Robot Utility Tank (R.U.T.)

Final Report

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Project Sponsor: David Willy

DISCLAIMER

EXECUTIVE SUMMARY

Currently off the shelf manufactured Utilitarian robots are upwards of $20,000 to purchase. The College of Engineering and Applied Sciences currently has a Utilitarian style robot tank base that houses the LOUIE Robot that will be used to give guided tours of the Engineering Building. Currently that Robotic base costs $18,000 to purchase for the manufacturer. Our goal for this project was to design and create a utilitarian robot for $2,000, this is a reduction in cost of 800%.

The team used reverse engineering techniques to manufacture a similar robot providing similar functionality. We designed a full metal frame housing the electrical components as well as a track system that was made in house. The frame was designed using 3/16th inch steel that was laser cut to form a solid foundation for our design. Custom length rubber tracks were purchased to meet the requirements of our vehicle. The front axle assembly was designed in a way for easy serviceability and allows the tracks to be tightened over their lifetime as the component wears.

With this design we were able to design a robot that can carry a load of 200lbs and average 2.1 mph for $2,000. This shows that one could design a similar robot to ones offered on the market while keeping the same functionality of a much more expensive product.

ACKNOWLEDGEMENTS

The team would like to acknowledge Northern Arizona University, Department of Mechanical Engineering. Our Capstone Advisor and Client Professor David Willy for giving us the opportunity to work on this project, and for guiding us through the development and testing of our design. Thank you to Perry Wood and the staff of the Northern Arizona University Machine Shop, for providing knowledge and tools to implement our design. We would also like to thank Professor Carson Pete for assisting the team in the early design phases of our project.

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1 BACKGROUND

1.1 Introduction

As part of the goals of the NAU Mechanical Engineering school, students will improve their learned skills into a multidisciplinary project which will turn us into resourceful, creative, and well-prepared professionals. The team is assigned with a reverse engineering/ manufacturing project, sponsored by the NAU Mechanical Engineering department and our direct client Professor David Willy, will be reverse engineering the NAU Louie Robot track system. This reverse engineering project will encompass all the engineering skills of the program to achieve similar functionality with a budget of $2000.00 dollars.

1.2 Project Description

The original project description for this project given by the sponsor was:

Design a robotic vehicle using reverse engineering techniques, to build a similar robot of the design used by the LOUIE robot. Our design must have similar components as the original while being dimensionally accurate to the original. The original budget for this project was $1,500.00. The vehicle must be no smaller than 3:4 scale of the original LOUIE robot vehicles overall length. We were tasked with designing the drive and track system so that the design could move under its own power. The original reverse engineered robot would be used as a teaching tool for other Mechanical engineering classes as either future projects or as a teaching tool in the 286-386 design courses for the college of engineering.

Our project description was modified slightly to the following:
Design a robotic vehicle using design for manufacturing engineering techniques, to build a similar utilitarian robot. Our design must have similar components as the original while being no smaller than 3:4 scale with a target wheelbase length of 30 inches long. The updated budget for this project was $2,000.00. We were tasked with designing the drive and track system so that the design could move under its own power. The original reverse engineered robot would be used as a teaching tool for other Mechanical engineering classes as either future projects or as a teaching tool in the 286-386 design courses for the college of engineering.

The project description was modified slightly to ensure the project could be completed by the December 2022 deadline. With the cost increase on components due to the Covid-19 Pandemic our budget was increased to $2,000.00 USD. Due to the fact we lost one team member the design requirements were modified for this to be a manufacturing project rather than reverse engineering. We were tasked with building our own design that we could manufacture with the budget given to us, this was done because the original LOUIE robots base design had many complex shapes and geometries that would cost more to manufacture in house.

2 REQUIREMENTS

In this section we will discuss the Customer requirements and Engineering Requirements needed to complete this project. The customer requirements provided in section 2.1 will list the requirements given to us by our sponsor David Willy, David tasked us with these in mind of designing an entire robot design and track system. To do this most of these requirements are focused on the design for manufacturing engineering processes. To fulfil these customers' needs the team needed Engineering requirements that would meet the demands of these customers' needs. In this section you will see a breakdown of these requirements as well as a House of Quality that values these requirements.

2.1 Customer Requirements (CRs)

Here you will find a list of customer requirements given to us by our sponsor David Willy. When explaining our project to us Professor Willy wanted a robot that could handle loads like the LOUIE robot while being more cost productive. The customer requirements given were as follows.

1. Cost within the budget of $2,000.00
2. Durable and robust design can handle 200lb loading
3. Reliable design
4. Safe to operate
5. No smaller than 3:4 scale of the LOUIE Robot
6. Complete Bill of Materials/ CAD Package
7. Has same components as original design
8. Functional Prototype Robot

These requirements are all weighed very highly in our House of Quality (QFD) because of the emphasis on being cheaper to manufacture and being able to handle loads. The budget of our capstone project must not exceed $2,000.00 so this was weighed at a 9 on a 1-9 scale on the QFD chart. With our given budget we are expected to create a durable and robust frame that not only will provide durability to the robot, but also support a payload requirement of the original robot we based our design off. For these requirements we rated this at a 7 on a 9 scale. This is important to the team, but we feel like if we use similar materials, it will be easy to provide a rigid frame to support our design.

Whenever excessive amounts of electricity are involved, safety is a major priority. This category would receive a 5 on our QFD chart if it were given as a customer need. The original design as a box so this robot will be safe to operate for future users.

Professor Willy originally tasked us with these requirements with the sole purpose of redesigning the original LOUIE robot base, our requirements were then shifted to build a robust frame that could provide similar functions as the Louie robot while being cheaper to manufacture and build at home. For this reason, we gave durable and reliable design a score of 9 on our QFD plot because at the end of the day if it does not perform like the original, we just made a robot and did not complete the goal of this project. By the end of this project Professor Willy would like a functional prototype that can be used for future learning endeavors in the mechanical engineering department, to be featured in classes such as 286 and 386 design courses or possibly a future capstone project.

2.2 Engineering Requirements (ERs)

In this section you will find the engineering requirements and how the team plans to verify these requirements. Our Engineering Requirements for this project are:

1. Length [ft.]
2. Weight [lbs.]
3. Torque [lbf.]
4. Power Consumption [W]
5. Max Payload [lbs.]
6. Reliable
7. Durable

We hope that with these engineering requirements we can meet all our customers' needs for this reverse engineering project. We feel if we follow the length, weight, and overall dimensions of the original design we can get a design the meets the ER's of length weight and maximum payload. In section 2.4 shows the House of Quality QFD where these Customer needs and Engineering requirements were compared against original designs manufactured by Super Droid robotics.

2.3 Functional Decomposition

For this project, the main three systems we plan to be focusing on are the electrical system, the track and wheel system, and the main frame system. In doing this we developed a black box model to fully illustrate how these systems work at a global level and how each form of energy interacts to make the robot perform its tasks. Next the functional model will be shown to illustrate the subfunctions and how they are all integrated into one system.

2.3.1 Black Box Model

The black box model is a useful tool in determining inputs and outputs of a initial design. When starting on this project we closely inspected the original robots' design characteristics and noted the inputs required to make the design useful. In the black box model below, you will find a number of inputs along with their corelated outputs. Because our design is a remote-controlled vehicle, we focused on how inputs into the controller will relate to the outputs or the robots' movements. This initial black box model helped the team with the initial wiring and inputs needed for our design to have a working electrical system for our design.

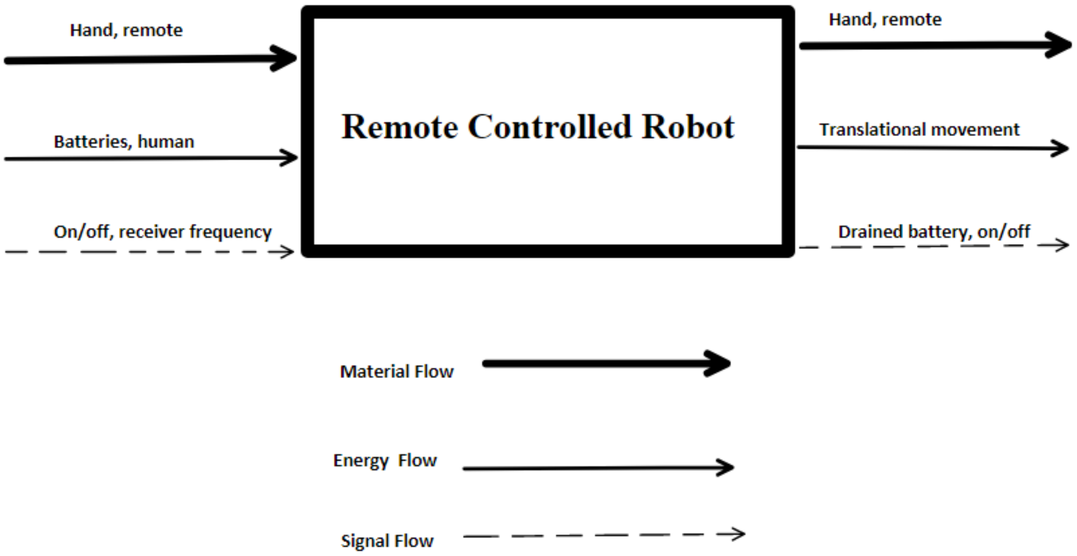


Figure 1: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

A step past the black box model we can examine the individual components that make up our design. This functional decomposition flow chart lists the major subcategories and components that make that major sub function. For our project we examined 4 sub functions, the frame, electronics, motors and drive assembly systems. This helped the team to visualize the main components of this progress and how we can break up this project into more manageable sections. Below you will find our Functional model of the remote-controlled robot.

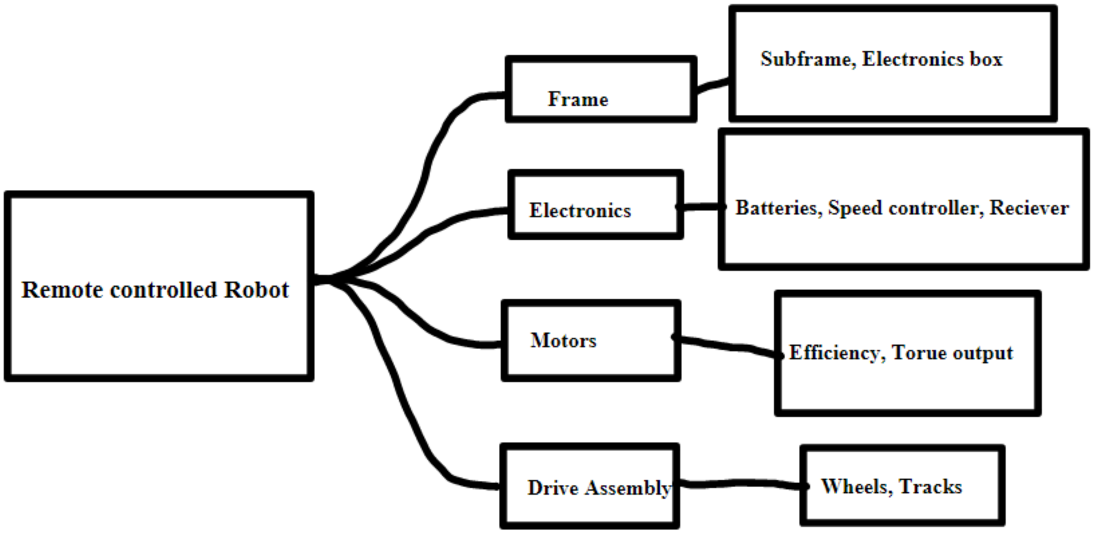


Figure 2: Functional Decomposition

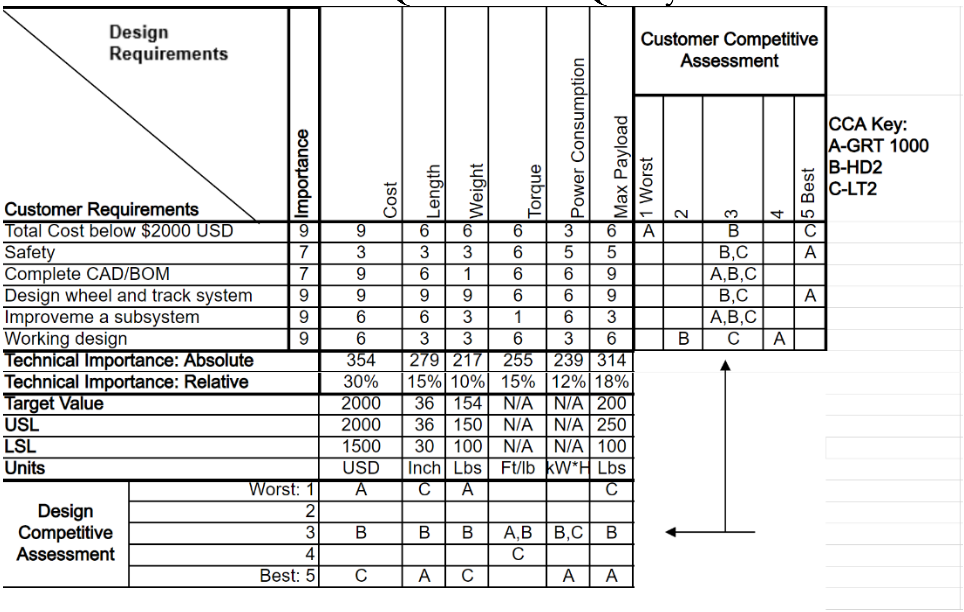
2.4 House of Quality (HoQ)

The house of quality is an essential tool for determining engineering requirements to meet customer needs. The house of quality for our project helped determine these key engineering requirements of sizing, torque and power consumption and maximum payload. These key engineering requirements will help ensure the overall cost of our project is within budget and that all customers' needs are met. In our project it is crucial that we can design and manufacture a robot that checks all the boxes, that can still perform adequately compared to the original design.

In our house of quality (HoQ) our design requirements are designed in a way that these values will be measurable during the testing phase of our project. The key design requirements that would require external testing are power consumption, maximum payload and safety. In the following figure 3 displays our HoQ comparing the original robot design. Noted in the key as design A. To two similar smaller scale robots. These robots provided great information on power consumption and torque values. Since all three designs were fairly similar besides scaling the team decided the robot with the best dollar to performance ratio would be the one we would attempt to replicate.

Design A will be the design we follow through with in this project. We plan to execute this by purchasing similar components as the original design, but scaling the overall size to meet the price requirements of the team. Table 1 denotes the testing procedures and the corresponding design requirement.

Table 1: QFD House of Quality



Design Requirements **Customer Requirements**	**Importance**	Cost	Length	Weight	Torque	Power Consumption	Max Payload	**Customer Competitive Assessment**				
								1 Worst	2	3	4	5 Best
Total Cost below $2000 USD	9	9	6	6	6	3	6	A		B		C
Safety	7	3	3	3	6	5	5			B,C		A
Complete CAD/BOM	7	9	6	1	6	6	9			A,B,C		
Design wheel and track system	9	9	9	9	6	6	9			B,C		A
Improveme a subsystem	9	6	6	3	1	6	3			A,B,C		
Working design	9	6	3	3	6	3	6		B	C	A	
Technical Importance: Absolute		354	279	217	255	239	314					
Technical Importance: Relative		30%	15%	10%	15%	12%	18%					
Target Value		2000	36	154	N/A	N/A	200					
USL		2000	36	150	N/A	N/A	250					
LSL		1500	30	100	N/A	N/A	100					
Units		USD	Inch	Lbs	Ft/lb	kW*H	Lbs					
Design Competitive Assessment	Worst: 1	A	C	A			C					
	2											
	3	B	B	B	A,B	B,C	B					
	4				C							
	Best: 5	C	A	C		A	A					

CCA Key:
A-GRT 1000
B-HD2
C-LT2

2.5 Standards, Codes, and Regulations

Standards and Codes that will be applied to our project located in table 2. Below is a list of the Standards and codes applied to our project. The bulleted list covers each organization covered in table 2.

- Aluminum Association (AA)
- American Gear Manufacturers Association (AGMA)
- American Iron and Steel Institute (AISI)
- American National Standards Institute (ANSI)
- American Society of Mechanical Engineering (ASME)
- American Society of Testing and Materials (ASTM)
- American Welding Society (AWS)
- American Bearing Manufacturers Association (ABMA)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Standards Organization (ISO)

Table 2: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
AA/ASTM B209	Standard Specification for Aluminum and flat sheet and plate	Our design may encompass the use of aluminum sheet metal. This standard specifies that the faces of the sheet metal we use have a milled finish.
AGMA 945-1-B20	Splines Design and Application	Helps in the design of how the drive wheels will interface with the motors in a safe manner. Through the use of keyways and keys. The keyway depth was determined using this AGMA standard
ANSI/AGMA 6134-C21	Practice for Enclosed cylindrical worm gear speed reducers and gearmotors.	Our design uses two gearmotors to propel our design. This standard is helpful when choosing the correct motor, no greater than 3600 rpm.
ASME Y14.5	Dimension and Tolerancing	Our project involves a lot of parts such as machined parts that will have tolerance that must be met to ensure the proper fit of components against mate. This standard overview of the dimensions and tolerancing of our project.
ASTM A 359	Methods and Definitions for Mechanical Testing of Structural Steel	Our design will have a structural steel frame. These methods and definitions combined with FEA analysis will allow us to test the strength of the steel in our design.
AWS D1.1	Structural Welding Steel	Our project will have welded components made from steel sheet metal bent and welded to make the chassis
ABMA STD 9	Load ratings and fatigue life for ball bearings	Our design will have two ball bearings to support the front idler wheels. These ball bearings will have to support the axle in our project.
IEEE 835-1994	Power Cable Ampacity tables	This table specifies dielectric power cables rated for high voltage applications; this will help the group. This standard describes a numerical method by which core and surface temperatures of cables interact with a system.

ISO 24351	General Requirements of three-dimensional modeling for mechanical products	We will adhere to ISO and ANSI standards for our CAD drawings as specified by the client. We will have a full CAD package and a Bill of Materials complete with drawings on this project.

3 DESIGN SPACE RESEARCH

3.1 Literature Review

Last semester for the literature reviews the team explored the different types of robots beig made by super droid robotics, who made the robot we were trying to replicate. The team explored the option of different types of electronics systems that could power the design as well as traction and torque coeficients when comparing a tracked robot design versus a robot with tires to provide traction. In the next section we will discuss the benchmarking done by the team.

3.2 Benchmarking

In this section we will examine 3 existing designs of robotic systems that meet customer needs and engineering requirements. This system level benchmarking was done by examining 3 different robots from Super Droid robotics. Super Droid produces heavy weight robots that can perform tasks that are for industry use rather than hobbyist use. All their products range in price from a cheaper do it yourself option, to full fledge autonomous systems costing over $50,000.00. The goal of this section is to break down the 3 existing designs and see what aspects are useful to our design project. We will also examine individual components and subsystems in section 3.2.2 where we analyze viable solutions for different components of our design.

3.2.1 System Level Benchmarking

In this section we will look at 3 designs offered by Super droid Robotics. These designs all come in varied sizes and are intended for different use depending on the amount of payload they can carry as well as the amount of torque each system has. Each of these designs has aspects that could be used to influence our proposed design, such as different motors and speed control options, and the scale of the design.

3.2.1.1 Existing Design #1: Super Droid GRT 1000

The Super Droid Robotics GRT 1000 [1] is a tracked robot vehicle which is the design that we were asked to redesign. The GRT 1000 is a tracked vehicle that has a payload capacity of over 200 lbs. This design is expensive, coming in at just around $7,000. This design meets all our customers' needs and engineering requirements except for the price. If we were to go this route, we would be able to scale the model as we see fit to obtain a design within a budget of $2,000.00

Figure 3: Super Droid GRT 1000 [1]

3.2.1.2 Existing Design #2: Super Droid HD2

The HD2 is another tracked robot offered by Super Droid robotics [2]. The HD2 is also a tracked platform coming in at slightly smaller than the GRT 1000 model. This tracked robot comes with a dual motor setup, so it is not as powerful as the original design. This existing design would be a viable solution, if we needed to scale down our design to be within our proposed budget of $2,000.00

Figure 4: Super Droid HD2 [2]

3.2.1.3 Existing Design #3: Super Droid LT2

The LT2 is a viable solution if we decide to make a much smaller version than the original GRT 1000 model [3]. This robot comes in at under half the size of the original. We lose functionality with something such as this because it does not have the weight capacity nor torque to be able to perform like the original. This two-motor design utilizes a steel frame weighing only 50 pounds but has a max payload of 35 pounds depending on the use. If we did not have strict design requirements this would be a very viable option for the team to build within our budget.

Figure 5: Super Droid LT2 [3]

3.2.2 Subsystem Level Benchmarking

3.2.2.1 Subsystem #1: Motors

The motor set up in this project plays an important role, due the fact that it needs to be powerful enough to carry an estimated of 150 lbs. While discussing new possibilities and keeping in mind the improvement areas we found ideas from existing devices that can be useful for this purpose.

3.2.2.1.1 Existing Design #1: Geared Output Drive Motor

Existing Design #2: Dual Drive motor

The dual drive motor are two identical motors that are independently controlled by an electronic speed controller. This design is what is in the OEM version and what is our datum for this project.

3.2.2.1.2 Existing Design #3: Dual output motor

The dual output motor is a motor like the dual drive motor however this motor has two output shafts. The one disadvantage to this motor is that these motors do not spin independently of each other. This would be hard to control as we need the power to be differentiated between both sides.

3.2.2.2 Subsystem #2: Electronics

Electronics are a crucial part of the system to electronics. This section will include batteries, motor controllers and reviver. Without these systems the robot would not be able to move without its electrical energy.

3.2.2.2.1 Existing Design #1: Batteries

The batteries in this system are what power all the electrical components. For this system there are two 12V batteries that are connected in parallel which in return makes the system a 24V system. This can provide all four motors with the voltage they need to run.

3.2.2.2.2 Existing Design #2: Motor Controllers/Receiver

The motor controllers are a part of the receiver. The receiver gets input from the remote control and then in return sends that signal to the reviver. This signal then gets sent to the controller and lets in the amount of voltage that is required. This is an important system as it helps move the motors independently for turns.

3.2.2.3 Subsystem #3: Drive Assembly

The drive assembly is the mechanical power of the system and what helps move the robot. This system is critical, and the geometry must be correct to move in a line.

3.2.2.3.1 Existing Design #1: Wheels

The wheels in this design are made from hardened plastic. They can move over the ground and can help dissipate the energy of the motors. These motors are held with a bolt and are splined to the shaft to help prevent rotation on the shaft itself. Without these wheels the robot would not be able to move correctly.

3.2.2.3.2 Existing Design #2: Tracks

The tracks are made from a rubber and are injection molded. These components are what help the robot to move on adverse ground conditions and are a critical part of the system.

3.2.2.3.3 Existing Design #3: Idler Wheels

The idler wheels are made from plastic and are a critical part of the system. These wheels help guide the track and give support to the overall system including the drive assembly.

4 Concept Generation

4.1 Full System Concepts

4.1.1 Full System Design #1: Tire Tracks

For this system the main component that was recommended was the tire tracks. Using an old car tire to make a functional track was proposed as well as using two motors instead of the original 4 motors. This in turn would help limit the cost of the overall robot in parts and manufacturing. However, there are a few major disadvantages to this system for. One, these old tires must be matted together to produce a worthy system that would be challenging to fabricate. The second one is that the full output of torque would be limited due to the two-motor option, and this would severely hinder performance.

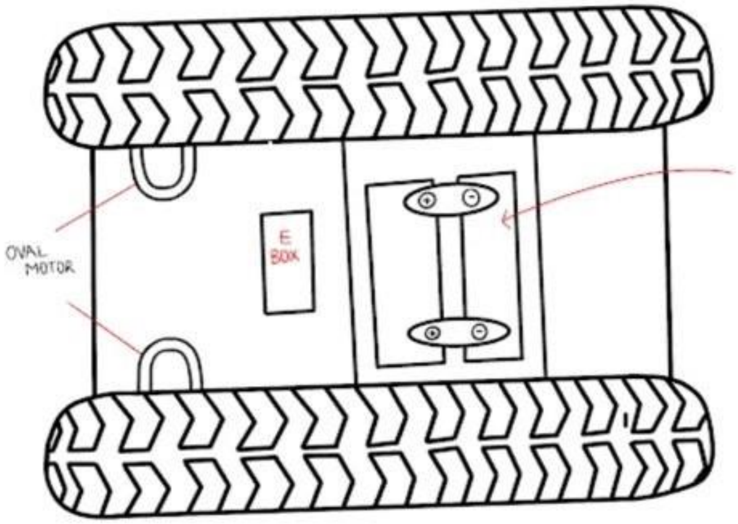


Figure 6: Tire Tracks system concept

4.1.2 Full System Design #2: Original Equipment Manufacturer "Plus"

For this full system design we incorporated an original look on the robot platform with our own twist to reduce the overall cost. This design incorporates 4 motor outputs while using DIY tracks found online. These tracks paired with 3D printed wheels allow the cost to be significantly reduced from the original robot. Some Pros and cons for this design are:

Pros

Meets all Engineering requirements

Has all safety standards as original

Cons

Most expensive design concepts

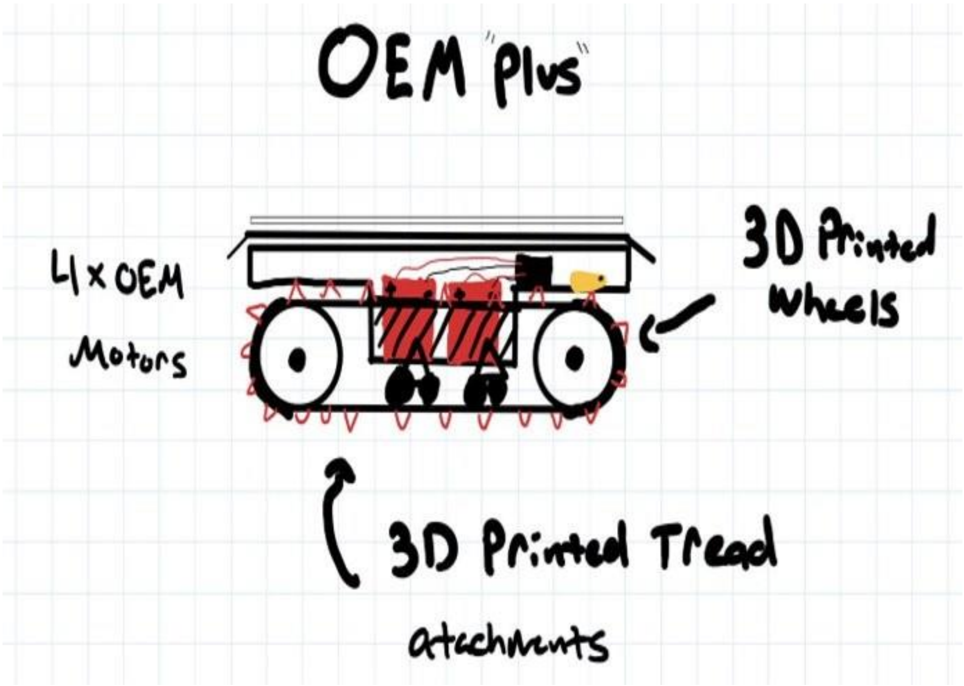


Figure 7: OEM Plus system concept

4.1.3 Full System Design #3: Trackless Concept

For the third concept we tough in a 3D printed set of wheels which were going to be considerable cheaper than the set of tracks, supported by a pair of dual output motor which also would be beneficial for our budget decreasing the number of motors, and the last improvement set into this model was the transmitter/receiver set planned for the speed control.

As mentioned before, one of the biggest advantages that this model brings with it is the low cost of its materials and the easy assembly of its parts, but in the other hand all this improvements that were thought to get a cheap model also lower some of the capabilities of the robot such as the maximum carry load and the max torque.

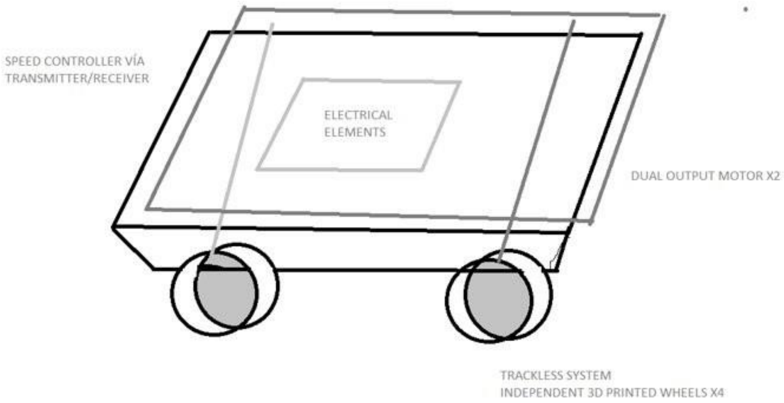


Figure 8: Trackless system concept

4.2 Subsystem Concepts

Having a complete understanding of our improvement areas has been essential for this point. Our main goal besides the ones already mentioned, was to look for improvements into the subsystem that would lead us to the objective. As product of a discussion, the improvement areas that we choose were the track system, motor setup and speed controller

4.2.1 Subsystem #1: Track System

Powered by a motor setup, the track system helps the robot to go from point A to point B. For the original design, the manufacturer has added personalized tracks that made lifelong lasting.

4.2.1.1 Design #1: 3d Printed Tread Extension

An important proposal on this was a 3D printed Tread extension where the design would give enough torque to move in different kinds of soil.

4.2.1.2 Design #2: Used Tire

Taking care of our budget was something that made us go creative. Using a used tire as part of our track system would give us a big advantage into the budget but one of the biggest challenges with this idea was finding a reliable way to put the sides of the tire together

4.2.1.3 Design #3: Trackless "Wheels Only"

Changing the tracks for wheels became a tentative option because besides saving money with the tracking system, working with also a different motor setup would make the savings even greater.

4.2.2 Subsystem #2: Motor Setup

The main goal was to find the right setup of motors to make the robot move from an starting point to its desired place while achieving its tasks and being able to carry up to 150 lbs.

4.2.2.1 Design #1: 4 Motors

In order to secure the maximum load, we considered the original motors used at the reference model giving us 50 lbs extra than needed.

4.2.2.2 Design #2: 2 Motors

Consider another kind of motor, with similar capacities which would generate significant battery savings. For these motors, the price was reduced compared to the ones proposed for design 1 with the difference of having lower torque.

4.2.2.3 Design #3: Dual Output Motor

The idea was proposed looking to safe battery life and fit the proposal of the independent wheels mentioned above in the track system. It was the cheapest option because we reduced the number of motors, but as expected, this number also came with the disadvantage of being able to carry less load and lower the maximum torque.

4.2.3 Subsystem #3: Speed Controller

Speed control for the robot is important when talking about its movement.

4.2.3.1 Design #1: Robot Speed Controller

Using a Robot Speed Controller was the first proposal due to it is meant to be used as a robot, which would fit perfectly with our product's profile but also is the most expensive option.

4.2.3.2 Design #2: Wheelchair Speed Controller

Looking for similar kinds of speed controllers, we found out that a wheelchair works with a speed controller as the robot does, meaning that we could adapt it to the robot. The biggest challenge with this option is the accessibility to the product.

4.2.3.3 Design #3: Aftermarket Speed Controller

Using an Aftermarket Speed controller is the cheapest option. Due to the robot's configuration, a basic aftermarket model would have been reliable for its use, however if trying to keep as close as possible to the original design this ended up not being an option.

5 DESIGN SELECTED – First Semester

The team's design for the end of the first semester was a design that closely resembled the super droid robotics GRT-1000 from section 3.2.1.1. This design would have cost the team a lot to construct and manufacture due to the amount of complex bends this design had. The team decided to have our frame laser cut and bent and this design would have exceeded the budget with the number of complex geometries it had. This design also incorporated the use of 4 DC gear motors compared to this semester's design of 2 DC gear motors. The changes from the first semester to the second semester were made to reduce the cost of manufacturing and reduce the complexity of the overall design the team could build in-house.

5.1 CAD DESIGN – First Semester

The CAD design for the first semester incorporated four DC gear motors to propel the design. This design was a straight replica of the Super droid robotics GRT-1000 that we were originally tasked to replicate. Some problems with the design included the fact that you could not tension the track on the system because each motor was fixed to the chassis.

This design was very heavy and had multiple different frame sections that all bolted together in the center chassis midframe through about 50 bolts and nuts. The team felt this was a bit overkill with the scope of our project and this could be simplified for easier manufacturability as well as reducing the overall cost.

Figure 9: Isometric View Proposed Design first semester

5.2 Final Prototype DESIGN – First Semester

The team's final prototype design for the first semester resembled the completed electrical system with one side of a track system being replicated. In figure 11 you will see the use of #D printed wheels attached to our drive motors that rotate a rubber track. This design incorporated the use of idler wheels which we eventually phased out in the second semester because the design did not need them to operate properly.

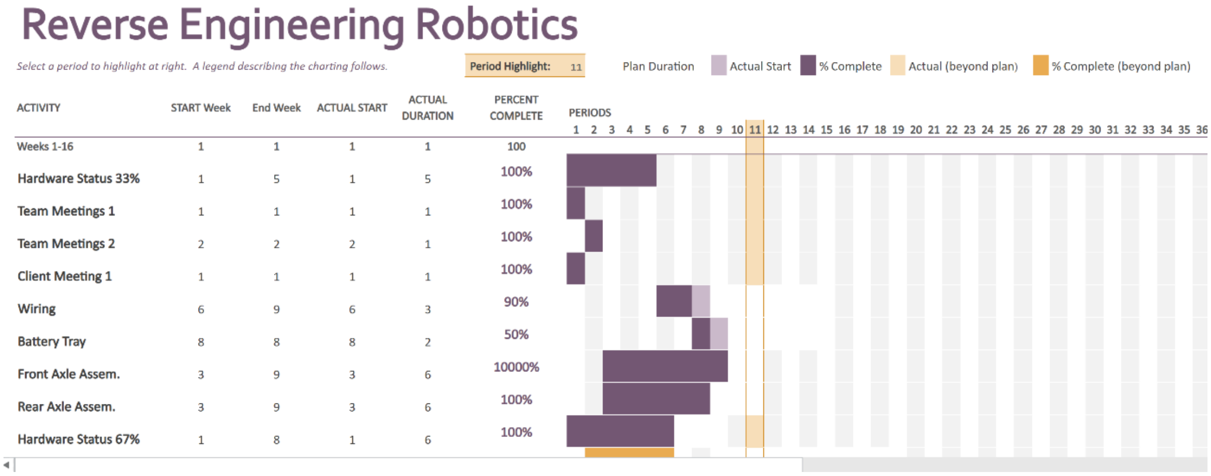
Figure 10: Isometric View Electronics Prototype Design first semester

Figure 11: Side View Electronics Prototype Design first semester

6 Project Management – Second Semester

6.1 Gantt Chart

The Gantt chart shown is only one half of the actual Gantt chart to see the full one reference the appendix below. The Gantt chart is organized in a way that follows the calendar of the semester. When the assignments are changed and the corresponding due dates as well the Gantt chart reflected that meaning this only changed slightly from the beginning of the semester. Things that the team would do differently is perhaps get another team member. Realistically the team did a good job in working with two team members and distributed the load evenly through the semester. We could have not waited until the last minute on some of the assignments but overall, the team did well and turned in all the reports on time.



Reverse Engineering Robotics

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

Period Highlight: 11

ACTIVITY	START Week	End Week	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Weeks 1-16	1	1	1	1	100
Hardware Status 33%	1	5	1	5	100%
Team Meetings 1	1	1	1	1	100%
Team Meetings 2	2	2	2	1	100%
Client Meeting 1	1	1	1	1	100%
Wiring	6	9	6	3	90%
Battery Tray	8	8	8	2	50%
Front Axle Assem.	3	9	3	6	10000%
Rear Axle Assem.	3	9	3	6	100%
Hardware Status 67%	1	8	1	6	100%

Figure 12: Gantt Chart

6.2 Purchasing Plan

Shown below is our purchasing plan that reflects all the materials bought and all of the items made as well. The team was still under budget at the end of the semester and left room for upgraded batteries. The team manufactured three items, and this was because of time and budget constraints. If we had had more time, we would have made more of our parts in-house but considering the time and lack of team members we decided to buy most of our materials from other suppliers. Even with this truth we still managed to keep the entire cost below our budget.

Subsytem	Manufacturer/ Component Name	Quantity	Price	Total	Lead Time	Make Vs. Buy	Status on part
Electrical	Amazon Motors	2	130	260	0	Buy	On hand
Electrical	Sabertooth Dual 60Amp motor driver	1	189.99	189.99	0	Buy	On hand
Electrical	Fly sky fs-1a6b	1	60	60	0	Buy	On hand
Electrical	Battery	2	40	80	0	Buy	On hand
Electrical	Circuit Breaker	1	26.99	26.99	0	Buy	On hand
Electrical	Power and Ground Wires	1	40	40	1 wk	Buy	Ordered
Frame	Osh Cut Frame	1	326	326	0	Buy	On hand
Frame	Battery Tie down	1	10	10	0	Make	On hand
Axle	Axle Shaft	1	10	10	1 wk	Buy	On hand
Axle	Axle Bearings	4	5.5	22	1 wk	Buy	On hand
Axle	Axle Blocks	2	20	40	2 wk	Make	On hand
Drive	Wheel Adapter	2	25	50	2 wk	Make	On hand
Frame	Frame Bolts	1	30	30	0	Buy	On hand
Drive	Tracks from Verco Track	1	400	400	2 wk	Buy	On hand
Drive	Harbor Freight 8 inch Wheels	4	7	28	0	Buy	On hand
Misc	Spray paint	2	7	14	0	Buy	On Hand
			Total USD $	1586.98			

Figure 13: Bill of Materials

6.3 *Manufacturing Plan*

The team's manufacturing plan stayed consistent throughout the course of the semester. The team only manufactured three main components the front axle assembly items, the wheel adapters and the frame itself. The team could have designed the frame last semester and welded it and that would have saved a lot of time this semester, but we did end up changing the design. The team did a good job at the beginning of the semester working in the machine shop early to manufacture the critical parts. Overall, the manufacturing plan was a success, and the team did a good job of utilizing the NAU machine shop to complete all the manufactured parts.

Manufacturer/ Component Name	Quantity	Price	Total	Lead Time	Make Vs. Buy
Power and Ground Wires	1	40	40	1 wk	Buy
Electrical Box Wiring	1	12	12	1wk	Make
Nutserts for frame	1	10	10	1 day	Buy
Frame Welding	1	0	0	2 wk	Make
Axle Shaft machining	1	10	10	1 wk	Buy
Axle Bearings pressed into wheels	4	5.5	22	1 wk	Buy
Axle Blocks machining	2	20	40	2 wk	Make
Front Axle Assembley	1	0	0	2 wk	Make
Wheel Adapter machining	2	25	50	2 wk	Make
Tracks from Verco Track	1	400	400	2 wk	Buy
Paint and Finishing					

Figure 14: Manufacturing Plan

7 Final Hardware

7.1 Final Hardware Images and Descriptions

The final system is shown below and works basically like an RC car, just a very big metal robust RC car. The inside of the robot can be seen below and shows the main components of the electrical system. The remote sends a signal to the ESC and the ESC sends the appropriate amount of current to the motors which in turn turns the motors in the system. The wheels then translate the rotational energy to the tracks through the wheels thus the robot moves under its own power. The front axle assembly puts tension on the tracks and the wheels keep the system in line relative to the tracks. This system is like how the Loui robot works so the team took inspiration from that.

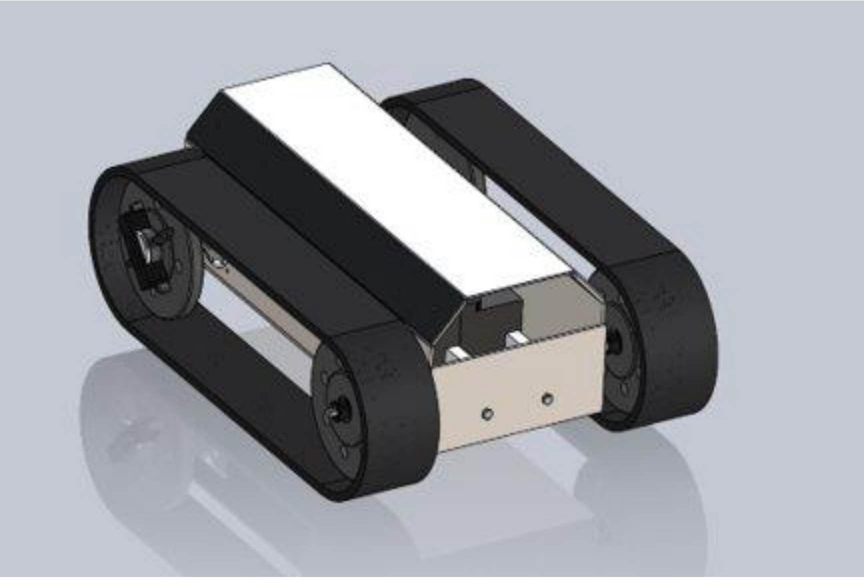


Figure 15: Completed Final Design

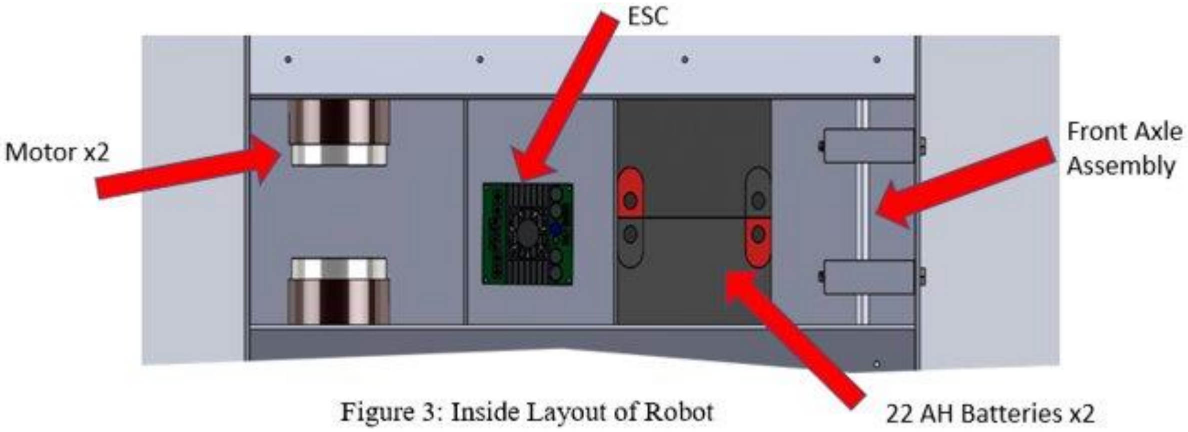


Figure 16: Electronics and inside layout

7.2 *Design Changes in Second Semester*

The main changes made this semester involve the main frame of the system. Originally, we had planned to make the robot very similar to the NAU robot but plans for that changed after the loss of a team member. We mainly tried to make the frame simple yet structurally robust, so we basically made a body with a lid out of 3/16 in. steel, and this provided a lot of rigid support to the system. With the ease of mounting holes directly on the robot it was a perfect option with the ease of sending out the CAD and getting the parts laser cut and then later welded together by the NAU machine shop.

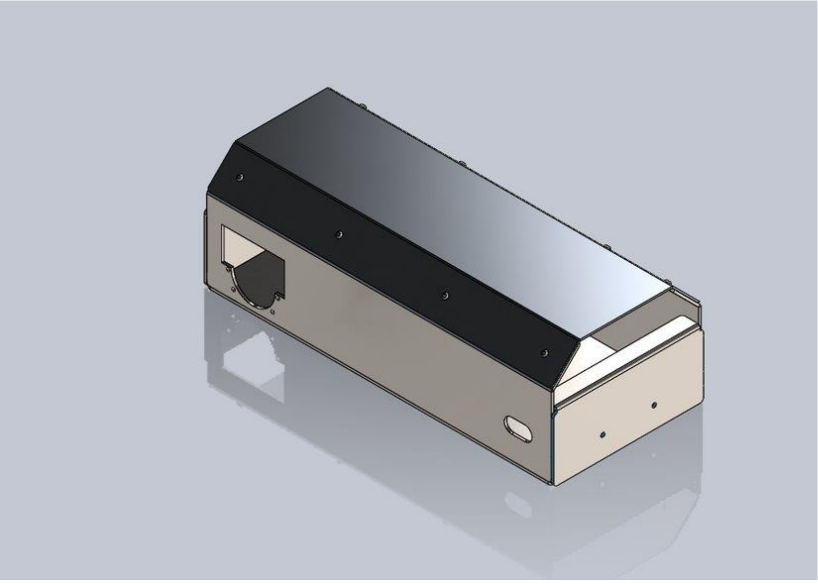


Figure 17: Chassis Design Change

7.2.1 Design Iteration 1: Change in [subsystem/component] discussion

The main design iteration that will be discussed in this section will be the change to 3D printed wheels instead of wheels bought from Harbor Freight. As can be seen in the figure below the robot is using the purchased wheels and the system worked well until the tracks came in. The wheel thickness did not fit in the inner cleat of the track so we needed to go with a different plan that would still fulfill the requirements. We decided to go with a 3D printed wheel, while not as string we could get enough strength for the loads our team is facing, and we could rapidly prototype to test the system. In the end the wheels worked well and provided all the functionality we needed while being cheap and easy to manufacture.

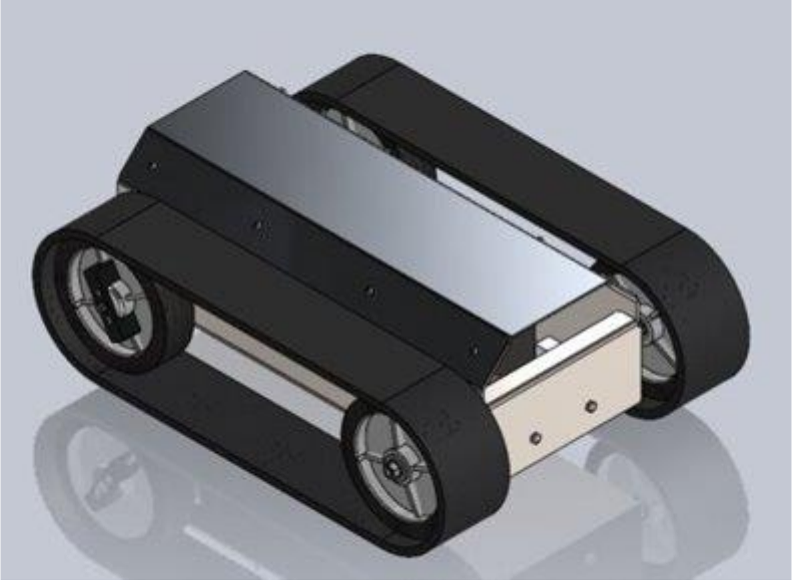


Figure 18: Design with Harbor Freight Wheels

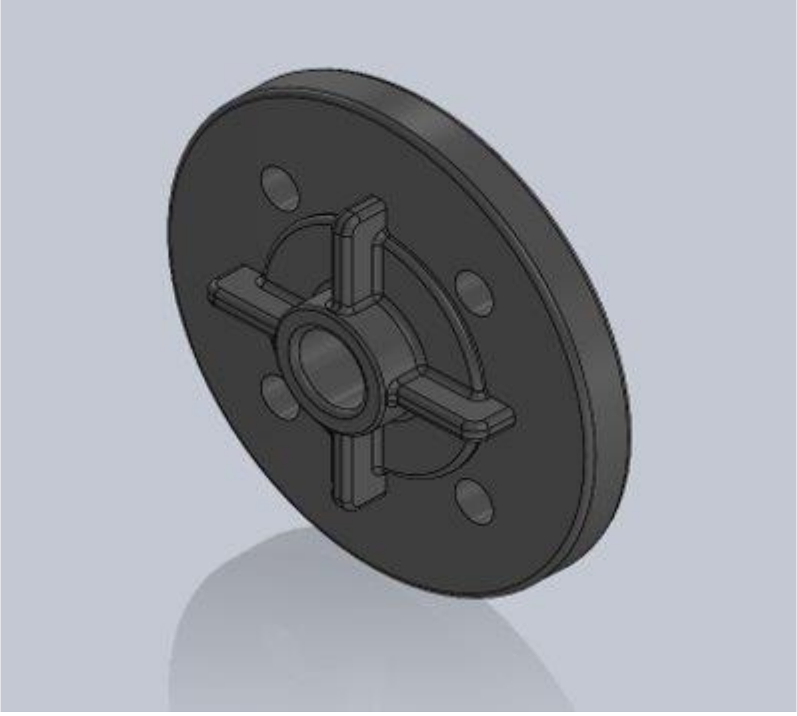


Figure 19: New 3D Printed Wheels Design

7.3 Challenges Bested

There were many challenges that the team faced when manufacturing our design with no prior knowledge of manufacturing processes. The main challenge the team faced was how to convert the rotational torue of our drive motors and transfer them to our wheels without having components break. The team originally planned to use off-the-shelf manufactured wheels that would need little to no machining, but this solution ended up not working. The team then ended up making our own wheels for our design in house which left problems from the designs cracking or failing all together.

After the team managed to find a manufacturing method to print the 3D printed drivetrain, we have had less problems with the design breaking due to the torque of the motors.

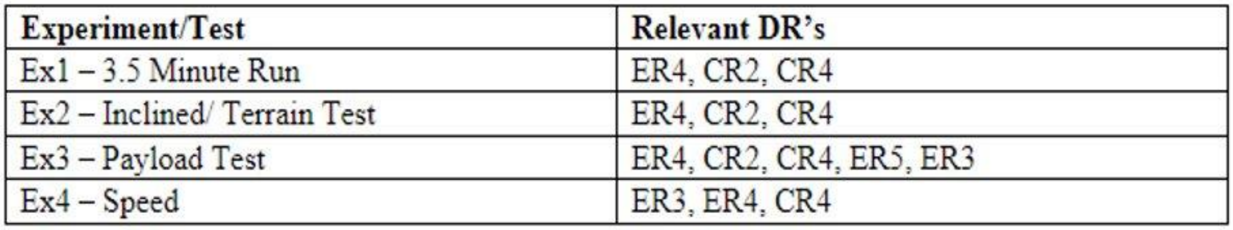
The next challenge we faced was track tension and wheels slipping in the rubber tank tracks. The team ordinally designed the wheels to replicate the ones found on the Super droid robotics robot base in which the LOUIE robot was built. Because these wheels and tracks were tighter, they are less prone to slipping. We found through testing that it is quite difficult to get adequate track tension to reduce the slipping of the drive wheels inside of the track system. The team plans for future work to design a sprocket rear drive wheel that interfaces with the track itself to reduce the slipping between the wheels and the tracks.

8 Testing

8.1 Testing Plan

Tests were created to test overall components working together and to ensure track system performs as designed. These tests encompass the entire range of systems that the robot has and utilizes a cross functional testing range to ensure reliability and functionality of our final design. The run test will show the team how light the vehicle is relative to the battery power output. While the inclined and payload tests will show how well the wheels and the tracks mate together to be able to withstand the loads required.

Table 3: Testing Plan

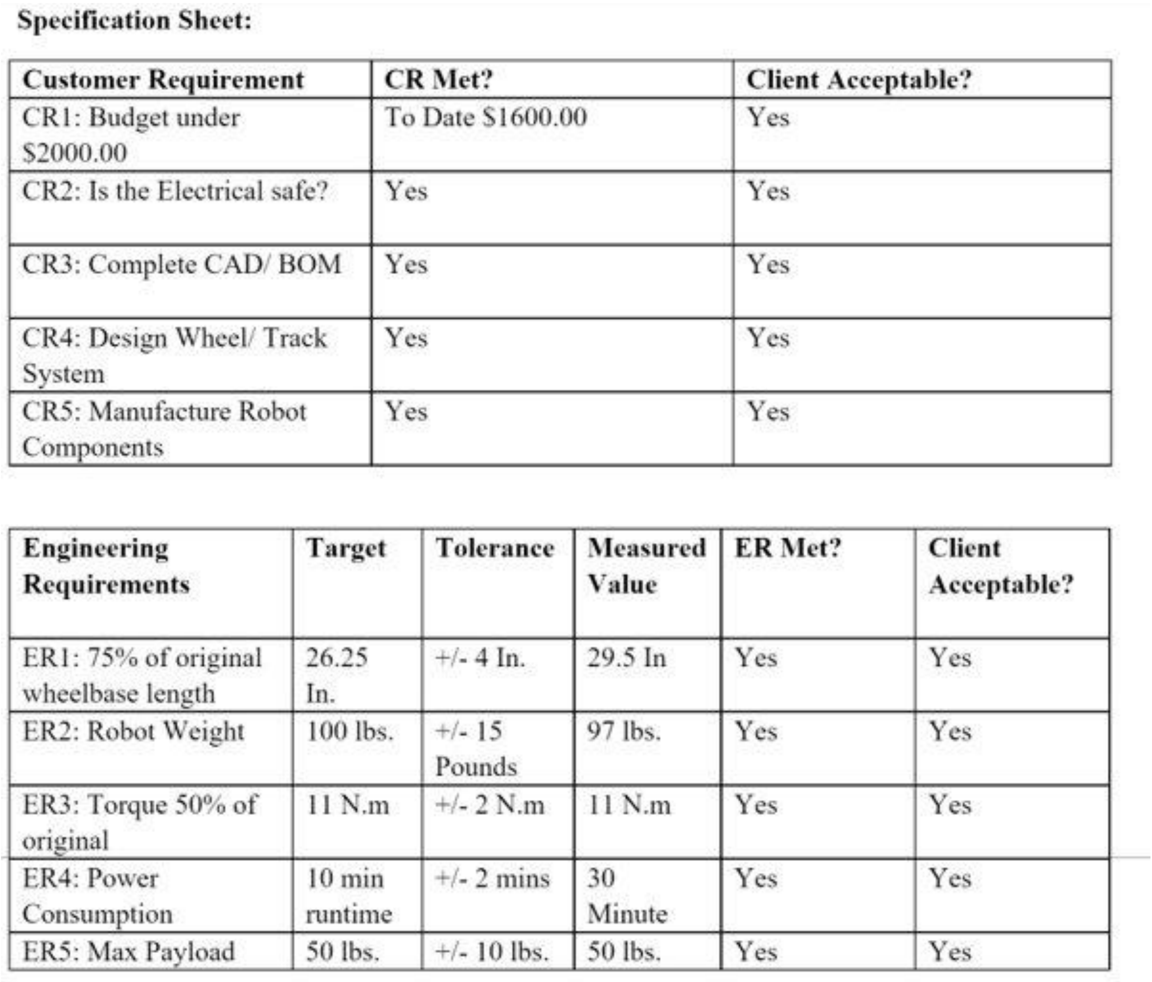


Experiment/Test	Relevant DR's
Ex1 – 3.5 Minute Run	ER4, CR2, CR4
Ex2 – Inclined/ Terrain Test	ER4, CR2, CR4
Ex3 – Payload Test	ER4, CR2, CR4, ER5, ER3
Ex4 – Speed	ER3, ER4, CR4

8.2 Testing Results

As can be seen below the team has successfully met all the customers and client's ER's and CR's. The robot's budget was well under $2000 at $1600 and the electrical system is certified with the specifications as seen earlier in the report to be safe. This means there are no loose wires and or missing ground connections on the robot that could have the potential to arc. The engineering requirements all met and exceeded expectations for utility and functionality as can be seen in the long run time. The robot can run for longer than 30 minutes but was not specified in this sheet as it was only to show that we have met the specified requirement. The two figures below the specification sheet show the trail runs of the maximum speed and the maximum payload the robot can take.

Table 4: Testing Results/ Spec Sheet



Specification Sheet:

Customer Requirement	CR Met?	Client Acceptable?
CR1: Budget under $2000.00	To Date $1600.00	Yes
CR2: Is the Electrical safe?	Yes	Yes
CR3: Complete CAD/ BOM	Yes	Yes
CR4: Design Wheel/ Track System	Yes	Yes
CR5: Manufacture Robot Components	Yes	Yes

Engineering Requirements	Target	Tolerance	Measured Value	ER Met?	Client Acceptable?
ER1: 75% of original wheelbase length	26.25 In.	+/- 4 In.	29.5 In	Yes	Yes
ER2: Robot Weight	100 lbs.	+/- 15 Pounds	97 lbs.	Yes	Yes
ER3: Torque 50% of original	11 N.m	+/- 2 N.m	11 N.m	Yes	Yes
ER4: Power Consumption	10 min runtime	+/- 2 mins	30 Minute	Yes	Yes
ER5: Max Payload	50 lbs.	+/- 10 lbs.	50 lbs.	Yes	Yes

Table 5: Speed Testing

Trial	Time (s)	Speed (Mph)
1	3.30	2.07
2	3.27	2.08
3	3.18	2.14

Table 6: Maximum Payload Testing

Trial	Weight (lbs.)
1	10
2	20
3	30
4	40
5	50
6	170

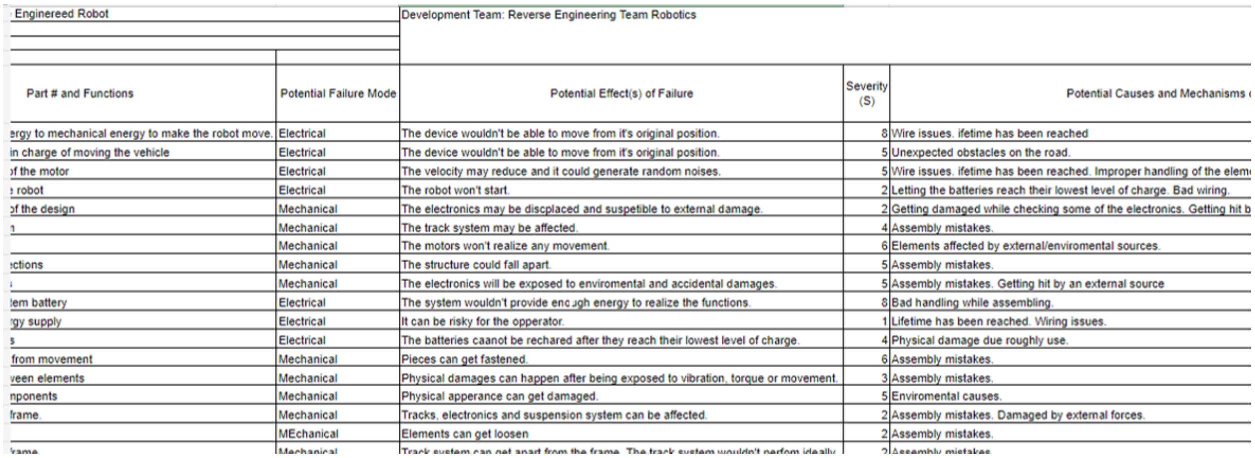
9 RISK ANALYSIS AND MITIGATION

In this section we will be going over the main risks in the project and how the teams was able to catch them in the beginning and solve them. The main risks came this semester when we actually started to build the robot because we didn't know what we didn't know. The next few sections will illustrate the main issues and how the team resolved those issues.

9.1 Potential Failures Identified First Semester

The main problems outlined in this shortened FMEA is electrical problems with the robot that being that robot not moving, these were all solved in the last semester as we demonstrated that the team could use the same electrical circuit as the last robot and provide the same functionality. To mitigate these risks, we followed standards outlined above concerning the safety of the electrical system. Another main concern outlined is the structure of the robot and we fixed that this last semester by making it out of 3/16 in. steel which is very strong and robust.

Table 7: FMEA Shortened



Engineered Robot		Development Team: Reverse Engineering Team Robotics		
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms
ergy to mechanical energy to make the robot move.	Electrical	The device wouldn't be able to move from it's original position.	8	Wire issues. ifetime has been reached
in charge of moving the vehicle	Electrical	The device wouldn't be able to move from it's original position.	5	Unexpected obstacles on the road.
f the motor	Electrical	The velocity may reduce and it could generate random noises.	5	Wire issues. ifetime has been reached. Improper handling of the elem
robot	Electrical	The robot won't start.	2	Letting the batteries reach their lowest level of charge. Bad wiring.
f the design	Mechanical	The electronics may be discplaced and suspetible to external damage.	2	Getting damaged while checking some of the electronics. Getting hit b
	Mechanical	The track system may be affected.	4	Assembly mistakes.
	Mechanical	The motors won't realize any movement.	6	Elements affected by external/enviromental sources.
ctions	Mechanical	The structure could fall apart.	5	Assembly mistakes.
	Mechanical	The electronics will be exposed to enviromental and accidental damages.	5	Assembly mistakes. Getting hit by an external source
tem battery	Electrical	The system wouldn't provide enough energy to realize the functions.	8	Bad handling while assembling.
gy supply	Electrical	It can be risky for the opperator.	1	Lifetime has been reached. Wiring issues.
s	Electrical	The batteries caanot be rechared after they reach their lowest level of charge.	4	Physical damage due roughly use.
from movement	Mechanical	Pieces can get fastened.	6	Assembly mistakes.
veen elements	Mechanical	Physical damages can happen after being exposed to vibration, torque or movement.	3	Assembly mistakes.
nponents	Mechanical	Physical apperance can get damaged.	5	Enviromental causes.
frame.	Mechanical	Tracks, electronics and suspension system can be affected.	2	Assembly mistakes. Damaged by external forces.
	MEchanical	Elements can get loosen	2	Assembly mistakes.
rame	Mechanical	Track system can get apart from the frame. The track system wouldn't perfom ideally	2	Assembly mistakes

9.2 Potential Failures Identified This Semester

The potential risks came when the team started the manufacturing of the robot. This came down to the tension of the robot tracks and the wheel interface with those tracks and will be given with much more detail below.

9.3 Risk Mitigation

The main risk that the team saw with the robot was the track tensioning system and the wheel and the track interface. To mitigate the failure of the track tensioning system and front axle assembly was made consisting of 2 two blocks the shaft would slide and of course the shaft which was made out of a very strong steel alloy. An analysis was done on bending of the shaft and the team confirmed that the axle would not bend with the given loads of our project. The only problem that came was that the axle would slide left to right when driving the vehicle. To mitigate these risks axle sleeves were placed on the outside of the robot to stop the axle sliding in those blocks. The system would then be under tension and would put enough tension on the system to hold the wheels.

The other risk the team faced was the challenge of interacting with the wheel and track. Originally, we had decided to use harbor freight wheels and we had that design all figured out until the tracks came in and the dimensions specified by the manufacture were not accurate to what we required. To fix this we 3D-printed our wheels with a high infill and large wall count to make them very strong and this worked for the team and was cheap and easy to manufacture.

10 LOOKING FORWARD

Looking forward the team would have liked to have a sprocket rear drive wheel design that would interface with our track setup to reduce the amount of wheel slippage when turning. The team observed that the driven wheels would occasionally slip when doing turns when the design was stationary and not moving. The team would have also liked to have a mounting system on the top plate of the robot so that attachments could be added at ease to the design.

10.1 Future Testing Procedures

The team would like to test the design in a variety of different terrain options not limited to concrete and hard surfaces, dirt and forest floor. Testing the capabilities of our design in various conditions such as rain mud and snow would be a nice touch to see the possibilities of our design and how it can hold up to the elements. Other tests on the team's radar were as follows.

Table 8: Future Testing Procedures

Test Name:	**Description**
All Terrain/ Harsh Weather	Test the design in rain, mud snow hot or cold. Test its limits
Lifecycle Test	Test the expected lifecycle of components, tracks batteries etc. after repeated use.
Inclined Load Test	Put load on the robot and see how steep of a incline it can traverse before the motors reach stall

10.2 Future Iterations

Future Iterations of this project could include building out the robot in ways the team was not able to complete. Some ideas include mounting systems and new wheel designs that interact with the tracks better than they do now. Making the robot autonomous would be a nice project for a group to dive into. Many utilitarian style robots can incorporate different types of tools such as a robotic arm, a future capstone team could design a 6-axis arm that could be mounted to the chassis of our design. These are just some ideas the team had for the future of this project, but our design is an open canvas for a future design team to build off where our team left off.

11 CONCLUSIONS

The team was successful in reverse engineering the NAU robot with the new given engineering requirements and customer requirements. The robot can travel a maximum of 2.2 mph and carry a load exceeding 50lbs, the robot can also provide similar torque output as the other robot while keeping the robot weight under 100lbs. The project was an overall success and the team worked well with just two members.

11.1 Reflection

The main skill that the team developed this project was technical communication and teamwork. This lesson was valuable because we originally had three members but came out with just two and this proved to be a very big challenge with workload, but the team was able to work together to turn in everything on time and provide great functionality to our client. Most of the parts we manufactured besides the frame were made from leftover metal in the machine shop so unknowingly the team was reusing and eliminating waste within in the manufacturing process. The project tested the team in many ways but the team was able to come out successful and give the client what they requested.

11.2 Resource Wishlist

If we were to do this project all over again, I would strongly recommend more team members. The workload this entire semester was challenging due to only having two team members. Another aspect of the project that would have been helpful would be if the machine shop was open on the weekends to manufacture. A lot of times this would have been very helpful to get ahead of the manufacturing if we were able to do it on the weekends.

11.3 Project Applicability

This project was a very big lesson on manufacturing for both of us. The school has prepared us well with not only design but know the very good skills of design for manufacturing. The R.U.T. team is prepared to move on to future careers in any industry with the skills that this project has gave us and the knowledge that the NAU mechanical engineering department has taught us.

12 REFERENCES

[1] “Configurable - GRT1000 heavy-duty tracked ATR Robot,” *SuperDroid Robots*. [Online]. Available: https://www.superdroidrobots.com/robots/robotic-kits-platforms/tracked-robots/product=3262. [Accessed: 01-Mar-2022].

[2] “Configurable - HD2 treaded ATR Tank Robot Platform,” *SuperDroid Robots*. [Online]. Available: https://www.superdroidrobots.com/robots/robotic-kits-platforms/tracked-robots/product=789. [Accessed: 01-Mar-2022].

[3] “Configurable - LT2 tracked ATR robot platform,” *SuperDroid Robots*. [Online]. Available: https://www.superdroidrobots.com/robots/robotic-kits-platforms/tracked-robots/product=1513. [Accessed: 01-Mar-2022].

[4] “PN00218-DME4 sabertooth 2x60 dual 60A motor driver,” *Makermotor*. [Online]. Available: https://makermotor.com/pn00218-dme4-sabertooth-2x60-dual-60a-motor-driver/. [Accessed: 02-Mar-2022].

[5] “Flysky FS-I6X 2.4g 6 channel transmitter & receiver,” *SuperDroid Robots*. [Online]. Available: https://www.superdroidrobots.com/electrical-parts/Remote-Control/RC-Controllers/product=3192. [Accessed: 04-Mar-2022].

[6] “Roboclaw 2X60A, 6-34VDC regenerative motor controller ...” [Online]. Available: https://www.robotshop.com/en/roboclaw-2x60a-6-34vdc-regenerative-motor-controller.html. [Accessed: 04-Mar-2022].

[7] “Turnigy TGY-I6 mode 1 AFHDS transmitter and 6CH receiver,” *Hobbyking*. [Online]. Available: https://hobbyking.com/en_us/turnigy-tgy-i6-mode-1-afhds-transmitter-and-6ch-receiver.html?wrh_pdp=2&utm_source=google&utm_medium=cpc&utm_campaign=google_us_shopping&countrycode=US&gclid=EAIaIQobChMIp6b75LSt9gIVdBatBh1THgo-EAQYFiABEgI9zPD_BwE. [Accessed: 04-Mar-2022].

[8] “Track vs wheeled equipment: Which type of machine should I rent?,” *MacAllister Rentals*, 12-Feb-2020. [Online]. Available: https://www.macallisterrentals.com/track-vs-wheeled-equipment-type-machine-rent/. [Accessed: 04-Mar-2022].

[9] “Wheels vs Tracks: Advantages and Disadvantages,” *Lite Trax*, Mar. 01, 2018. https://litetrax.com/wheels-vs-tracks-advantages-disadvantages/.

[10] StackPath,” *www.gxcontractor.com*. https://www.gxcontractor.com/equipment/article/13025532/skidsteer-wheels-vs-tracks-the-debate-over-compact-loaders-part-1 (accessed Mar. 05, 2022).

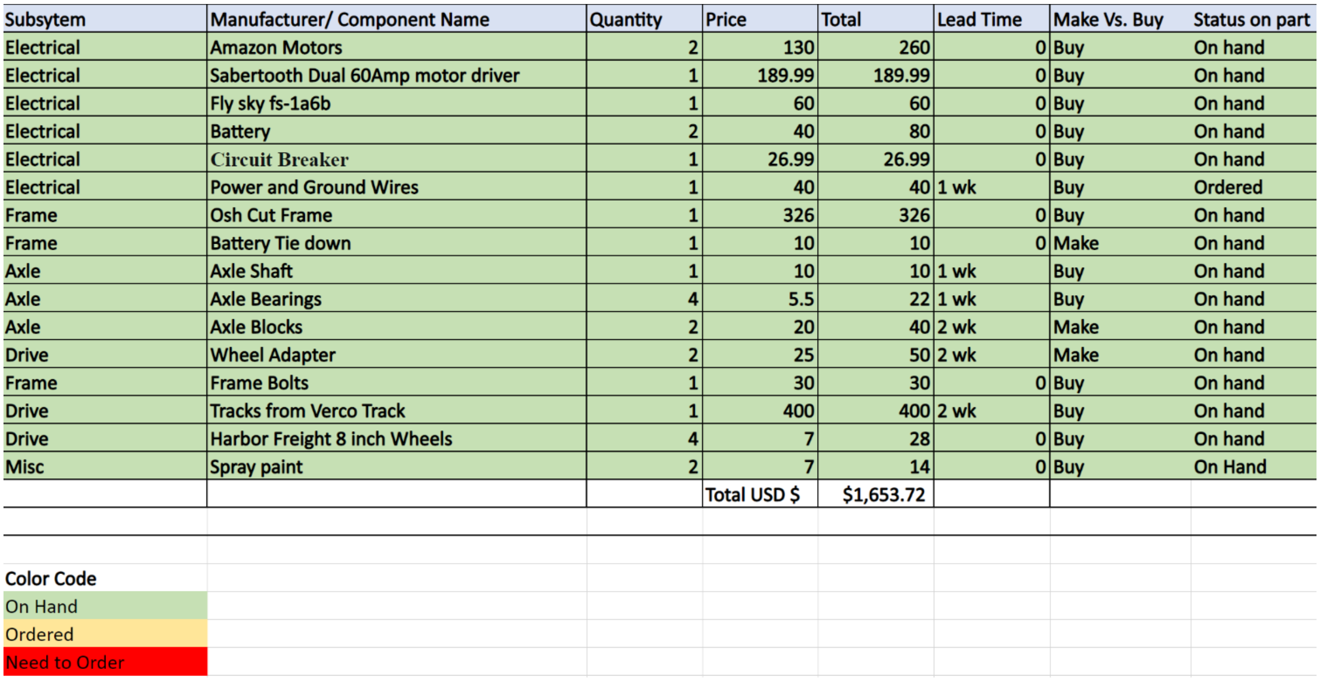
13 APPENDICES

13.1 *Appendix A: QFD House of Quality*

Design Requirements Customer Requirements	Importance	Cost	Length	Weight	Torque	Power Consumption	Max Payload	Customer Competitive Assessment				
								1 Worst	2	3	4	5 Best
Total Cost below $2000 USD	9	9	6	6	6	3	6	A		B		C
Safety	7	3	3	3	6	5	5			B,C		A
Complete CAD/BOM	7	9	6	1	6	6	9			A,B,C		
Design wheel and track system	9	9	9	9	6	6	9			B,C		A
Improveme a subsystem	9	6	6	3	1	6	3			A,B,C		
Working design	9	6	3	3	6	3	6		B	C	A	
Technical Importance: Absolute		354	279	217	255	239	314					
Technical Importance: Relative		30%	15%	10%	15%	12%	18%					
Target Value		2000	36	154	N/A	N/A	200					
USL		2000	36	150	N/A	N/A	250					
LSL		1500	30	100	N/A	N/A	100					
Units		USD	Inch	Lbs	Ft/lb	kW*H	Lbs					
Design Competitive Assessment	Worst: 1	A	C	A			C					
	2											
	3	B	B	B	A,B	B,C	B					
	4				C							
	Best: 5	C	A	C		A	A					

CCA Key:
A-GRT 1000
B-HD2
C-LT2

13.2 *Appendix B: Budget Analysis*



Subsytem	Manufacturer/ Component Name	Quantity	Price	Total	Lead Time	Make Vs. Buy	Status on part
Electrical	Amazon Motors	2	130	260	0	Buy	On hand
Electrical	Sabertooth Dual 60Amp motor driver	1	189.99	189.99	0	Buy	On hand
Electrical	Fly sky fs-1a6b	1	60	60	0	Buy	On hand
Electrical	Battery	2	40	80	0	Buy	On hand
Electrical	Circuit Breaker	1	26.99	26.99	0	Buy	On hand
Electrical	Power and Ground Wires	1	40	40	1 wk	Buy	Ordered
Frame	Osh Cut Frame	1	326	326	0	Buy	On hand
Frame	Battery Tie down	1	10	10	0	Make	On hand
Axle	Axle Shaft	1	10	10	1 wk	Buy	On hand
Axle	Axle Bearings	4	5.5	22	1 wk	Buy	On hand
Axle	Axle Blocks	2	20	40	2 wk	Make	On hand
Drive	Wheel Adapter	2	25	50	2 wk	Make	On hand
Frame	Frame Bolts	1	30	30	0	Buy	On hand
Drive	Tracks from Verco Track	1	400	400	2 wk	Buy	On hand
Drive	Harbor Freight 8 inch Wheels	4	7	28	0	Buy	On hand
Misc	Spray paint	2	7	14	0	Buy	On Hand
			Total USD $	$1,653.72			

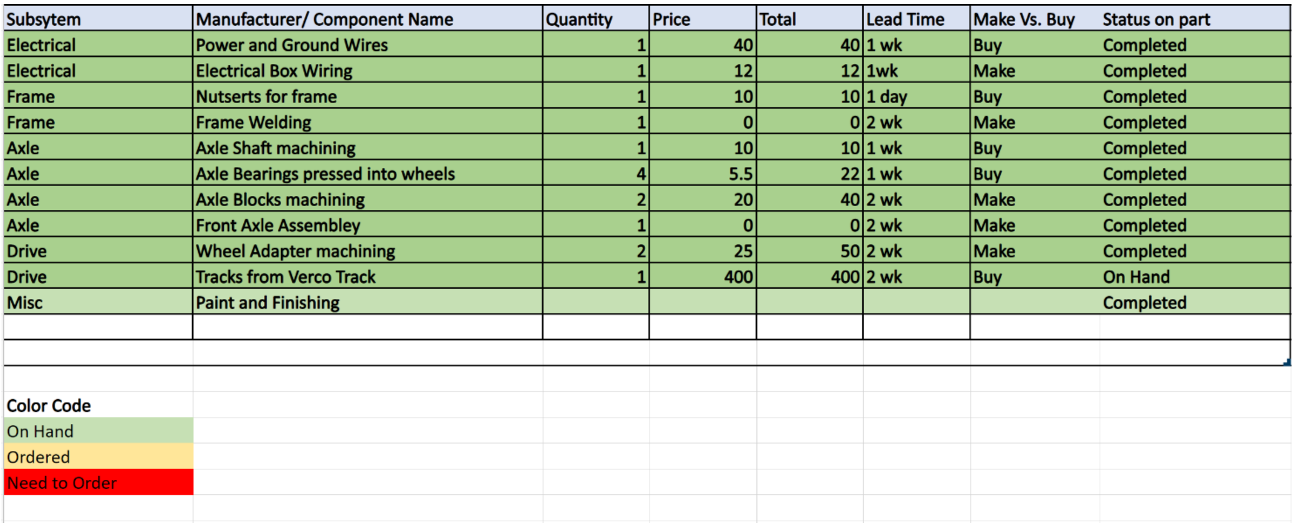
Color Code

🟩 On Hand

🟨 Ordered

🟥 Need to Order

13.3 Appendix C: Manufacturing Plan



Subsytem	Manufacturer/ Component Name	Quantity	Price	Total	Lead Time	Make Vs. Buy	Status on part
Electrical	Power and Ground Wires	1	40	40	1 wk	Buy	Completed
Electrical	Electrical Box Wiring	1	12	12	1wk	Make	Completed
Frame	Nutserts for frame	1	10	10	1 day	Buy	Completed
Frame	Frame Welding	1	0	0	2 wk	Make	Completed
Axle	Axle Shaft machining	1	10	10	1 wk	Buy	Completed
Axle	Axle Bearings pressed into wheels	4	5.5	22	1 wk	Buy	Completed
Axle	Axle Blocks machining	2	20	40	2 wk	Make	Completed
Axle	Front Axle Assembley	1	0	0	2 wk	Make	Completed
Drive	Wheel Adapter machining	2	25	50	2 wk	Make	Completed
Drive	Tracks from Verco Track	1	400	400	2 wk	Buy	On Hand
Misc	Paint and Finishing						Completed

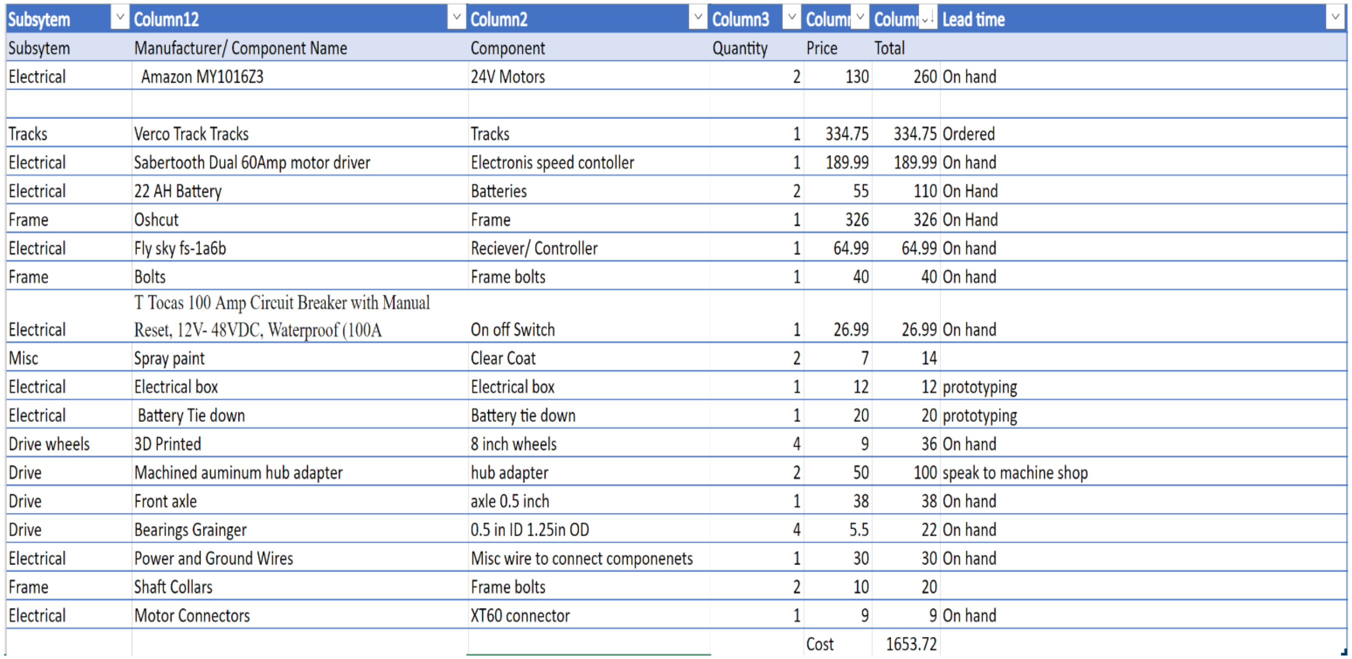
Color Code

On Hand

Ordered

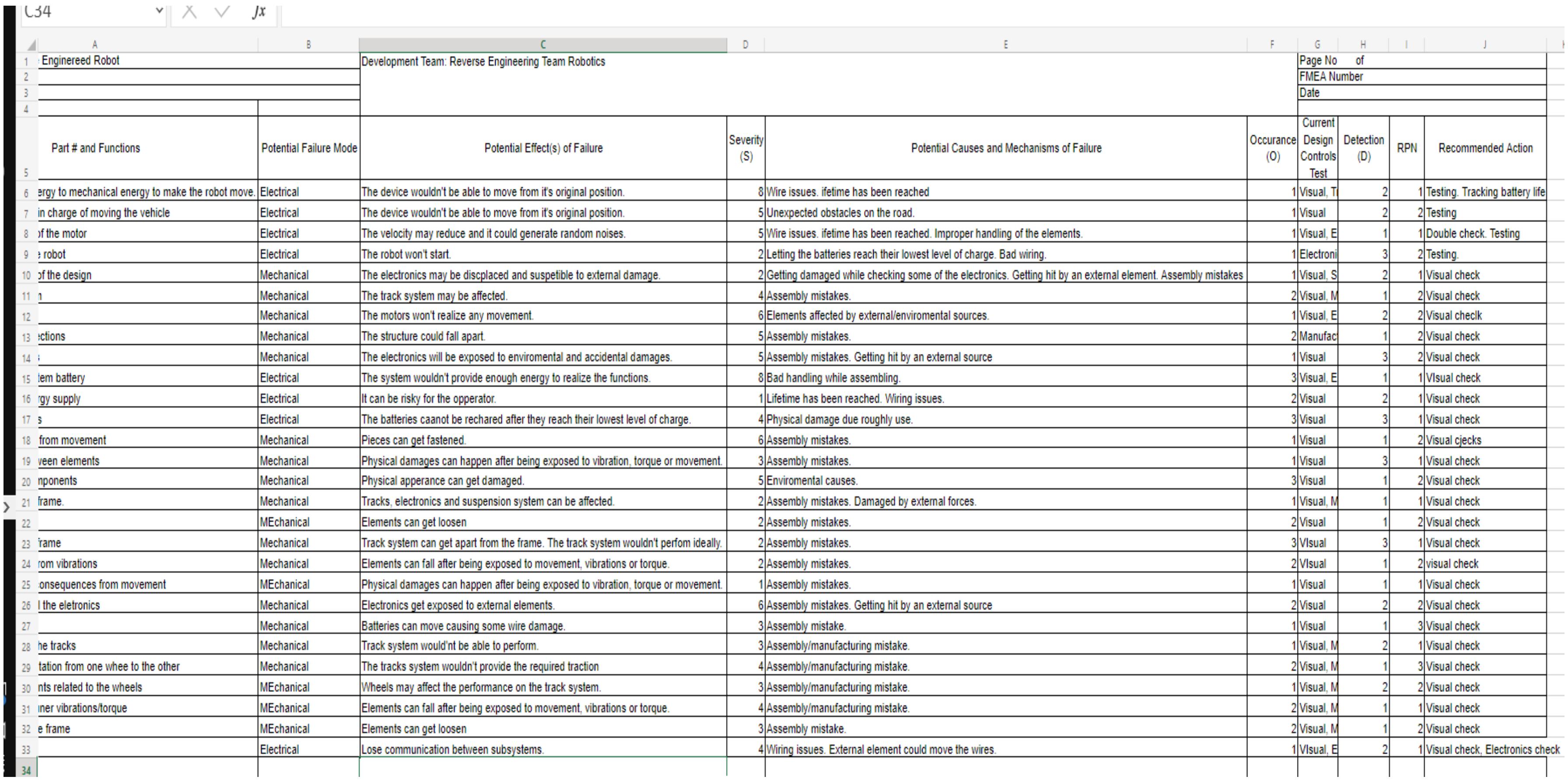
Need to Order

13.4 Appendix D: Bill of Materials



Subsytem	Column12	Column2	Column3	Colum	Colum	Lead time
Subsytem	Manufacturer/ Component Name	Component	Quantity	Price	Total	
Electrical	Amazon MY1016Z3	24V Motors	2	130	260	On hand
Tracks	Verco Track Tracks	Tracks	1	334.75	334.75	Ordered
Electrical	Sabertooth Dual 60Amp motor driver	Electronis speed contoller	1	189.99	189.99	On hand
Electrical	22 AH Battery	Batteries	2	55	110	On Hand
Frame	Oshcut	Frame	1	326	326	On Hand
Electrical	Fly sky fs-1a6b	Reciever/ Controller	1	64.99	64.99	On hand
Frame	Bolts	Frame bolts	1	40	40	On hand
Electrical	T Tocas 100 Amp Circuit Breaker with Manual Reset, 12V- 48VDC, Waterproof (100A	On off Switch	1	26.99	26.99	On hand
Misc	Spray paint	Clear Coat	2	7	14	
Electrical	Electrical box	Electrical box	1	12	12	prototyping
Electrical	Battery Tie down	Battery tie down	1	20	20	prototyping
Drive wheels	3D Printed	8 inch wheels	4	9	36	On hand
Drive	Machined auminum hub adapter	hub adapter	2	50	100	speak to machine shop
Drive	Front axle	axle 0.5 inch	1	38	38	On hand
Drive	Bearings Grainger	0.5 in ID 1.25in OD	4	5.5	22	On hand
Electrical	Power and Ground Wires	Misc wire to connect componenets	1	30	30	On hand
Frame	Shaft Collars	Frame bolts	2	10	20	
Electrical	Motor Connectors	XT60 connector	1	9	9	On hand
				Cost	1653.72	

13.5 Appendix E: FMEA



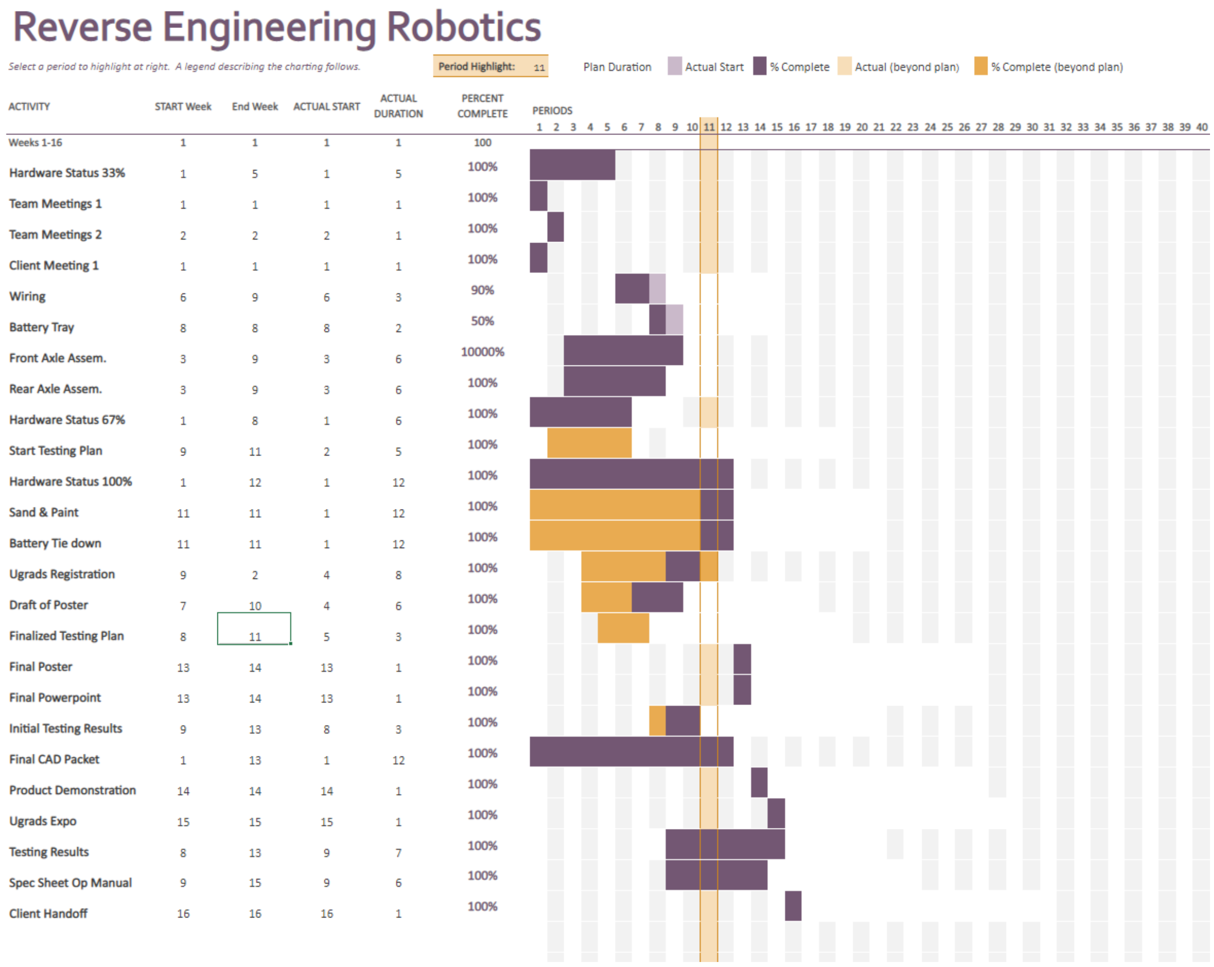
Engineered Robot

Development Team: Reverse Engineering Team Robotics

Page No of
FMEA Number
Date

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
ergy to mechanical energy to make the robot move.	Electrical	The device wouldn't be able to move from it's original position.	8	Wire issues. ifetime has been reached	1	Visual, T	2	1	Testing. Tracking battery life
in charge of moving the vehicle	Electrical	The device wouldn't be able to move from it's original position.	5	Unexpected obstacles on the road.	1	Visual	2	2	Testing
of the motor	Electrical	The velocity may reduce and it could generate random noises.	5	Wire issues. ifetime has been reached. Improper handling of the elements.	1	Visual, E	1	1	Double check. Testing
robot	Electrical	The robot won't start.	2	Letting the batteries reach their lowest level of charge. Bad wiring.	1	Electroni	3	2	Testing.
of the design	Mechanical	The electronics may be discplaced and suspetible to external damage.	2	Getting damaged while checking some of the electronics. Getting hit by an external element. Assembly mistakes	1	Visual, S	2	1	Visual check
n	Mechanical	The track system may be affected.	4	Assembly mistakes.	2	Visual, M	1	2	Visual check
	Mechanical	The motors won't realize any movement.	6	Elements affected by external/enviromental sources.	1	Visual, E	2	2	Visual checlk
ections	Mechanical	The structure could fall apart.	5	Assembly mistakes.	2	Manufac	1	2	Visual check
s	Mechanical	The electronics will be exposed to enviromental and accidental damages.	5	Assembly mistakes. Getting hit by an external source	1	Visual	3	2	Visual check
tem battery	Electrical	The system wouldn't provide enough energy to realize the functions.	8	Bad handling while assembling.	3	Visual, E	1	1	VIsual check
rgy supply	Electrical	It can be risky for the opperator.	1	Lifetime has been reached. Wiring issues.	2	Visual	2	1	Visual check
s	Electrical	The batteries caanot be rechared after they reach their lowest level of charge.	4	Physical damage due roughly use.	3	Visual	3	1	Visual check
from movement	Mechanical	Pieces can get fastened.	6	Assembly mistakes.	1	Visual	1	2	Visual cjecks
veen elements	Mechanical	Physical damages can happen after being exposed to vibration, torque or movement.	3	Assembly mistakes.	1	Visual	3	1	Visual check
nponents	Mechanical	Physical apperance can get damaged.	5	Enviromental causes.	3	Visual	1	2	Visual check
frame.	Mechanical	Tracks, electronics and suspension system can be affected.	2	Assembly mistakes. Damaged by external forces.	1	Visual, M	1	1	Visual check
	MEchanical	Elements can get loosen	2	Assembly mistakes.	2	Visual	1	2	Visual check
frame	Mechanical	Track system can get apart from the frame. The track system wouldn't perfom ideally.	2	Assembly mistakes.	3	VIsual	3	1	Visual check
rom vibrations	Mechanical	Elements can fall after being exposed to movement, vibrations or torque.	2	Assembly mistakes.	2	VIsual	1	2	visual check
consequences from movement	MEchanical	Physical damages can happen after being exposed to vibration, torque or movement.	1	Assembly mistakes.	1	Visual	1	1	Visual check
l the eletronics	Mechanical	Electronics get exposed to external elements.	6	Assembly mistakes. Getting hit by an external source	2	Visual	2	2	Visual check
	Mechanical	Batteries can move causing some wire damage.	3	Assembly mistake.	1	Visual	1	3	Visual check
he tracks	Mechanical	Track system would'nt be able to perform.	3	Assembly/manufacturing mistake.	1	Visual, M	2	1	Visual check
tation from one whee to the other	Mechanical	The tracks system wouldn't provide the required traction	4	Assembly/manufacturing mistake.	2	Visual, M	1	3	Visual check
nts related to the wheels	MEchanical	Wheels may affect the performance on the track system.	3	Assembly/manufacturing mistake.	1	Visual, M	2	2	Visual check
ner vibrations/torque	MEchanical	Elements can fall after being exposed to movement, vibrations or torque.	4	Assembly/manufacturing mistake.	2	Visual, M	1	1	Visual check
e frame	MEchanical	Elements can get loosen	3	Assembly mistake.	2	Visual, M	1	2	Visual check
	Electrical	Lose communication between subsystems.	4	Wiring issues. External element could move the wires.	1	VIsual, E	2	1	Visual check, Electronics check

13.6 Appendix D: Gantt Chart



Reverse Engineering Robotics

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

Period Highlight: 11

ACTIVITY	START Week	End Week	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Weeks 1-16	1	1	1	1	100
Hardware Status 33%	1	5	1	5	100%
Team Meetings 1	1	1	1	1	100%
Team Meetings 2	2	2	2	1	100%
Client Meeting 1	1	1	1	1	100%
Wiring	6	9	6	3	90%
Battery Tray	8	8	8	2	50%
Front Axle Assem.	3	9	3	6	10000%
Rear Axle Assem.	3	9	3	6	100%
Hardware Status 67%	1	8	1	6	100%
Start Testing Plan	9	11	2	5	100%
Hardware Status 100%	1	12	1	12	100%
Sand & Paint	11	11	1	12	100%
Battery Tie down	11	11	1	12	100%
Ugrads Registration	9	2	4	8	100%
Draft of Poster	7	10	4	6	100%
Finalized Testing Plan	8	11	5	3	100%
Final Poster	13	14	13	1	100%
Final Powerpoint	13	14	13	1	100%
Initial Testing Results	9	13	8	3	100%
Final CAD Packet	1	13	1	12	100%
Product Demonstration	14	14	14	1	100%
Ugrads Expo	15	15	15	1	100%
Testing Results	8	13	9	7	100%
Spec Sheet Op Manual	9	15	9	6	100%
Client Handoff	16	16	16	1	100%