the conveyor belts, servo motors etc., and a robotic arm which will pick up objects and place them in another spot. The article also uses MATLAB with the Arduino microcontroller for image processing. The article describes two ways of sorting objects in a continuous flow. The first is by using AI so that the system can learn to distinguish objects, and the other is by using decisional algorithms that need to be hardcoded into the system. This source is useful because it outlines the necessary items to create a system which has a high sorting accuracy and sorts any type of object with conventional items that are low cost and readily available [17]. The final source, Object Sorting System in MATLAB using Robotic Arm [18], is nearly identical to the previous one and will useful for the same reasons. The main difference between the two articles is that the latter one goes into more detail regarding the image processing, and that is why it is included alongside the last one [18].

3.2 Benchmarking

In benchmarking our team analyzed competitor Lego Sorting Designs. We initially compared their overall designs to our customer requirements to find the pros and cons of each system. Then the team looked at each individual's subsystems to compare which concepts could work best for our Lego sorting Machine.

3.2.1 System Level Benchmarking

The design team researched current ideas and mechanisms used to accomplish goals similar to the project. In this section each of the four different competitors will be examined in a big picture perspective. In this section, requirements such as overall system portability, how many types of Legos a system can sort, structure must not be made from Legos, and high sorting accuracy are all under consideration for each competitor's complete design.

3.2.1.1 Existing Design #1: Lego Mindstorms NXT Vision Guided Brick Sorter

In this design by Akiyuky, [19] the overall system appears to be rather large, potently unmovable even. Additionally, all subsystems excluding the imaging and the AI program recognition appear to be constructed out of Legos. Some of the positive design choices are how large the initial inlet is, as well as having little user input after the machine is turned on. While the AI is capable of recognizing a large variety of Legos, the overall system only has eight output bins which is a waste of potential in increased variety of Legos (Figure 3.3).

Figure 3.3: Existing Design #1

3.2.1.2 Existing Design #2: AI Sorter

The second design discovered comes from an article on the IEEE.org website [20]. This design incorporated an extremely large input volume to handle two metric tons of Legos. These Legos are slowly moved on conveyor belt to an AI recognition system powered by expensive graphic processor and program called TensorFlow. Once the Legos are recognized they are pushed off the second half of the conveyor belt by air nozzles. Using these tools this design was able to recognize types of Legos, with an accuracy of ninety percent. Based on Figure 3.4 below it is evident that the design is not made out of Legos and seems to be rather durable.

Figure 3.4: Existing design #2

3.2.1.3 Existing Design #3: Tensor Flow Raspberry Pi

The next existing design [21] is relatively compact, though its size does come at a cost. For example, the inlet can only hold about a handful of Legos at a time, and also only has a small variety of types of Legos bricks it can sort. Despite these flaws, this design does do a lot right, such as having the highest recorded accuracy of all existing designs. Figure 3.5 shows that it also has a metal frame, making it more durable and filling our requirement of not being made out of Legos.

Figure 3.5: Existing Design #3

3.2.1.4 Existing Design #4: Lego Parts Sorter Version 1.0

The final existing design (Figure 3.6) is made without any imaging or computer programing [22]. By opting to only use the Lego's geometry for the recognition process the overall design is the largest of all other existing designs, meaning this machine is without a doubt not portable. This design also featured a small input volume that could only sort Legos that were predetermined, due to any type of block that wasn't considered in its design could potentially break the system. Additionally, this existing design goes against other customer requirements such as not being user friendly and being made out of Legos.

Figure 3.6: Existing Design #4

3.2.2 Subsystem Level Benchmarking

Subsystem level benchmarking is the analysis of each competitor's designs on their individual functions. This section may also include concepts discussed in the literature review. Each subsystem will be put under consideration for concept generation.

3.2.2.1 Subsystem #1: Lego Conveyance

Lego Conveyance is the process of moving Legos from one subsystem to another. Such as moving the Legos from the inlet subsystem to the imaging station. This subsystem cannot be avoided because it is necessary to space out a bulk set of Legos into a single file line for any of the recognition subsystems to process each type of block correctly. Otherwise the program would have to able to recognize Legos piled up on top of each other. This subsystem essentially contributes to making the other subsystems tasks more manageable.

Existing Design #1: Conveyer Belt

This is a standard conveyor belt with a fixed velocity, which uses walls to orient the bricks and line them up. However, with a single belt it the bricks will flow in a constant stream of each Lego touching the last along the line. This will ensure that multiple Lego types enter the Lego recognition subsystem at the same time, meaning the imaging will have to recognize multiple Legos at once. This will in turn cause more errors and reduce the overall accuracy. This subsystem comes from existing design #3 [21], this is better illustrated in the Figure 3.7 below.

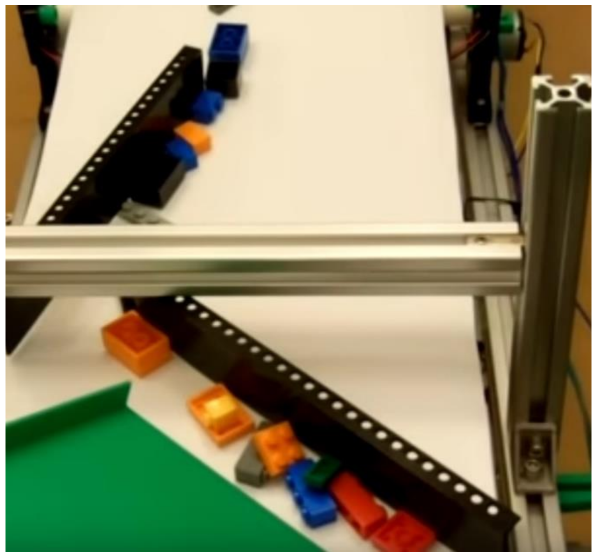


Figure 3.7: Conveyor belt using walls

Existing Design #2: Double Conveyer Belt

A double conveyor belt is an initial belt that receives the Legos from the inlet subsystem and moves them towards the second belt. The second conveyor belt will be moving much faster than the initial belt, therefore spacing each Lego from the last to allow time for the recognition system to process each part properly. Allowing the recognition system to process one Lego at a time will yield a higher accuracy, but may also lead to a longer overall completion time. An example of this concept can be found in Lego Mindstorms NXT Vision Guided Brick Sorter [19] or in Figure 3.7.

Figure 3.8: Double Conveyor Belt

Existing Design #3: Multi Level Conveyor belts

This concept comes from existing design #4 [22]. As shown in Figure 3.9, this design has three conveyor belts. Due to this system only using geometry to sort the larger Legos will stay on the top conveyor belt while the smaller Legos will fall down to the next levels to the following conveyor belt. This way all sortable Lego types can run at the same time as other bricks are being sorted. This concept would increase overall sorting time; however, this design cannot sort that many types of blocks and if it wishes to expand how many types of Legos it can sort it would have to add on more levels. As the video demonstrates three conveyor belts is rather loud, if the team used this concept, it would certainly go over the preset decibel ceiling.

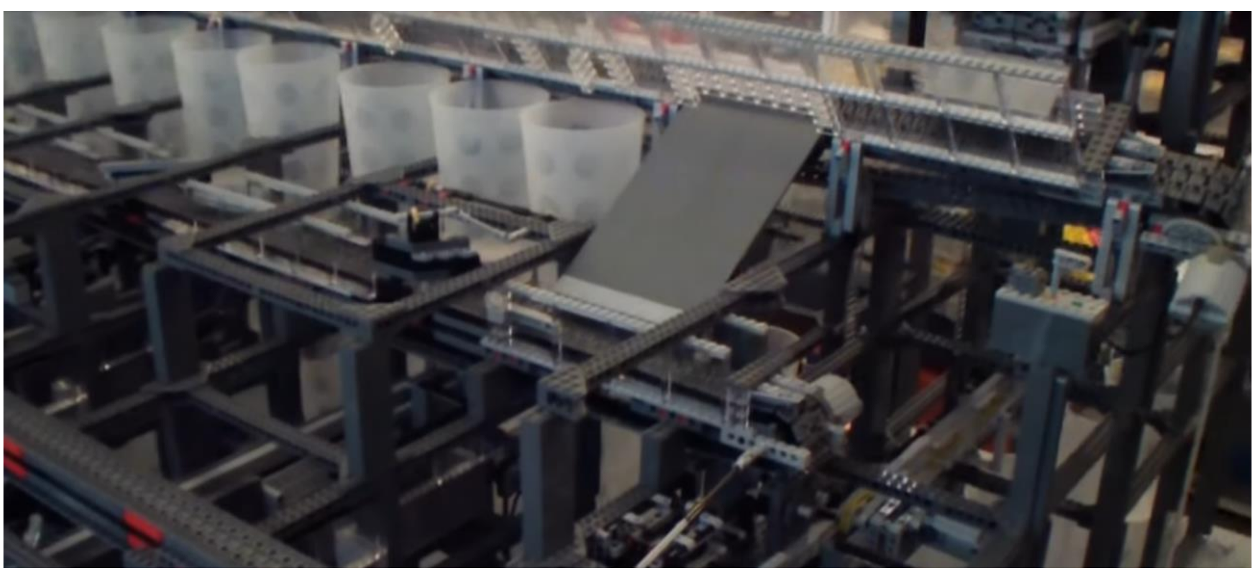


Figure 3.9: Multi Level Conveyor Belts

3.2.2.2 Subsystem #2: Lego Recognition

The subsystem that recognizes Lego type is the most important part of the system. The entire project is based on the system's ability to recognize Legos and determine how to sort them.

Existing Design #1: Fisheye Lens Camera

The fisheye lens was developed to image items from an isometric view and dimension them based on the captured image. This would give the system the ability to use one camera and one algorithm that is able to compare the dimensions of a Lego to a known Lego library. Once a match is found, the Lego would be correctly identified. The benefit of this method is lower cost because only one camera is used.

Existing Design #2: Geometry

This existing design concept is used in Lego Parts Sorter Version 1.0 [22]. This concept uses the height of each Lego type to determine what level each Sortable Lego can go down. From there each level has a stair stepping maximum clearance. Each clearance ensures that no bricks taller can the clearance can pass. If the Lego is too tall it will be forced into the bin just below, while the Legos that could pass under move along to the next lower clearance. While this system is fairly accurate the downfall comes from how large the system would have to be to meet our goal of types of sortable Legos.

Existing Design #3: Multiple Cameras

The group that generated the TensorFlow Raspberry Pi sorter started out with one camera for imaging, and then moved to multiple. This increased accuracy of recognition by reducing problems from random orientation [21]. Allowing the Lego to be randomly oriented requires fewer design considerations for the conveyance system. While increasing the number of cameras will increase cost, it greatly reduces the number of conveyance subsystems that would be needed to consistently orient Lego pieces.

3.2.2.3 Subsystem #3: Software

Existing Design #1: TensorFlow on Raspberry Pi

The subsystem is based on a source that uses TensorFlow on a Raspberry Pi to recognize different types of Legos [21]. TensorFlow is an AI that utilizes machine based learning that creates algorithms that sends signals to mechanisms on the Lego sorting machine, ultimately sorting the Legos. This subsystem relates to the Lego team's requirements because it is a system that sorts Legos very accurately, and also controls every electronic mechanism in the system.

Existing Design #2: Hard Coding

This design uses a computer along with image recognition software that was written to be compatible with Lego Mindstorms [19]. This source is useful because it uses a computer to recognize Legos with high accuracy which is an important requirement.

Existing Design #3: Imaging Processing Using MATLAB with Arduino

This subsystem uses an Arduino microcontroller coupled with a MATLAB software package installed [18]. The benefit to using MATLAB is because its existing imaging recognition software can be manipulated to identify Legos.

3.3 Functional Decomposition

This section includes the black box model as well as the functional model. The purpose of these two models is to gain a deeper understand standing of the main function of the Lego sorting machine as well as how the main function and sub-functions relate to one another.

3.3.1 Black Box Model

Every design project can be broken down into a few, or in some cases a singular crucial function. The black box model is an abstract form of that function that has inputs which are material energy, and signal flows. Figure 3.10 displays the black box model referring to the Lego sorting machine.

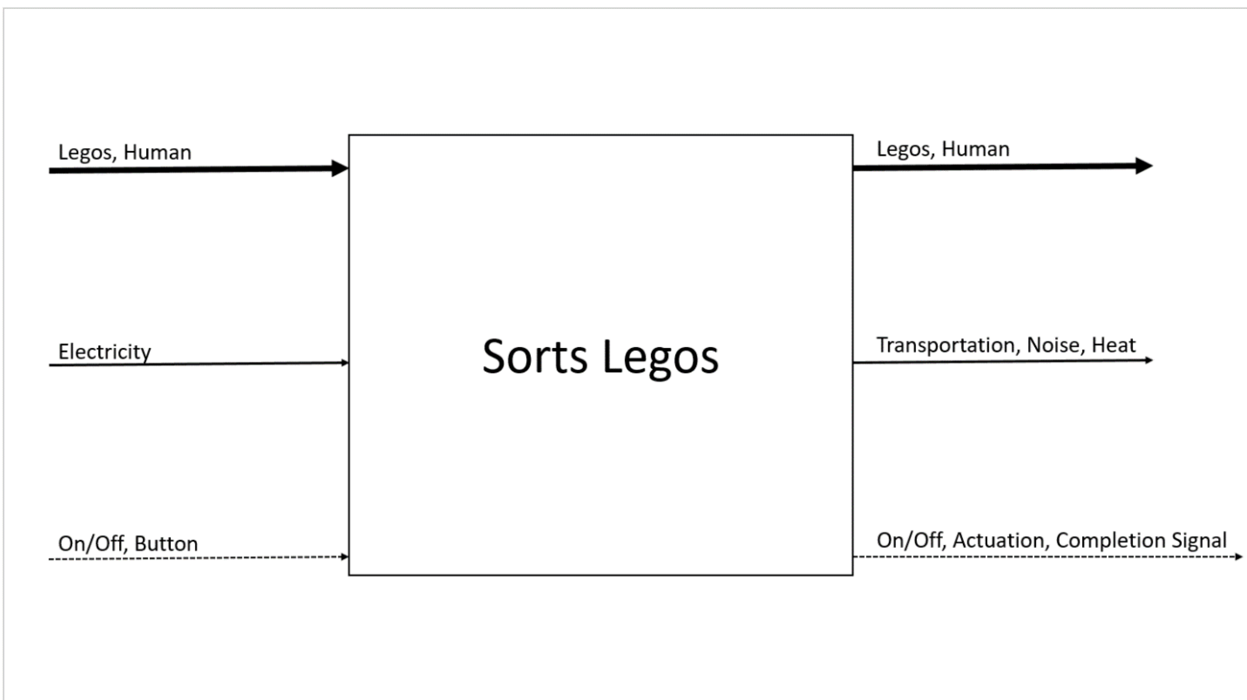


Figure 3.10: Black Box Model

The Lego sorting machine had one most significant function, and that is to sort Legos and is represented in the center box. The inputs are represented by the arrows on the left side of the box. The thick black arrow is for material in, the thin black arrow is for energy in, and the dashed arrow is for signal in. The outputs are whatever comes out of the system and are represented in a similar fashion. The black box model is a way to visually understand what the most important function of the Lego sorting machine, once that function is understood by the Lego team, every other aspect of the design can be modified to boost the efficacy of the main function.

3.3.2 Functional Model

Akin to the black box model, the function model is a visual representation of the material, energy, and signal flows. The difference is that the functional model lists more than one functions, along with sub-functions that are related to other functions. The purpose of the functional model is to gain comprehensive understanding of the product being created, and what it is supposed to do. The functional model is listed below as Figure 3.11.

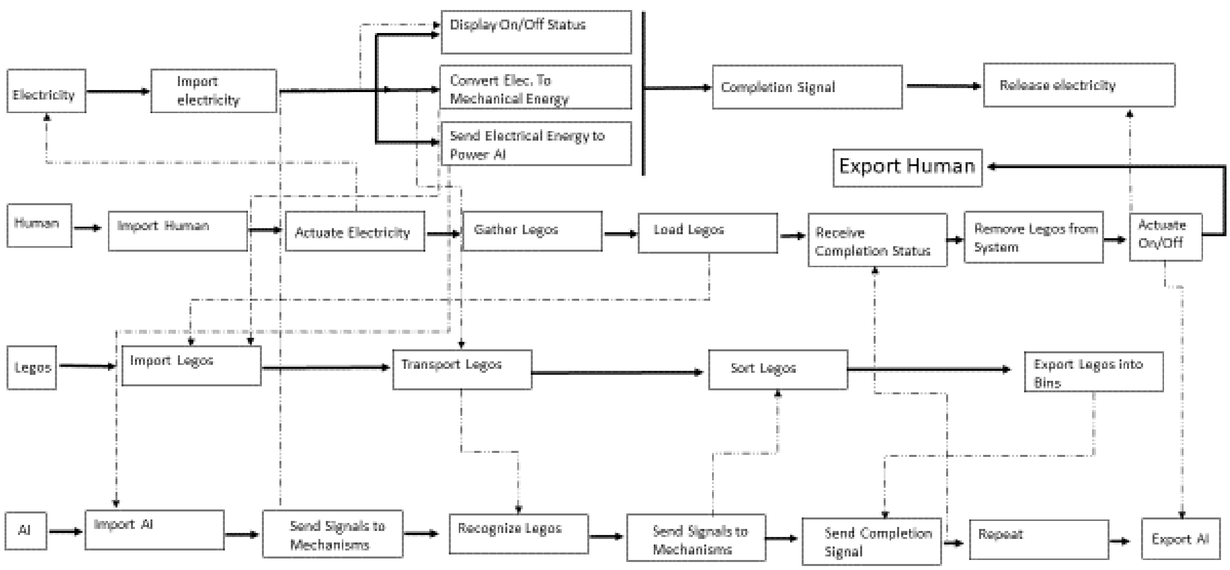


Figure 3.11: Functional Model

The thick black arrows show the flow from the beginning of the system to the end of the system. The dashed arrows represent the flows between the beginning and the end, connecting inputs to outputs, and demonstrating how each function relates to the others. This functional model demonstrates how a Lego sorting machine would work in terms of all the functions and is represented in an abstract form. The Lego sorting team can refer to this diagram during the design process to make sure no function is being overlooked, and ensure no new functions don’t suddenly show up in the design that are not supposed to be there.

4 Concept Generation

4.1 Full System Concepts

The team used three categories of subsystem designs to generate three full system designs. The first design used Inlet #2, Belt #1, and Bin #4. The second design used Inlet #1, Belt #2, and Bin #2. The final design used Inlet #3, Belt #2, and Bin #5.

4.1.1 Full System Design #1

The first full system considered uses a vibrating funnel (Figure 4.3), simple conveyor belt system (Figure 4.1), and a sideways tank track bin design (Figure 4.9). The funnel has a stopper that outlets one Legos at a time onto the conveyor belt. From there, the conveyor belt aligns them, and dumps them onto another belt. The second belt moves around five times faster than the original belt in order to create space between Legos. This is where the Legos will be imaged individually. Once categorized a sideways tank track with bins around the perimeter rotates so that the Lego goes into the corresponding bin.

Pros:

- Allows for many bins to place categories of parts
- Sideways tank track can be wrapped around system to use less space
- Would precisely dump Legos one at a time

Cons:

- Difficult to properly design funnel to avoid clogs
- Vibrating or shaking Legos will be noisy
- Simple Belt uses too much space

4.1.2 Full System Design #2: Descriptive Title

The second full system uses a lift platform (Figure 4.3) to raise a small number of Legos onto a compact conveyor belt (Figure 4.2). The compact conveyor belt centers Legos, and dumps onto a belt below going the opposite direction about five times as fast. This creates space between Legos for imaging. Once imaged, a rotating ramp (Figure 4.7) moves to the appropriate stationary bin, and the belt deposits the Lego on the ramp. From there, the Lego slides down the ramp into the correct bin.

Pros

- Compact
- Few moving parts
- Easy to design

Cons

- Unable to utilize many bins
- Low Lego storage capacity

4.1.3 Full System Design #3: Descriptive Title

The final design utilizes a conveyor belt with platforms (Figure 4.5) to lift a small number of Legos onto a conveyor belt. The compact conveyor belt design is employed to center Legos on the belt, and separate them for imaging. Once imaged, a horizontal tank track Figure 4.10) moves to bring the correct bin cluster below the rotating ramp. The rotating ramp pivots to the correct bin in the cluster. Next, the conveyor belt deposits the Lego onto the ramp, and it slides down the ramp into the appropriate bin.

Pros

- Compact
- High capacity for Lego types
- Efficiently supplies Legos to camera
- Efficiently selects appropriate bin for Lego

Cons

- Difficult to design
- Many moving parts

4.2 Subsystem Concepts

The following section lists different subsystems of the Lego Sorting machine. There are at least 2 unique designs for each subsystem.

4.2.1 Subsystem 1: Conveyor Belt Designs

The system for this project was broken down into inlet, conveyance, and bin subsystems. Ideas for each were generated and recorded, and are detailed below.

4.2.1.1 Belt Design 1: Simple Conveyor Belt System

The simple conveyor belt system consists of two belts that run at different speeds. The second conveyor belt (examining left to right) has rails that allow the Legos to spread out. It is necessary to have individual Legos spread out so that the AI can recognize one at a time. This system also has rollers that will support the belt should the mass of Legos become too great. Below is a pros and cons list of this system.

Pros

- Simple Design would be easy to set up
- Multiple Conveyor Belts Means that Individual Speeds of the Belts can be controlled
- Rails on this System Allow Individual Legos to Spread Out

Cons

- This Design takes Up a Large space

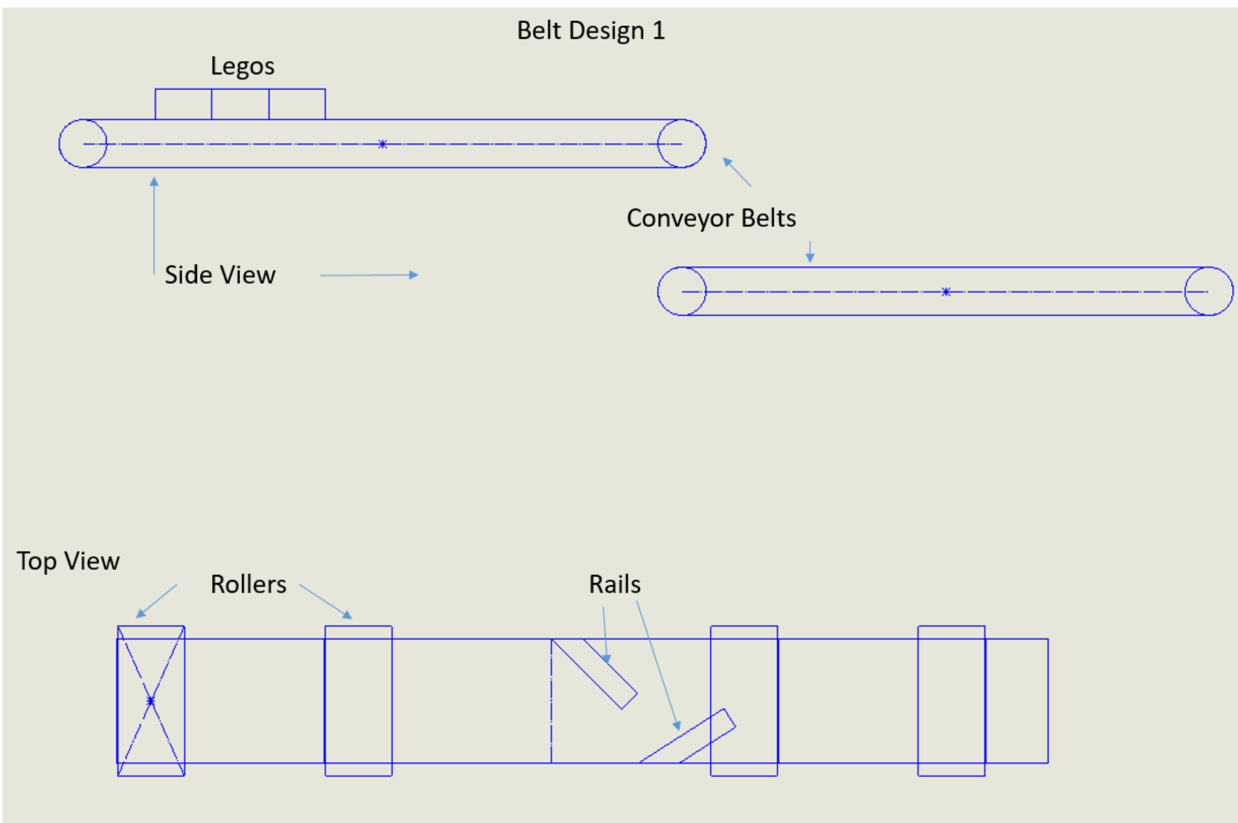


Figure 4.1: Belt Design #1

4.2.1.2 Belt Design 2: Compact Conveyor Belt Design

The compact conveyor belt design is similar to previous design, except the second belt is now placed underneath the first belt for compactness. Below is a pros and cons list. A figure of this design is provided after the list.

Pros

- More Compact than the Simple Conveyor Belt Design
- Multiple Conveyor Belts Means that Individual Speeds of the Belts can be controlled
- Rails on this System Allow Individual Legos to Spread Out

Cons

- More Difficult to Set Up When Compared to the Simple Conveyor Belt Design

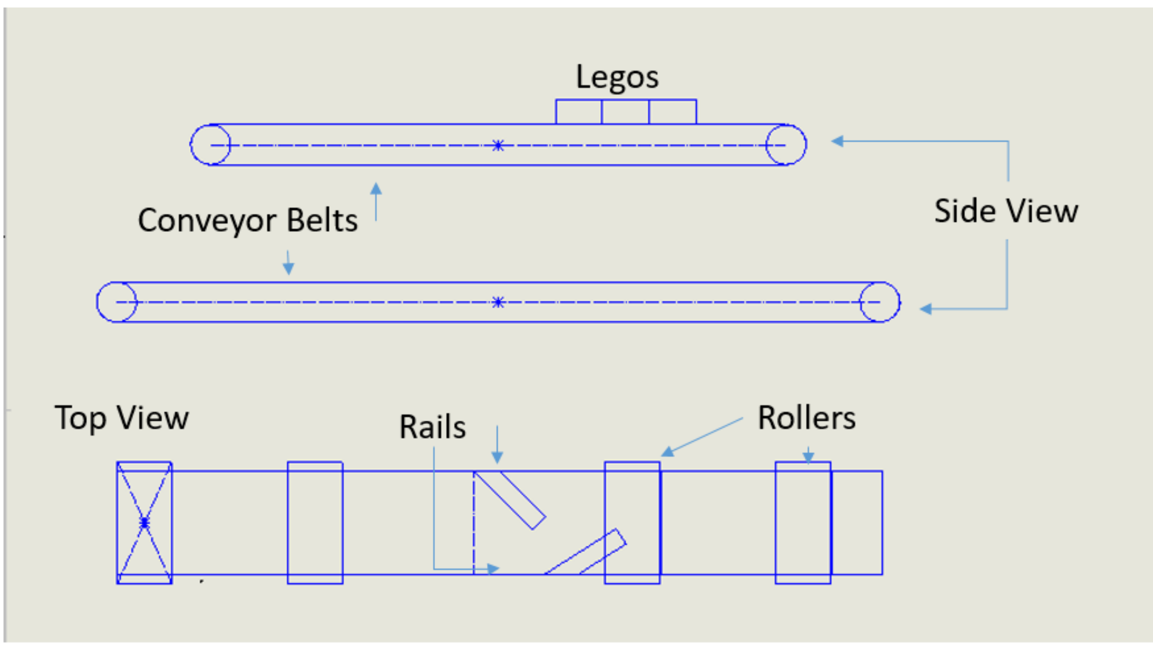


Figure 4.2: Belt Design #2

Subsystem 2: Inlet Designs

This section lists three unique inlet designs for the Lego sorting machine. The inlet is where all the Legos would be placed into the system.

4.2.1.3 Inlet Design 1: Vibrating Funnel

Inlet design 1 consists of a large funnel that has a moving gate at the bottom to allow a set number of Legos through at a time. The funnel would have a motor with a rotating unbalanced weight that would cause vibration to coax the Legos into sliding down the incline of the funnel. Below is a list of pros and cons. A Figure of the vibrating funnel is provided after the list.

Pros

- Large Containment Volume
- Automated gate
- Gravity Fed; Less Moving Parts than Other Design

Cons

- Legos Clog Easily
- Gate Jamming
- Vibrating Motor Causes Extra Noise

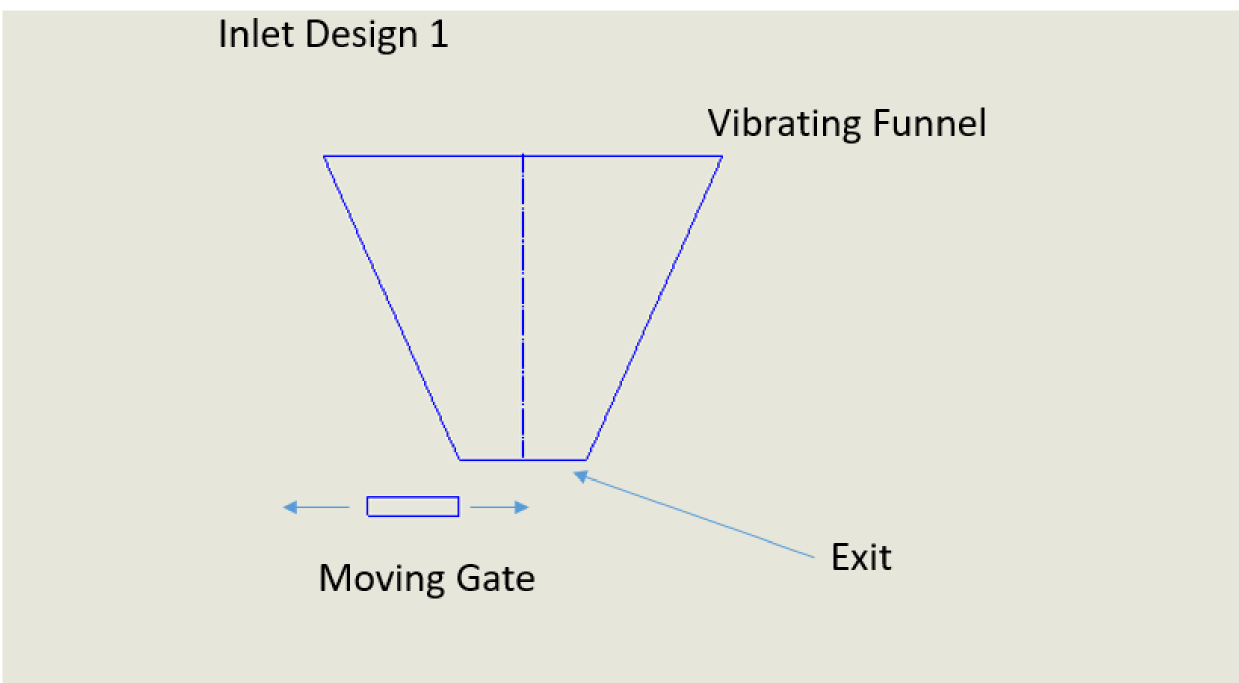


Figure 4.3: Inlet Design #1

4.2.1.4 Inlet Design 2: Lift Platform

Inlet Design 2 consists of an inclined containment area which will allow Legos to slide down to a platform which will move up and down. The Legos will then be pushed onto an inclined ramp which will cause the Legos to slide onto a conveyor belt.

Pros

- Legos Are Reliably Transferred from the Containment Area to the Conveyor Belt System

Cons

- Moving Platform Requires a Large amount of Space to Move

Inlet Design 2

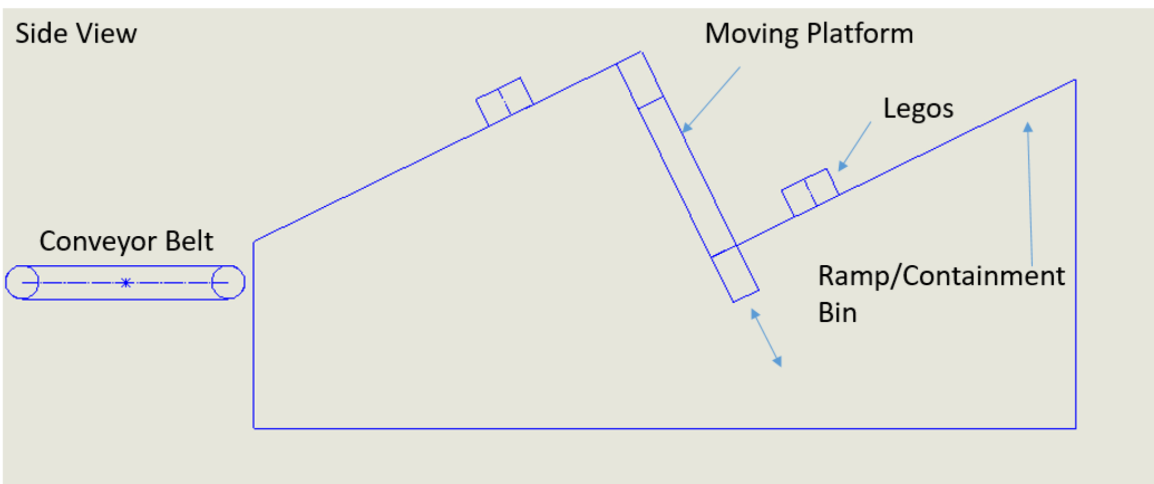


Figure 4.4: Inlet Design #2

4.2.1.5 Inlet Design 3: Conveyor Belt with Platforms

Inlet Design 3 consists of an inclined containment system that will allow Legos to slide to an inclined conveyor belt system that has equally spaced flexible platforms attached that will lift a set number of Legos to another conveyor belt. Below is a pros and cons list. A figure is provided for the system after the list.

<u>Pros</u>

- Legos Are Reliably Transferred from the Containment Area to the Conveyor Belt System
- Requires Less Space than the Lift Platform

<u>Cons</u>

- Rotating Belt Might Cause Legos to Jam

Inlet Design 3

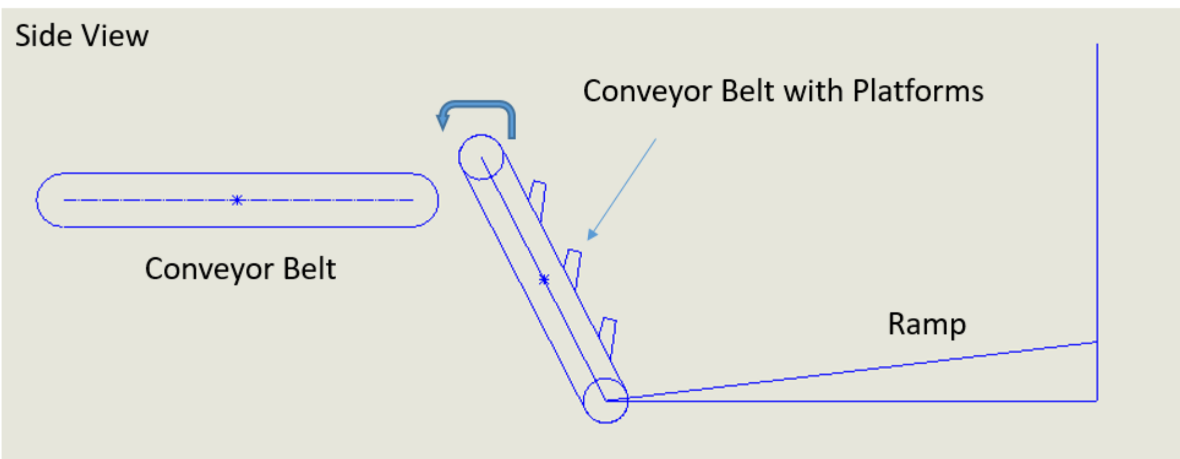


Figure 4.5: Inlet Design #3

4.2.2 Subsystem 3: Bin Designs

The section details the various bin systems for the Lego sorting machine. The purpose of the bin system is for the final location of the Legos after they move through the system. Ideally, the Legos are sorted into a different bin for each specific Lego type.

4.2.2.1 Bin System 1: Linearly Moving Bins

Bin System 1 is composed of a stationary ramp that allows Legos to move into a number of bins that move from side to side. Below is a pros and cons list for this subsystem. There is also a figure provided after the list.

<u>Pros</u>

- Simple Design
- Can be designed to accommodate a large variety of Legos

<u>Cons</u>

- Bins Will Take up a Lot of Space

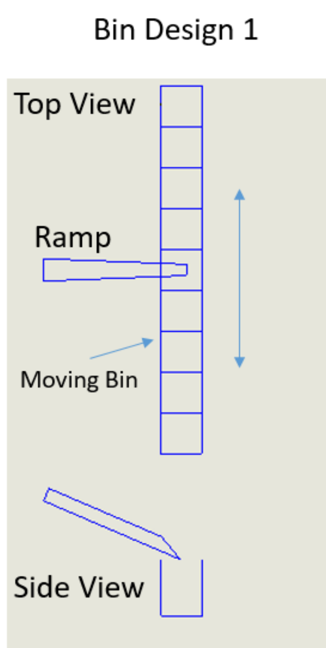


Figure 4.6: Bin Design #1

4.2.2.2 Bin System 2: Rotating Ramp with Stationary Bins

Bin system 2 is made up of a rotating ramp which will allow Legos to slide down into bins which are designed to be more compact than bin system 1. Below is a pros and cons list. A figure is listed for this design after the list.

<u>Pros</u>

- Designed for Compactness
- Rotating Ramp is a reliable way to transport Legos into Bins

<u>Cons</u>

- Only accommodates a small variety of Legos
- Still Takes Up a Considerable Amount of Space

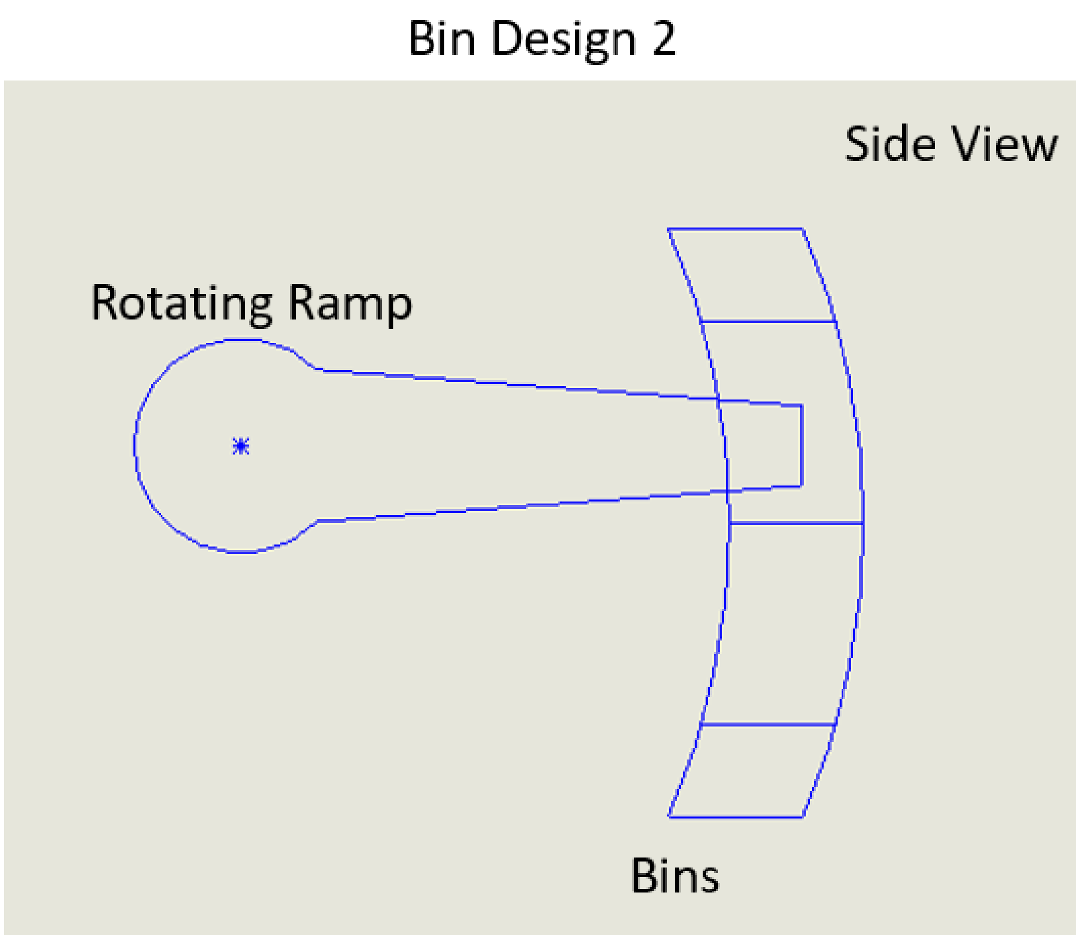


Figure 4.7: Bin Design #2

4.2.2.3 Bin System 3: Rotating Bins

Bin System 3 is a design that incorporates a number of bins that are mounted on a rotating wheel. Below is a pros and cons list. A figure is supplied after the list.

Pros

- Can be designed to accommodate a large variety of Legos
- More Compact than Bin Design 1

Cons

- Weight of the Sorted Legos could become an issue

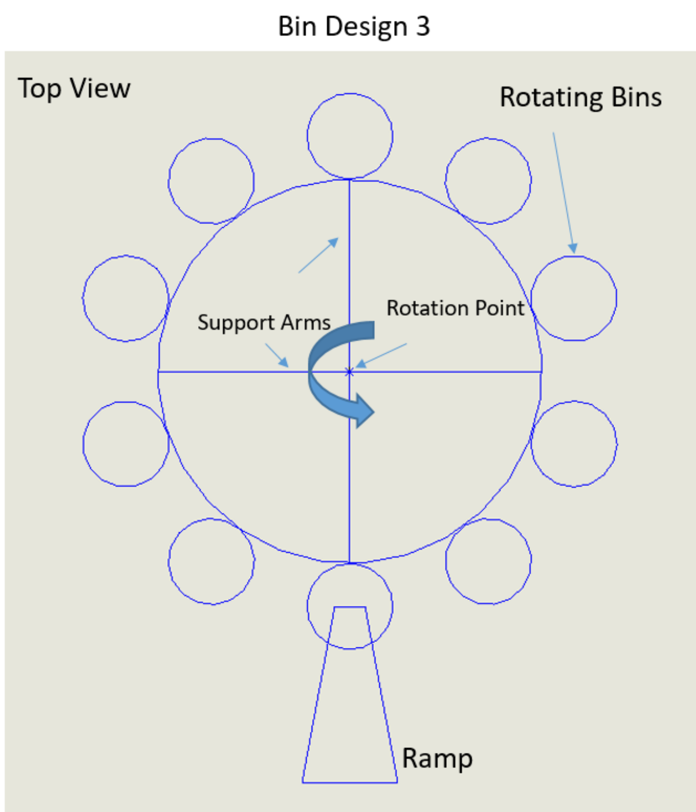


Figure 4.8: Bin Design #3

4.2.2.4 Bin System 4: Sideways Tank Track

Bin System 4 uses a tank track turned on its side with bins attached to the perimeter. The tank track can rotate, and the bins will move so that Legos can be placed in their correct bins.

Pros

- Can be wrapped around perimeter of system to effectively use space

High capacity for bins

Cons

- Many moving parts
- Difficult to design

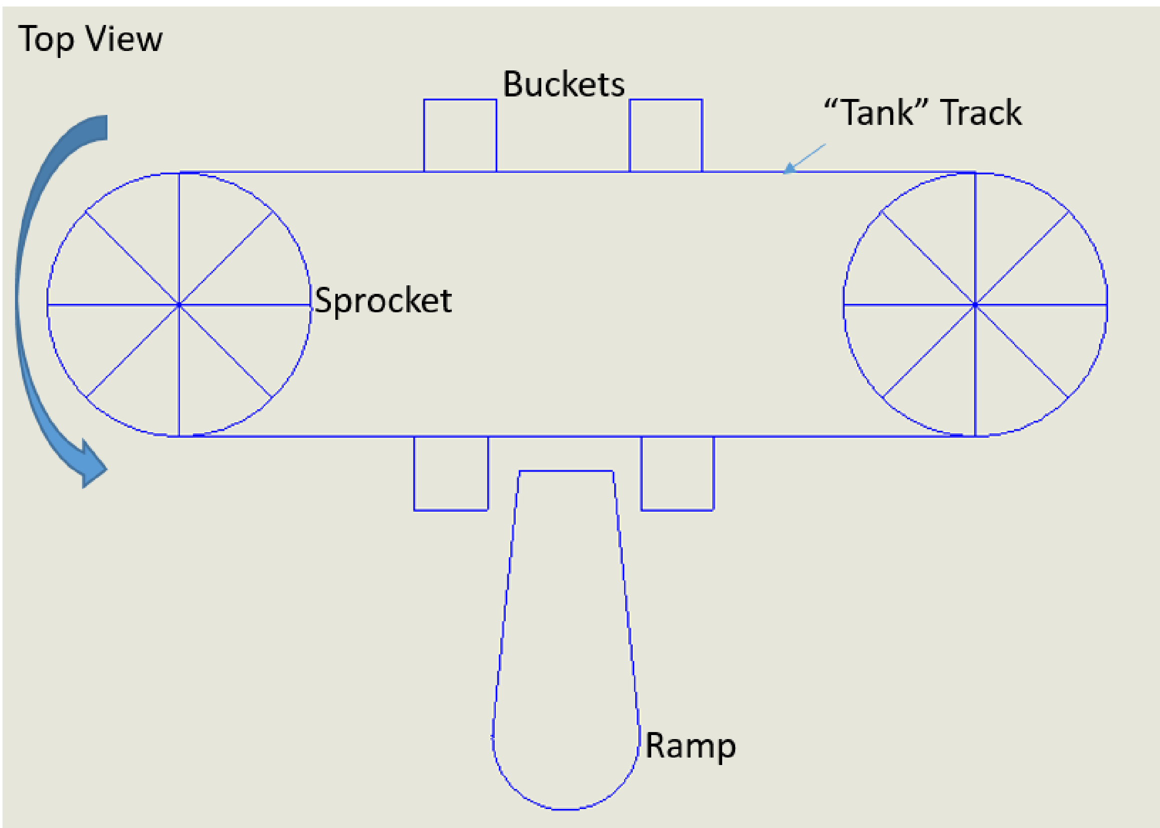


Figure 4.9: Bin Design #4

4.2.2.5 *Bin System 5: Horizontal Tank Track*

Bin System 5 uses the same principle as a Ferris wheel, but instead uses a tank track to reduce the height, and increase the number of bins. Additionally, the buckets are divided into sections parallel to the track, and the ramp can pivot to place each Lego in the correct bin.

<u>Pros</u>

- Compact
- Efficient way of locating the correct bin

<u>Cons</u>

- Many moving parts
- Difficult to design

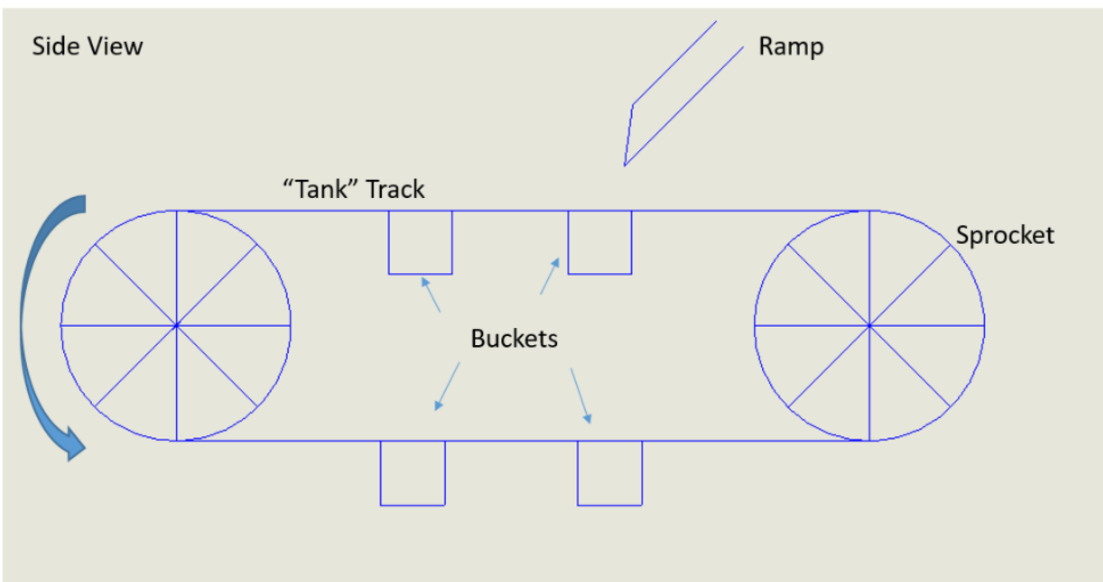


Figure 4.10: Bin Design #5

5 DESIGN SELECTED – First Semester

Chapter 5 will consist of the final design selection, and detailed reasoning for the decision. Additionally, a Pugh Chart and Decision Matrix will be included.

5.1 Technical Selection Criteria

The three types of subsystems will each be compared based on their own set of criteria. These include cycle time, portability, and ability to withstand abuse, effectiveness of an emergency stop, large input volume, intuitive operation, pinch point prevention, and sorting accuracy. Cycle time relates to how fast a Lego piece can pass through the conveyance system. Portability directly relates to weight and size. Ability to withstand abuse refers to how strong the system will be. Effectiveness of an emergency stop is based on how fast the system could stop if needed. Large input refers to how many Legos can be input at once. Intuitive operation is based on how easily somebody can operate the system without knowing anything about it. Another important aspect is preventing areas where the operator can be pinched by the system, so eliminating these points is important. Lastly, sorting accuracy relates to how well the system will be able to correctly recognize each Lego type.

5.2 Rationale for Design Selection

Below is the rationale for the final design that was chosen. This section includes a Pugh chart analysis as well as a decision matrix analysis.

5.2.1 Pugh chart

The Pugh chart is a visual means of comparing criteria and concepts. Each subsystem has its own Pugh chart with its own criteria. Additionally, each subsystem has a datum or a neutral standard. The figures for each subsystem are shown below, and are the belt systems, inlet systems, and bin systems. Each subsystem criteria is given a plus, S, or minus. Plus means the system is better in its respective criterion, minus worse, and S stands for same as the datum. The pluses and minuses are then summed up to determine which system is better. Determining which subsystem is best is further refined with the decision matrix.

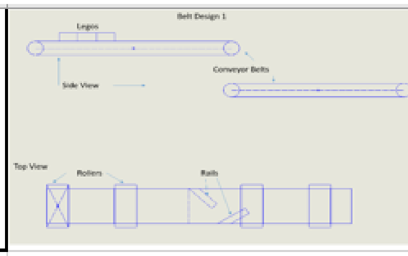
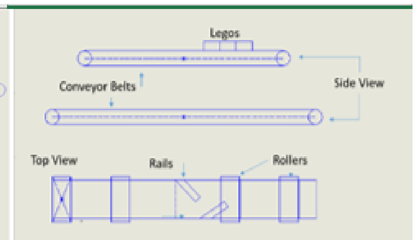
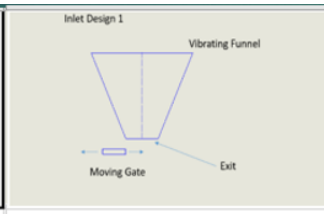
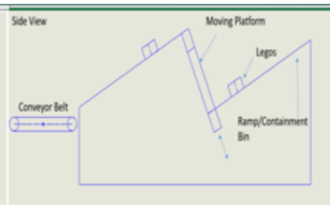
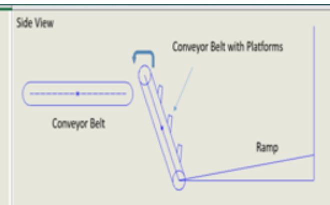
	Concepts		
Criteria		D	
Base Area		A	+
Mass		T	+
Large Input Volume		U	S
Durability		M	S
$\Sigma +$		0	2
$\Sigma -$		0	0
ΣS		4	2
Σ_{total}		0	2

Figure 5.1: Belt systems (Pugh Chart)

Based on the decision matrix and Pugh chart Team 10 concluded that inlet conveyor belt with platforms was the best choice for the Team's design because it had an outstanding cycle time potential, while also being able to accommodate the largest input volume. Additionally, the horizontal tank track bin also proved to be the choice. Additionally, the compact conveyor belt system was overwhelmingly the superior concept due to its portability and having a faster cycle time due to not needing as long of an initial belt to orient Legos, while having a higher sorting accuracy due to the frame work that would be provided for multiple imaging systems. Lastly, the horizontal tank track bin also proved to be the best choice because it has the fastest cycle time, meaning multiple bucket types can be included on the same tank track. This would optimize the maximum number of sortable Lego types and would require less cycling through the bin possibilities due to how compact the subsystem could be. The combination of each decision can be seen in Figure 5.2 and Figure 5.3

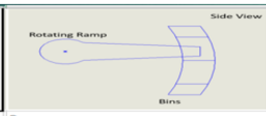


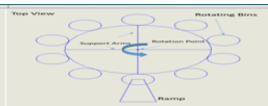


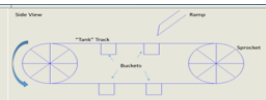


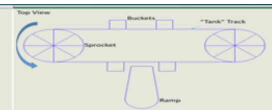
	Concepts			
Criteria		D		
Base Area		A	-	-
Mass		T	S	S
Large Input Volume		U	+	+
Durability		M	+	+
$\Sigma +$		0	2	2
$\Sigma -$		0	-1	-1
ΣS		4	1	1
Σ_{total}		0	1	1

Figure 5.2: Inlet Systems (Pugh Chart)









	Concepts				
Criteria		D			
Base Area		A	-	++	-
Mass		T	-	-	-
Large Input Volume		U	S	+	+
Durability		M	S	+	S
$\Sigma +$		0	0	4	1
$\Sigma -$		0	-2	-1	-2
ΣS		4	2	0	1
Σ_{total}		0	-2	3	-1

Figure 5.3 Bin Systems (Pugh Chart)

5.2.2 Decision Matrix

In Team 10's Decision Matrix, found in Appendix 7.1, the team determined the relevant customer requirements for each subsystem. Then, the team agreed upon how well each design meet each task and multiplied the agreed upon value by the engineering requirements weighting. From there all requirements and weighs were added together to determine which subsystem would be the optimal choice for the Lego Sorting Machine.

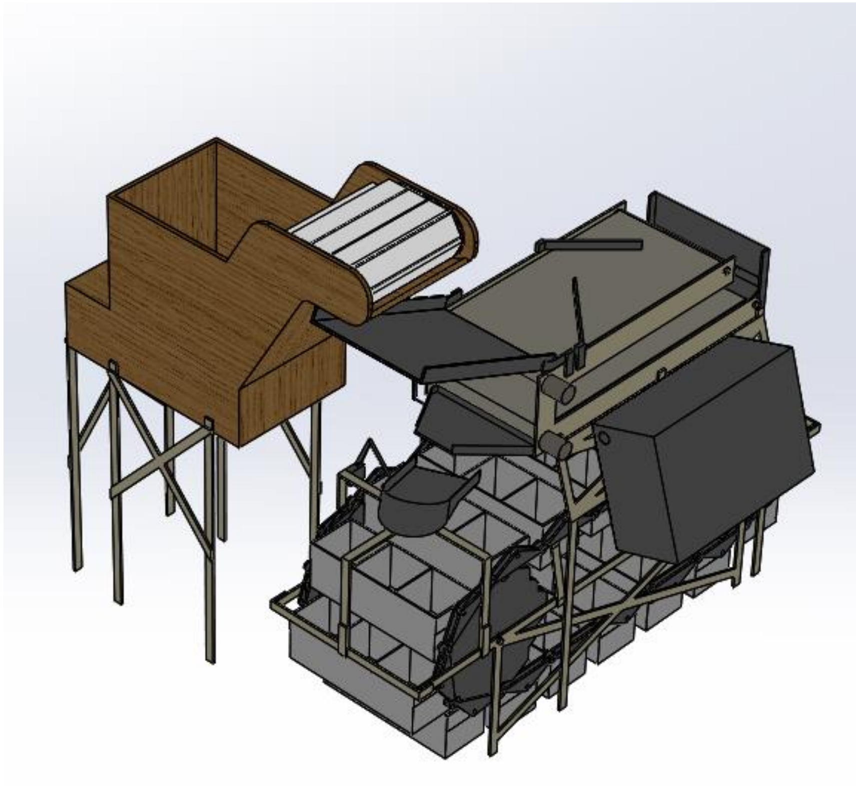


Figure 5.4: Isometric View of Final Design

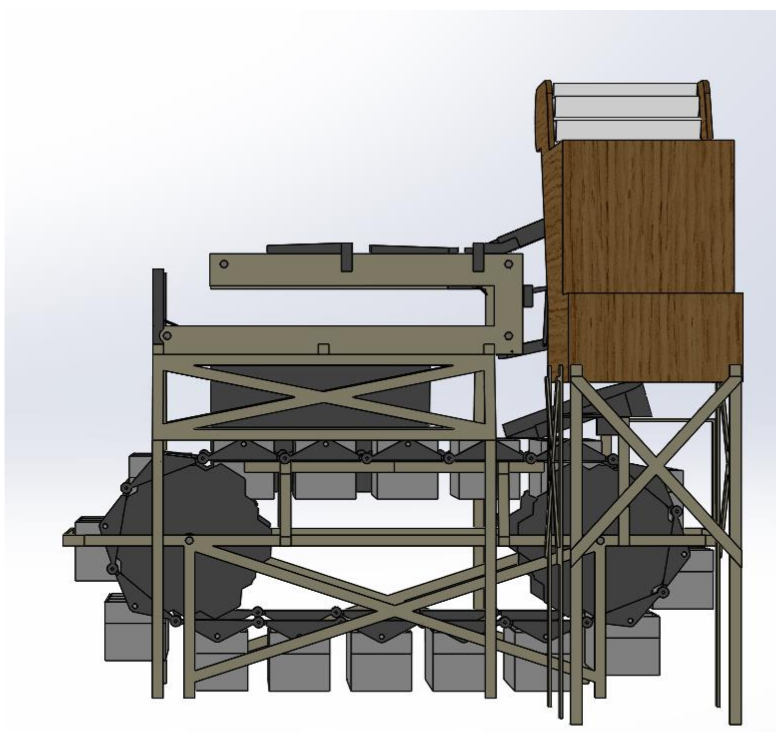


Figure 5.5: Front View of Final Design

5.3 Analytical Summaries

The Lego Team's analytical reports are used to study tasks needed to design the Lego sorting Machine. The first report is to select motors that have sufficient rated torque capabilities for moving the conveyor belts. The second analysis is to design the conveyor belts diameters and the loads on each belts to calculate actual torques, that will be compared to the rated torques form the selected motors. The third analysis focus on the getting the Raspberry Pi to run the entire Lego sorting machine. That is, getting the system to recognize and sort Legos accurately in a timely manner without using too much RAM.

5.3.1 Motor Analysis and Selection: Eric Pisciotta

The outcomes of this analysis determined the specification requirements for the motors that will drive the conveyor belts. Several specifications regarding motors were selected simply by weighing the customer requirements. A table outlining these requirements is shown below.

Figure 5.6: Motor Selection Criteria

Motor Type:	Brushless
Voltage:	12VDC
Max Current:	5 Amps
Gearbox Type: (spur or worm gear):	Spur Gear
Max dimensions:	4" x 4" x 4"
Output Signal	Yes

Any motors in the final product must be brushless in order to meet the life expectancy of the device. Brushed motors wear out over time and require maintenance. This is completely avoided by choosing brushless motors. Additionally, brushless motors output more torque while using

A 12V DC power supply has been selected to power all components within the assembly for added safety. The capacity of this supply will allow each motor to draw 5 amps. Any motor chosen must be able to operate on 12VDC and less than 5 Amps.

In order to eliminate the need to design gearboxes, motors will be ordered pre fitted with gearboxes that output the desired rpm. These gearboxes can either be geared with spur gears, or a worm gear. Spur gears will be preferred so that the system can be manipulated by hand when the machine is off. Worm gears are typically self-locking, so it would be impossible to move any driven components by hand if the motors aren't geared with spur gears.

Since space is a concern for this project, the motors will need to be small so that they don't interfere with placements of other components. By selecting small motors, weight will also be reduced, as there is a weight constraint that effects the design as well.

Some motors have an output signal that tells a computer how fast it is spinning. This is important so that the Raspberry Pi can keep the motors spinning at the correct speeds so that the system stays synchronized. Without this signal, the Raspberry Pi would be blind to the motor speed, and driven components could operate out of synch which would reduce efficiency, or cause items to pile up within the system.

The final aspect of motor selection is the torque requirement. The torque required for each motor to move a Lego from the start of the belt to the end of the belt can be calculated by Equation 1 [19].

$$T = \frac{1}{2}D(F + \mu W g) \tag{1}$$

Equation 1 is a function of diameter, external force, friction, mass, and gravity. The cross-sectional area of the belt will be small, and a material with a very low rigidity will be selected, so the external force from the belt will be negligible. Assuming F, which is the force to turn the belt is negligible, and setting D (diameter) as a function of velocity and rotational speed of the motor, the torque required for a belt can be calculated using Equation 2.

$$T = \frac{1}{2}\left(\frac{(V * 60)}{\pi * \omega(RPM)}\right)\mu W g \tag{2}$$

Once a suitable motor is selected that meets the criteria in Figure 5.6, the output rpm must be plugged into Equation 2, to verify that its output torque is sufficient. Due to the difficulty of finding a motor that meets all of the criteria in Figure 5.6, the first one that had a high enough torque output was selected.

5.3.2 Conveyor Belt Analysis: Austin Shorr

This analysis is the designing of the conveyor belts required to transport Legos from the release of the lift inlet to the imaging system that will recognize Legos Types of future sorting. The type of belt being designed is a powered roller conveyor. I order to design the belts a speed for each must be selected. Conveyor belt 1 is five times slower than Conveyor belt 2. This choice was made to space out each Lego when the oriented Legos transition from belt 1 to 2. Using the selected 12 Volt Aobbmock motors form a separate analysis the diameters of the rollers were calculated to be roughly ¾ an inch. Using that information, the velocity of the lift was determined by calculating the time between each lift arm's release of Legos onto conveyor belt 1 divided by the distance between each arm. Knowing that the load on Belt 1 is then found under the assumption of how many 2x2 Lego bricks can fit on each step arm and how may lift arm releases would be on the belt at any point and time. This was done by taking into account the maximum distance possible for a single Lego to travel form one end of the belt to the other when sliding against orienting walls. Now that Load and the roller diameters are found, the torque can be calculated by calculating the external force on each belt along with assuming a motor efficiency of 90%, a gear ratio of one to one, and a recommended coefficient of friction form conveyor belt manufactures of 0.14 [20] The calculated torques for each conveyor belt's corresponding selected motors are compared against the rated torque allowances for each motor. The comparison demonstrated that the loads applied by the Legos on the belts would be significantly less than 1%, meaning the torques would be negligible and the motors selected should work without major complication for the geometry specified in the designs of conveyor belts 1 and 2.

5.3.3 Raspberry Pi Analysis: Tristian Vigueria

The purpose of this analysis is to provide insight into the portion of the Lego sorting machine that deals with the Raspberry Pi. The Raspberry PI is mounted on the Lego sorting machine and has motors and a camera connected to it. Image recognition software and hard coded algorithms have been preloaded onto the Raspberry Pi. Upon testing, the image recognition software takes up 50-70% of the Pi's RAM. This leaves approximately 30% of the memory that will be used for the hard coded algorithms that run the motors. It should be noted that no more cameras should be added since it will seriously tax the RAM used and would render the system unusable. Before the neural network within the image network is properly trained, Lego recognition could take as long as 1 minute recognize and sort 1 Lego. This can be remedied by further training the neural network to optimize for efficient recognition. It is anticipated that the Raspberry Pi's software recognition system can be trained to sort Legos as fast as 3.8 seconds [21] which is well below the 5 seconds per Lego according to the customer requirements. Furthermore, it is expected that the Legos are to be sorted with an initial 89% accuracy [21], which falls short of the 95% accuracy cutoff set by the client. It is believed that with proper optimization and iterative training of the systems neural network that 95% accuracy can be achieved.

5.4 Design Description

The purpose of this design is to fully explain how the Lego sorting machine will operate. There are 3 main subsections that comprise the Lego sorting machine. They are the inlet system, conveyor belt system, and bin system respectively. The inlet system is a large bin which is suspended above the conveyor belt system. The inlet bin contains an escalator which will continuously transport Legos onto a slide which feeds to the conveyor belt system. The inlet system is shown in Figure 5.7. The conveyor belt system consists of two conveyor belts which have been stacked on top of each other and are held together by a frame. There are two bumpers atop the first conveyor belt which will uniformly distribute the Legos into a single file line. After the Legos move from the first conveyor belt to the second, they will stop one by one to be imaged by the camera which has been placed between the two conveyor belts. Next the Legos fall onto another slide which is controlled by a servo and will move up and down to dump it down onto a rotating ramp; it moves up and down to ensure that the Legos do not fall onto the rotating slide prematurely so that the proper bin has enough time to rotate around the chain path. The conveyor belt system is shown in Figure 5.8. Once the Lego gravitate off of the rotating ramp. The bins rotate around using a chain and sprocket method and stops at a predetermined location by the Raspberry Pi. The bin system is shown in Figure 5.9. Every part and every part drawing is included in a .zip file submitted along with this document.

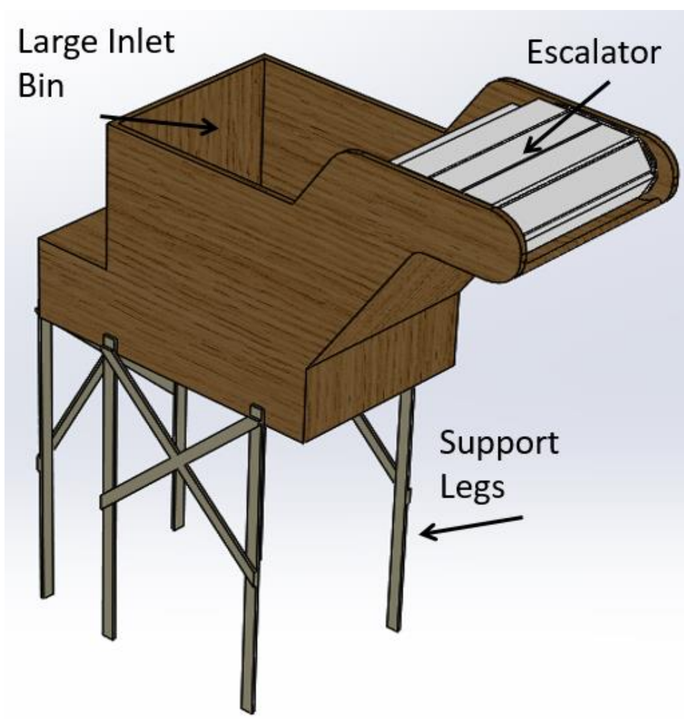


Figure 5.7: Inlet System

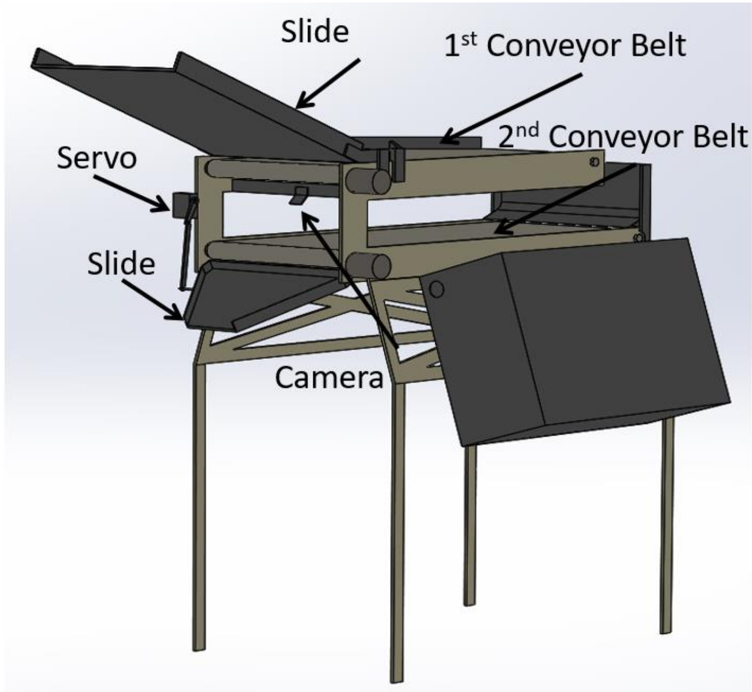


Figure 5.8: Conveyor Belt System

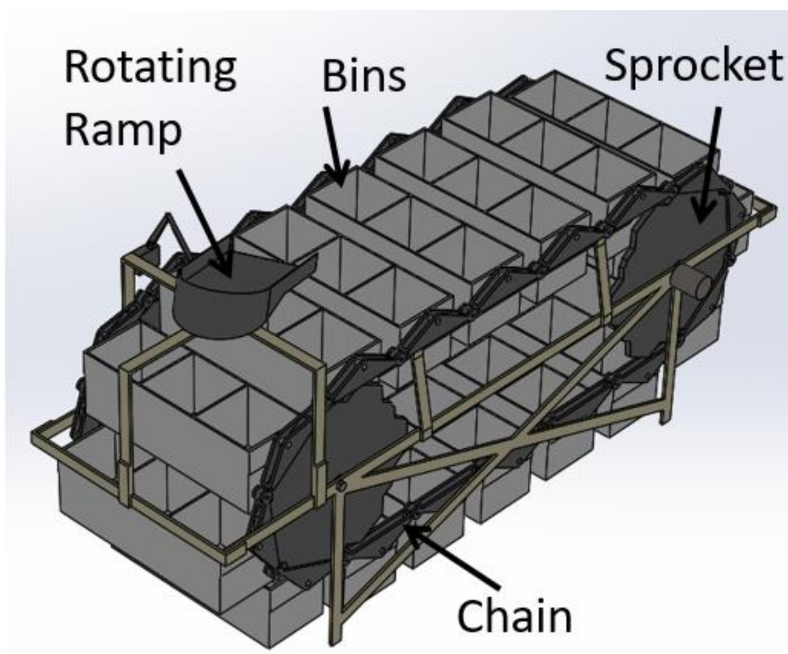


Figure 5.9: Bin System

6 Implementation Plan – First Semester

The Lego teams is mimicking the final design for the prototype. The prototype will demonstrate a proof on concept by creating the lower powered roller conveyor belt. The belt's surface material is made of fabric. The fabric is wrapped around 2 copper rods that are 24 inches apart from center to center. The copper rods have an outer diameter of 0.875 inches. 19mm deep groove ball bearings are press fit to the inside diameter of 0.745 of the copper tube. Due to motor shipment complications the prototype is using a hand drill instead of the selected motors. The hand drill is operated by the user that will be told when to turn the drill on or off via monitor image output form the Raspberry Pi. A camera is used to image the Legos, so that the Raspberry Pi can identify the Lego brick type and communicate to the computer monitor. The Raspberry Pi is connected to a computer that determines when the Lego is in frame of the camera. The software will then identify the Lego, draw a box around it and label the Lego by brick type for future sorting by designated bin type.

In Appendix 5 a bill of materials is listed that includes implementation costs. The total cost of all parts is \$377.29 out of a total budget of \$500. It must be noted that there is an adjusted weight column which is not self-explanatory. The column is there because we are 3D printed some parts with a 25% in-fill, therefore we have to calculate the new mass to get an accurate cost. The mass for each part was originally calculated using SolidWorks. Also, in the bill of materials some parts are listed as \$0, this is because the Lego Team has acquired these parts for free. There is an assembly view and exploded view of the CAD model for the purposed design below. Directly after is a Gantt chart which has been updated and is up to date.

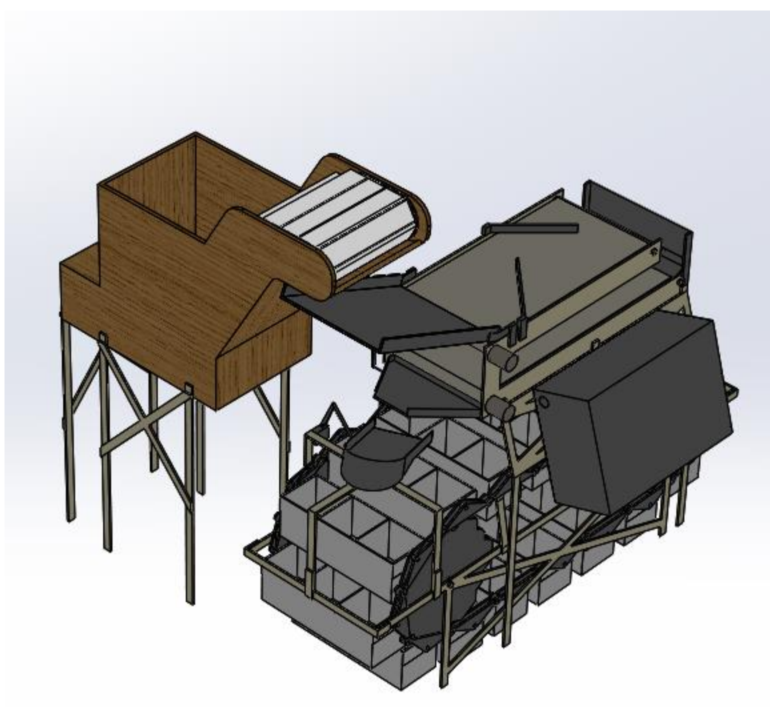


Figure 6.1: Assembly View of Purposed Design

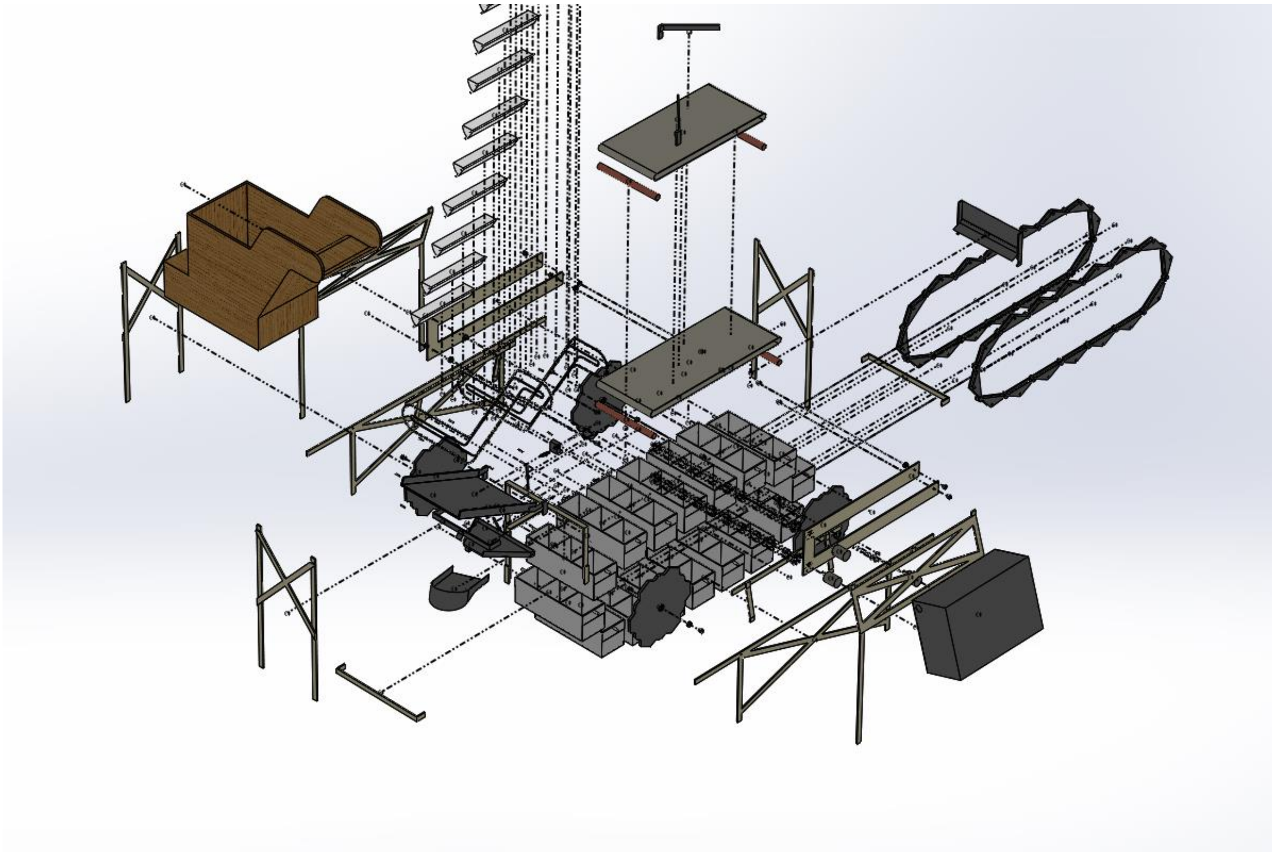


Figure 6.2: Exploded View of Purposed Design

Gant Chart

Select a period to highlight at right. A legend describing the charting follows.

Period Highlight: 26 | Plan start | Working Duration | Finished Work from Last Activity | Plan Finish | % Complete

PLAN START	WORKING DURATION	ACTUAL START	ACTUAL DURATION	ACTIVITY	PERCENT COMPLETE
1	2	1	3	Staff Meeting 1	100%
1	3	1	4	Team Charter	100%
3	3	4	3	Meet the TA	100%
3	4	4	5	Presentation 1	100%
7	3	8	3	Staff Meeting 2	100%
11	2	12	2	Staff Meeting 3	100%
7	7	8	7	Preliminary Report	100%
11	4	12	4	Presentation 2	100%
4	3	5	10	Website Check 1	100%
13	4	14	4	Analyses Memo	100%
15	3	16	3	Staff Meeting 4	100%
4	16	5	16	Website Check 2	100%
17	4	18	4	Staff Meeting 5	100%
20	3	21	3	Staff Meeting 6	100%
24	3	25	3	Staff Meeting 7	100%
15	13	20	9	Final Report	33%
5	24	6	24	Website check 3	90%
18	13	19	13	BOM	60%
18	13	19	13	CAD	60%

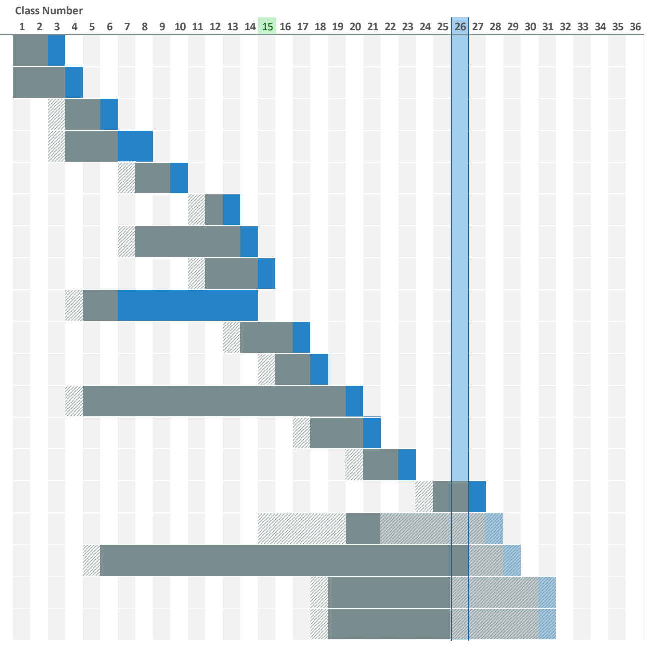


Figure 6.3: Gantt Chart

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8 Appendices

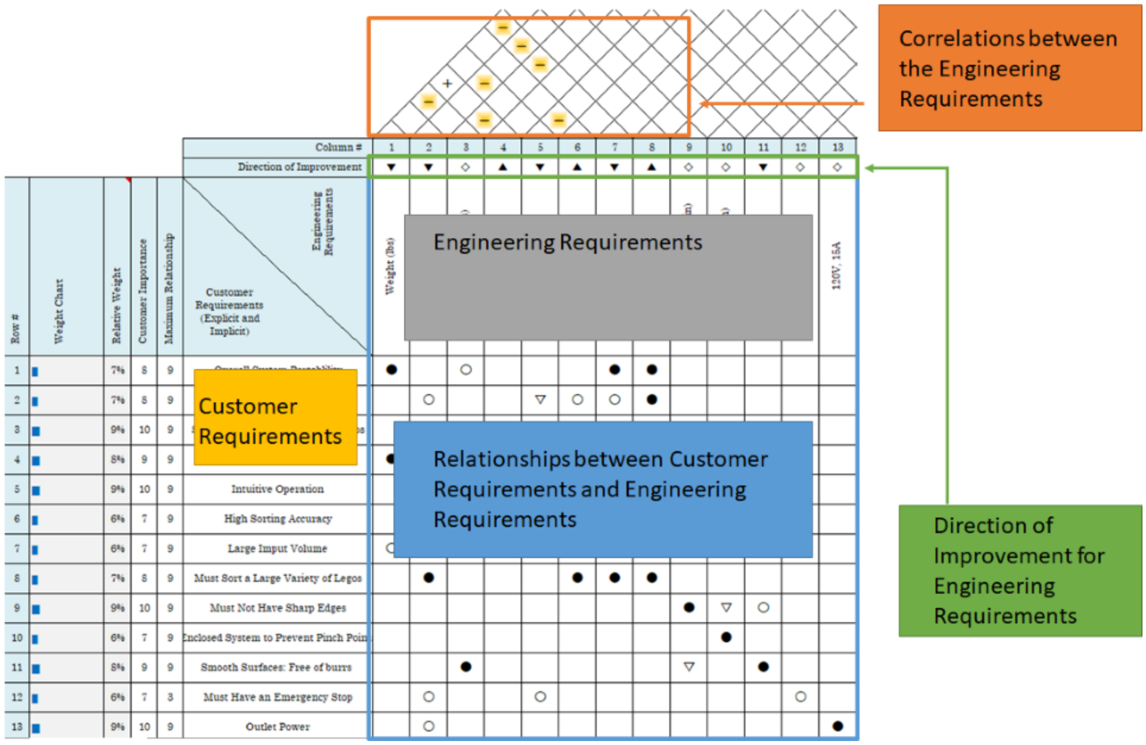
8.1 Appendix 1: Decision Matrix

Inlets	cycle time	weight	overall system portablity	weight	withstands impact/ Mild Abuse	weight	Intutive operation	weight	Large imput Volume	weight	outcome
designs		0.13		0.08		0.05		0.05		0.12	
Lift platform	8	0.13	3	0.08	5	0.05	8	0.05	8	0.12	2.89
funnel	6	0.13	4	0.08	3	0.05	8	0.05	7	0.12	2.49
conveyorbelt with platforms	9	0.13	4	0.08	4	0.05	8	0.05	10	0.12	3.29

Belts	cycle time	weight	overall system portablity	weight	withstands impact/ Mild Abuse	weight	Must have an Emergency Stop	weight	High Sorting accuracy	weight	outcome
designs		0.13		0.08		0.05		0.01		0.1	
simple conveyor belt system	6	0.13	3	0.08	4	0.05	8	0.01	5	0.1	1.8
compact conveyor belt system	8	0.13	5	0.08	3	0.05	8	0.01	7	0.1	2.37

Bins	cycle time	weight	overall system portablity	weight	withstands impact/ Mild Abuse	weight	Enclosed System to Prevent Pinch Points	weight	outcome
Designs		0.13		0.08		0.05		0.04	
Linearly moving bins	4	0.13	3	0.08	5	0.05	2	0.04	1.09
rotating ramp with stationary bins	5	0.13	4	0.08	5	0.05	2	0.04	1.3
rotating bins	5	0.13	3	0.08	4	0.05	4	0.04	1.25
sideways tank track	5	0.13	3	0.08	4	0.05	6	0.04	1.33
horizontal tank track	6	0.13	3	0.08	4	0.05	6	0.04	1.46

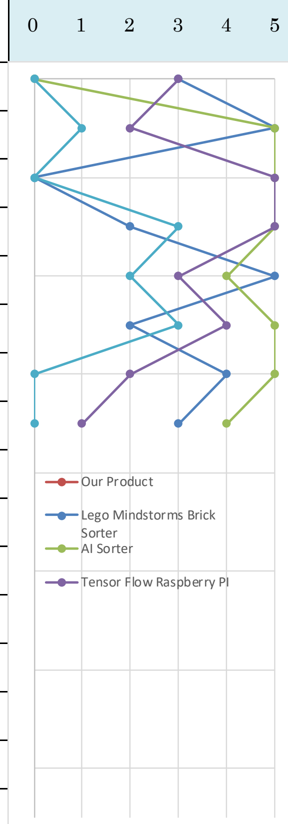
8.2 *Appendix 2: House of Quality (labeled)*



8.3 *Appendix 3: Customer Competitive Assessment (House of Quality)*

Customer Competitive Assesment

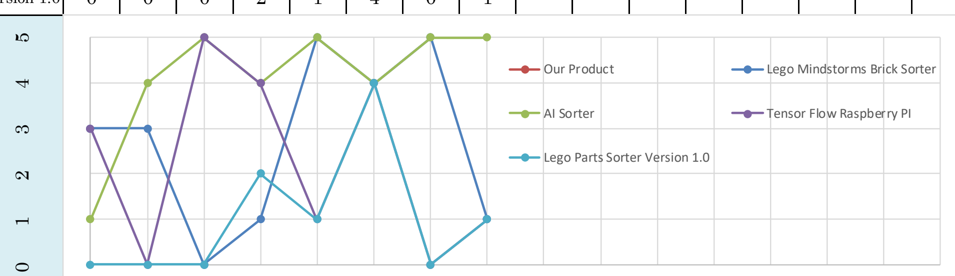
Our Product	Lego Mindstorms Brick Sorter	AI Sorter	Tensor Flow Raspberry PI	Lego Parts Sorter Version 1.0
	3	0	3	0
	5	5	2	1
	0	5	5	0
	2	5	5	3
	5	4	3	2
	2	5	4	3
	4	5	2	0
	3	4	1	0



8.4 *Appendix 4: Technical Competitive Assessment (House of Quality)*

Technical Competitive Assesment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Our Product																
Lego Mindstorms Brick Sorter	3	3	0	1	5	4	5	1								
AI Sorter	1	4	5	4	5	4	5	5								
Tensor Flow Raspberry PI	3	0	5	4	1	4	0	1								
Lego Parts Sorter Version 1.0	0	0	0	2	1	4	0	1								



Column #

8.5 *Appendix 5: Bill of Materials*

PART NUMBER	DESCRIPTION	QTY.	Weight	Adjusted Weight	Adjusted total Weight	Cost of Material per lb (USD)	Material	Total of parts	Total
bucket tread		16	0.15	0.0375	0.6	10	ABS	6	377.29
bucket wheel		4	1.29	0.3225	1.29	10	ABS	12.9	
chain path		2	N/A	N/A	N/A	N/A	N/A	0	
bin		16	1.08	0.27	4.32	10	ABS	43.2	
pin		9	0.02	0.02	0.18	10	Steel	1.8	
Groove Ball Bearing		9	0.084	0.084	0.756	10	Steel	1.62	
Motor bushing		3	0.01	0.0025	0.0075	10	ABS	0.075	
Bin frame with motor		1	1.7	1.7	1.7	0	Aluminum	0	
Motors		4	0.55	N/A	N/A	N/A	Steel	100	
Bin frame		1	1.7	1.7	1.7	0	Aluminum	0	
bin frame end brackets		2	0.24	0.24	0.48	0	Aluminum	0	
chain pin		16	0.01	0.01	0.16	10	Steel	1.6	
screw		3	0.01	0.01	0.03	0	Steel	0	
Conveyor belt 1		1	0.24	0.24	0.24	N/A	Fabric	3	
copper tubing		4	0.56	0.56	2.24	5	Copper	11.2	
Conveyor belt 2		1	0.29	0.29	0.29	N/A	Fabric	3	
Conveyor Frame NO motor		1	1.85	1.85	1.85	0	Aluminum	0	
Conveyor Frame		1	2.33	2.33	2.33	0	Aluminum	0	
screw		12	0.01	0.01	0.12	N/A	Steel	0	
bumper 1		1	0.06	0.015	0.015	10	ABS	0.15	
bumper 2		1	0.05	0.0125	0.0125	10	ABS	0.125	
inlet ramp		1	2.64	0.66	0.66	10	ABS	6.6	
backboard		1	0.19	0.0475	0.0475	10	ABS	0.475	
Rotating arm		1	0.8	0.2	0.2	10	ABS	2	
slide bracket		1	0.74	0.185	0.185	10	ABS	1.85	
servo		2	0.33	N/A	N/A	N/A	Steel	25	
servo arm		1	0.01	0.0025	0.0025	10	ABS	0.025	
servo linkage		1	0.01	0.0025	0.0025	10	ABS	0.025	
bin guide		2	0.44	0.11	0.22	10	ABS	2.2	
paralell legs		2	1.95	1.95	3.9	0	Aluminum	0	
Belt transition		1	0.35	0.0875	0.0875	10	ABS	0.875	
servo arm 1		1	0.01	0.0025	0.0025	10	ABS	0.025	
electronics box		1	1.49	1.49	1.49	10	Steel	14.9	
camera bracket		1	0.08	0.02	0.02	10	ABS	0.2	
servo linkage 1		1	0.1	0.025	0.025	10	ABS	0.25	
lift Chain tread		154	0.02	0.005	0.77	10	ABS	7.7	
Lift Chain Path		2	N/A	N/A	N/A	N/A	N/A	0	
Dump N'GO Bin		1	10.08	10.08	10.08	N/A	Plywood	15	
Lift step		20	0.71	0.1775	3.55	10	ABS	35.5	
Raspberry Pi 3		1	1.06	1.06	1.06	10	N/A	79.99	
1080p Camera		1	1.06	1.06	1.06	10	N/A	29.95	
Power Suppy		1	1.06	1.06	1.06	10	N/A	5	