THE WOW! FACTOR

Mech 202 Group 17

Project 2: Autonomous Device Design Competition - 5/9/2019

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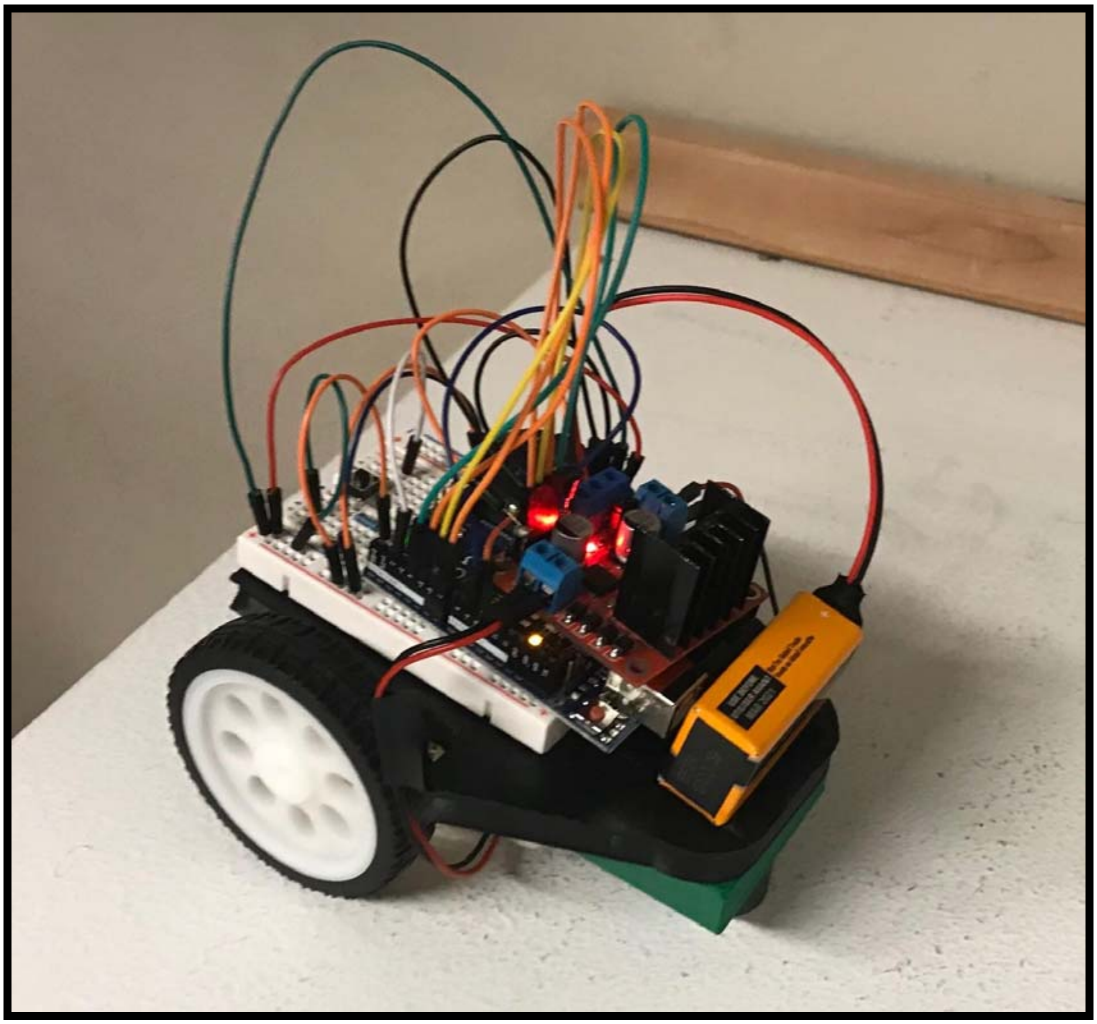

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Figures and Tables

2. Design Problem Statement

In order to improve problem solving skills, as well as gain experience in robotics, 3D printing, and coding, teams of 4-5 students worked together to complete this project.

The objective of this project is to design and assemble a device that can complete the task of reaching the top of one of two ramps. The first option is a ramp at a ~33 degree angle with tight winding turns. Alternatively, there is a much steeper ramp with wooden blocks along the path in which a device could latch onto. Each team has to solve the problem of creating a robot or device to autonomously overcome one of these paths.

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3. Specifications Development

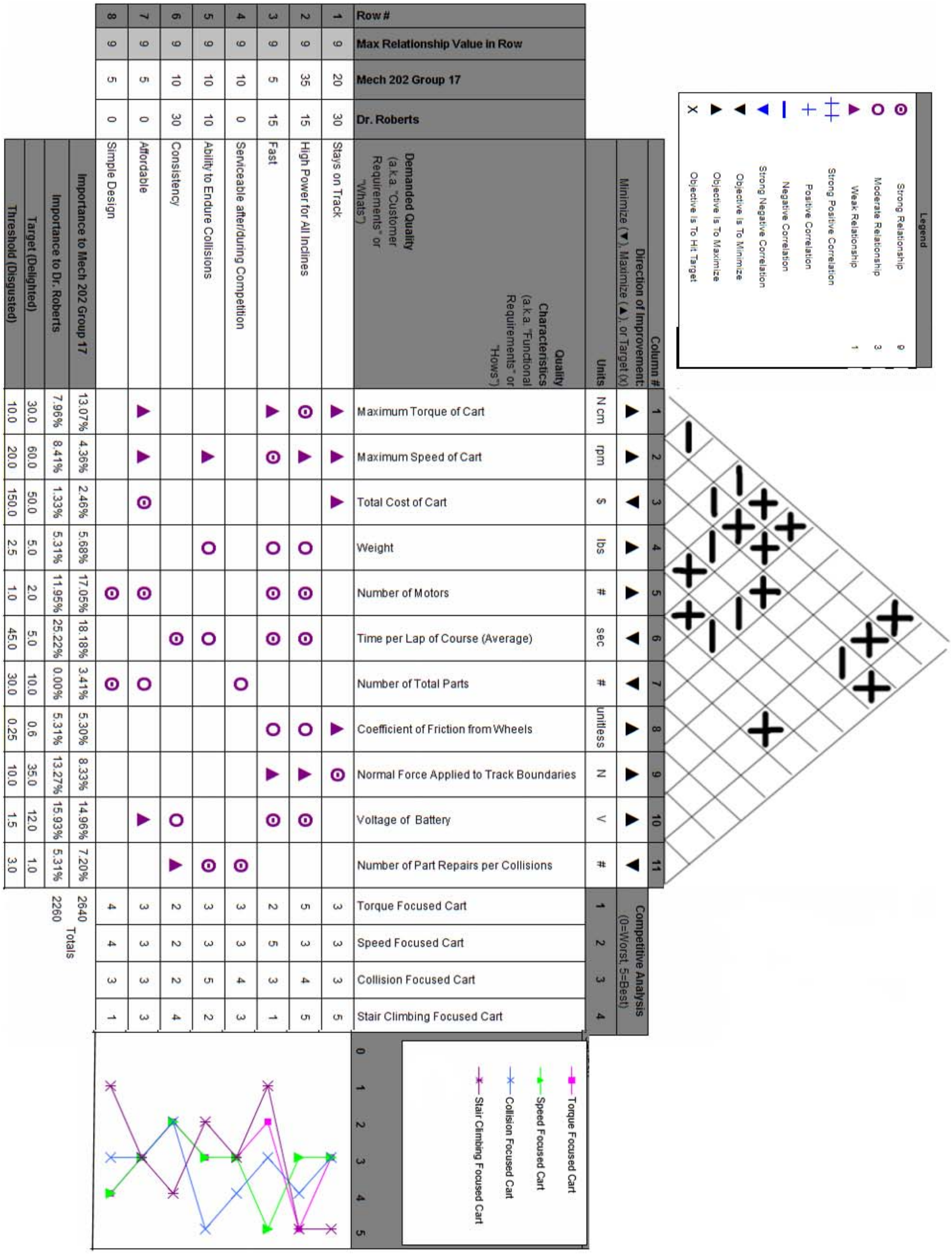


Figure 3.1 Quality Function Deployment

The Quality Function Deployment (QFD) chart shows how potential ideas meet the customer requirements of getting up the track and how these requirements can be tested.

The QFD's major customers were:

- Mech 202 Group 17
- Dr. Roberts

The requirements for a quality cart were determined to be:

- Stays on the track
- High power for incline
- Fast
- Serviceable after/during competition
- Ability to endure collisions
- Consistency
- Affordable
- Simple design

The customer requirements were determined from the overall goal of getting to the top of an incline track the fastest. Concepts that were determined to be critical to get up the track became customer requirements.

The chart below indicates how important each requirement is to the specific customer. Each member of group 17 voted on which requirement they believed to be the most important. Dr. Roberts' importance values were estimated from the idea that she mainly cares about how well the cart gets up the track and couldn't care less about how the cart was designed and made.

Mech 202 Group 17	Dr. Roberts	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")
20	30	Stays on Track
35	15	High Power for All Inclines
5	15	Fast
10	0	Serviceable after/during Competition
10	10	Ability to Endure Collisions
10	30	Consistency
5	0	Affordable
5	0	Simple Design

Figure 3.2: QFD Who vs What

General cart ideas were evaluated to determine the best type of design. The four cart concepts were:

- Torque focused cart
- Speed focused cart
- Collision focused cart
- Stair Climbing focused cart

During competitive analysis, scores were estimated by how well each group member thought each cart would meet customer requirements. In situations where general cart concepts did not give enough information to how well certain customer requirements would be met, a score of three was given.

	Competitive Analysis (0=Worst, 5=Best)			
	1	2	3	4
	Torque Focused Cart	Speed Focused Cart	Collision Focused Cart	Stair Climbing Focused Cart
Stays on Track	3	3	3	5
High Power for All Inclines	5	3	4	5
Fast	2	5	3	1
Serviceable after/during Competition	3	3	4	3
Ability to Endure Collisions	3	3	5	2
Consistency	2	2	2	4
Affordable	3	3	3	3
Simple Design	4	4	3	1

Figure 3.3: QFD Now vs What

The table shows the results of the competitive analysis. The torqued focused cart and stair climbing focused cart performed the best. Both cart types require high torque motors which was the largest customer requirement at 35%. The most underperforming customer requirement for all carts in general was consistency.

To assess each each customer requirement, quality characteristics/specifications were chosen that could be physically tested.

The specifications chosen were:

- Maximum Torque
- Maximum Speed
- Total Cost
- Weight
- Number of Motors
- Total Parts
- Time per Lap of Course
- Coefficient of Friction from Wheels
- Normal Force Applied to Track Boundaries
- Voltage of Battery (s)
- Number of Part Repairs per “Collusion” (Run)

The units of all engineering specifications as well as the direction of improvement are shown in the figure.

Column #	1	2	3	4	5	6	7	8	9	10	11
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▼	▲	▲	▼	▼	▲	▲	▲	▼
Units	N cm	rpm	$	lbs	#	sec	#	unitless	N	V	#
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Maximum Torque of Cart	Maximum Speed of Cart	Total Cost of Cart	Weight	Number of Motors	Time per Lap of Course (Average)	Number of Total Parts	Coefficient of Friction from Wheels	Normal Force Applied to Track Boundaries	Voltage of Battery	Number of Part Repairs per Collisions

Figure 3.4: QFD Engineering Specifications

Experiments were designed to test each specification. Go to the test section of the report to access full documentation. Number of motors, voltage of the battery, and weight required no experimentation.

In order to make sure each customer requirement was met, at least one engineering specification had a strong relationship to it. Therefore it was important to verify this with a "How versus What" table.

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Maximum Torque of Cart	Maximum Speed of Cart	Total Cost of Cart	Weight	Number of Motors	Time per Lap of Course (Average)	Number of Total Parts	Coefficient of Friction from Wheels	Normal Force Applied to Track Boundaries	Voltage of Battery	Number of Part Repairs per Collisions
Stays on Track	▲	▲	▲					▲	⊝		
High Power for All Inclines	⊝	▲		○	⊝	⊝		○	▲	⊝	
Fast	▲	⊝		○	⊝	⊝		○	▲	⊝	
Serviceable after/during Competition							○				⊝
Ability to Endure Collisions		▲		○		○					⊝
Consistency						⊝				○	▲
Affordable	▲	▲	⊝		⊝		○			▲	
Simple Design					⊝		⊝				

Figure 3.5: QFD How vs What

△ = 1, ○ = 3, ⊘= 9

A nine represents strong correlation while a one represents weak correlation. In order to gain significance from the table, scaling must occur to factor in customer importance. The next table shows the results from scaling.

The importance of each engineering specification relative to the customer was analyzed and calculated. Targets and thresholds were estimated based on what group 17 believed would produce a cart that could get to the top. The threshold was believed to be the minimum requirements to get to the top, while the target requirements would get the cart to the top fast and efficiently.

Units	N cm	rpm	$	lbs	#	sec	#	unitless	N	V	#
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Maximum Torque of Cart	Maximum Speed of Cart	Total Cost of Cart	Weight	Number of Motors	Time per Lap of Course (Average)	Number of Total Parts	Coefficient of Friction from Wheels	Normal Force Applied to Track Boundaries	Voltage of Battery	Number of Part Repairs per Collisions
Importance to Mech 202 Group 17	13.07%	4.36%	2.46%	5.68%	17.05%	18.18%	3.41%	5.30%	8.33%	14.96%	7.20%
Importance to Dr. Roberts	7.96%	8.41%	1.33%	5.31%	11.95%	25.22%	0.00%	5.31%	13.27%	15.93%	5.31%
Target (Delighted)	30.0	60.0	50.0	5.0	2.0	5.0	10.0	0.6	35.0	12.0	1.0
Threshold (Disgusted)	10.0	20.0	150.0	2.5	1.0	45.0	30.0	0.25	10.0	1.5	3.0

Figure 3.6: QFD Specifications Target

Many of the engineering specifications are either directly or inversely related to one another. It’s important to analyse these relationships to understand tradeoffs.

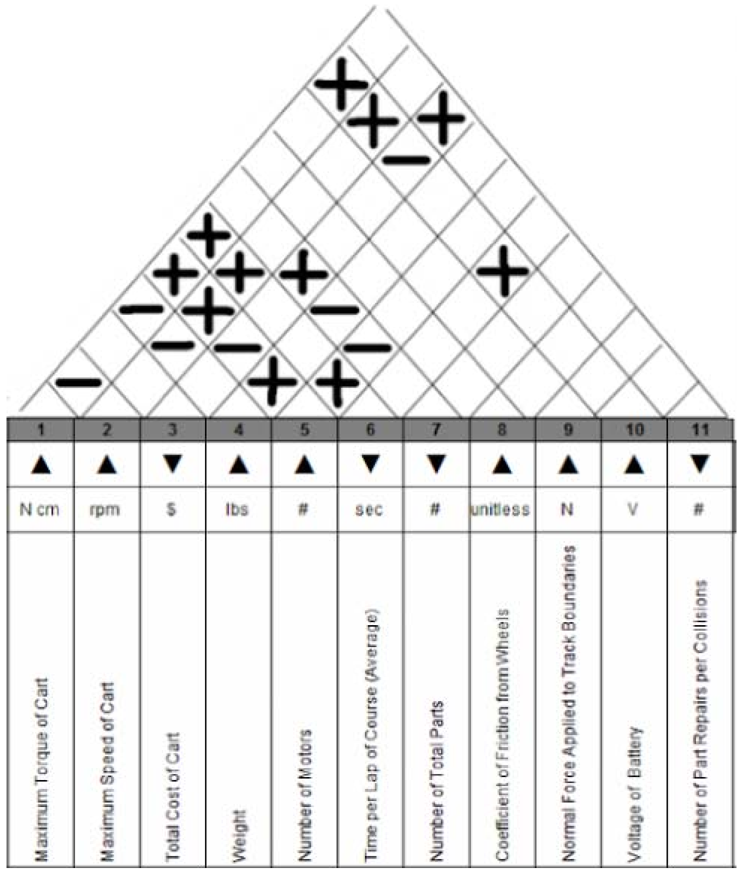


Figure 3.7: QFD How vs. How

A plus sign represents a positive correlation between two specifications in the indicated direction of improvement. For example, if the number of motors increases, the maximum torque of the cart will increase too. A negative sign represents an inverse relationship. For example, if the total number of motors increases, the total cost of the cart would increase which is in the opposite indicated direction. The design of the cart had to balance out these specifications.

Table 3.1: Customer Requirements Template

Customer Requirements

Design Organization: Mech 202 Group 17	**Date: 3/15/19**
Product: Mech 202 Competition Cart	

Who:

1. Who are the primary users of the product? **Mech 202 Group 17, Dr. Roberts**
2. What skills or education will the primary users have? **Building skills, arduino coding back group, circuit experience**
3. Describe any primary user physical conditions that affect the design of the product: **resistance against impact with little damage**
4. Who will purchase the product? **N/A**
5. Who else is a stakeholder in the design of the product?
6. Describe any cultural practices or customs related to the product. **N/A**
7. How much is the purchaser willing to pay for the product? **N/A (Cost analysis in report)**
8. How much is the user willing to pay to operate the product? **$2 (1 9V battery)**
9. How much is the user willing to pay to maintain the product? **$5 for general repairs each week**

How:

1. For what specific purposes will the product be used? **To get to the top of an inclined track**
2. What is the current process used? **N/A New Technology needed**
3. How often will it be used? **2 to 12 times on competition day**
4. How long will it be used each time? **5 minutes or less**
5. Describe the quality expected by the user: **The cart will move up the track and overcome the force of gravity as well as not get caught on edges**
6. How far, how often and in what way will product be transported? **By hand, 3 times a week for testing and competition**

Where:

1. Describe the surroundings for normal use: **Indoors on a 33 degree incline track with sharp zigzag turns**
2. Describe the noise, weather, temperature or other environmental factors that may affect the design of the product. **N/A**
3. Describe any size or weight limitations. **Must have a 4 in width or less and a 5 in length or less as well as weigh less than 3 lbs**
4. Describe the energy available when the product is in use: **The energy is supplied by a 9V battery that is hooked up to a motor (converts electrical energy to mechanical energy)**

Customer Requirements (include how well the product fulfills each requirement from 1-5, 5 being the best):
1. Stays on track 3 2. High power for all inclines 5 3. Fast 4 4. Service after/during Competition 4 5. Ability to endure collisions 3 6. Consistency 2 7. Affordability 3 8. Simple Design 4
Who Else (List other products that fulfill the requirements)**:**
1. Torque Focused Cart 2. Speed Focused Cart 3. Collusion Focused Cart 4. Stair climbing focused cart *The Mechanical Design Process* Designed by Professor David G. Ullman Copyright 2018 Form # 16

Competitive Analysis

1. **Competitor 1: EMO Smart Robot Car Chassis Kit with Motors, Speed Encoder and Battery Box for DIY**

Figure 3.8: Competitor 1 EMO SmartRobot Car Image [9]

This DIY kit had a basic structure that was well liked by Group 17. The wheels, castor wheel, and battery pack were all favorable features that were later purchased for the final project. The base on this kit was too large for the restraints on the project so it could not be reused. The simplicity and affordability ($12) of this amazon kit made it a great reference. There are many videos on how to integrate this cart with an arduino to navigate a track.

Competitor 2: Arduino DC Motor Control Tutorial – L298N | PWM | H-Bridge

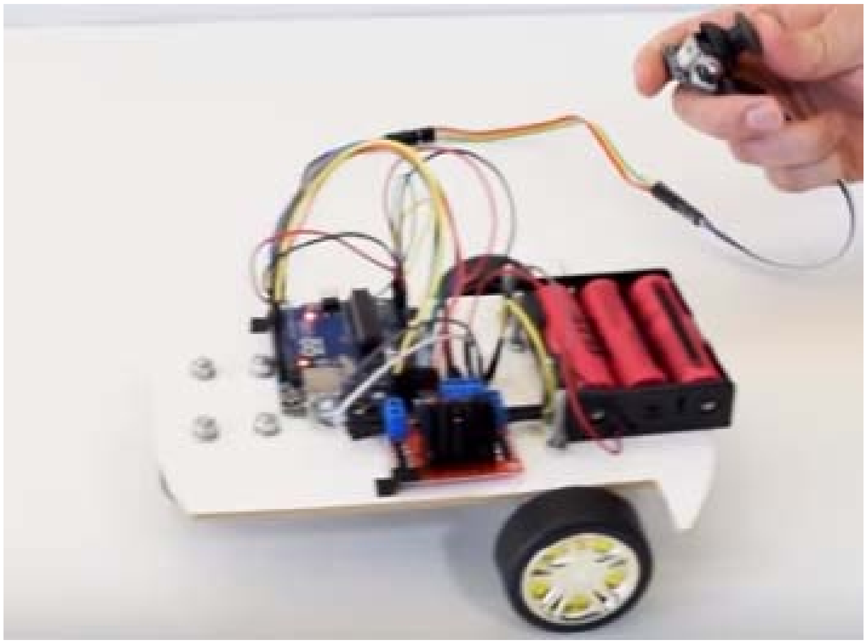


Figure 3.9: Competitor 2 Arduino Motor Control Cart Image [8]

This tutorial showed how to program an arduino as well as design a device to be controlled by a joystick. The site also provided information on how to use a L298N motor control, PWM ports, and H-Bridges. The general concepts about L298N motor controllers and PWM ports were taken and used on the final cart.

4. Concept Generation & Selection

As a group we decided on four basic cart ideas:

- Torque-focused cart
- Speed focused Cart
- Collision focused cart
- Stair climbing cart

The ideas were evaluated in the QFD and the top choice based on the customer requirements of the mech 202 group 17 was a torque based cart. A torque based cart works great at travelling up inclines and is fairly simplistic compared to a stair climber.

The major components of a torque based cart were determined to be the

- Push force
- Defense
- Navigation
- Computer Control

The following functional requirements were evaluated in the Morphology Table below.

Table 4.1: Morphology Table

Morphology					
Product: Mech 202 Project 2	Organization Name : Mech 202 Group 17				
Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Push Force	DC Motor	Combustion Engine	Springs	Gravitation energy	
Defense	High Torque for carrying/ pushing	Speed to pass by	Spiked wheels	Sharp edges	
Navigation	Circular Wheels	Square Wheels for stepping	Latching method	Tank treads	
Computer Control	Motion detectors	Physical contact sensors	Light Sensor	Pre-programmed Route	A color-sensor (for line of track)
Team member: Hunter Becvar	Team member: Alec DeStefano	Prepared by: Josh Ehr			
Team member: Garrett Johnson	Team member: Jethro Leroux	Checked by: Hunter Becvar	Approved by: Alec DeStefano		
The Mechanical Design Process Designed by Professor David G. Ullman Copyright 2018					

Push Force

Issue: Reach the top of the track the fastest		**Default: DC Motor**	Combustion Engine	Springs	Gravitational Energy
Efficiency by Mass	20	0	0	0	1
Size	15	0	-1	1	1
Cost	10	0	-1	1	1
Force	25	0	1	-1	-1
Consistent Force	20	0	1	-1	-1
Ease of Use	10	0	-1	-1	-1
Satisfaction		0	10	-30	-10

Table 4.2: Pughs Diagram for Push Force

Defense

Issue: Ability to overcome tactics of opponents		**Default: High Torque for carrying/ pushing**	Speed to Pass by	Spiked Wheels	Sharp Edges
Size	20	0	0	-1	-1
Cost	10	0	0	1	1
Efficiency by Mass	20	0	0	0	1
Versatility	10	0	0	-1	0
Reliability	10	0	-1	-1	0
Ease of Use	30	0	0	0	0
Satisfaction		0	-10	-30	10

Table 4.3: Pughs Diagram for Defense

Navigation

Issue: Navigate around the obstacles and get to the top of the track		**Default: Circular Wheels**	Square Wheels	Latching Method	Tank Treads
Traction	20	0	0	-1	1
Size	10	0	0	-1	-1
Reliability	20	0	-1	-1	0
Cost	10	0	0	-1	0
Effectiveness	15	0	-1	-1	0
Simplicity	25	0	-1	-1	-1
Satisfaction		0	-60	-100	-15

Table 4.4: Pughs Diagram for Navigation

Computer Control

Issue: Ability to smoothly drive the vehicle up the incline track and around the obstacles		**Default: Motion Detector**	Physical Contact Sensors	Light Sensors	Pre-Programmed route	Color-Sensors
Cost	10	0	0	0	0	0
Reliability	20	0	1	0	1	0
Ease of Installation	15	0	0	0	0	0
Ease of Programming	20	0	1	0	1	0
Effectiveness	20	0	0	0	1	0
Mass	15	0	0	0	0	0
Satisfaction		0	40	0	60	0

Table 4.5: Pughs Diagram for Computer Control

Based on the analysis of the Pugh's Diagrams, three unique torque carts were drawn up as well as one stair climbing design. The basis for all four drawings is a DC motor that can produce high torque for defense, with circular wheels, and a pre-programmed route.

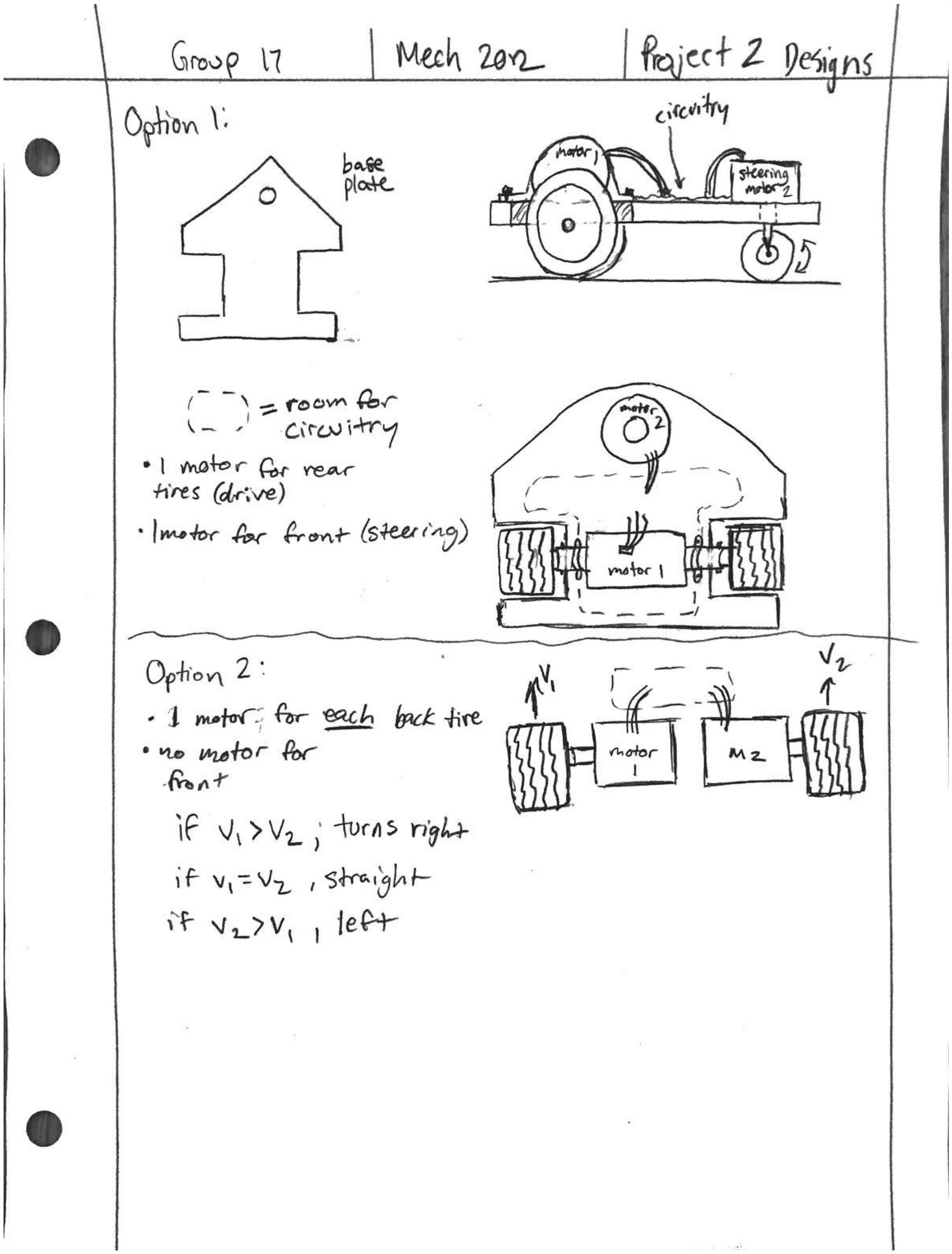


Figure 4.1:Concept Generation Drawing 1

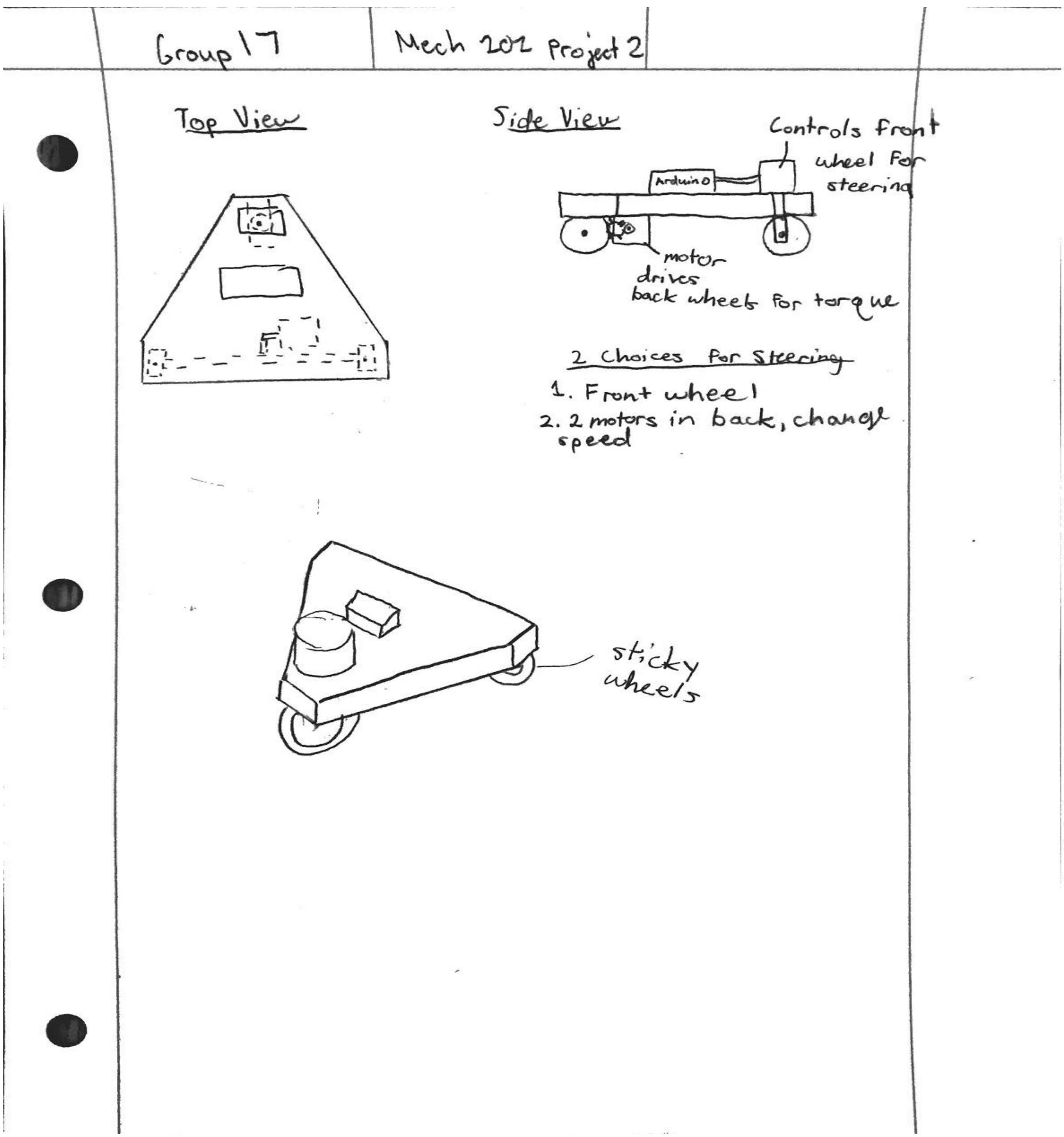


Figure 4.2:Concept Generation Drawing 2

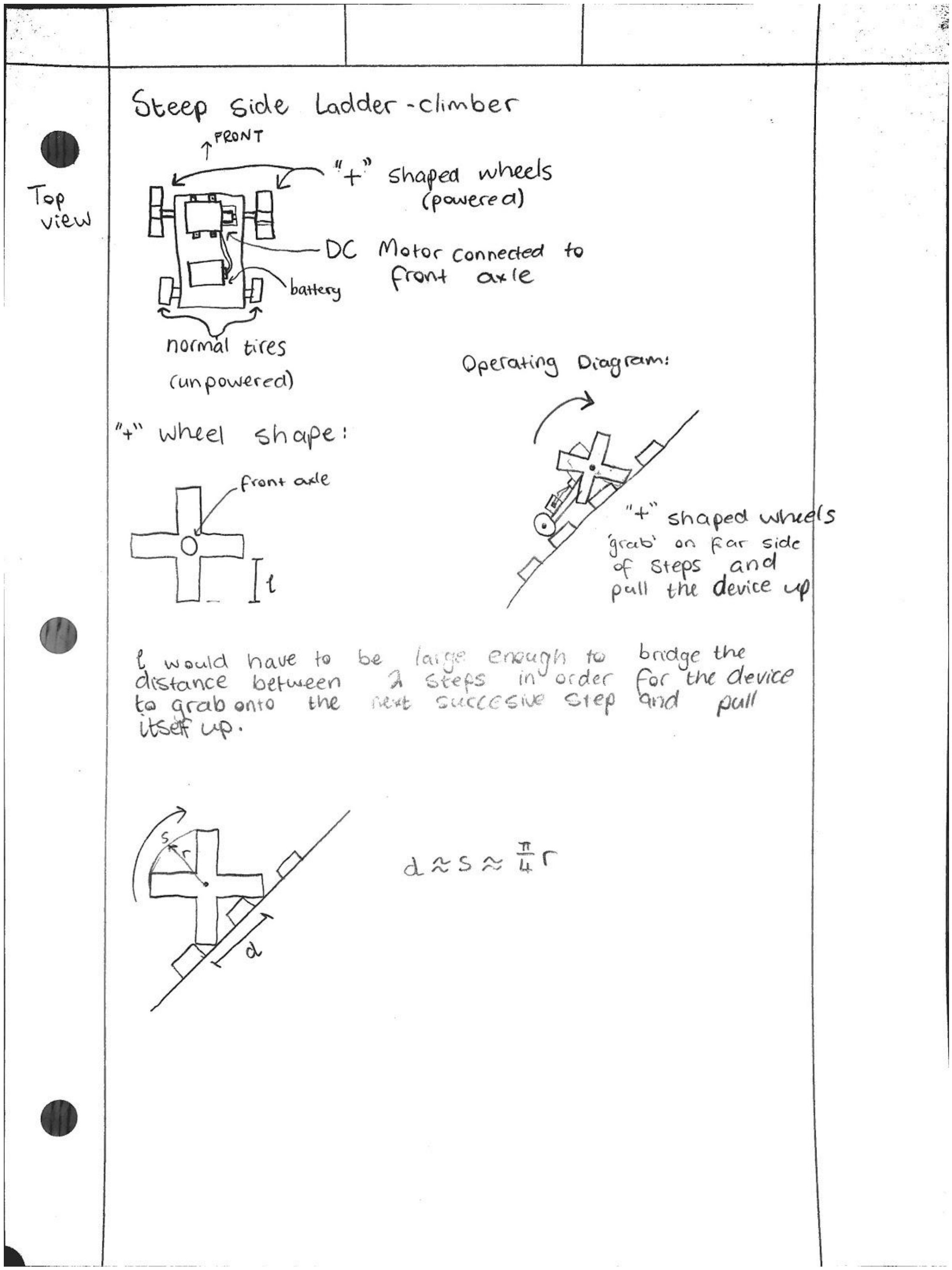
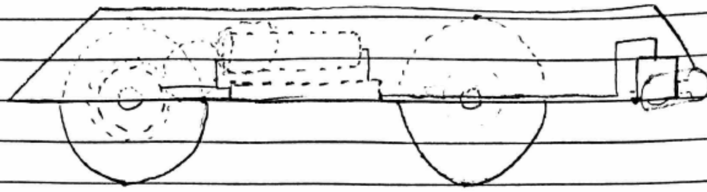
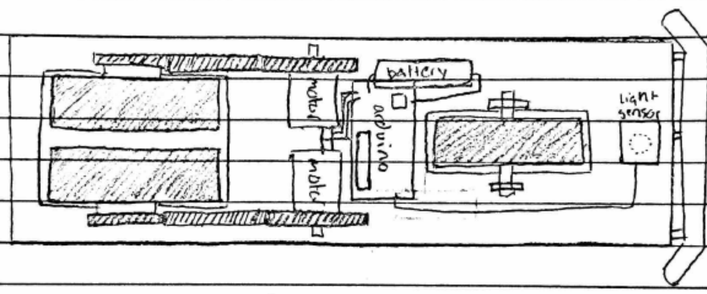


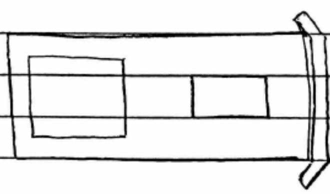
Figure 4.3:Concept Generation Drawing 3

"bike"





-rwd, slick front wheel
-geared for torque small → big
-sensor follows line



Improvements
- Front wheel is swivel wheel
- less gears
- shorter frame

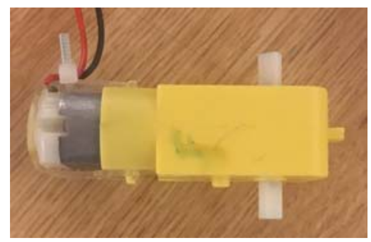
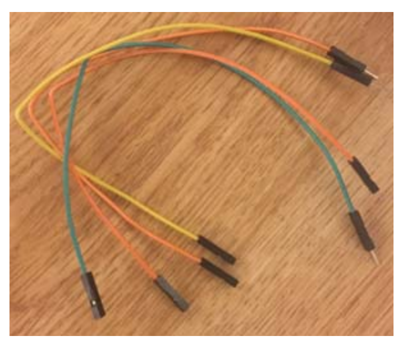
Figure 4.4:Concept Generation Drawing 4

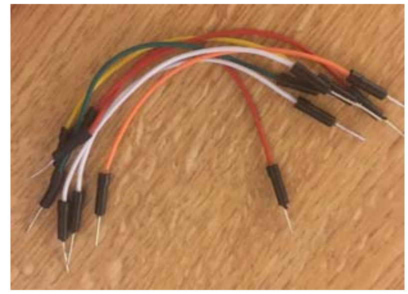
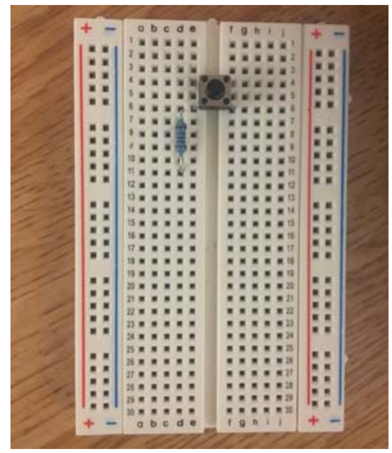
Design Selection

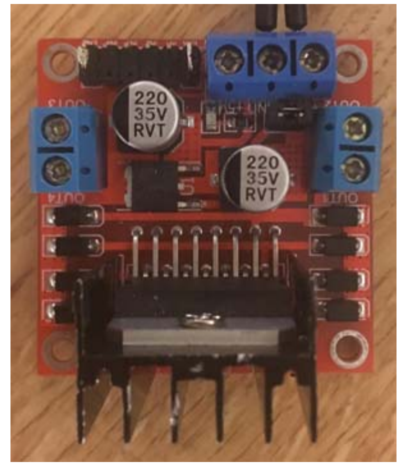
As a group, using the tables above, we decided on pursuing the design of Option #2 from the Drawing 1 image. This cart seemed like it would be the most reliable if we could find powerful enough motors to drive the back wheels independently and slowly traverse the winding side of the competition fixture. We also decided that using a line follower or proximity sensors would be tedious and just add to the complexity and weight of the design. We decided to try and keep the cart simple and manually code the turns by using the arduino and its PWM output control to differentiate between motor speeds as the cart is travelling up to make it turn left or right. This method yielded the best satisfaction weighting from the ‘Computer Control’ Table above (Table 4.5) when compared to other methods. We envisioned that this would be really simple and the most reliable as there would be no possible error from the line follower failing to follow the black line or the proximity sensor failing to sense the walls around it on the track. Both these methods were more complex, but do provide some sort of error correcting if the sensors fail, unlike our chosen design of manually coding the turns in to the arduino code. However, we decided that it would be simple enough to line up the cart accurately enough each time at the start of each heat for the competition. Circular wheels were obviously used for this side of the track, and when compared to the other types of wheels, circular came out with the highest score from the Pughs Diagram above (Table 4.4).

5. Bill of Materials (BOM)

Table 5.1: Bill of Materials

Part #	Part Name	Qty	Material	Mfg Process	Image
1	9 V Battery	1	Combination of Zinc, Magnesium, and Potassium with plastic covering	Granulation of ingredients, Compaction into preforms, Indentation in order to put the parts together, Sealing the battery entirely	
2	DC Motor	2	Steel with ABS plastic and copper wire	Injection molds for plastic base and parts, interior motor is created by coiled wire	
3	Ball Caster	1	Steel with ABS mount	Die-Casting to make the steel ball, injection moulding toi make the plastic mount.	
4	Male to Female Wires (8”)	4	Copper and Plastic Covering	Copper is Ground up, Annealed in a furnace to make it soft, Made into thin wires, Dipped in melted plastic and coated with the plastic	

5	Male to Male Wires (4”)	1	Copper and Plastic Covering	Copper is Ground up, Annealed in a furnace to make it soft, Made into thin wires, Dipped in melted plastic and coated with the plastic	
6	Breadboard	1	PVC plastic with nickel plated strips	Injection modeled plastic with folded metal strips embedded inside	
7	Arduino Uno R3	1	Laminate board with epoxy resin, glass fiber and copper inlay	Laser Printed	

8	DC Motor Controller (L298N)	1	Laminate board with epoxy resin, glass fiber and copper inlay	Laser Printed	
9	Cart Base	1	ABS plastic	3D Printed	
10	10K Ohm Resistor	1	Nichrome with ABS plastic	Nichrome wound helically and covered in plastic	

11	Button	1	ABS plastic, Copper and Aluminum	Injection molded plastic and stamped aluminum with copper soldered inside	
12	Cart Wheel	2	ABS Plastic	Injection molded	

Table 5.2: Cost Estimator

Part #	Part Name	Part Quantity in Final Design	Net Part Cost [$]	Miscellaneous Costs	Total Part Cost (Quantity*Net Cost + Miscellaneous Costs) [$]
1	9 V Battery	1	2.50	9V terminal connector: $1.63	4.13
2	DC Motor	2	2.95	N/A	5.90
3	Ball Caster	1	2.09	Originally caster wheel: $4.89	6.98
4	Male to Female Wires (8”)	4	0.10	N/A	0.40
5	Male to Male Wires (4”)	1	0.10	N/A	0.10
6	Breadboard	1	2.62	N/A	2.62
7	Arduino (Elegoo) Uno R3	1	11.86	N/A	11.86
8	DC Motor Controller (L298N)	1	6.99	N/A	6.99
9	Cart Base	1	N/A	I2P Lab Access Fee: $20 Total Filament used on 4 separate prints: $10	30.00
10	10K Ohm Resistor	1	0.50	N/A	0.50
11	Button	1	0.50	N/A	0.50
12	Cart Wheel	2	1.55	Originally yellow thicker wheels: $2.10 each	7.30
TOTAL COST:					**$77.28**

Since $77.28 < $200, our device falls within the specified cost restraints given by the Project II description documents.

6. Device Description

Table 6.1 Product Decomposition and Reverse Engineering

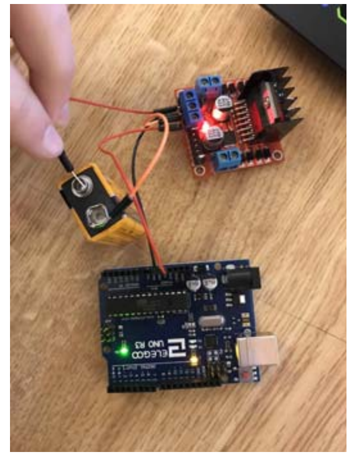
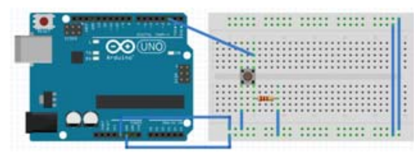
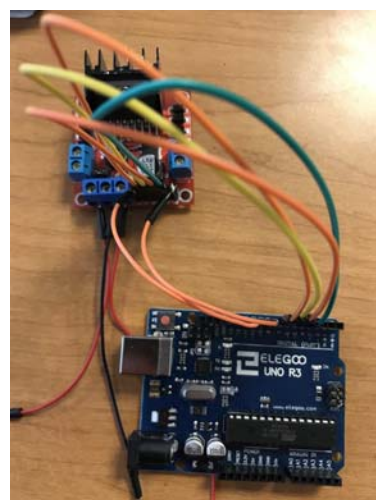
Product Decomposition & Reverse Engineering

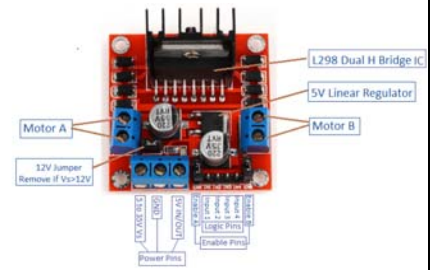
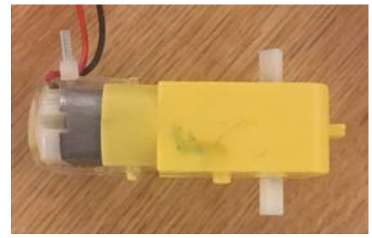
Design Organization: Mech 202 - Group 17 | **Date: 2/21/19**

Disassembly:

Step #	Procedure	Part # Removed
1	Disconnect all wires from the battery, arduino, L298N motor controller, breadboard, DC motors by hand or screwdriver	4,5
2	Remove battery, breadboard, arduino, and L298N motor controller from their taped position by hand	1,6,7,8
3	Remove cart wheels by hand from the DC motor	12
4	Remove caster wheel by unscrewing the bolts holding it to the underbelly of the cart	3
5	Remove DC motors by unscrewing them from their position beneath the platform of the cart	2

Interfaces with Other Objects (Flows of Energy, Information, and/or Materials)**:**

	Part	Energy Flow	Information Flow	Material Flow	Image
1	Battery	Battery supplies electricity to both motor controller through 12V and Ground terminals, which in turn supplies the arduino through the motor controller 5V output and battery ground.	N/A	N/A	
2	Button Circuit	Current flows through button when pressed.	Arduino reads the current throw the button circuit as low. Arduino code is initiated.	N/A	Button Circuit **[1]** 
3	Arduino	Arduino code is initiated, current is sent to motor controller through pins 4, 5, 6 ,7, 9 and 10.	Arduino code establishes the high and low voltage ports on the motor controller inputs. Arduino sends analog current to enable ports of each motor.	N/A	Two short orange wires are going from pins 9 and 10 to the enabler pins on the motor controller 
4	L298N Motor Controller	Voltage drop across motor control pins causes current to flow to the motors.	Based on the amount of current sent to the enabler pins via the arduino, the voltage	N/A	**[2]**

			drop across the motors is varied and speed is controlled.		
5	Motors	The current sent to the motors via the motor control is converted into mechanical energy. The motor axle turns.	N/A	The motor axles start to spin.	
6	Wheels	The axles spinning motion gets transferred to the wheels through the center bore connection.	N/A	The cart begins to move due to friction between the wheels and track.	

Team member: Hunter Becvar	Team member: Garrett Johnson
Team member: Alec DeStefano	Prepared by: Hunter Becvar, Alec DeStefano, Josh Ehr
Team member: Josh Ehr	Checked by: Garrett Johnson
Team member: Jethro Leroux	Approved by: Jethro Leroux

Exploded Assembly (Minor electrical components not shown)

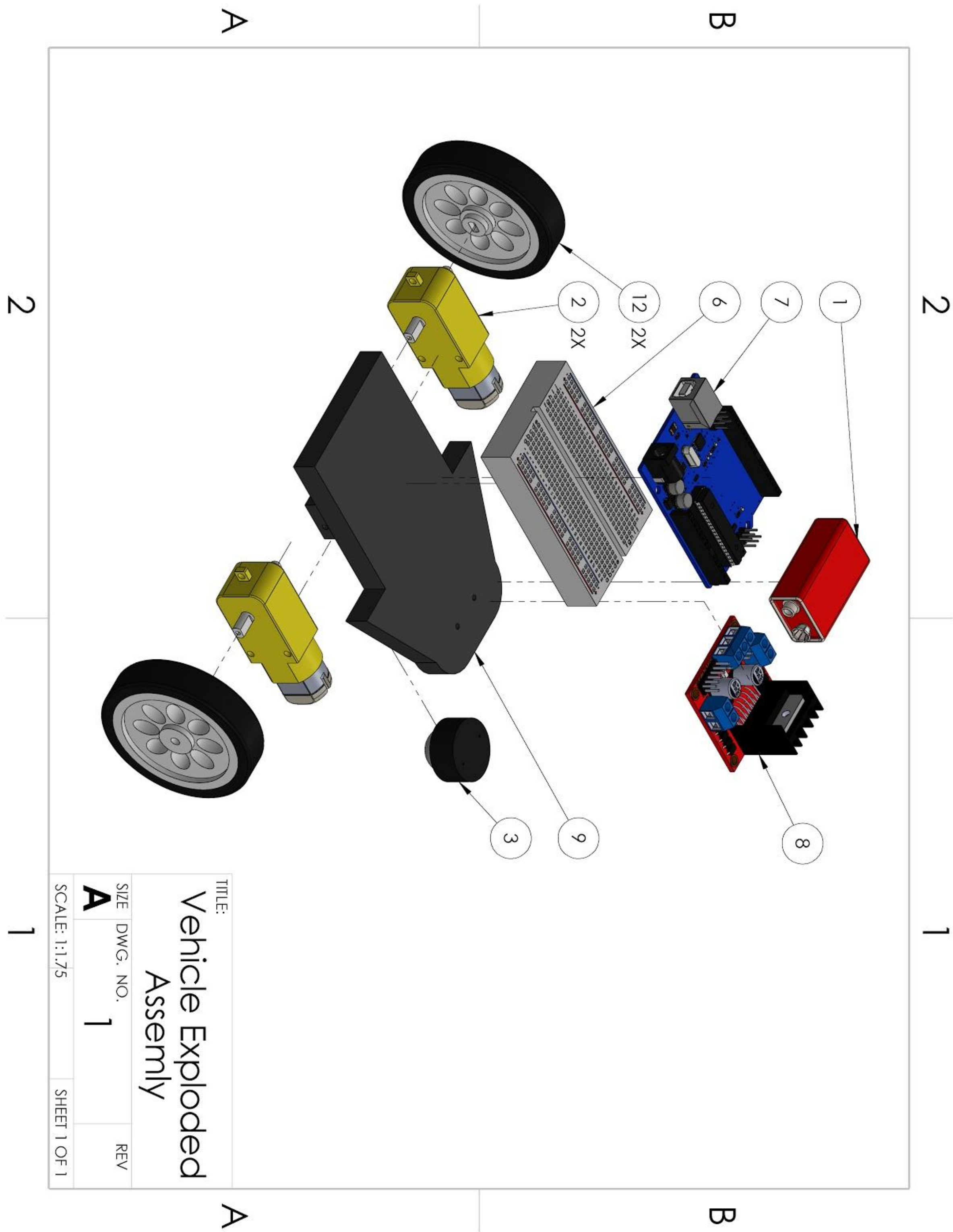


Figure 6.1: Exploded Assembly

Part References:

9V Battery [3], Arduino[4], Motor Controller[5], DC Motor[6], Breadboard[7]

Energy Flow DSM

Energy Flow DSM							
Part		A	B	C	D	E	F
Battery	A	A		**X**	**X**		
Button Circuit	B		B	**X**			
Arduino	C		**X**	C	**X**	**X**	
Motor Controller	D				D	**X**	
Motors	E					E	**X**
Wheels	F						F

Table 6.2 : Energy Flow DSM

"**X**" shows transfer or flow of energy from one part to another via impact.

The 9V battery directly supplies energy in the form of voltage to the arduino and motor controller. The button circuit initiates the arduino code and is connected to the arduino supplying power directly relating both parts. In order for the motor controller to supply voltage to the DC motors the arduino must send different voltages to the input pins on the motor controller. This voltage difference across the inputs tells the controller to allow voltage to flow through the DC motor, which creates torque on the wheel. For the motors and wheels to work properly, the arduino and motor controller must be properly powered and communicate to control voltage throughout the circuit.

Device Function

The user presses the button to initiate the code. Once the button is pressed, the arduino reads the voltage at pin 2 as low and initiates a while loop inside the arduino.

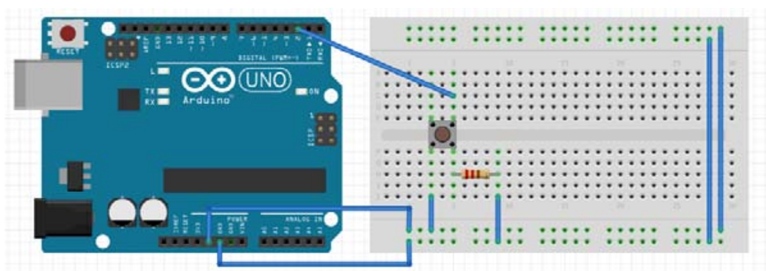


Figure 6.2: Push Button Circuit [1]

Once the code begins, current is sent from the arduino to the motor controller (L298N) via output pins 4, 5, 6, 7, 9, and 10. The motors speed can be controlled via current to the enabler outputs (in the arduino wire configuration figure, the orange wire controls the left motor and purple controls the right motor) via pins 9 and 10 (PWM pins) on the arduino. An analogWrite function controls the voltage to the enablers and thus the motors speed. The A motor will start when a voltage difference is defined across inputs one and two of the motor controller. For example, input one is defined as low via pin four on the arduino and pin two is defined as high via pin 5 in the arduino code. The direction of the motor can be reversed by flipping the high and low voltage definitions in the code. Inputs three and four are used to control the direction of motor B in the same exact way.

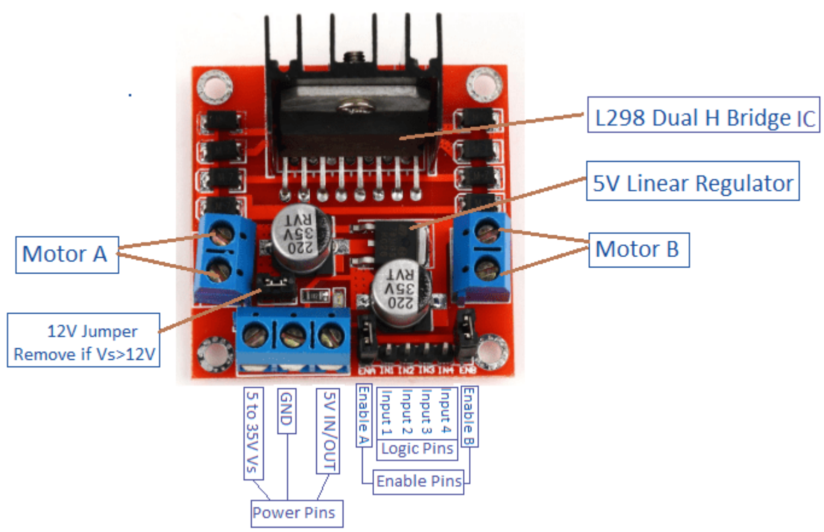


Figure 6.3: Motor Control Pin I/O Descriptions [via Electronic Hobbyist] ***[2]***

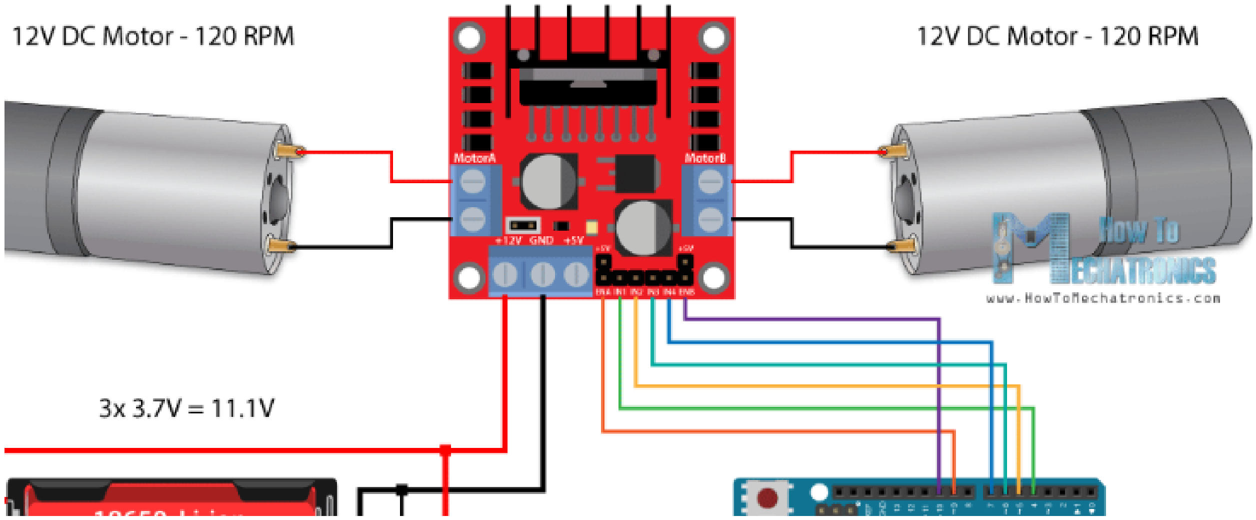


Figure 6.4: Arduino Wire Configuration [How to Mechatronics] ***[3]***

By limiting the voltage supplied to the wheels, Group 17 can control the direction of the cart and make sure the cart will travel in a straight line despite DC motors normally never producing the same axial speeds. Group 17 made the cart turn by turning one motor off and keeping the other motor on. The static coefficient between the wheels and track had to be relatively high to make sure no slipping occurs on the start and on the turns. Instead of programming sensors into the cart, Group 17 decided to code the motors for the specifications of the track based on time. The final arduino code for the cart is in appendices.

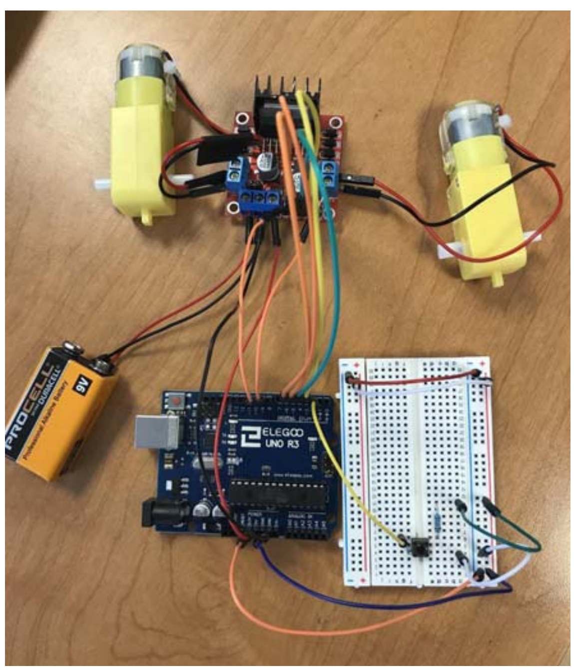


Figure 6.5: Complete Wire Configuration

Design Process

Our device has been designed to reach the top of the winding ramp. To achieve this goal, we have made sure to contain our robot within the dimension restrictions of the project and ensured that our robot is able to complete the small turns on the ramp.

The design of our robot is based around the two DC motors that control two rear wheels. The speeds of these motors will be operated by voltage outputs through a motor control and arduino. In order to complete the turns, the difference in wheel speeds will cause the robot to rotate. The change in wheel speed will be controlled by time in our arduino coding.

We feel that our robot's time based code will be reliable because it is specifically designed for this particular ramp. To ensure a repeatable precise run up the ramp we will use pulse width modulation (PWM) output to our DC motors to interrupt the frequency at which voltage is provided to each motor. Doing this in turn slows down the motors allowing for higher precision turning with less chance for a wheel to slip. While the overall robot will move more slowly, it will work better for our code because it allows larger timing errors to occur while the robot remains on track. The DC motors will be rigidly attached to our 3D printed base with bolts and nuts. Attaching them like this will eliminate the error of parts shifting positions that could occur if we used glue or tape to put our robot together.

Engineering knowledge of statics and dynamics has helped us to calculate certain aspects of our design that will ensure it gets to the top. For instance, balancing our weight distribution to make sure our robot will not tip over backwards was crucial to our design. Rotational velocities and knowing how to using instantaneous centers of rotation helped us determine how our turns need to be programmed into our code as well as the spacing of our wheels. The coefficient of static between the wheels and track was analyzed to determine the best type of wheel. The wheel chosen for the cart has an extremely high coefficient of friction. The cart can sit on the incline of the track and not move even with the addition of three extra pounds.

7. Engineering Analysis

Previous engineering helped us greatly in completing this task. Although this project required our group to acquire new engineering skills, our background in topics like Statics, Dynamics, 3D printing, and Design I gave us an edge on the first stages of producing a robot.

Understanding Statics and Dynamics enabled us to calculate how our weight should be distributed using free body diagrams and kinetic body diagrams in order to prevent the device from tipping backwards while accelerating up the ramp. The back wheels of our cart sit higher than our front wheel to further prevent tipping. We were also able to determine the amount of friction needed between the ramp and our wheels in order to be able to move up the incline.

Knowing how to operate a 3D printer saved us a lot of time in the development stage. Accounting for shrinkage of material as well as printer errors was only possible from past experience. This knowledge played a large role in developing our cart base (Part 9). In order to adhere to the size constraints of 4x5 inches, our base was designed to fit all components like the power source, motor control, and arduino on its top surface. Tolerances were used in our cart base as well. This was necessary because shrinkage of the ABS plastic would not allow the motor bolts to pass through the piece unless the holes were made bigger than the actual diameter of the bolts.

Even with this amount of engineering knowledge, we were still unable to make our robot without learning how to code an arduino. We had to learn how to control two DC motors with different output voltages with a timed based code. The output voltages were controlled through a motor control chip. Much of our time was put into understanding how to work the motors through the motor control chip with the arduino. Knowledge from high school robotics and ECE 204 such as basic circuitry, breadboards, and soldering assisted us in wiring our robot.

Designing a robot to complete this task would be almost impossible without engineering analysis. This project was a great way of utilizing much of the skills we have obtained throughout our engineering courses.

8. Device Testing

Table 8.1: Test 1 Cart Speed

Test Report 1

Design Organization: Mech 202 Group 17 | **Date: 4/28/19**

Device or system tested: Project 2 Cart, Speed

Objective of experiment (Engineering Specifications to be verified): Determine speed range of cart with two DC motors. Determine speed difference between motors to make the cart travel in a straight line (two exact DC motors do not run at same RPMs with same voltage, large source of error normally).

Background and Materials (or Equipment): Setup cart based on reverse engineering and bill of materials. Obtain a computer to program arduino. Using the motor controller, the speed of the motor can be controlled with the PWM port using an AnalogWrite arduino function.

```
analogWrite(enLeft,65);
```

The speed range that can be inputted into the analogwrite function is between 0 and 255. During this experiment, the input to the analogwrite function is going to be altered to determine the minimum speed the cart can go as well as the difference in the inputs required to make the cart go exactly straight.

Experimental Procedure:

Cart Goes Straight

Place a piece of duct tape in a straight line on a smooth surface. Program cart motors initially as **analogWrite(enLeft, 80)** and **analogWrite(enRight, 80)**. Upload code to arduino and run the cart on the line. If the cart turns left, decrease the input speed to the right motor by 10 (analogWrite(enRight,70)). If the cart turns right, decrease the input speed to the left by 10. Keep adjusting until the cart goes straight.

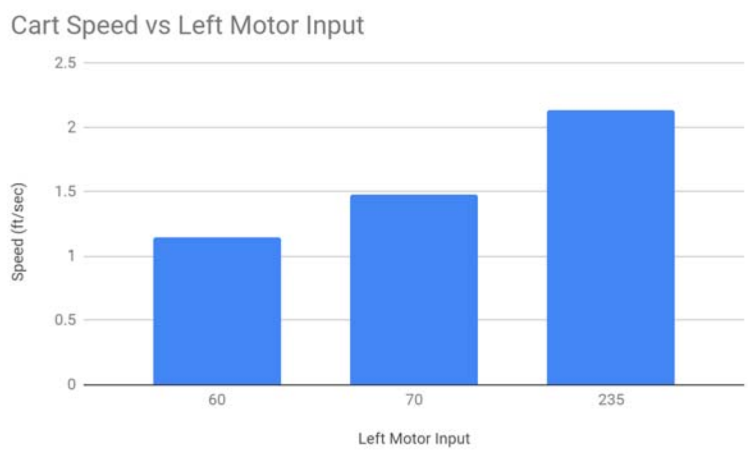
Min and Max Speeds

Once the speeds required for straight line travel are known, start decreasing each motors input by 10 until the wheels are unable to turn (example for an initial difference of 10: **analogWrite(enLeft,80-10x)** and **analogWrite(enRight,70-10x)**). Once the lowest input is known, measure out a distance of three feet and time how long the cart takes to travel the distance. Calculate the minimum speed of the cart. Repeat same procedure but jump each motors input to 255 (one motor should be less than 255 due to the initial input differences among motors). Calculate max speed.

Results:

Type of Travel (flat surface)	Left Motor Input	Right Motor Input	Time to travel 3 feet (sec)	Speed (ft/sec)
Straight Line	70	85	2.03	1.48

Min Speed	60	75	2.60	1.15
Max Speed	235	255	1.40	2.14



Discussion: In order for the cart to go straight there needs to be a motor input difference of about 15. The difference must get slightly larger as the motor speed increases. The left motor stops turning when the motor speed input gets below 60. Depending on if a new 9 V battery is being used or an old one, the left motor can sometimes function at an input of 50.

Analysis: Since higher speeds will help the cart overcome the incline but lower speeds will allow for more wiggle room for coding turns, an optimal speed inbetween the minimum and maximum must be determined. As a group, the decision was made to determine the slowest speed the cart could go at to overcome the incline. That speed occured when the left motor was set to an input of 65 and the right motor was set to 80.

Interpretation: In order for the cart to meet the engineering specifications of speed and simplicity, the final speed inputs of each motor were determined to be 65 for the left motor and 80 for the right motor. With these inputs, the cart can easily go up an incline but is still slow enough to program turns in consistently.

Team member: Alec DeStefano	Prepared by: Hunter Becvar
Team member: Jethro Leroux	Checked by: JL
Team member: Josh Ehr	Witnessed by: JE
Team member: Garrett Johnson	

Table 8.2: Test 2 Wheel Coefficient of Friction

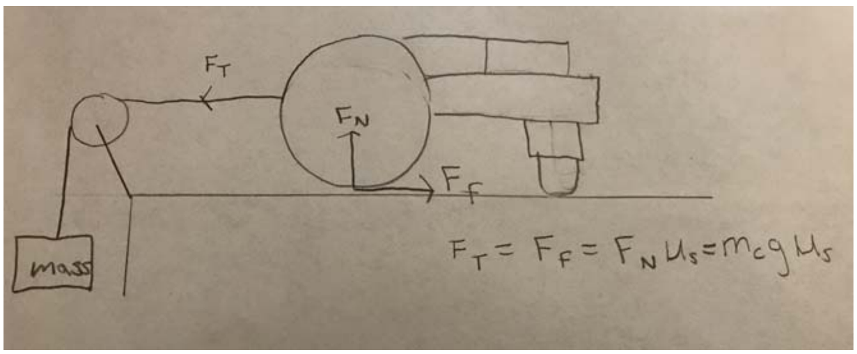
Test Report 2

Design Organization: Mech 202 Group 17 | **Date: 4/28/19**

Device or system tested: Project 2 Cart, Wheel Coefficient of Friction

Objective of experiment (Engineering Specifications to be verified): Determine coefficient of static friction of wheels.

Background and Materials (or Equipment): Coefficient of friction keeps the wheels from slipping on a track. The higher the coefficient, the more traction the cart will have.



The coefficient of static friction can be solved for once the cart reaches impending motion. By adding mass, impending motion can be created. Once the mass at impending motion is known, the coefficient of static can be calculated.

An assumption made was that the cart will slip before the wheels will turn. A hand was used to hold front wheel down so the cart would not flip (attempted to hold cart from side to prevent the addition of a larger normal force).

The materials for the experiment were the cart, a pulley table connector, a mass holder, and tape (pulley connector and mass holder were borrowed from PH141 lab).

Experimental Procedure:

Place the cart on the flat surface of the track. Setup the diagram above in background. Add 100 gram increments until the cart slips. Sequentially increase/decrease using smaller standard mass increments until the most accurate mass can be determined using the standard masses available (These were 100g, 50g, 10g, 5g and 1g increments).

Results/Calculations:

Known:

$m_c = .3687\ kg$

$F_N = m_c g = .3687 kg \bullet 9.81 m/s^2 = 3.62\ N$

Added .270 kg to reach impending motion

$m_{Added} = .270\ kg$

$\frac{m_{added} \bullet g}{m_c \bullet g} = \mu_S = .732$

Discussion: The coefficient of static friction for the wheels is .732. That is a relatively high static coefficient but it is in the range for the coefficient of static friction for rubber and wood (.7 to 1).

Analysis:
The cart is able to rest on the 33 degree incline and remain stationary. The cart will have no trouble with slipping.

Interpretation:
With a coefficient that large, slipping between the wheels and track should not occur as long as the wheels stay in contact with the ground. The cart has had trouble bouncing up and down as it goes up the track.

Team member: Alec DeStefano	Prepared by: Hunter Becvar
Team member: Jethro Leroux	Checked by: JL
Team member: Josh Ehr	Witnessed by: JE
Team member: Garrett Johnson	

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Table 8.3: Test 3 Weight

<table>
<tr><td colspan="2">Test Report 3</td></tr>
<tr><td>Design Organization: Mech 202 Group 17</td><td>Date: 4/28/19</td></tr>
<tr><td colspan="2">Device or system tested: Project 2 Cart, Weight</td></tr>
<tr><td colspan="2">Objective of experiment (Engineering Specifications to be verified): Determine the weight of the cart to make sure it falls within the Mech 202 Competition design constraints.</td></tr>
<tr><td colspan="2">Background and Materials (or Equipment): The entire device must weigh less than 3 pounds, as stated by the Project II Description. A digital scale from the EMEC was used to weigh the vehicle. The scale measure in grams.</td></tr>
<tr><td colspan="2">Experimental Procedure:
The digital scale was zeroed and the vehicle with all its components was placed on the scale. The scale provided a mass to one decimal place in grams. The mass in grams was then converted to a mass in pounds using the following equation: $m_{pounds} = (m_{grams})(2.2046226218\,\frac{lb}{kg})(0.001\,\frac{kg}{g})$</td></tr>
<tr><td colspan="2">Results: Simply by using the above equation, it was found that the vehicles mass was 0.8128lb.</td></tr>
<tr><td colspan="2">Discussion: Since 0.8128lb < 3lb, our device falls well within the constraints given by the Mech 202 Project 2 description document.</td></tr>
<tr><td>Analysis: Since a larger mass will put more strain on our small DC motors, it is in our best interests to keep this weight small as to aid us in navigating up the 33 degree slope of the project competition fixture.</td><td>Interpretation: Although certain improvements could be made to the device to decrease its mass, such as thinning out the 3D printed base, using a different infill when printing,or eliminating the breadboard on the device, it was decided that 0.8128lb was an adequate and fair weight to try and put to the test of driving up the hill based on the torque tests of the 2 DC motors as the motors should provide a sufficient driving force to drive the vehicle up the shallow incline.</td></tr>
<tr><td>Team member: Alec DeStefano</td><td>Prepared by: Hunter Becvar</td></tr>
<tr><td>Team member: Jethro Leroux</td><td>Checked by: JL</td></tr>
<tr><td>Team member: Josh Ehr</td><td>Witnessed by: JE</td></tr>
<tr><td>Team member: Garrett Johnson</td><td></td></tr>
<tr><td>The Mechanical Design Process
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</table>

Table 8.4: Test 4 Torque

Test Report 4

Design Organization: Mech 202 Group 17	Date: 4/28/19

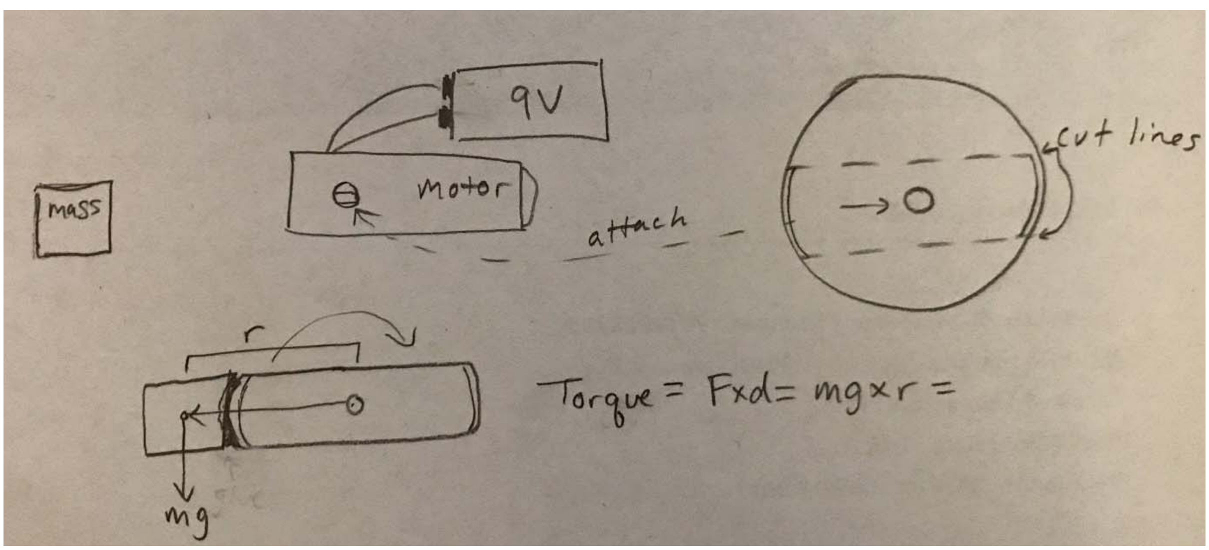
Device or system tested: Project 2 Cart, Torque

Objective of experiment (Engineering Specifications to be verified): Determine the maximum torque output by the motors given maximum voltage.

Background and Materials (or Equipment): This experiment was conducted using an unneeded wheel that attached to our DC motors. The wheel was cut with a bandsaw in the EMEC in a way where it could still be attached to our motor securely and a mass could be glued to the outer radius of the wheel. The masses were borrowed the Mech 231 Experimentation lab.

Experimental Procedure:

With our precut wheel attached to a full powered DC motor at 9V, we added mass in increments of 50g or 25g onto the outer radius of the wheel until it could no longer spin. Assuming the wheel strip is massless, this gave us a gravitational force (mg) and a radius (wheel+center of mass of mass).



Results:

Mass	Will the motor turn?
75g	Yes
125	Yes

175g	Yes
200g	Yes
225g	Yes, but much slower
250g	No, mg*radius=T!
275g	Weight overpowers torque of motor, motor spins backward

With the newfound maximum mass we used the formula mass*gravity*radius=Torque.
(.25kg)*(9.81m/s^2)*(.03175m+.004m)= **0.08767N*m= Maximum Torque output**

Discussion: This amount of torque will be plenty of force to get our robot up the path considering each motor can support approximately 0.6 lbs. We also have two motors to help our 0.812lb robot up the ramp. Having an excess amount of torque to work with will greatly benefit our robot.

Analysis: Using the arduino to fluctuate the voltage given to each motor, our maximum torque will not even be necessary achieve our goal.

Interpretation: We will need to greatly reduce our voltage supplied to each motor in order to control our robot. With our robot running at maximum torque calculated, it would make jerky turns and be unable to complete the tight turns on the ramp.

Team member: Alec DeStefano	Prepared by: Hunter Becvar
Team member: Jethro Leroux	Checked by: JL
Team member: Josh Ehr	Witnessed by: JE
Team member: Garrett Johnson	

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Table 8.5: Test 5 Part Repairs per Run

Test Report 5

Design Organization: Mech 202 Group 17 | **Date: 4/28/19**

Device or system tested: Project 2 Cart, Part Repairs per Run

Objective of experiment (Engineering Specifications to be verified): Determine average number of part repairs per run in order to prepare for competition day.

Background and Materials (or Equipment): The cart generally has specific things that need to be repaired after each test run. Common repairs are wires disattaching, the button disattaching, and new code needing to be uploaded. In order to determine total number of repairs, repairs are going to be categorized as circuitry, power supply, physical design, or code.

Experimental Procedure:

Using the finalized cart, practice tests were performed for 10 runs. After each run, the number of repairs were documented and categorized.

Results: Number of Repairs

Run	Circuitry (wires, buttons, etc)	Power Supply (battery)	Physical Design (glue, wheels, etc)	Code Issue
1	1	0	0	1
2	0	0	0	1
3	2	0	0	0
4	0	0	0	1
5	1	1	0	1
6	1	0	0	0
7	1	0	0	1
8	0	0	1	1
9	0	0	0	0
10	1	1	0	2
Total	**7**	**2**	**1**	**8**

Total Repairs: 18 repairs, 1.8 per run

Discussion: The average number of repairs was 1.8 per run which is within the 1 to 3 target range set in the QFD. The number is still slightly high. The most common issues were button and wires disconnecting. A code issue was almost present every time.	
Analysis: The most repairs came from circuitry and code issues. If more time is going to be spent on repairs, the focus should be arduino code and connecting wires and buttons more securely.	**Interpretation:** More time should be focused on finding issues in coding and wire connections. Soldering should be used to connect any wires that aren't connected to the breadboard. This will eliminate repairs.
Team member: Alec DeStefano	Prepared by: Hunter Becvar
Team member: Jethro Leroux	Checked by: JL
Team member: Josh Ehr	Witnessed by: JE
Team member: Garrett Johnson	
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Test Report 6: Cost

Table 8.6: Test 6 Cost

Part #	Part Name	Part Quantity in Final Design	Net Part Cost [$]	Miscellaneous Costs	Total Part Cost (Quantity*Net Cost + Miscellaneous Costs) [$]
1	9 V Battery	1	2.50	9V terminal connector: $1.63	4.13
2	DC Motor	2	2.95	N/A	5.90
3	Ball Caster	1	2.09	Originally caster wheel: $4.89	6.98
4	Male to Female Wires (8”)	4	0.10	N/A	0.40
5	Male to Male Wires (4”)	1	0.10	N/A	0.10
6	Breadboard	1	2.62	N/A	2.62

7	Arduino (Elegoo) Uno R3	1	11.86	N/A	11.86
8	DC Motor Controller (L298N)	1	6.99	N/A	6.99
9	Cart Base	1	N/A	I2P Lab Access Fee: $20 Total Filament used on 4 separate prints: $10	30.00
10	10K Ohm Resistor	1	0.50	N/A	0.50
11	Button	1	0.50	N/A	0.50
12	Cart Wheel	2	1.55	Originally yellow thicker wheels: $2.10 each	7.30
TOTAL COST:					**$77.28**

Since $77.28 < $200, our device falls within the specified cost restraints given by the Project II description documents.

Other specifications from the QFD such as Number of Motors and Number of Total Parts can be found very simply or elsewhere in this document and do not require a full test report.

9. Reliability Analysis

Table 9.1: FMEA

FMEA

Device Name: The Wow Factor
Team Number: 17
Team Member Names: Hunter Becvar, Alec DeStefano, Josh Ehr, Garrett Johnson, Jethro Leroux

Prepared By: Alec DeStefano
Checked By:
Approved By:
FMEA Date (Orig.): 4/18/19 (Rev.):

#	Function affected	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended	Resp.	Actions Taken	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN
1	Device propulsion	Motors drives wrong direction	Device turns wrong direction	8	Improper connection of wires	1	Visual Inspection	6	48	Hand test the connections	Alec	Connections tested every run	8	1	2	16
2				8	Improper arduino coding	2	Arduino coding verification	3	48	Visually verify coding	Hunter	Coding inputs checked	8	1	1	8
3			Device drives away from ramp	8	Improper connection of wires	1	Visual Inspection	6	48	Hand test the connections	Alec	Connections tested every run	8	1	2	16
4				8	Improper arduino coding	2	Arduino coding verification	3	48	Visually verify coding	Hunter	Coding inputs checked	8	1	1	8
5		Motor doesn't turn on	Device doesn't move	5	Improper connection of wires	1	Visual Inspection	6	30	Hand test the connections	Josh	Connections tested every run	5	1	2	10
6				5	Button falls out of breadboard	8	None	10	400	Replace button every 20 runs	Garrett	Button replaced	5	4	1	20
7				5	9V battery is dead	9	Physial Inspection	9	405	Replace old batteries	Jethro	Batteries replaced	5	5	5	125
8		Device gets stuck on wall	Device flips over	10	Improper arduino coding	2	Arduino coding verification	3	60	Visually verify coding	Hunter	Coding inputs checked	10	1	1	10
9				9	Wheels slip on the ramp	10	None	10	900	Wipe dust off ramp and wheels	Garrett	Wheels wiped off every run	9	7	5	315
10			Device doesn't move	6	Improper arduino coding	2	Arduino coding verification	3	36	Visually verify coding	Hunter	Coding inputs checked	6	1	1	6
11			Device drives off ramp	10	Coding unprepared to hit wall	2	Arduino coding verification	3	60	Visually verify coding	Hunter	Coding inputs checked	10	1	1	10
12		Motor turns off mid run	Device stops moving	7	Motor wire slips out of clamp	2	Visual Inspection	6	84	Hand test the connections	Josh	Connections tested every run	7	1	2	14
13				8	9V battery dies	9	Physial Inspection	9	648	Replace old batteries	Jethro	Batteries replaced	8	5	5	200
14			Device can only turn one way	7	Motor wire slips out of clamp	2	Visual Inspection	6	84	Hand test the connections	Josh	Connections tested every run	7	1	2	14
15		Parts seperate from device	Device can't move	10	Motor bolt loosens and falls off	6	Physical Inspection	2	120	Tighten motors every 20 runs	Alec	Bolts tightened on motors	10	3	1	30
16			Device doesn't follow path	9	Front guide breaks off	7	Visual Inspection	6	378	Hand test the guide	Alec	Attachment tested every run	9	4	3	108
17	Device Turning	Device Turns Wrong Direction (Left vs Right)	Device turns into wall	8	Improper Arduino coding	2	Arduino code verification	2	32	Visually verify code	Hunter	Code tested with cart	8	1	1	8
18		Device over/under Turns	Device runs into wall	8	Improper Arduino Code	6	Arduino code verification	5	240	Arduino code tested on flat surface	Hunter	Arduino code tested on flat surface	8	4	2	64
19				8	Addition torque of turn caused by incline and gravity	10	Visual Inspection	2	160	Apply counteractive torque from wheels to fight torque from	Hunter	On turns, the speed of inside wheel doesn't go to zero	8	9	2	144
20			Device turns around on track	8	Improper Arduino Code	5	Arduino code verification	5	200	Arduino code tested on flat surface	Hunter	Arduino code tested on flat surface	8	4	3	96
21				8	Addition torque of turn caused by incline and gravity	8	Visual Inspection	2	128	Apply counteractive torque from wheels to fight torque from gravity	Hunter	Arduino code tested on flat surface	8	8	2	128
22		Device fails to turn	Runs into wall	8	Improper arduino coding	3	Arduino code verification	2	48	Visually verify coding	Josh	Visually verified code	8	1	2	16
23				8	Whiggling wheels don't have enough contact on ground to turn	3	Visual Inspection	2	48	Tighten and glue motors to body	Josh	Glued motors to base as well as tightned screws	8	3	2	48

FTA

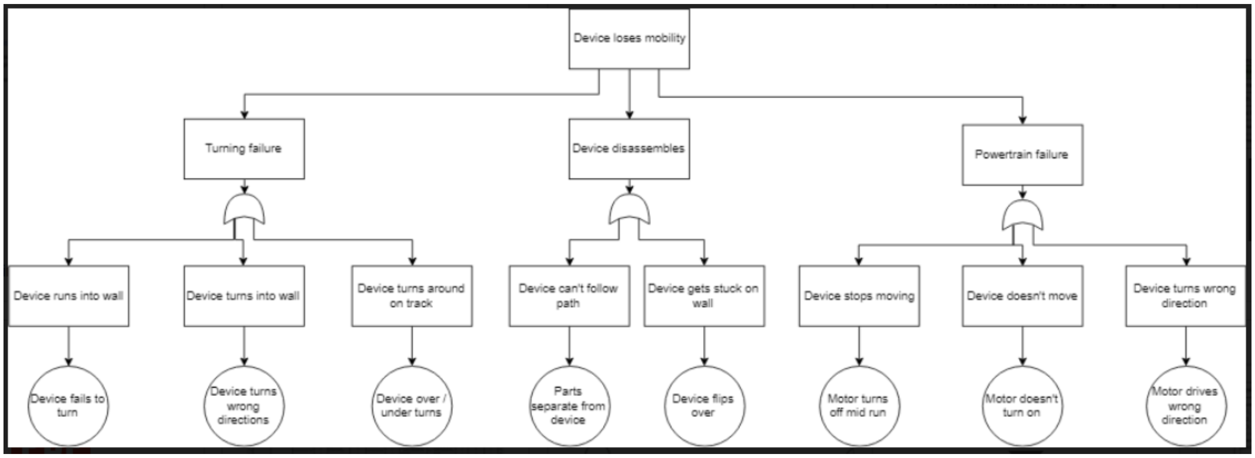

Figure 9.1: FTA Chart

Improvements Made

Powertrain Failure

In Order to account for the powertrain failure, group 17 always carries at least two 9V spare batteries. The 9V batteries run out of charge after about 5 to 10 runs so it is critical to have extra. The wiring of the cart is checked prior to each run. Wiring issues mainly occur in the power supply ports of the motor controller so extra time is spent checking them.

Device Disassemblies

The wheels and ball castor are attached with screws and super glue instead of electrical tape. The PWM ports are soldered instead of held together by friction. The arduino, motor controller, and breadboard are still held together with electrical tape to limit the force applied on each wire. Wires will break before an arduino or bread board.

Turning Failures

Extra time was spent mastering the coding for turning. The cart was easily able to make turns on a flat surface but unfortunately the cart still struggles to maneuver up the incline. In an effort to lower the center of gravity, the castor wheel was replaced with a castor ball. The cart still can not overcome the force of gravity on turns and fails to get around the second turn.

10. Safety Analysis

Table 10.1: Safety Analysis

Hazard Risks	Risk Areas	Resolutions for the Risks	Current Level of Concern
Pinched fingers	Cart could run over fingers, causing pain and possible swelling	Cart has been made lighter, and the rubber wheels should protect from injury	Low
Shocked fingers	Wires could come unplugged and send shocks through a user that cannot properly operate the cart	The wires have been sautered, taped, and held in tightly to prevent any issues caused from loose wires	Low
Cut foot from falling cart	The cart could move too rapidly and cause the cart to fall off of the table and injure someone on the way down	The cart is steadier in order to protect viewers from possibly having the cart fall onto their feet	Medium
Burnt fingers from the cart combustion	The cart could combust if the wires are put into incorrect places	The full set up of the assembly has been put together by the creators many times, forcing them to memorize the setup correctly	Very Low

11. Service & Support Plan

Table 11.1: Service and Support Plan

Possible Part Failures	Support Plan	Spare Items for Competition Day	Responsibility
Power Supply is out of charge	Have extra 9V batteries	4 9V Batteries	Jethro Leroux
Rear Wheels wiggling	Bring glue and hex-wrench to tighten wheels	3M super glue	Alec DeStefano
Ball Castor detaches from base	Bring super glue and electrical tape to reattach	3M super glue, electrical tape	Alec DeStefano
Wires disconnect or break	Bring extra wires and an electrical diagram to reattach for next race	2 male to male wires, 2 male to female wires, electrical diagram print out	Hunter Becvar
Button Detaches	Bring extra button to insert into breadboard (new buttons remain in position better)	1 button (4 port)	Josh Ehr
Breadboard, Motor Controller, or arduino separates from base	Bring electrical tape to attach items to base	Electrical tape	Garrett Johnson
Cart turn timing is slightly off due to cart slippage	Bring laptop and adjust turn timing and re-upload code	Arduino computer cable, computer	Hunter Becvar

12. Project Plan

Table 12.1: Project Plan

Project Planning	
Design Organization: Mech 202 Group 17 Project 2	**Date: 5/9/19**
Product Name: Project 2	
Task: #1	**Name of Task:** Idea Brainstorm
	Objective: Generate ideas for design of the robot
	Deliverables: Two ideas for design from each team member List of great concepts for final design
	Decisions/Milestones with Dates: 1. How do we determine design criteria? 2. How do we determine a good design concept?
	Personnel Needed: Title: All Hours: 4 Percent full time: 8%
	Time: Estimated Total Hours: 20 Actual Total Hours: 20
	Sequence: Predecessors: none Successors: Tasks 2-11 Planned Start Date: 3/21/19 Planned Finish Date: 3/26/19 Actual Start Date: 3/25/19 Actual Finish Date: 4/20/19
	Costs: Capital Equipment**: $0 (paid by fees)** Disposables: $0
Task: #2	**Name of Task:** Testing Conceptual Ideas
	Objective: Perform testing on ideas developed in task one. Determine designs that will or will not work
	Deliverables: Throw out poor designs Understand possible manufacturing processes for concepts
	Decisions/Milestones with Dates: 1. How will we test the prototypes? 2. What is the criteria to determine quality ideas?
	Personnel Needed: Title: Designer Hours: 10 Percent full time: 11.4% Title: Tester Hours: 10 Percent full time: 20%
	Time: Estimated Total Hours: 20 Actual Total Hours: 20
	Sequence: Predecessors: Task 1 Successors: Tasks 3-11 Planned Start Date: 3/26/19 Planned Finish Date: 3/31/19 Actual Start Date: 3/26/19 Actual Finish Date: 4/20/19
	Costs: Capital Equipment **$0** Disposables: $0
Team member: Hunter B	Team member: Alec D
Team member: Josh E	Prepared by: Hunter B and Alec D
Team member: Garrett J	Checked by: Josh E
Team member: Jethro L	Approved by: Jethro L and Garrett J
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Project Planning

Design Organization: Mech 202 Group 17 Project 2		Date: 5/9/19
Product Name: Project 2		
Task: #3	**Name of Task:** Prototyping	
	Objective: Build a prototype that reflects the concepts developed in previous tasks	
	Deliverables: A test product that is functional and able to perform tests on	
	Decisions/Milestones with Dates: 1. What materials to use for prototype? 2. How to manufacture the prototype?	
	Personnel Needed: Title: Manufacturer (1 and 2) Hours: 20 Percent full time: 28.2%	
	Time: Estimated Total Hours: 20 Actual Total Hours: 40	
	Sequence: Predecessors: Task 1-2 Successors: Tasks 4-11 Planned Start Date: 3/31/19 Planned Finish Date: 4/7/19 Actual Start Date: 4/02/19 Actual Finish Date:4/20/19	
	Costs: Capital Equipment**: $20 (paid by fees)** Disposables: $0	
Task: #4	**Name of Task:** Prototype Testing	
	Objective: Acquire information on how the arduino works	
	Deliverables: Determine if the prototype will work or not	
	Decisions/Milestones with Dates: 1. What is the best way to program the arduino? 2. How well will the prototype get up an incline?	
	Personnel Needed: Title: Tester Hours: 10 Percent full time: 20%	
	Time: Estimated Total Hours: 8 Actual Total Hours: 10	
	Sequence: Predecessors: Task 1-3 Successors: Tasks 5-11 Planned Start Date: 4/7/19 Planned Finish Date: 4/11/19 Actual Start Date: 4/05/19 Actual Finish Date: 4/20/19	
	Costs: Capital Equipment **$0** Disposables: $0	

Team member: Hunter B	Team member: Alec D
Team member: Josh E	Prepared by: Hunter B and Alec D
Team member: Garrett J	Checked by: Josh E
Team member: Jethro L	Approved by: Jethro L and Garrett J
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Project Planning

Design Organization: Mech 202 Group 17 Project 2 | **Date: 5/9/19**

Product Name: Project 2

Task: #5

Name of Task: Analysis of Concepts

Objective: Analysis size, part function, and material to efficiently design the robot

Deliverables:
Record of changes made to design

Decisions/Milestones with Dates:
1. What calculations can be made to show improvement?
2. How do we test each part?

Personnel Needed:
Title: Engineer Hours: 5 Percent full time: 20%
Title: Designer Hours: 5 Percent full time: 5.68%

Time: Estimated Total Hours: 20 Actual Total Hours: 10

Sequence: Predecessors: Tasks 1-4 Successors: Tasks 6-11
Planned Start Date: 4/11/19 Planned Finish Date:4/15/19
Actual Start Date: 4/05/19 Actual Finish Date: 4/20/19

Costs: Capital Equipment**: $0** Disposables: $0

Task: #6

Name of Task: Initial Design Report

Objective: Make the necessary changes found to the design of the robot

Deliverables: Ensure the design will work correctly

Decisions/Milestones with Dates:
1. Figure out how much the previous design changes helped
2. Determine if another redesign is necessary
3. If redesign is necessary, determine time and money necessary

Personnel Needed:
Title: Designer Hours: 5 Percent full time: 5.68%

Time: Estimated Total Hours: 5 Actual Total Hours: 5

Sequence: Predecessors: Tasks 1-5 Successors: Tasks 7-11
Planned Start Date: 4/15/19 Planned Finish Date: 4/17/19
Actual Start Date: 4/20/19 Actual Finish Date: 4/29/19

Costs: Capital Equipment **$0** Disposables: $30

Team member: Hunter B	Team member: Alec D
Team member: Josh E	Prepared by: Hunter B and Alec D
Team member: Garrett J	Checked by: Josh E
Team member: Jethro L	Approved by: Jethro L and Garrett J

THE WOW! FACTOR

Project Planning

Design Organization: Mech 202 Group 17 Project 2 | **Date: 5/9/19**

Product Name: Project 2

Task: #7	**Name of Task:** Final Design
	Objective: Create an entirely finished prototype design that will be used for the project
	Deliverables: Solidworks Parts finished Solidworks Drawings for the parts and full assembly Design notes to go along with the solidworks parts
	Decisions/Milestones with Dates: 2. As determined from testing, are there any issues with specific pieces of the robot? 3. Are there improvements that are necessary to ensure the prototype works correctly?
	Personnel Needed: Title: Engineer Hours: 10 Percent full time: 40% Title: Designer Hours: 12 Percent full time: 13.6% Title: Manufacturer Hours: 11 Percent full time: 15.5%
	Time: Estimated Total Hours: 30 Actual Total Hours: 33
	Sequence: Predecessors: Tasks 1-6 Successors: Tasks 8-11 Planned Start Date: 4/17/19 Planned Finish Date: 4/20/19 Actual Start Date: 4/10/19 Actual Finish Date: 4/20/19
	Costs: Capital Equipment**: $40 (paid by fees)** Disposables: $20
Task: #8	**Name of Task:** Final Testing
	Objective: Figure out if the prototype works correctly by testing it on the track made. Push the limits of the car to determine if it works in tougher cases. Look into any last-minute adjustments that need to be made
	Deliverables: Look into all aspects of the car to determine whether or not it all works smoothly Determine the final improvements to be made (if any) Ensure the design is going to be fully functional and in top condition on competition day
	Decisions/Milestones with Dates: 1. Determine ways to test the competition against our design 2. Are there ways to push our design past the limits that other groups cannot achieve? 3. Determine if there are any final adjustments necessary for the project
	Personnel Needed: Title: Designer Hours: 20 Percent full time: 22.7% Title: Manufacturer Hours: 20 Percent full time: 28.2% Title: Tester Hours: 20 Percent full time: 40%
	Time: Estimated Total Hours: 60 Actual Total Hours: 60
	Sequence: Predecessors: Tasks 1-7 Successors: Tasks 9-11 Planned Start Date: 4/20/19 Planned Finish Date: 4/24/19 Actual Start Date: 4/20/19 Actual Finish Date: 5/02/19
	Costs: Capital Equipment **$25** Disposables: $5

Team member: Hunter B	Team member: Alec D
Team member: Josh E	Prepared by: Hunter B and Alec D
Team member: Garrett J	Checked by: Josh E
Team member: Jethro L	Approved by: Jethro L and Garrett J

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Project Planning

Design Organization: Mech 202 Group 17 Project 2	**Date: 5/9/19**
Product Name: Project 2	

Task: #9	**Name of Task:** Failure Examination
	Objective: Determine if there are improvements that must be made to the prototype. Find ways to make the necessary improvements.
	Deliverables: Failure analysis report
	Decisions/Milestones with Dates: 1. What went wrong with the prototype? (if anything) 2. What did we miss in the design process? 3. What adjustments could have ensured the car did better on competition day?
	Personnel Needed: Title: Manufacturer Hours: 10 Percent full time: 14.1% Title: Designer Hours: 10 Percent full time: 11.4%
	Time: Estimated Total Hours: 22 Actual Total Hours: 20
	Sequence: Predecessors: Tasks 1-8 Successors: Tasks 10-11 Planned Start Date: 4/24/19 Planned Finish Date: 4/30/19 Actual Start Date: 4/20/19 Actual Finish Date: 5/02/19
	Costs: Capital Equipment**: $0** Disposables: $0
Task: #10	**Name of Task:** Team Health Report
	Objective: Look into the ways that the group worked together. Figure out things that worked and things that didn't in the group. Determine ways to improve in the future.
	Deliverables: Information about how the group worked together. Reports about the team health through the project.
	Decisions/Milestones with Dates: 1. Was every team member included in the project and project decisions? 2. Did all of the team members provide their share of time/work toward the project? 3. If the team didn't work well together, what could have been done differently?
	Personnel Needed: Title: All Hours: 1 Percent full time: 2%
	Time: Estimated Total Hours: 5 Actual Total Hours: 5
	Sequence: Predecessors: Tasks 1-9 Successors: Task 11 Planned Start Date: 4/30/19 Planned Finish Date: 5/02/19 Actual Start Date: 5/06/19 Actual Finish Date: 5/08/19
	Costs: Capital Equipment **$0** Disposables: $0

Team member: Hunter B	Team member: Alec D
Team member: Josh E	Prepared by: Hunter B and Alec D
Team member: Garrett J	Checked by: Josh E
Team member: Jethro L	Approved by: Jethro L and Garrett J

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Project Planning		
Design Organization: Mech 202 Group 17 Project 2		**Date: 5/9/19**
Product Name: Project 2		
Task: #11	**Name of Task:** Turn in Report	
	Objective: Get the final project report ready to be turned in.	
	Deliverables: Final Project Report	
	Decisions/Milestones with Dates: 1. What needs to be done to complete the report? 2. Who will be responsible for which sections? 3. Does anything done previously need to be changed/corrected?	
	Personnel Needed: Title: All Hours: 5 Percent full time: 10%	
	Time: Estimated Total Hours: 25 Actual Total Hours: 25	
	Sequence: Predecessors: Tasks 1-10 Successors: None Planned Start Date: 5/02/2019 Planned Finish Date: 5/08/2019 Actual Start Date: 4/20/19 Actual Finish Date: 5/08/19	
	Costs: Capital Equipment**: $0** Disposables: $0	

Team member: Hunter B	Team member: Alec D
Team member: Josh E	Prepared by: Hunter B and Alec D
Team member: Garrett J	Checked by: Josh E
Team member: Jethro L	Approved by: Jethro L and Garrett J
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Table 12.2: DSM Project Plan

DESIGN STRUCTURE MATRIX (MECH 202 TEAM 17 PROJECT 2)												
TASKS		A	B	C	D	E	F	G	H	I	J	K
Idea Brainstorm	A	**A**										
Testing Conceptual Ideas	B	X	**B**									
Prototyping	C	X	X	**C**								
Prototype Testing	D	X	X	X	**D**							
Analysis of Concepts	E				X	**E**						
Initial Design Report	F				X	X	**F**					
Final Design	G			X	X	X	X	**G**				
Final Testing	H							X	**H**			
Failure Examination	I								X	**I**		
Team Health Report	J										**J**	
Turn in Report	K	X	X	X	X	X	X	X	X	X	X	**K**

***X in row show inputs to row element from other elements. X in column show outputs from column element to other elements.**

Tasks List (Actual finish Dates can be found on Gantt Chart)

Number	Task Title	Task Owner	Predecessors	Successors	Start Date	Due Date
	Project 2					
1	Project Plan and Gantt Chart	AD, HB, JE	None	All	2/11/19	2/19/19
2	Brainstorm Meeting	All	1	3-14	2/19/19	2/28/19
3	Testing Concepts	All	2	4-8	2/21/19	3/5/19
4	Build Design Prototype	All	2,3	5-8	2/28/19	4/16/19
5	Initial Design Testing	All	2,3	6-8	3/15/19	4/15/19
6	Performance Analysis	All	5	7-14	3/19/19	4/30/19
7	Prototype Revisions	All	4,5	9-14	4/2/19	4/23/19
8	Initial Design Report	All	2-7	11-14	4/15/19	5/1/19
9	Final Design Build	All	3,4,5,7	10-14	4/18/19	4/25/19
10	Final Design Testing	All	9	11-14	4/25/19	5/2/19
11	Failure Analysis	All	10	12-14	4/30/19	5/2/19
12	Team Heath Assessment	All	All	13,14	5/1/19	5/7/19
13	Report Preparation	All	All	14	5/2/19	5/8/19
14	Turn in Report	All	All	None	5/8/19	5/9/19

Figure 12.1: Tasks List

Gantt Chart Progress (2/11/19 - 5/9/19)

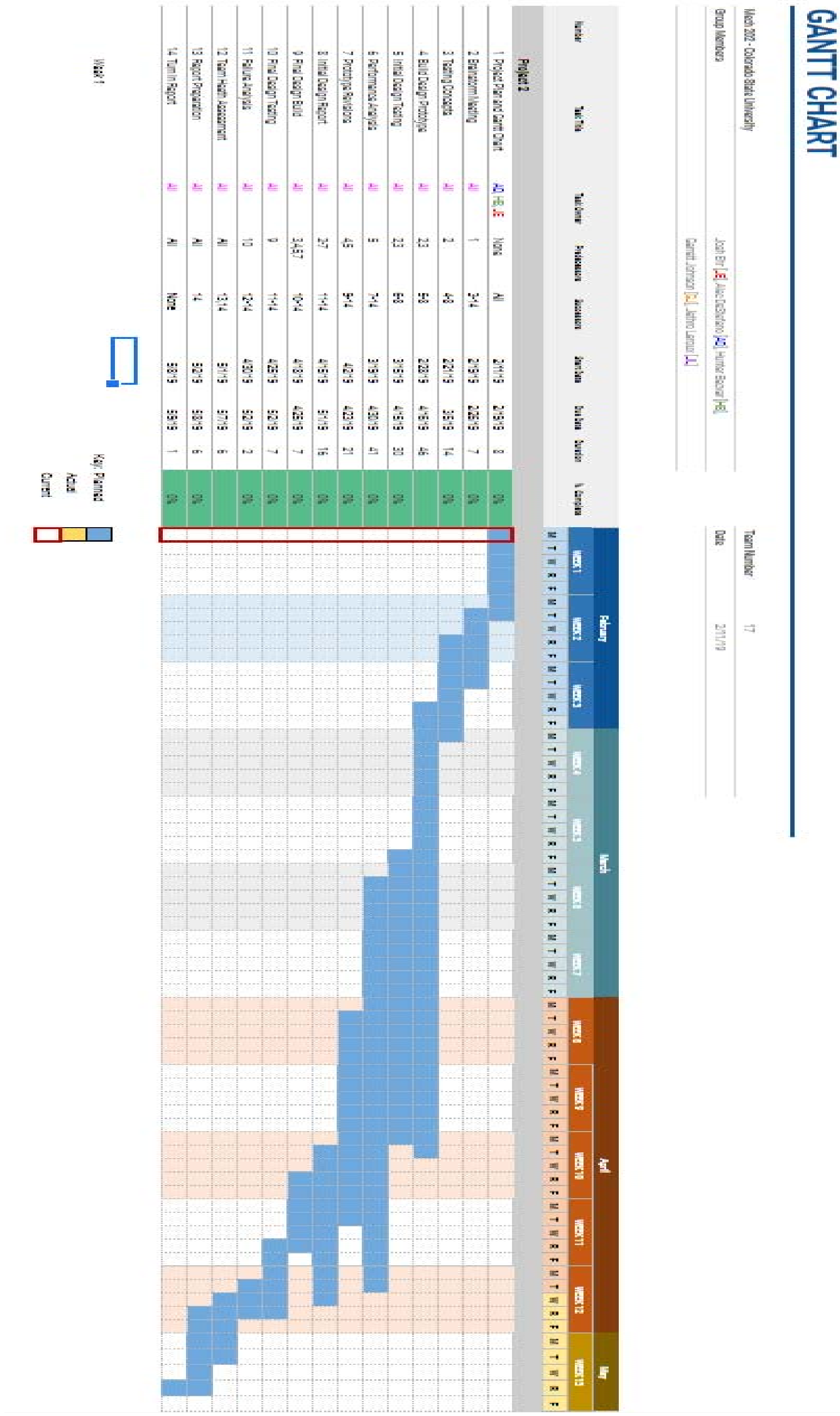

Figure 12.2: Gantt Chart Week 1

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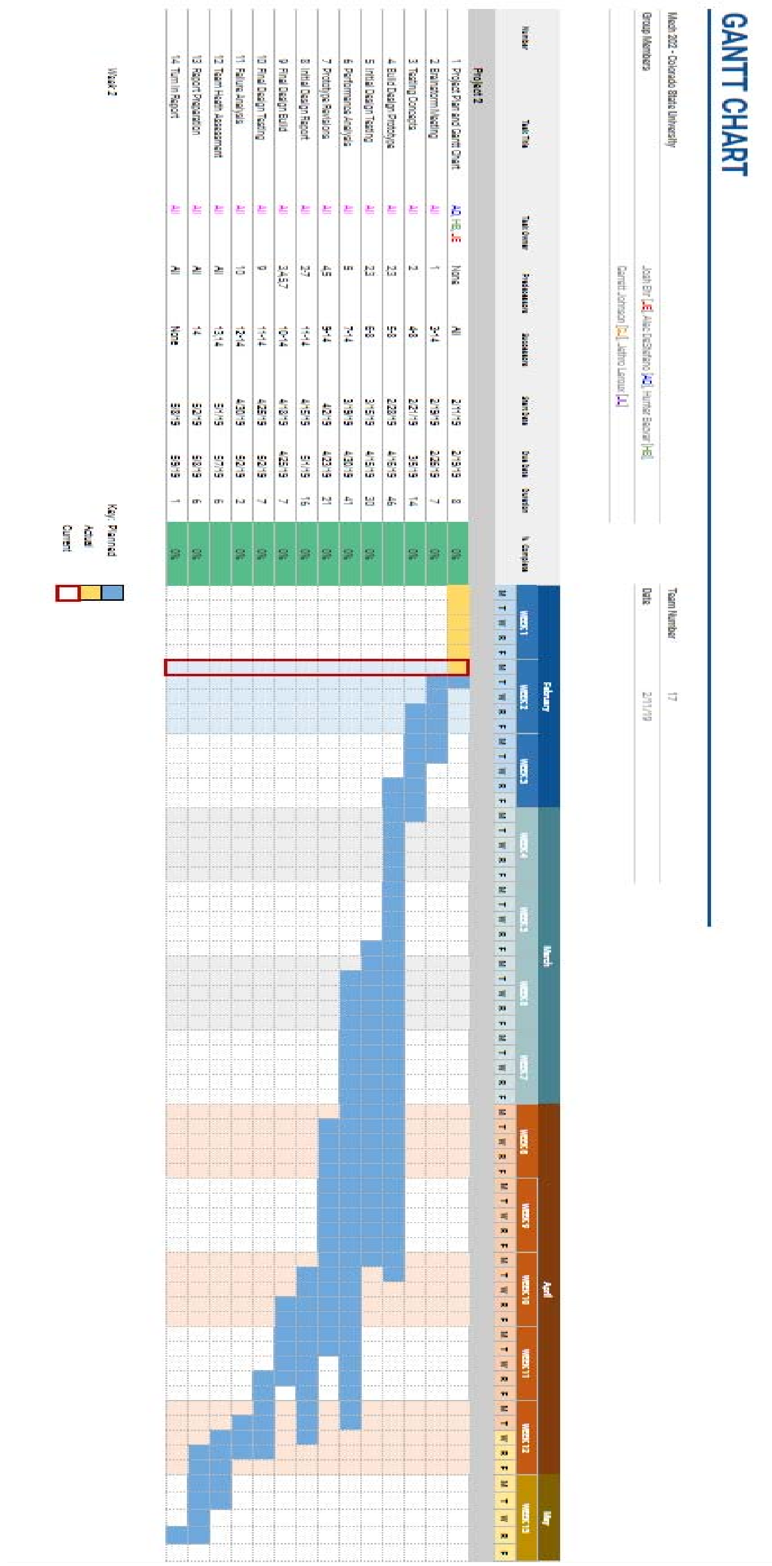

Figure 12.3: Gantt Chart Week 2

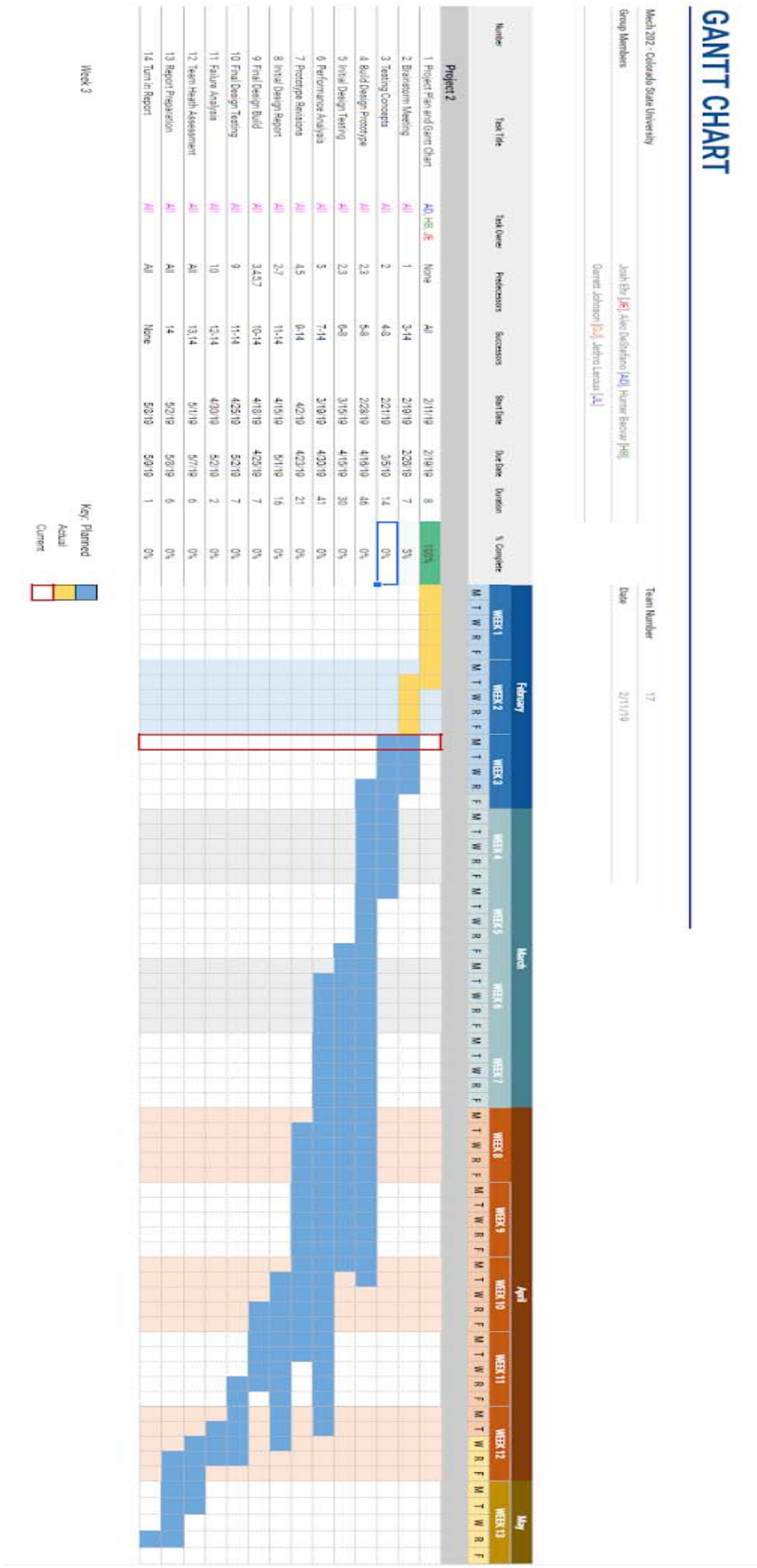

Figure 12.4: Gantt Chart Week 3

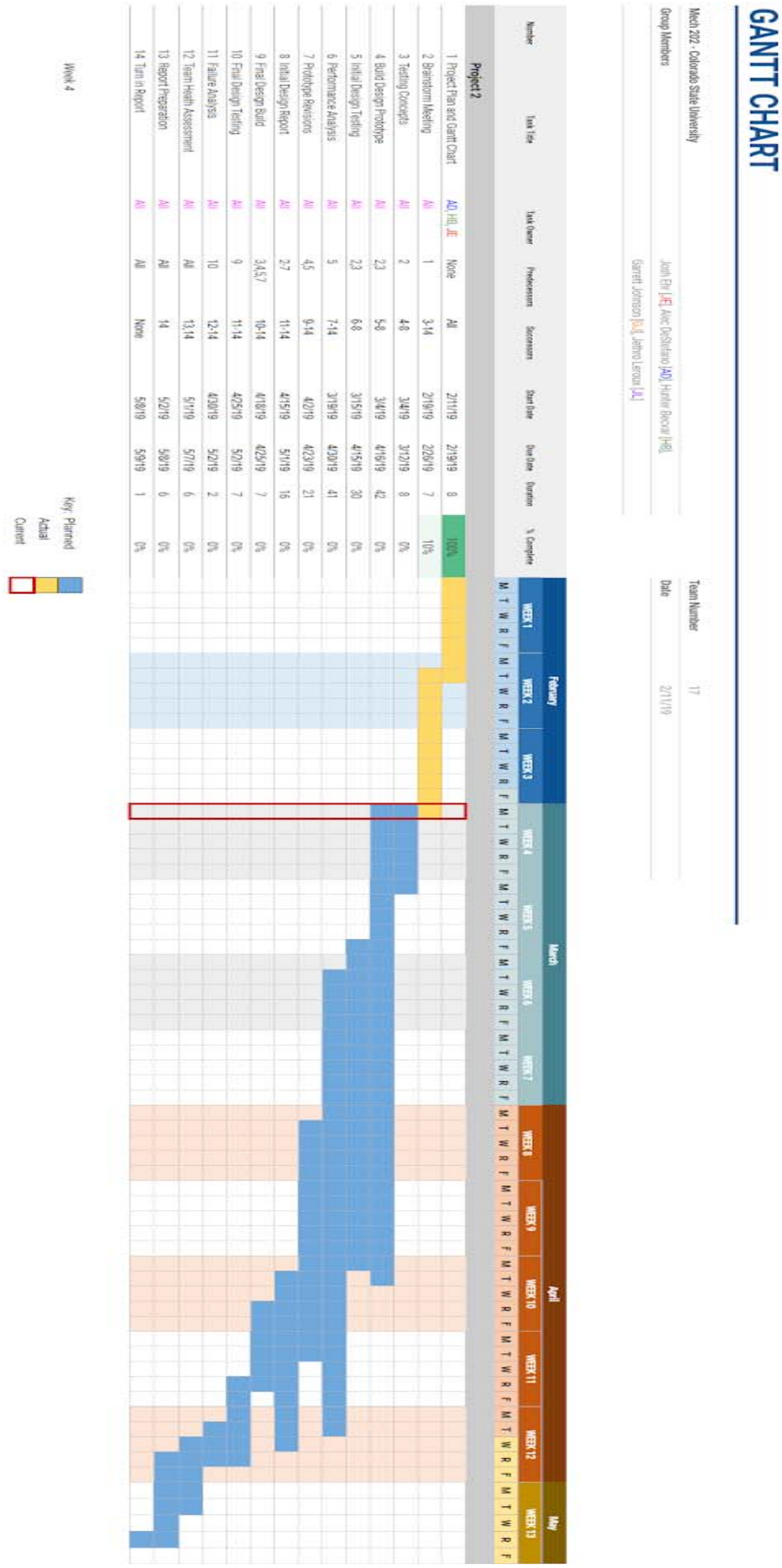

Figure 12.5: Gantt Chart Week 4

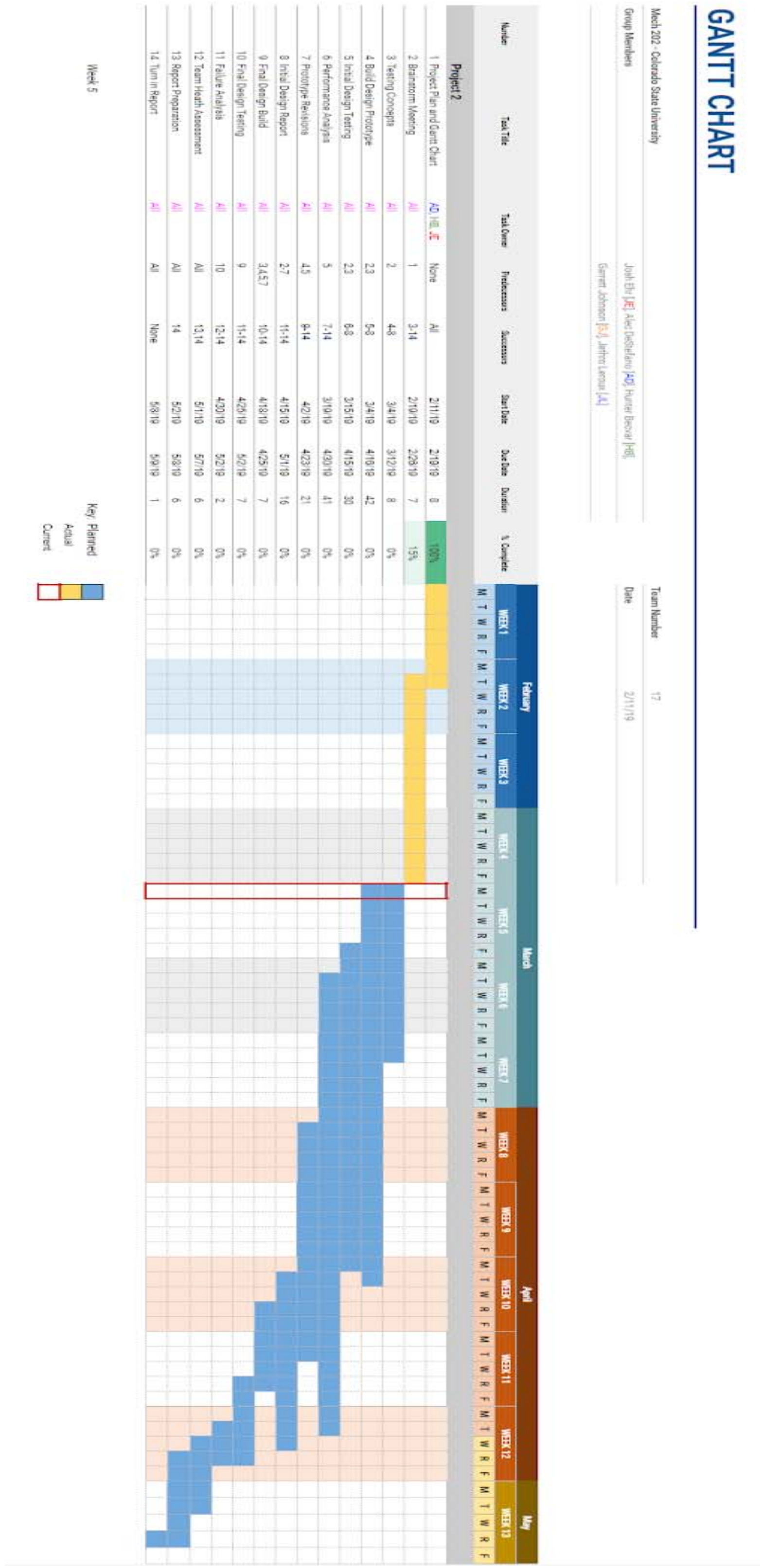

Figure 12.6: Gantt Chart Week 5

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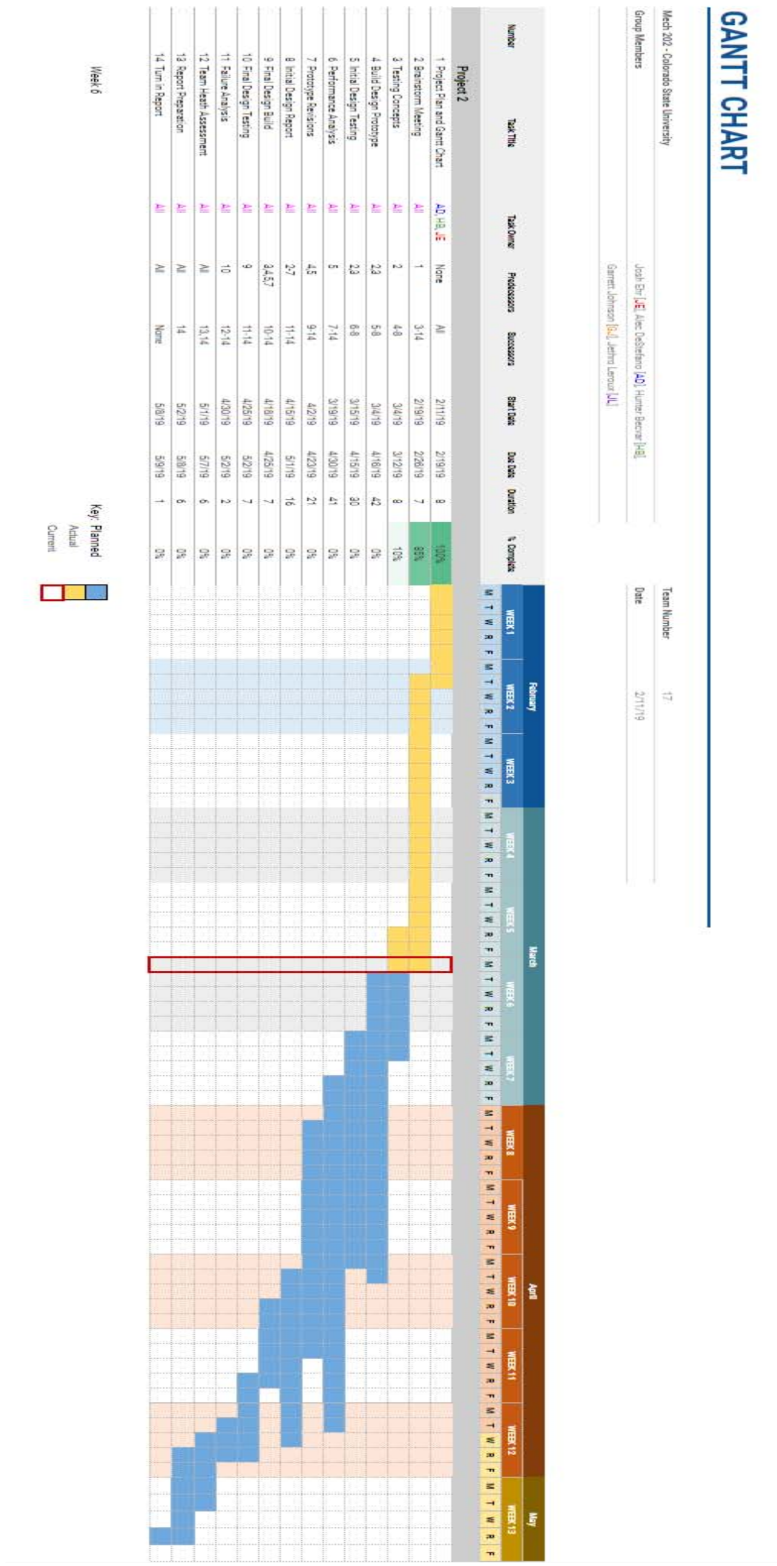


Figure 12.7: Gantt Chart Week 6

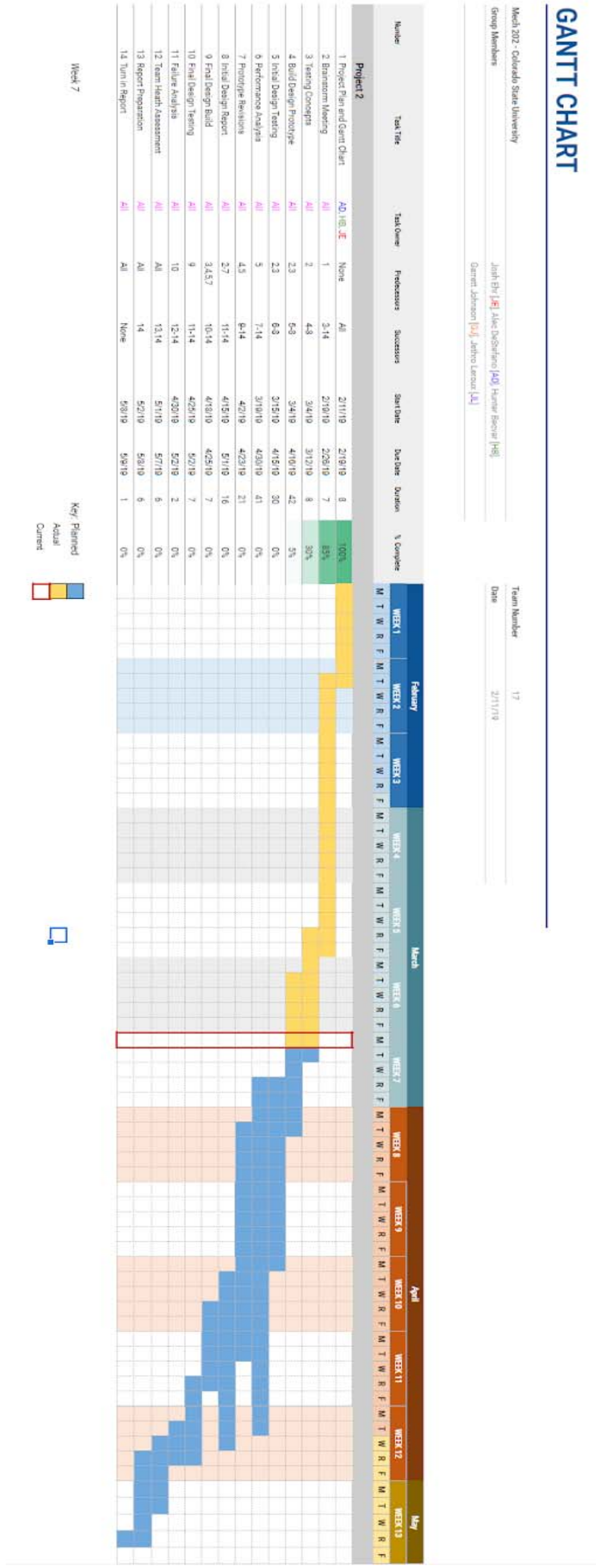
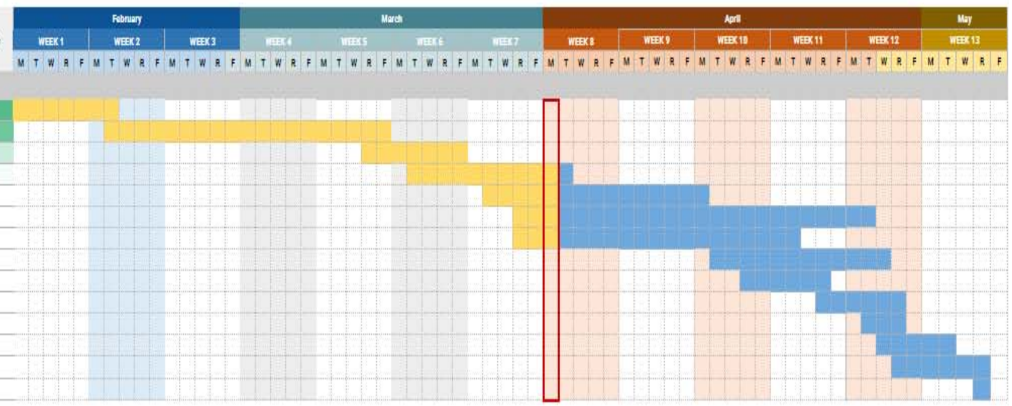


Figure 12.8: Gantt Chart Week 7

GANTT CHART

Mech 202 - Colorado State University		Team Number	17
Group Members	Josh Ehr [JE], Alec DeStefano [AD], Hunter Becvar [HB],	Date	2/11/19
	Garrett Johnson [GJ], Jethro Leroux [JL]		

Number	Task Title	Task Owner	Predecessors	Successors	Start Date	Due Date	Duration	% Complete
	Project 2							
1	Project Plan and Gantt Chart	AD, HB, JE	None	All	2/11/19	2/19/19	8	100%
2	Brainstorm Meeting	All	1	3-14	2/19/19	2/26/19	7	85%
3	Testing Concepts	All	2	4-8	3/4/19	3/12/19	8	30%
4	Build Design Prototype	All	2,3	5-8	3/4/19	4/16/19	42	5%
5	Initial Design Testing	All	2,3	6-8	3/15/19	4/15/19	30	0%
6	Performance Analysis	All	5	7-14	3/19/19	4/30/19	41	0%
7	Prototype Revisions	All	4,5	9-14	4/2/19	4/23/19	21	0%
8	Initial Design Report	All	2-7	11-14	4/15/19	5/1/19	16	0%
9	Final Design Build	All	3,4,5,7	10-14	4/18/19	4/25/19	7	0%
10	Final Design Testing	All	9	11-14	4/25/19	5/2/19	7	0%
11	Failure Analysis	All	10	12-14	4/30/19	5/2/19	2	0%
12	Team Heath Assessment	All	All	13,14	5/1/19	5/7/19	6	0%
13	Report Preparation	All	All	14	5/2/19	5/8/19	6	0%
14	Turn in Report	All	All	None	5/8/19	5/9/19	1	0%



Week 8

Key: Planned
Actual
Current

Figure 12.9: Gantt Chart Week 8

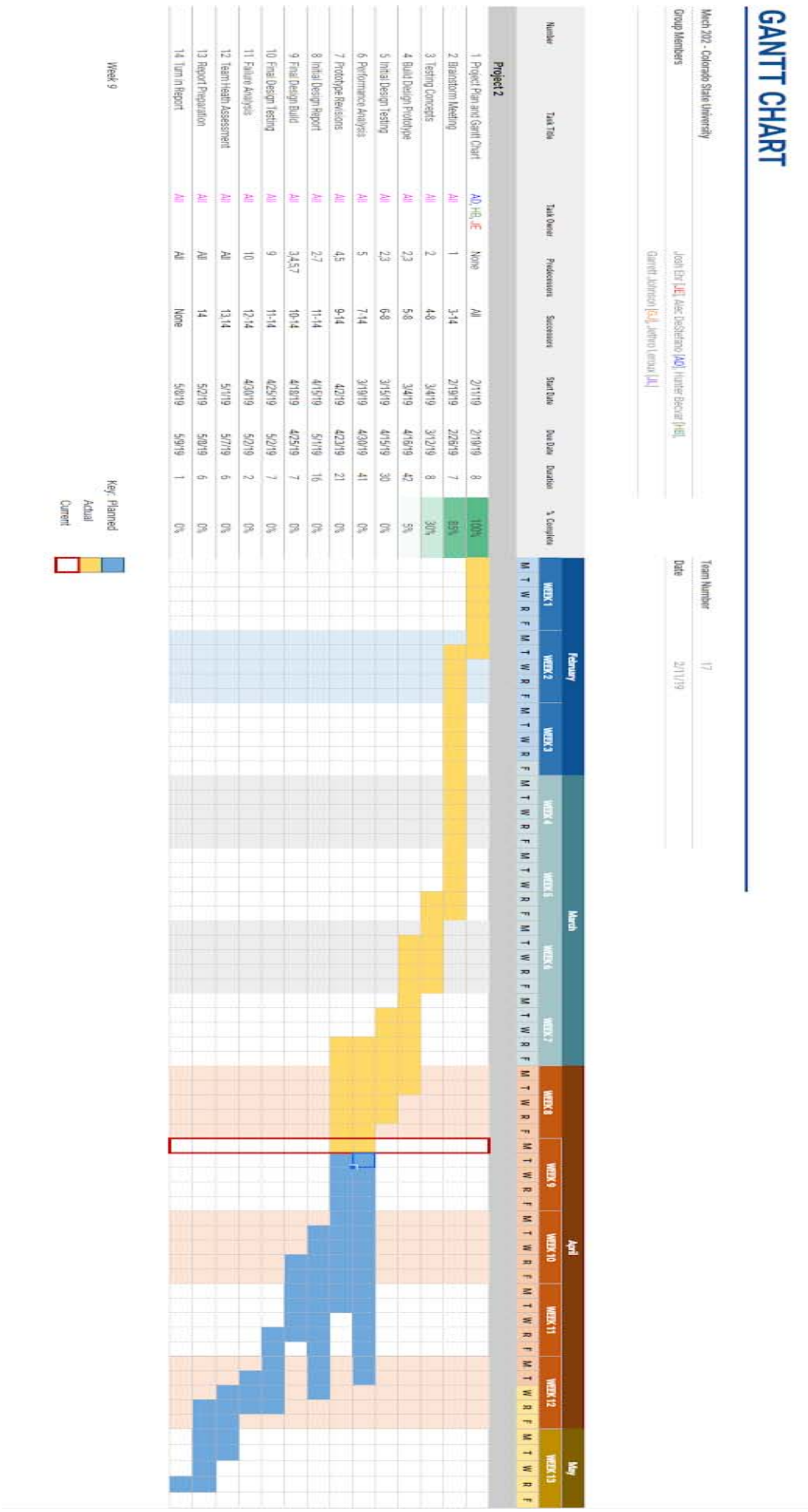


Figure 12.10: Gantt Chart Week 9

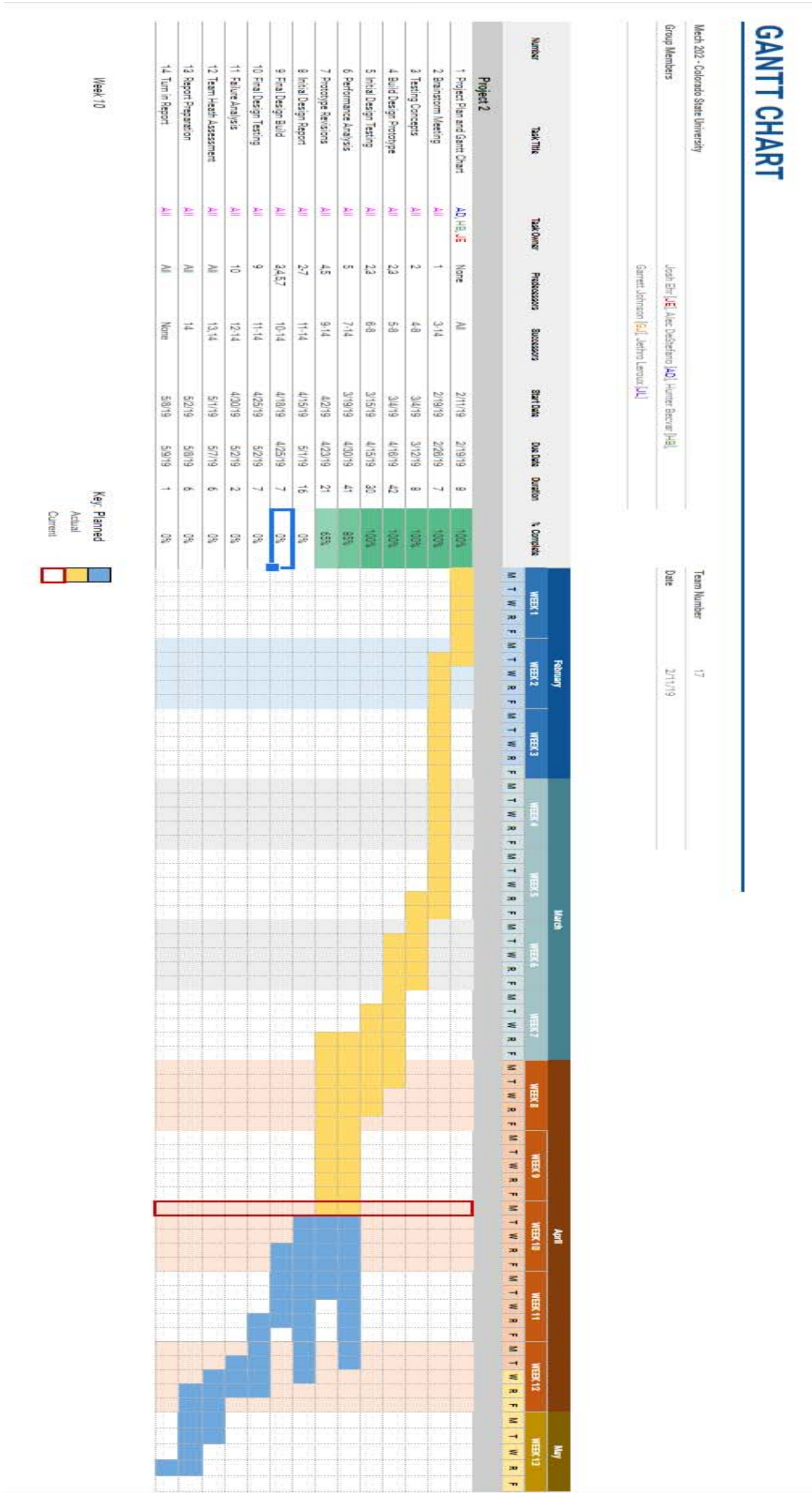


Figure 12.11: Gantt Chart Week 10

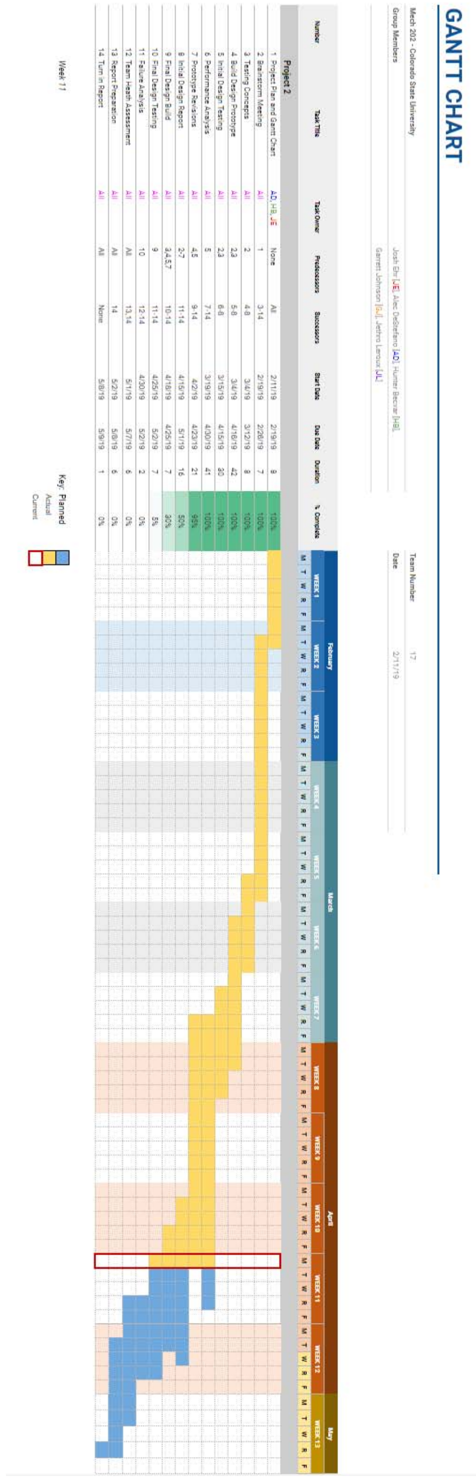


Figure 12.12: Gantt Chart Week 11

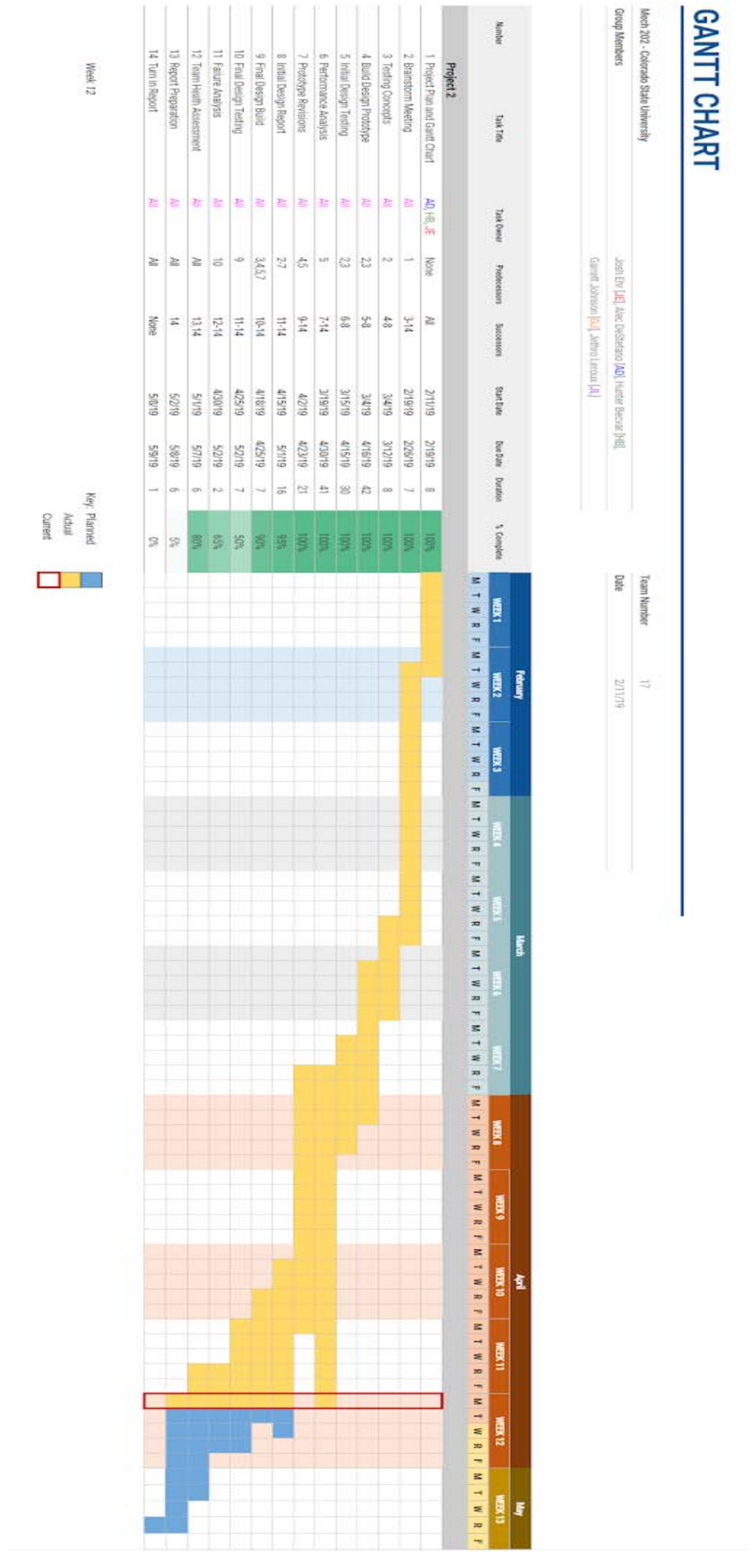


Figure 12.13: Gantt Chart Week 12

THE WOW! FACTOR

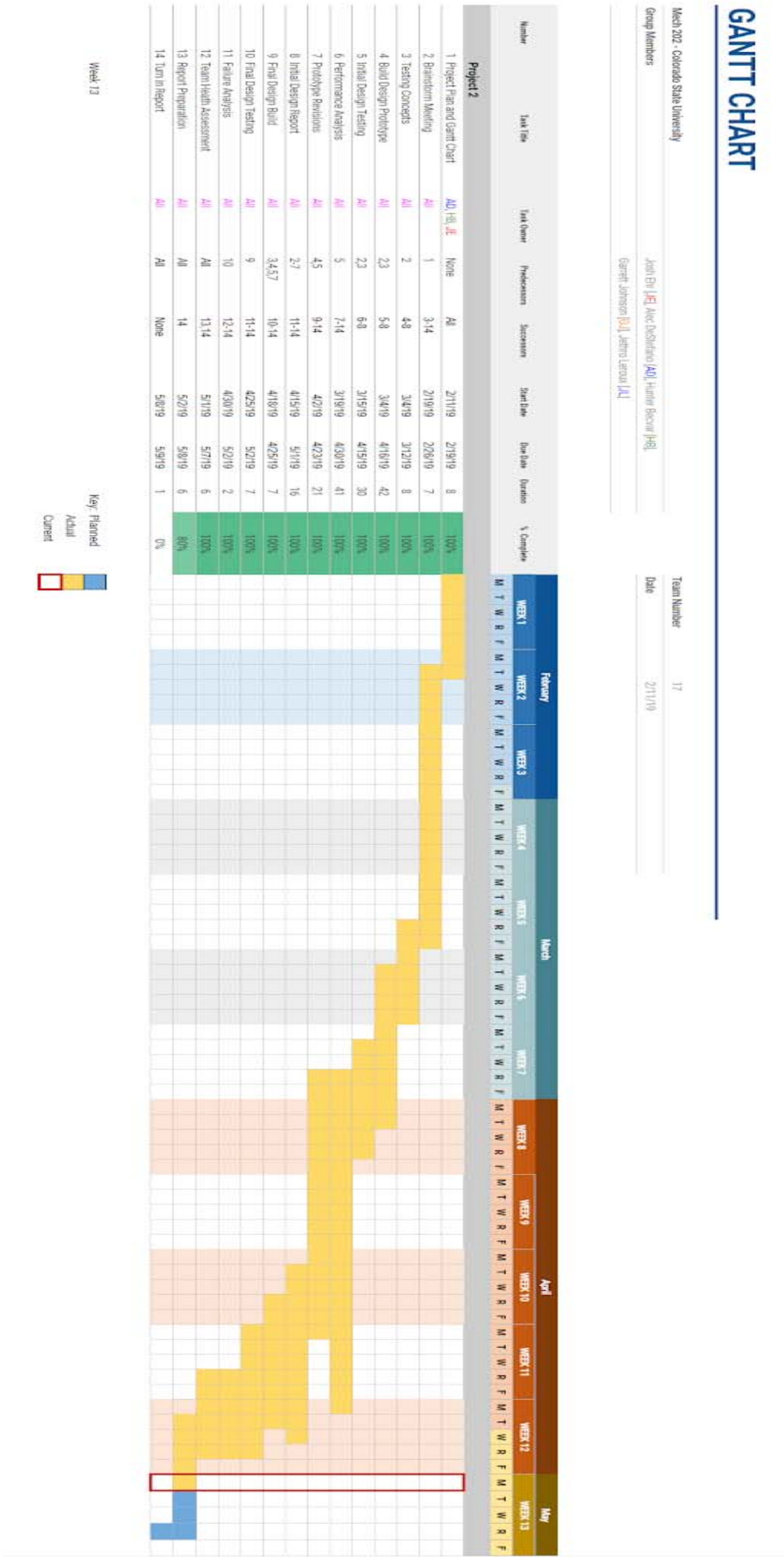


Figure 12.14: Gantt Chart Week 13

13. Team Assessment

Our team decided to take on different jobs based upon previous skill sets coming into this project. All of the members performed different tasks in order to get the entire project done well.

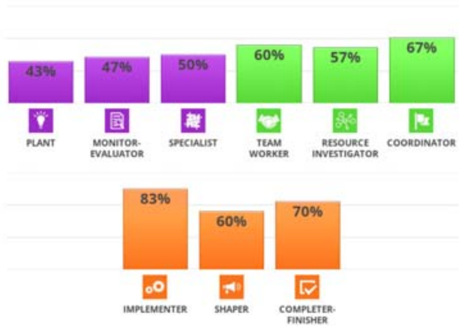
Garrett and Jethro have strong skills in Solidworks, so they worked on designing the parts, the drawings, and the assembly on Solidworks. Alec, Hunter, and Josh utilized their skills in order to complete the QFD, the templates, and the more "paperwork" side of the project. All team members played integral roles in the design and implementation of the vehicle. Overall, there were not any real issues between members of the group, the teamwork flowed very smoothly. All of the partners had a say in what, when, and how everything would get done in order to accomplish the project. We worked together for a couple hours every week, and that allowed us to help each other in person and bounce ideas off of each other very quickly. This proved to be very successful because it allowed us to get everything finished in an efficient manner.

The team worked very well as a group, and incorporated every person to get the full project together. We learned that teamwork involves different skill sets that come together in order to accomplish a common goal. Instead of trying to find people just like us to work with, it is good to find people that think differently in order to get a different perspective on a project. Teams only work when all of the members have a say in what is going on, and all of the members are allowed to be involved in working on a project.

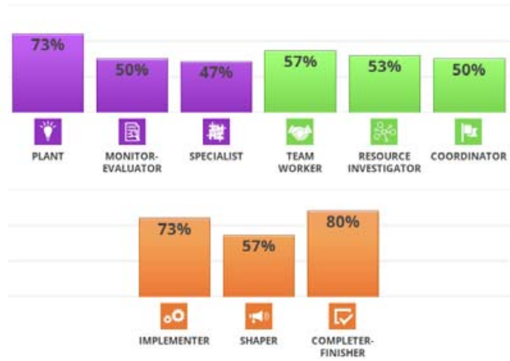
Team Contract

Team Role Test Results

Hunter Becvar

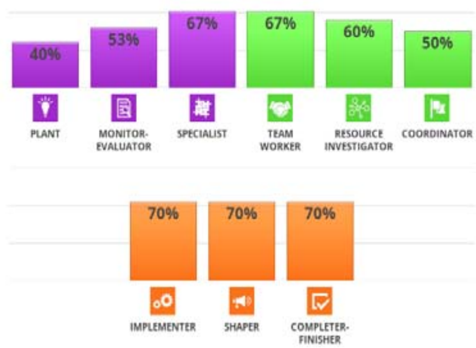


Alec Destefano



Josh Ehr

Garrett Johnson



Jethro Leroux

Figure 13.1: Team Role Assessment

Team Member Personality Traits

The following table summarizes each members top 3 roles from the test and their subsequent traits.

Table 13.1: Team Member Personality Traits

Hunter Becvar	1. **Implementer**: Implementers take the suggestions and ideas of their teammates and turn them into action. 2. **Completer-Finisher**: Completer-Finishers are perfectionists and will often go the extra mile to make sure everything is exactly right. 3. **Coordinator:** are most often the chairperson of a team, since they have a talent for taking a step back and seeing the bigger picture.
Alec DeStefano	1. **Implementer**: Implementers take the suggestions and ideas of their teammates and turn them into action. 2. **Plant:** Plants are creative and unorthodox generators of ideas. Plants can also have a tendency to ignore details and specifics. 3. **Completer-Finisher**: Completer-Finishers are perfectionists and will often go the extra mile to make sure everything is exactly right.
Josh Ehr	1. **Coordinator:** are most often the chairperson of a team, since they have a talent for taking a step back and seeing the bigger picture. 2. **Monitor-Evaluator**: Monitor-Evaluators are fair and logically-minded observers and judges of what is going on with the team. 3. **Completer-Finisher**: Completer-Finishers are perfectionists and will often go the extra mile to make sure everything is exactly right.
Garrett Johnson	1. **Implementer**: Implementers take the suggestions and ideas of their teammates and turn them into action. 2. **Shaper**: are task-focused and driven by tremendous energy and the need to achieve. For them, winning is the name of the game. 3. **Completer-Finisher**: Completer-Finishers are perfectionists and will often go the extra mile to make sure everything is exactly right.
Jethro Leroux	1. **Implementer**: Implementers take the suggestions and ideas of their teammates and turn them into action. 2. **Monitor-Evaluator**: Monitor-Evaluators are fair and logically-minded observers and judges of what is going on with the team. 3. **Completer-Finisher**: Completer-Finishers are perfectionists and will often go the extra mile to make sure everything is exactly right.

Team Dynamics

Given our unique personality traits, we as a team decided to delegate certain tasks based on our individual strengths, as well as keep some tasks as a group effort in order to let each of our strengths culminate into an ideal finished product that the entire team is happy with. A summary of each team members roles based on their strengths can be found in the Team Contract below.

Table 13.2: Team Contract

Team Member	Role	Initials
Hunter Becvar	Timeline Management	HB
Alec DeStefano	Paperwork Engineer	AD
Josh Ehr	Project Manager	JE
Garrett Johnson	Design Engineer	GJ
Jethro Leroux	Design Engineer	JL
Team Goals		**Responsible Member**
1. Research autonomous devices and vehicles, arduinos, electrical components		HB AD JE GJ JL
2. Generate and Evaluate Concept		HB AD JE GJ JL
3. Create a comprehensive Bill of Materials for assembly		GJ JL
4. 3D Model all parts in Solidworks		GJ JL
5. Continually work on sections 7-11 of Final Report		HB AD JE
6. Create an exploded assembly diagram of device		JL
7. Compile & Proofread Final Report		HB AD JE GJ JL
Team Performance Expectations		**Initials**
1. Strive to complete all assigned tasks before or by deadline		HB AD JE GJ JL
2. Complete all tasks to the best of ability		HB AD JE GJ JL
3. Listen carefully and attentively to all comments at meetings		HB AD JE GJ JL
4. Accept and give criticism in a professional manner		HB AD JE GJ JL
5. Focus on results before the fact, rather than excuses after		HB AD JE GJ JL

6. Provide as much notice as possible of commitment problems	HB AD JE GJ JL
7. Attend and participate in all scheduled group meetings	HB AD JE GJ JL
8. Obtain a grade of A or better	HB AD JE GJ JL
Strategies for Conflict Resolution	**Initials**
1. Hold a group meeting with all members.	HB AD JE GJ JL
2. Have the involved members explain their situations.	
3. Group vote.	
4. If a unanimous decision cannot be reached, Project Manager will decide on the outcome and solution, or give up and complain about how hard group projects are.	

Table 13.3: Team Health Assessment (Alec Destefano)

Team Health Assessment

Team Assessed: 17 | **Date: 4/30/2019**

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.	X					
3	I feel good about the team's progress	X					
4	Respect has been built within the team for diverse points of view.	X					
5	Team environment is characterized by honesty, trust, mutual respect, and teamwork	X					
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value		X				
8	Team encourages individual differences.	X					
9	Conflicts within the team are aired and worked to resolution.	X					
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution	X					
11	Decisions are made with input from all in a collaborative environment.	X					
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					

13	When one team member has a problem others jump in to help	X					
14	Dysfunctional behavior is dealt with in an appropriate manner	X					
15	When someone on the team says they are going to do something, the team can count on it being done.		X				
16	There is no "them and us" on the team	X					
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.		X				

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
N/A

Assessor: Hunter Becvar

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Table 13.4: Team Health Assessment (Alec Destefano)

Team Health Assessment

Team Assessed: 17	**Date: 4/30/2019**

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.		X				
3	I feel good about the team's progress	X					
4	Respect has been built within the team for diverse points of view.	X					
5	Team environment is characterized by honesty, trust, mutual respect, and teamwork		X				
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value	X					
8	Team encourages individual differences.	X					
9	Conflicts within the team are aired and worked to resolution.	X					
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution	X					
11	Decisions are made with input from all in a collaborative environment.	X					
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help	X					

14	Dysfunctional behavior is dealt with in an appropriate manner		X				
15	When someone on the team says they are going to do something, the team can count on it being done.	X					
16	There is no "them and us" on the team	X					
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.	X					

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
N/A

Assessor: Alec Destefano	

Table 13.5: Team Health Assessment (Josh Ehr)

Team Health Assessment							
Team Assessed: 17		**Date: 4/30/2019**					
SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable							
Measure		SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.		X				
3	I feel good about the team's progress		X				
4	Respect has been built within the team for diverse points of view.	X					
5	Team environment is characterized by honesty, trust, mutual respect, and teamwork	X					
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value	X					
8	Team encourages individual differences.	X					
9	Conflicts within the team are aired and worked to resolution.	X					
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution	X					
11	Decisions are made with input from all in a collaborative environment.	X					
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help	X					

14	Dysfunctional behavior is dealt with in an appropriate manner		X				
15	When someone on the team says they are going to do something, the team can count on it being done.	X					
16	There is no "them and us" on the team	X					
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.	X					

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
N/A

Assessor: Josh Ehr	

Table 13.6: Team Health Assessment (Garrett Johnson)

Team Health Assessment

Team Assessed: 17 | **Date: 4/29/2019**

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.	X					
3	I feel good about the team's progress	X					
4	Respect has been built within the team for diverse points of view.		X				
5	Team environment is characterized by honesty, trust, mutual respect, and teamwork		X				
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value	X					
8	Team encourages individual differences.	X					
9	Conflicts within the team are aired and worked to resolution.	X					
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution		X				
11	Decisions are made with input from all in a collaborative environment.	X					
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help	X					

14	Dysfunctional behavior is dealt with in an appropriate manner	X					
15	When someone on the team says they are going to do something, the team can count on it being done.		X				
16	There is no "them and us" on the team	X					
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.	X					

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
N/A

Assessor: Garrett Johnson	

Table 13.7: Team Health Assessment (Jethro Leroux)

Team Health Assessment

Team Assessed: 17	Date: 5/1/2019

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.	X					
3	I feel good about the team's progress	X					
4	Respect has been built within the team for diverse points of view.		X				
5	Team environment is characterized by honesty, trust, mutual respect, and teamwork	X					
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value		X				
8	Team encourages individual differences.	X					
9	Conflicts within the team are aired and worked to resolution.	X					
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution	X					
11	Decisions are made with input from all in a collaborative environment.		X				
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help	X					

14	Dysfunctional behavior is dealt with in an appropriate manner		X				
15	When someone on the team says they are going to do something, the team can count on it being done.		X				
16	There is no "them and us" on the team	X					
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.	X					

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
N/A

Assessor: Jethro Leroux	

Table 13.8: Team Meeting Minutes 1

Team Meeting Minutes

Design Organization: 17	**Date: 3/25/2019**

Agenda:

1. Figure out a plan for the remainder of the semester
2. Determine roles for everybody for this project
3. Set a timeline for the rest of the project

Discussion: Who will do each job in order to complete the project in the most efficient way possible? When and where should we meet to begin the prototype? What resources do we need to begin getting in order to make the prototype? Who will complete the drawings and the morphology template for the assignment this week?

Decisions Made: We will meet at the normal times that we have met all semester, and the location will depend on the part of the project we are looking to complete at each meeting. All of the members will contribute to the ideas for the prototype. Alec, Jethro, and Garrett will begin drawings for the prototype. Hunter and Josh will complete the morphology template and the other templates that go along with that.

Action Items	Person Responsible	Deadline
Complete Drawings	Jethro, Alec, Garrett	3/26/2019
Complete Templates	Hunter and Josh	3/26/2019

Team member: Hunter Becvar	Date for next meeting: 4/1/19
Team member: Alec DeStefano	
Team member: Josh Ehr	
Team member: Garrett Johnson	
Team member: Jethro Leroux	

Table 13.9: Team Meeting Minutes 2

Team Meeting Minutes

Design Organization: 17 | **Date: 4/1/2019**

Agenda:
1. Begin working on the prototype
2. Look into multiple ideas just in case the first idea doesn't work
3. Book a time to get into the 3-D print shop

Discussion: Who has resources we could use for the prototype? What should be buy in order to complete the prototype? What types of wheels, batteries, etc do we need? What all should we 3-D print in the shop? What can we do to complete the prototype in time?

Decisions Made: We have some wheels, but we need to try different sizes with different batteries in order to get the right torque for the robot. We need to figure out a motor to use and get it. We need to figure out a plan for the arduino, so we can program it according to the vehicle we make.

Action Items	Person Responsible	Deadline
Gather materials	All Members	4/10/2019
Look into other materials online	Hunter and Josh	4/6/2019
Begin working on arduino Program	Garrett and Jethro	4/4/2019
Book and Begin work for the 3-D Lab	Garrett and Jethro	4/4/2019
Work on Templates for Final Project	Alec, Josh, Hunter	4/10/2019

Team member: Hunter Becvar	Date for next meeting: 4/8/19
Team member: Alec DeStefano	
Team member: Josh Ehr	
Team member: Garrett Johnson	
Team member: Jethro Leroux	

Table 13.10: Team Meeting Minutes 3

Team Meeting Minutes

Design Organization: 17 | **Date: 4/8/2019**

Agenda:

1. Continue buying parts and finding the correct pieces that we want
2. Look into the coding for the arduino
3. Look for other ideas in case our first idea fails

Discussion: What do we already have that can be used for the cart? What else should we buy? Do we logically think our idea will work for this project? What are possible failures we need to be ready for going into the competition?

Decisions Made: We have many of the parts we need. The only things we will need to continue buying are batteries for the cart. We believe our cart will work, but the coding and timing is going to be very difficult. They are multiple ways that the cart can fail, so we are going limit those as much as possible.

Action Items	Person Responsible	Deadline
Look for improvements	All Members	4/28/2019
Work on the coding	Hunter and Alec	4/20/2019
Book the 3-D Lab for Base	Garrett and Jethro	4/20/2019
Work on Templates for Final Project	Alec, Josh, Hunter	4/28/2019

Team member: Hunter Becvar	Date for next meeting: 4/15/19
Team member: Alec DeStefano	
Team member: Josh Ehr	
Team member: Garrett Johnson	
Team member: Jethro Leroux	

Table 13.11: Team Meeting Minutes 4

Team Meeting Minutes

Design Organization: 17	**Date: 4/15/2019**

Agenda:

1. Work on getting the code figured out for the arduino
2. Test the power of the cart
3. Get the cart all put together and begin working on the programming

Discussion: What should we make the program do? How can we get the program to run correctly on the arduino? What is the best way to put the cart together? Are there any obvious improvements that need to be made?

Decisions Made: We have all of the parts that we need, we just need to figure out how to make them work efficiently. The program is getting put together, and we will use that to change the amount of voltage going to the motors. The cart is bulky, so we will work on getting it smaller and more simple to run.

Action Items	Person Responsible	Deadline
Look for improvements	All Members	4/28/2019
Fix and finish the coding	Hunter and Alec	4/20/2019
Begin testing the cart	All Members	4/20/2019
Work on Templates for Final Project	Alec, Josh, Hunter	4/28/2019

Team member: Hunter Becvar	Date for next meeting: 4/22/19
Team member: Alec DeStefano	
Team member: Josh Ehr	
Team member: Garrett Johnson	
Team member: Jethro Leroux	

Table 13.12: Team Meeting Minutes 5

Team Meeting Minutes		
Design Organization: 17	**Date: 4/22/2019**	
Agenda: 1. Test the cart 2. Work on the programming and timing of the arduino 3. Correct any issues on the cart		
Discussion: How can we make the cart more efficient? Are there any piece we could remove to make the cart lighter? What further improvements can we make? How do we think the competition will go?		
Decisions Made: We have a successful cart, but it is struggling to make the turns. The program is very tough because of the timing of the turns. No parts can be removed without causing bigger issues to the cart. The competition will be interesting because the cart is not extremely consistent.		
Action Items	Person Responsible	Deadline
Look for improvements	All Members	4/28/2019
Perfect the Code	Hunter and Alec	4/30/2019
Test and Retest the Cart	All Members	4/30/2019
Work on the Project Report	All Members	4/28/2019
Team member: Hunter Becvar	Date for next meeting: 4/29/19	
Team member: Alec DeStefano		
Team member: Josh Ehr		
Team member: Garrett Johnson		
Team member: Jethro Leroux		
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Table 13.13: Team Meeting Minutes 6

Team Meeting Minutes		
Design Organization: 17	**Date: 4/29/2019**	
Agenda: 1. Make the cart competition ready 2. Ensure the program is successful 3. Make any last adjustments and keep testing the cart		
Discussion: Is there any way to make the cart more successful? Is the program exactly how we need it? Can the cart do what it needs to do in the competition? How should we take on the project report?		
Decisions Made: The cart is finished, we have made all of the improvements we can at this point. The program is good, however the cart runs it much more smoothly on the ground. The report will be evenly split up, and all of the members can add pieces that they have finished throughout the project.		
Action Items	Person Responsible	Deadline
Continue Testing Cart	All Members	5/3/2019
Ensure Program is Correct	Hunter and Alec	5/3/2019
Work on the Project Report	All Members	5/9/2019
Team member: Hunter Becvar	Date for next meeting: 5/6/19	
Team member: Alec DeStefano		
Team member: Josh Ehr		
Team member: Garrett Johnson		
Team member: Jethro Leroux		
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Table 13.14: Team Meeting Minutes 7

Team Meeting Minutes

Design Organization: 17 | **Date: 5/6/2019**

Agenda:

1. Complete the Project Report
2. Ensure Everything is in the report

Discussion: How much of the report have already completed? What else needs to be done? What can we do to stand out to get a nice wow factor?

Decisions Made: Everything we had to complete earlier for smaller assignments can get added to the project report. We will get everything from the project report description, and ensure all of the different pieces are included.

Action Items	Person Responsible	Deadline
Finish the Project Report	All Members	5/9/2019

Team member: Hunter Becvar	Date for next meeting:
Team member: Alec DeStefano	
Team member: Josh Ehr	
Team member: Garrett Johnson	
Team member: Jethro Leroux	

Table 13.15: DSM Project 2

DESIGN STRUCTURE MATRIX (MECH 202 TEAM 17 PROJECT 2)												
TASKS		A	B	C	D	E	F	G	H	I	J	K
Idea Brainstorm	A	**A**										
Testing Conceptual Ideas	B	X	**B**									
Prototyping	C	X	X	**C**								
Prototype Testing	D	X	X	X	**D**							
Analysis of Concepts	E	X			X	**E**						
Initial Design Report	F				X	X	**F**					
Final Design	G			X	X	X	X	**G**				
Final Testing	H			X				X	**H**			
Failure Examination	I			X					X	**I**		
Team Health Report	J										**J**	
Turn in Report	K	X	X	X	X	X	X	X	X	X	X	**K**

***X in row show inputs to row element from other elements. X in column show outputs from column element to other elements.**

14. References

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15. Appendices

15.1. Arduino Code for Cart

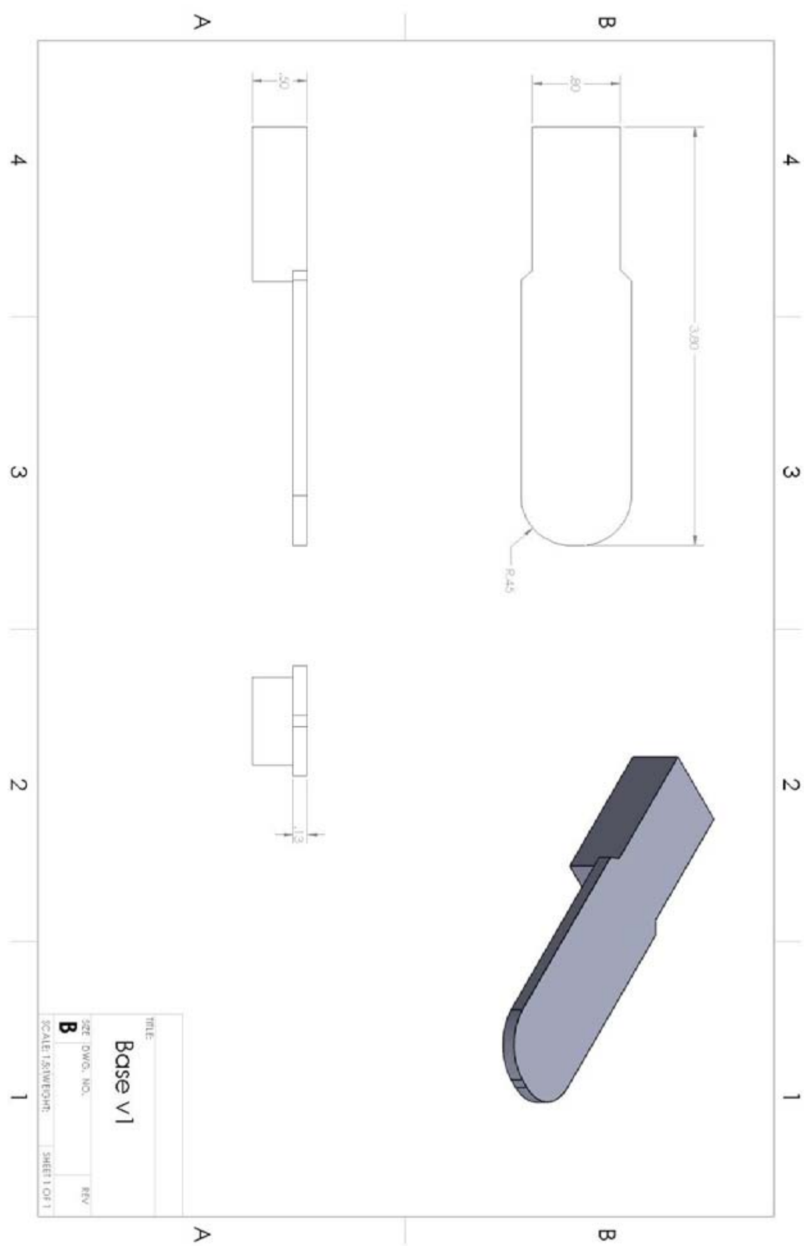
```
/*

*/
#define enLeft 9 //defines what pin controls what pin on motor controller. Pin 9 controls speed through
// enabler 1 on motor controller (see diagram in reverse engineering for pins)
#define in1 4    //pin 4 on arduino goes to inlet one of motor control
#define in2 5   //you get the idea
#define enRight 10
#define in3 6
#define in4 7

const int buttonPin = 2;     // defines what pin the button circuit goes into, goes into pin 2
int buttonState = 0;  //No idea what this means, copied it from other site. Defines button state

void setup () {   //void setup loops only run once through the code
  pinMode(enLeft, OUTPUT); //defines pin type, all are outputs because outputing voltage to motor controller
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
  pinMode(buttonPin, INPUT);  // initialize the pushbutton pin as an input, recieves info
}


void loop () {// reads the state of the pushbutton value before going through code
  // void loops go through the code repeatable

  while(digitalRead(buttonPin)==LOW){  //if the button is pressed, the pin reading is low and the code starts
  }

  // Makes cart Go Straight, both motors turn on
  analogWrite(enLeft,65);   //sets speed of left motor (speed can vary from 0 to 255; motor doesnt
  // turn if speed is below 50ish. The speed of each motor is different because DC motors dont run at same
  //speeds with same voltages. We adjusted to make them equal speeds)

  digitalWrite(in1,HIGH);    // defines voltage drop which controls direction of wheels. If high and low were
  //switched, the wheel would turn the other direction
  digitalWrite(in2,LOW);
  analogWrite(enRight,80);  //sets speed of right motor
  digitalWrite(in3,HIGH);
  digitalWrite(in4,LOW);
  delay(1000); // Amount of Time the two motors go straight in milliseconds, 2000ms=2secs

  // Turns Right
  digitalWrite(in3,LOW); //by making both pins 3 and 4 low, no voltage drop occurs so motor turns off
  digitalWrite(in4,LOW);
  //since left motor never was told to turn off it stays on
  delay(300); //time the motor is turning right


  //Goes straight
  digitalWrite(in3,HIGH); //by making both pins 3 and 4 low, no voltage drop occurs so motor turns off
  digitalWrite(in4,LOW);
  delay (400);

  //Turns Left
  digitalWrite(in1,LOW);
  digitalWrite(in2,LOW);
  delay (500);

```

```
  //Goes Straight
  digitalWrite(in1,HIGH);
  digitalWrite(in2,LOW);
  delay(600);


 //Turns Right
  digitalWrite(in3,LOW);
  digitalWrite(in4,LOW);
  delay(400);

  //Goes Straight
  digitalWrite(in3,HIGH);
  digitalWrite(in4,LOW);
  delay(400);

//Turns Left
  digitalWrite(in1,LOW);
  digitalWrite(in2,LOW);
  delay(300);

  //Goes Straight
  digitalWrite(in3,HIGH);
  digitalWrite(in4,LOW);
  delay(400);

 //Turns Right
  digitalWrite(in3,LOW);
  digitalWrite(in4,LOW);
  delay(250);

  //Goes Straight
  digitalWrite(in3,HIGH);
  digitalWrite(in4,LOW);
  delay(1000);
}
```

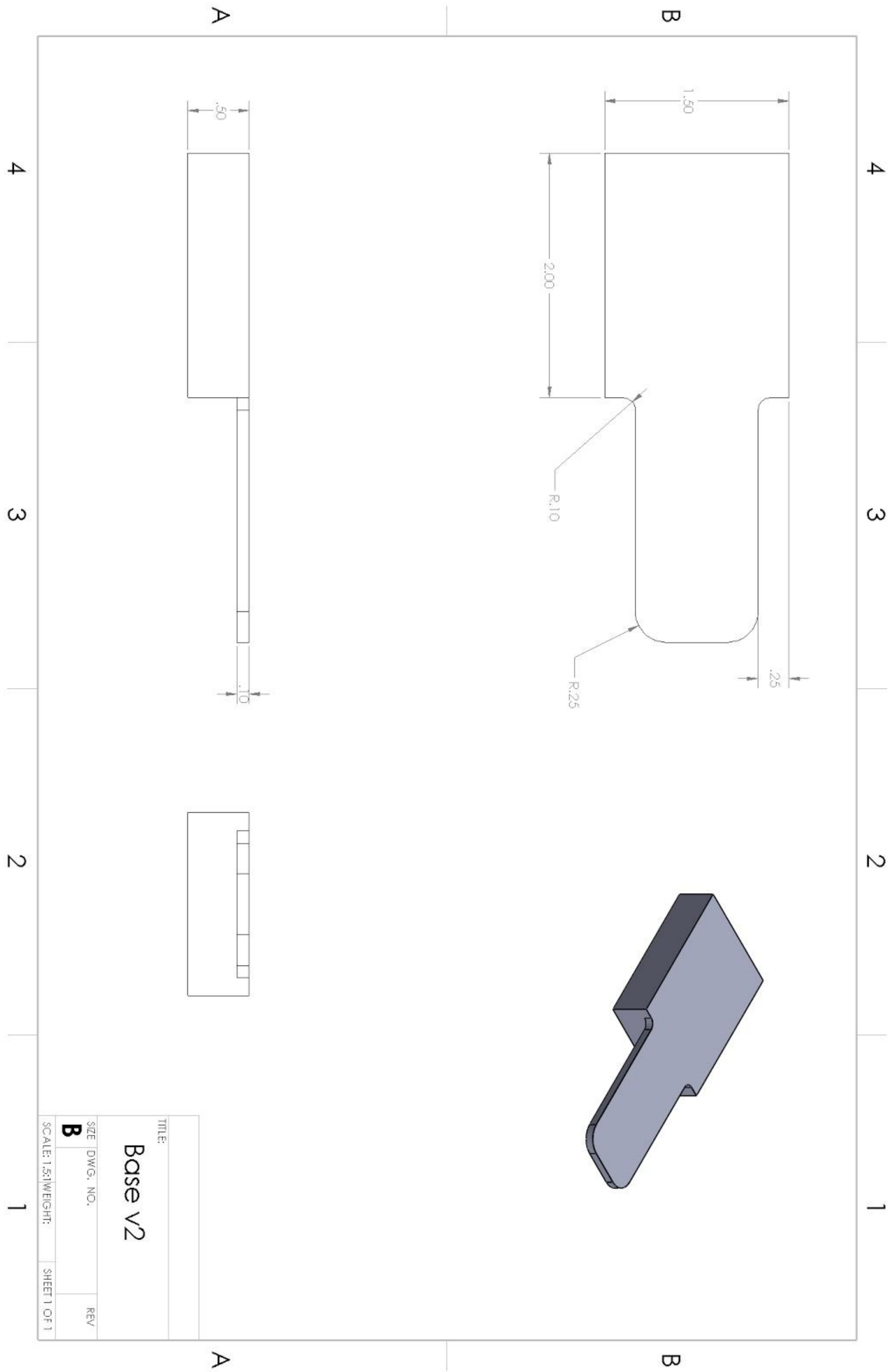
15.2. SolidWorks Drawings

It took 3 attempts to come up with a final design for the base of the cart. We printed and tested each one, however each one had its own downfall until we reached the final design of our cart. The final base has sturdy supports for the 2 DC motors and clearance gaps for the large wheels. It was dimensioned perfectly so that once all the final parts were added on, the entire device was exactly 4”x5” and perfectly on the constraint dimensions.

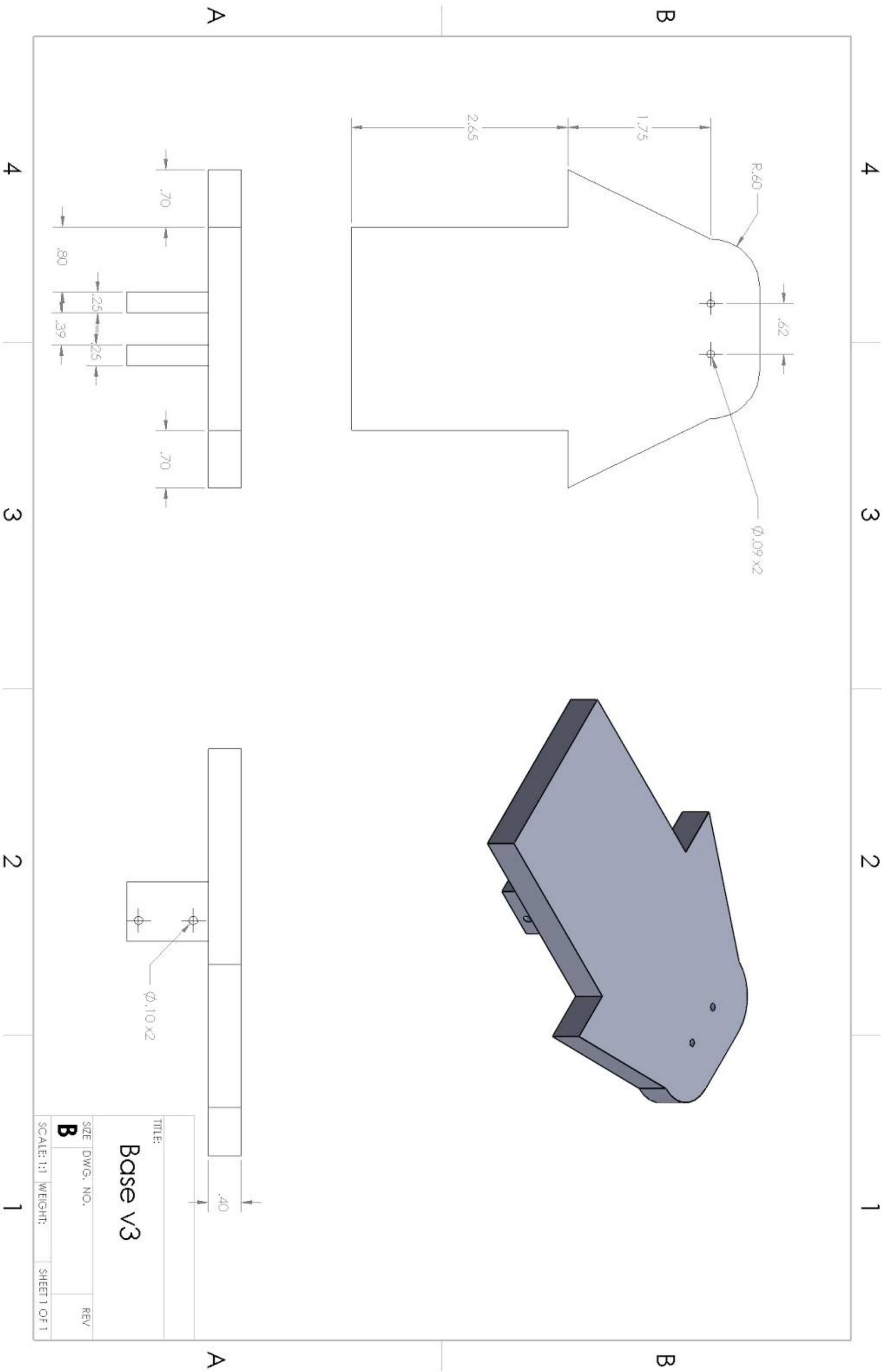
Base v1:



Base v2:


A
B
4
3
2
1
.50
1.50
2.00
R.10
R.25
.25
.10
TITLE:
Base v2
SIZE
B
DWG. NO.
REV
SCALE: 1.5:1
WEIGHT:
SHEET 1 OF 1

Base v3 (FINAL):



16. Failure Analysis

Unfortunately, our device did not make it within the top 3 standings of the competition. If the competition were held again there are several improvements we would make to correct our mistakes.

Some of the main reasons our device did not win include: sporadic motors, slight slipping of the wheels when turning on incline, differing placement of device, and overthinking the goal. Our motors were very responsive and fast. With this in mind, our cart struggled with the initial jerk of the motors that was necessary to accelerate onto the incline. The jerkiness of the motors also implemented a factor of unreliability when completing the sharp delicate turns of the course. This unreliability caused a problem with our coding. Being based on time, our code would not always match up with when the device needed to turn due to the inaccuracy of where the cart would be at the turns caused by the motor jerk. Another struggle our device had was slipping when completing a turn. Our device did perfectly fine with our Statics/Dynamics calculations of weight distribution and friction necessary to get up the incline. However, these were only considered on a straight path incline. When turning, these values would change because the cart would be nearing perpendicular to the ramp. This fact threw off our calculations and left a wide margin for error. A second problem with our sensitive time-based code was simply placing it in the exact same spot at the base of the ramp each run. If the initial placement was off by half an inch or so our device would run into a wall. After attending the competition and seeing groups who were successful most of the time, we realized that we overthought our design. The winner of the competition had a similar design to our device and did not even include an arduino to control the cart. Knowing this fact, if we had to redo this project we would focus more on the physical body of our device and less on using code. But, before scrapping our device from this competition we would try several improvements.

To solve some of the flaws in our device we developed some ideas to correct them. One idea we think would work is replacing our ball caster wheel (Part 3) with a 3D printed 'plow.'(seen in figure below) The plow would be glued onto the front of the base and have sand paper glued onto the bottom of it. This would slow the device down by dragging the sandpaper against the ramp as opposed to the smooth caster ball sliding along it. Firstly, the increased friction would deplete some of the jerk of the motors and the smooth convex front would ease the transition of the device from the horizontal platform onto the incline. Additionally, the plow could solve our problem of slipping/tipping on the tight turns through increased friction and the possibility of adding weight inside the hollow portion to keep the front end down. The shape of the plow would also increase our chances of bouncing off the walls to correct our course if something goes wrong. In order to complete precise runs we would find the exact dimensions we tested at during our 45 seconds of preparation and place our cart there.

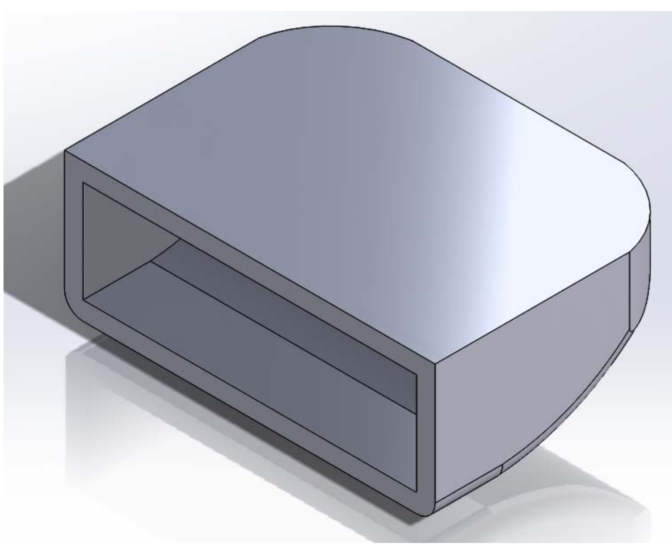


Figure 16.1. Plow Concept Solidworks Model

17. Project Reflection

Overall, the performance was satisfying but far beneath initial expectations. In the beginning we collectively decided to design a robot that would change its path based on time but by the end of the competition we learned that we simply over designed for the robots performance. Our design process (shown below in Figure 17.1) began with a robot just moving forward and we should've kept it that way similar to the groups with the most success in the competition. As our robot progressed further along we realized that we had overthought the competition fixture and we fell victim to the sunk-cost fallacy near the end of the project when we realized the best design bounced off walls to get to the top and a complete redesign would be necessary to have the most success.

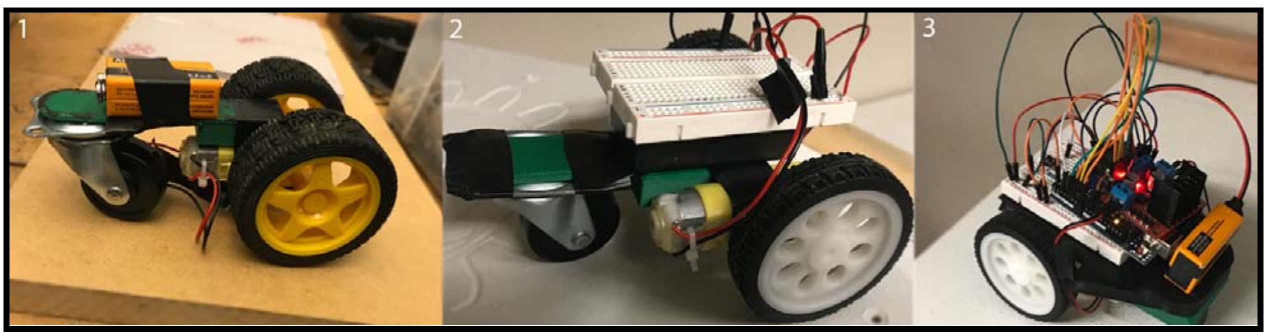


Figure 17.1: Prototype Design Process

The entire design process wasn't disappointing and proved to be a great learning experience, despite tail-end failure. Basic coding, wiring, and design skills were learned through hands on applications. The group initially started with essentially no coding experience so the beginning of the project was initially working with the coding just to figure out how to power the motor controller properly to get the DC motor to function. Once the group learned how to program the arduino to drive the motor we sought further control over the speed of the DC motor with pulse width modulation. By the end of the project we had learned how to configure the motors (which naturally spun at different frequencies) to spin at the same velocity, which gave us more control over the device's movements. Similarly to coding, the groups wiring skills improved from researching which wires should be plugged into what part of the circuit to knowing the basic configuration of our device's circuit and being able to place a new part into the circuit like the button that was added to initiate the code and start the movement up the track. Our group learned the most about the design process after reflecting on decisions made in the later stages of the competition. Looking back at our major decisions made to progress to our final design highlighted the crucial decision points in the project. When we used an arduino just because we were given one was our first fork in the road. Deciding to use the arduino over-complicated the project and pushed our device away from a simple successful design. The next crucial decision came when we decided to continue to use our current design after realizing the friction between the track and device wasn't consistent enough to allow us to traverse the course based on timing. A final crucial decision was our approach during the competition. Knowing our device wouldn't make it to the top we decided (like a lot of other groups) to let the robot drive forward from the bottom and make it up as far as possible before getting stuck on a wall. Although this method brought us quick failure without a plow to guide the device, this strategy seemed populous among opposing groups with similar plow problems and from the competitions the group observed it seemed that our robots consistency to run every time placed us above at least half the competition. This knowledge is what brought satisfaction but not excitement because regardless of our device's comparison to the competition it still failed to complete the task it was designed for.