Design for Manufacturing, Reliability, and Economics

Team #11
Robo-Weeder
4/1/2016

Submitted to: Dr. Gupta (Faculty Advisor)
Jeff Phipps (Sponsor)

Authors: Steven Miller (ME)
Christopher Murphy (ME)
Arriana Nwodu (ME)
Aquiles Ciron (EE)
Steven Williamson (EE)
Zhang Xiang (ME)

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Abstract

The Robo-Weeder senior design project is sponsored by Jeff Phipps M.E., the owner of Orchard Pond Organics. Orchard Pond Organics is an 8 acre organic farm that has a pressing need for the assistance in weed control. The primary objective of the Robo-Weeder senior design project is to design and create a robotic system that will aid in this need by using a shearing mechanism to remove weeds on the seedbeds of planted vegetables. Team 11 has contacted and met with Mr. Jeff Phipps, the project sponsor, and discussed the final design. The final Robo-Weeder design has been approved by the sponsor as well as the faculty advisor and the final Robo-Weeder design has been built and tested by Team 11.

Acknowledgements

Team 11 would first like to thank our Faculty Advisors Professors Nikhil Gupta and Jerris Hooker. They've been invaluable in the development of the Robo-Weeder. They've guided us not only on the technical aspects, but also in team morale and because of that we learned to perform in an optimal and cohesive manner. We would also like to thank our team's sponsor Mr. Jeff Phipps of Orchard Pond Organics. Due to his vision of providing more nutritious food at a lower cost, thousands if not millions of low income families can have the option of a healthier diet. Finally we would like to thank the FAMU-FSU College of Engineering Machine shop as well as Brandon Shaw of the Applied Superconductivity center for aiding in the assembly process.

1. Introduction

The Robo-Weeder senior design project was created with the desire to improve the production rate of organic farms at a lower cost. The purpose of this year's project is to design and fabrication of a proof-of-concept robotic system that will assist in weed control on farms that cannot use pesticides or other conventional farming techniques. The use of advancing technology on farms is not a new idea, but it is becoming more popular.

Unlike traditional farming techniques that use tilling, herbicides and pesticides to control unwanted pests and weeds, organic farming use a more natural however labor intensive approach. Leaving the soil undisturbed promotes biodiversity, and promotes higher quality by allowing microorganisms such as earthworms to naturally aerate the soil. With the absence of chemicals and tilling methods to control pests and weeds, farmers are confronted with a massively labor intensive task that requires the manual removal of weeds from the seedbed.

The Robo-Weeder is approaching completion and our team of four mechanical engineers and two electrical engineers are confident that the robotic system will perform admirably when faced with the many challenges it'll face in the farming environment.

2. Design for Manufacturability

2.1 Complete Mechanical Assembly

The Robo-Weeder prototype can be broken down into four main subsystems: Frame, Steering & Drive, Auger, and Lift. Each subsystem needs to be assembled individually, then mounted to the central frame.

2.1.1 3-D Models

For simplification, the 3-D model and exploded view for each of the subassemblies can be found in Appendix A.

2.1.2 Tools

- Common and Phillips Screwdriver
- Socket Set
- Allen Key Set
- Adjustable Wrench
- Channel Lock or Vice Grip Pliers

2.1.3 Frame Assembly

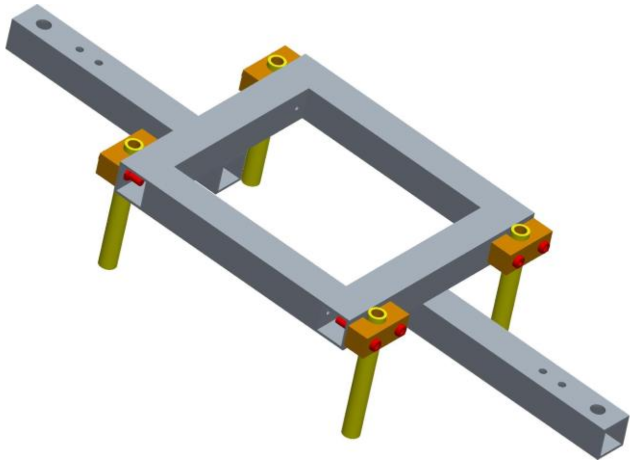


Figure 1: Frame assembly.

The frame of the Robo-Weeder is made of Aluminum square tubing that was welded prior to assembly. The vertical portion of the lift system also needed to be welded to the central portion of the frame. All other subassemblies will be attached to this central component of the chassis. The frame only needs four ½ inch bushings into the front and rear drive steering assembly mounting locations.

2.1.4 Drive & Steering Assembly

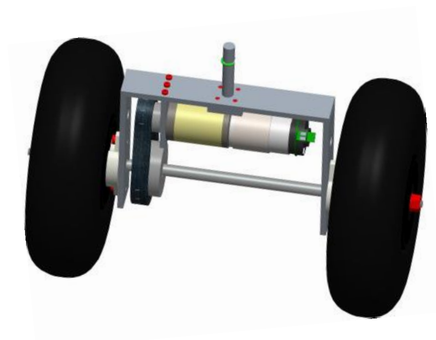


Figure 2: Steering assembly.

There will be two separate drive and steering assembly for the front and rear ends of the Robo-Weeder. For this assembly we needed, the socket set, Allen key set, and a pair of pliers. First we attached the steering pin into the main wheel housing by passing the pin up through the inside and use four bolts. Next, attach one flange bearing to the outer edge of each side of the main wheel housing using two bolts each. With the bearings now attached, we inserted the axle shaft through each bearing, making sure to mount the 18 tooth sprocket inside the wheel housing. We then secured the axles' position by pressing two e-clips into the two small grooves located on the inside of the wheel housing and secured the set screws onto the axle located on the flange bearings. With the axle and sprocket installed, next we inserted the ¼ inch shaft bushing in the upper hole on the wheel housing. We proceeded to mount the drive motor to the drive motor plate using 4 M4 screws, and installed the shaft motor shaft extension with the 10 tooth sprocket. Next we inserted the drive motor extension into the ¼ inch bushing and use three 5-32 screws to mount the motor to the wheel housing. Ensuring that the sprockets are aligned, we tighten the set screws on the sprockets to lock them into their prospective shaft. We finally, mounted each 10 inch diameter pneumatic wheel on either side of the wheel housing and secured the wheels with a locking nut. Next we prepared the steering motor for installation by using 4 M4 screws to attach the motor to the steering motor mount and installed the coupler onto the steering motor shaft. We repeated the process for the second drive and steering assembly.

2.1.5 Auger Housing Assembly

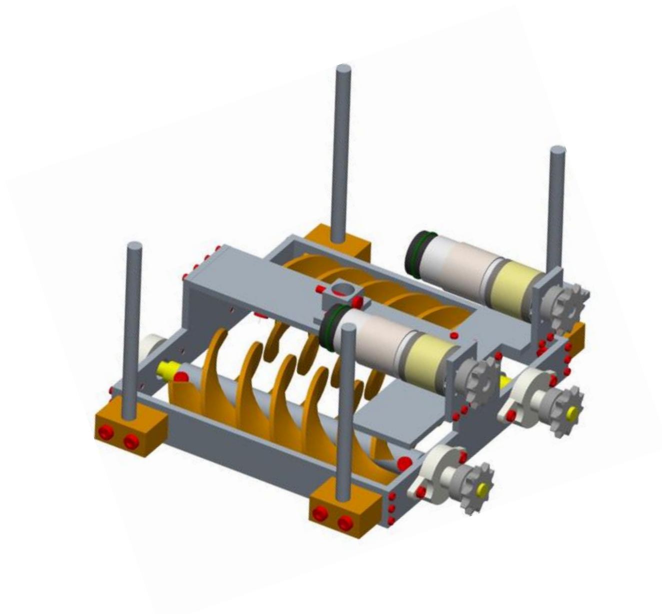


Figure 3: Auger assembly.

For the Auger Housing assembly we first prepared the socket set, Allen keys and pliers. It should be noted that the auger housing was designed to allow removal of the augers. We located the front, back, left, right, motor mount and top plates that make the main housing structure. We attached four two flange bearings onto both the left and right housing plates. We attached the right plate to the front, top and rear plates using ten 5-32 screws. At this time, we inserted the extension pins into their perspective auger and inserted the extended augers into the bearings installed on the right plate. Note: we needed to ensure that the auger with right hand flighting is installed towards the front of the auger housing. With the augers inserted into the right housing plate, we inserted the auger extensions into the left housing plate and attached it using ten 5-32 screws. We then proceeded to align the augers and tighten the flange bearing set screws. With the augers installed and the main housing assembled, we attached the auger motors to the motor mount plate, and attached 10 tooth sprockets to both the motor shafts and the auger motor extension pins and finally mounted the auger motor mount onto the auger housing top plate.

2.1.6 Lift Assembly

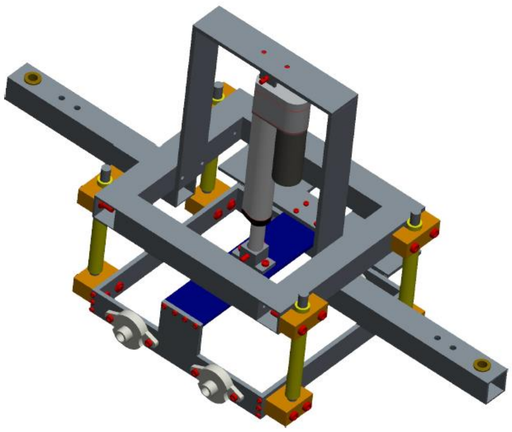


Figure 4: Frame and lift assemblies.

The lift system is a relatively simple structure that was mounted directly to the auger housing and the frame. The socket set is the only tool needed for assembly. We first located the four ½ inch diameter stainless rod and the four 1 inch steel tubes. These are the stabilizing posts of the lift system and serve to keep proper alignment. We loosely installed the inner and outer aluminum brackets to the auger housing front and rear plates using eight 5/16 inch bolts and locking hardware. We then inserted the ½ inch stainless steel rods between the aluminum brackets ensuring the rod is flush with the bottom of the bracketry and tighten the bolts. With the rods attached to the auger housing, we aligned the 1 inch steel tubes flush with the top of their perspective mounts, then install ½ inch bushings inside the steel tubing. Using eight 5/16 bolts and locking hardware, we installed the tubes onto the central frame such that the tubes protrude downward. Finally, we installed the bracketry on the vertical portion of the lift and the auger top plate for installation of the linear actuator.

2.1.7 Final Assembly

With each of the sub-assemblies completed, we raised the frame over the auger housing and slid the ½ inch rods through the bushings in the 1 inch steel tubing. We then took the auger housing to the highest position and installed the linear actuator using the provided pins. Next we inserted the steering pin of each drive and steering assembly through the bushings located on the front and rear ends of the frame. We then secured each assembly into their prospective locations by installing two e-clips into the small grooves on the steering pin just above the bushing. Locating the steering motor, we inserted the mounted coupler over the steering pin and mounted the motors of the frame using four 5/16 bolts and locking hardware. Finally, we locked the coupler to each perspective shaft by securing the set screws located on each coupler we also, installed the drive chain for each of the drive and auger motors.

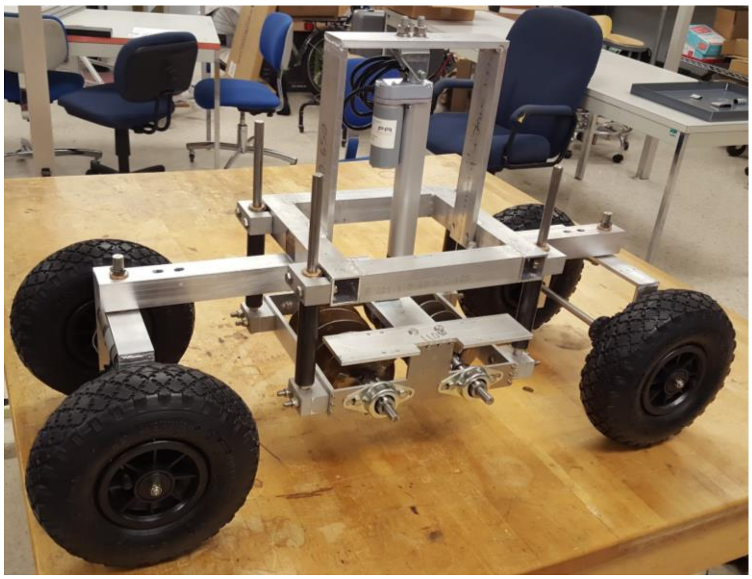


Figure 5: Robo-Weeder Prototype.

2.1.8 Completed Prototype and Components

The design team in charge of the Robo-Weeder project completed a single prototype but had plans to construct a wooden model for testing functionality. However, due to time constraints, the wooden model never came into fruition. The prototype took longer to design than originally expected due to the complex nature of the robots many components and subassemblies.

Components

QTY **Component Name**

- 4 10” Pneumatic Wheels
- 8 ½” Flange Bearings
- 6 10 Tooth Sprocket
- 2 18 Tooth Sprocket
- 4 Roller Chain (Variable Lengths)
- 8 E-Clip ½“ Shaft
- 2 AndyMark 71:1 DC Gear Motor with Encoder
- 2 AndyMark 188:1 DC Gear Motor

2	BaneBots 104:1 DC Gear Motor
2	Optical Encoder
2	Absolute Encoder
1	Linear Actuator - Firgelli Automations
2	Linear Actuator Mounting Bracket
12	5/16 - 18 Bolt (2.5” Length
8	5/16 - 18 Bolt (1.75” Length
30	5-32 Cap Head Screw
8	10-32 Cap Head Screws
10	1/4 - 20 Set Screws
24	1/4 - 20 Bolt (0.5” Length
10	1/4 - 20 Locking Nut
15	5/16 - 18 Locking Nut
12	½” Brass Bushing
2	¼” Brass Bushing

Total: **176**

Note: Raw Materials were purchased for the fabrication of unique components through the College of Engineering Machine Shop and the materials are listed below.

Materials

Material Description

- 1.5” Square Aluminum Tubing (0.125” Wall Thickness)
- 1.5” Aluminum Flat Bar (0.25” Thick)
- 2.5” Aluminum Flat Bar (0.375” Thick)
- 0.5“ Diameter Stainless Steel Rod (7’ Length)
- 1” Diameter Carbon Steel Tubing (3’ Length)
- 0.75” Diameter Stainless Rod (1’ Length)

The current Robo-Weeder prototype houses approximately 72 fabricated components from the machine shop bringing the final component count to 233. It should be noted that this count takes into consideration welded assemblies as 1 component. A large portion of the included components is comprised of bolts, screws and nuts and further consideration could be taken to weld more components therefore reducing the total number of components in the final prototype. The reasoning for not welding more components was for the ease of replacement or augmentation of the current prototype if any design changes were necessary.

2.2 Complete Electrical Assembly

2.2.1 Preparation for Assembly

The electronic system housed on the Robo-Weeder is diverse in nature and allows for the control of up to 6 DC motors. To control these 6 DC motors, three Roboclaw motor controllers are implemented along with an Arduino Mega. Each Roboclaw motor controller is able to control up to 2 motors each: 2 for the drive function, 2 for the steering function, and 2 for the shearing function. All of the electrical components will be housed inside of a sealed electrical box located centrally on the Robo-Weeder chassis.

In order to correctly attach all of the electrical components to their corresponding electro-mechanical components, wiring and connectors need to be prepared. To deliver power to all of the DC gear motors, 8 AWG power and ground cable is used to ensure proper current carrying capability. Furthermore, after sizing of the cabling, crimp style connectors are affixed to either end to ensure proper power transmission.

The coding process for the Robo-Weeder started out with different coding for each separate components; a separate code for the drive, the auger, and the steering system. The final code will be the combination of the entire components into a single master code, later to be downloaded into the microcontroller for field operational use.

2.2.2 Electrical Components

QTY	Component Name
1	Arduino Mega
3	Polulu Roboclaw Motor Controllers
1	Sabertooth Motor Controller
1	Flysky 6 Channel Wireless transmitter/Receiver
1	Polycarbonate Electrical Housing
1	25’ 8 AWG Power Cable - RED
1	25’ 8 AWG Power Cable - BLACK
2	8 AWG 40A Power Distribution Block
40	8 AWG Crimp Connectors

2.2.3 Electrical Installation

To begin the installation and assembly of all of the electrical components onto the Robo-Weeder, first attach the following components onto the floor of the electrical housing: 1 Arduino Mega, 3 Robo-Claws, 1 SaberTooth, and 1 Distribution Block. With the components in place, attach the appropriate power cabling between each motor controller and the power distribution block. Next, attach the appropriate power cabling between each motor controller and their perspective motors. Before connecting the distribution block to the battery, connect the power switch and fuse to the positive terminal of the battery, respectively. Finally, connect the negative terminal of the battery and the end of the fuse cable, from the positive terminal, to their respective distribution block.

The electrical system is a moderately simple system that uses a single microcontroller as the central processing point. The transmitter is used to control the Robo-Weeder's many functions. The receiver is directly connected to the Arduino Mega which will interpret the signal from the transmitter and send the corresponding signal to appropriate motor controller. To simplify the system, 2 channel motor controllers were used so that the total number of components could be reduced. **Figure 1** shows the following power connection of the Robo-Weeder:

1. 12V battery will supply power to the distribution blocks.
2. From the distribution block, power will be supplied directly to the three Roboclaw motor controllers and sabretooth motor controller.
3. The receiver and Arduino Mega will each be powered by a 5V power supply from a Roboclaw motor controller.

3. Design for Reliability

The primary electrical concern that is still remaining for the Robo-Weeder project is the available runtime provided by the power system. Three areas of interest were evaluated while determining the appropriate battery system: size and weight, capacity and cost. The primary factor affecting the battery system was the cost. This was due to the optimal battery with the appropriate size and capacity was determined to be too expensive.

Another electrical concern for the Robo-Weeder would be the steering function. The steering function is controlled using an absolute encoder attached to a DC motor and it is designed to turn approximately 20°. However, during testing of the steering function, it was hard to control due to the absence of a load. During testing of the steering motor, it would tend to over shoot its reference location when returning to center. It was suggested that the team test the steering function with a load on the DC motor in hopes of preventing the overshoot.

3.1 Reliability of Design

During a single test of the individual components, there was no visible stress on any single component. All mechanical components performed as expected. After inspection, there were no loose bolts or bent/failed components. After 100 uses, due to the quality of materials used, it is highly unlikely that any of the mechanical components would have failed. The component that would be under the highest stress is the auger. The auger assembly is made from high strength carbon steel and will be very resilient to stresses seen under normal operating conditions. However, due to the nature of the carbon steel some oxidation could be present if the protective coating has worn off. It is recommended that the parts of the auger that are not in contact with the soil be closely monitored for oxidation. When considering 1000 uses of the prototype, there is expected to be little to no physical damage to the structural components of the Robo-Weeder. Due to the operating environment of a farm and the moisture and dirt that is present, it is possible that after 1000 uses the flange bearings could begin to fail and that minor oxidation could be observed on the augers. However, due to the sealed nature of the bearings that were selected, their failure along with unwanted oxidation is still an unlikely occurrence if proper maintenance procedures are followed and the robot is used as intended. Finally, when considering a usage rate of 10,000 times, the design team still anticipates very little wear on the mechanical structure of the Robo-Weeder. However, it is entirely possible for motor failure to occur due to the rate of use. The Andymark motors used in the drive function of the prototype can tend to reach elevated temperature levels which could lead to a loss in performance or failure. Also, the flange bearings and oxidation of the augers could potentially be a threat at this level of usage. Finally, at a usage rate of 10000, wear of the absolute encoder could be a concern due to the physical rotation of the encoder shaft.

From the above analysis, the primary concern would have to be the flange bearings. These bearings are used with the drive shafts and the auger shafts and are in close proximity to the soil. Under dry conditions, they will most certainly be exposed to large amount of dirt that could potentially cause failure if the dirt managed to pass the bearing seals. For this reason, regular cleaning should be practiced to ensure dirt is flushed from problem areas.

Under prolonged usage, motor failure would be a significant concern. The motors that were used in the Robo-Weeder design may not be ideal as this prototype is mainly a “Proof of Concept” design. An upgrade of the drive motors would be the appropriate action to ensure reliability of the product under prolonged usage.

3.2 Failure Modes and Effects Analysis

Design teams often use failure modes and effects analysis or FMEA tools to analyze a given design to determine modes of failure. Team 11 conducted an FMEA of the Robo-Weeder and the full analysis can be seen in Appendix C. From the failure modes and effects analysis, it was determined that that DC motors and bearings were the most susceptible to failure during operation.

3.3 Finite Element Analysis

Another useful tool used by design teams is Finite Element Analysis or FEA. When constructing Computer Aided Design drawings or CAD drawings of the prototype, often times FEA will be conducted on components that are load bearing or are susceptible to failure. FEA analysis was conducted on several key components of the Lift system to ensure proper function and to lower the likelihood of failure. It was determined that the tested components were not at risk of failure at the conclusion of the analysis. The full results of the FEA analysis can be viewed in Appendix A.

4. Design for Economics

4.1 Current Prototype

The Robo-Weeder project was given a budget of $3,000.00. At the current status of the project, all components aside from the batteries have been purchased. With that being said, team 11 has spent a total of $2,594.07 leaving a remaining balance of $405.93. To properly power the Robo-Weeder prototype, the battery system would cost approximately $600 dollars which would exceed the budget for the design. Currently the largest portions of the budget were spent on the electronics and the electro-mechanical components with a total of 58% between the two. A complete breakdown of the spending associated with the Robo-Weeder and component costs can be seen in Appendix A. At completion of the Robo-Weeder project, the final prototype will cost approximately $3,500.00 - $4,000.00.

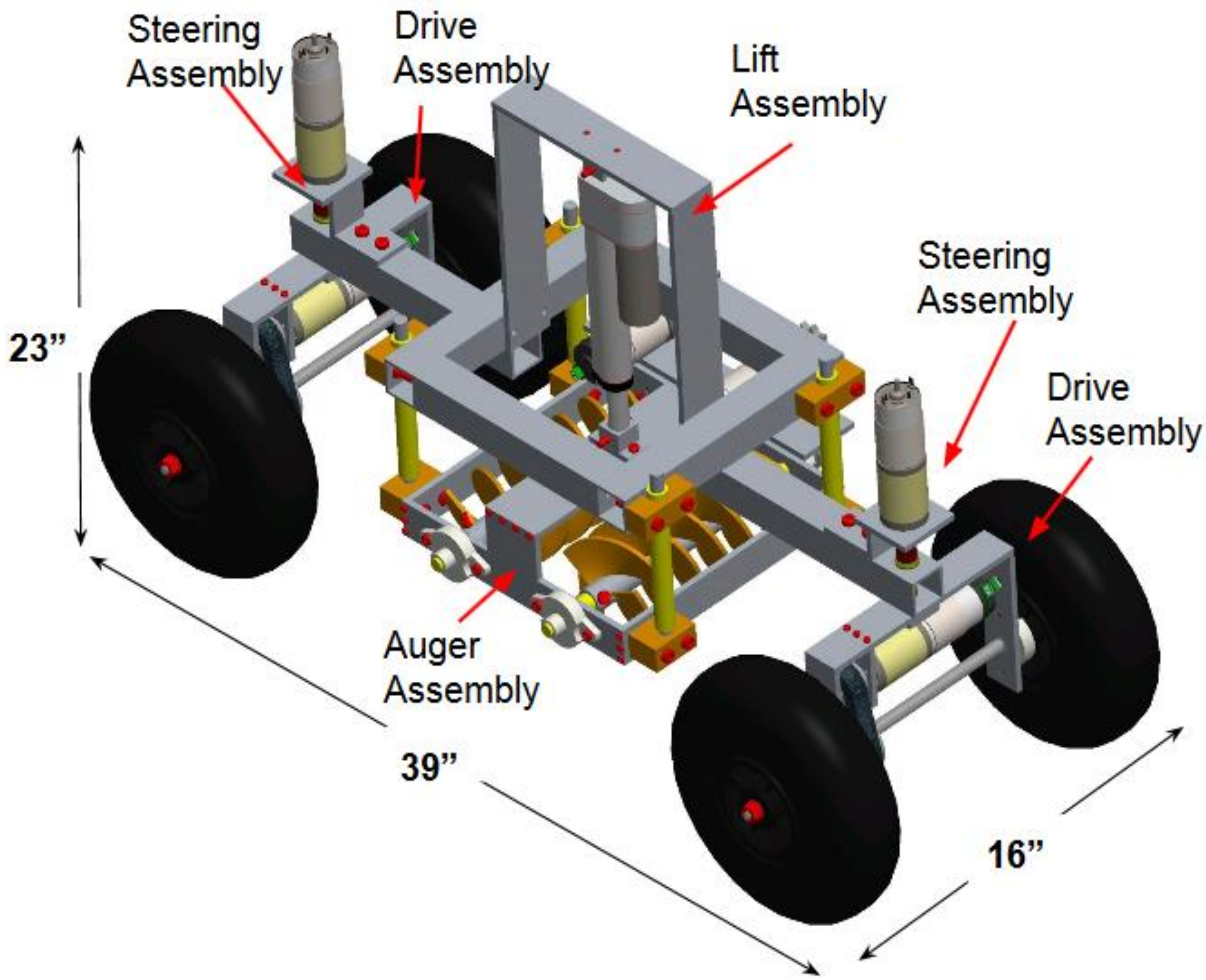
4.2 Market Competition

Currently there are no other devices in the market that have the capabilities of the Robo-weeder. The closest comparison to the Robo-Weeder project is a new robot from a Bosch startup called Deepfield Robotics. Their Robot named BoniRob currently is not available but presents clear competition to the functionality of the Robo-Weeder. Appendix A offers a comparison of some of the physical parameters between BoniRob and the Robo-Weeder.

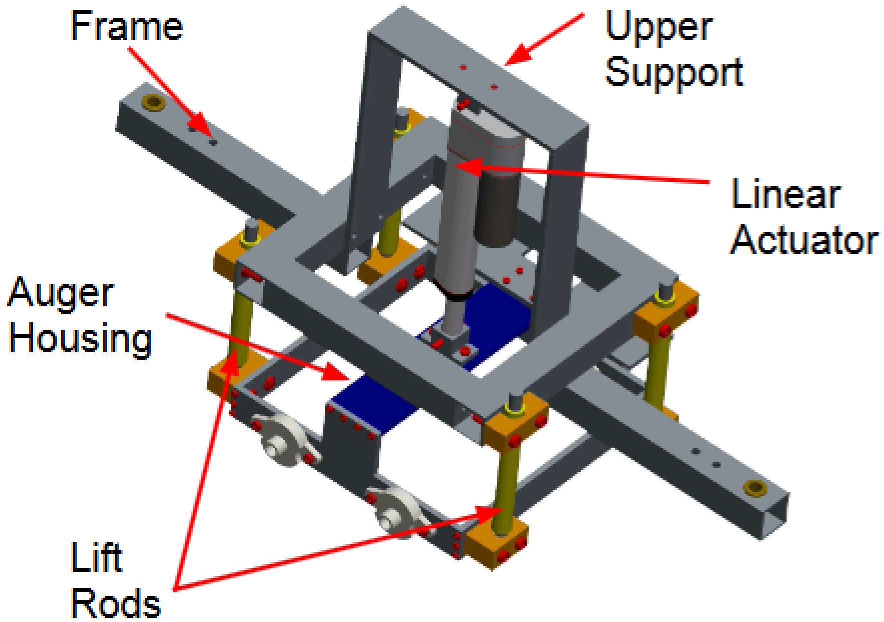
5. Conclusion

The Robo-Weeder senior design projects primary goal was to design and fabricate a remotely operated robotic system to aid in weed control on organic farms. The weeding mechanism that is housed on the Robo-Weeder is an auger design that will remove weeds by applying a shear force to the soils surface resulting in the uprooting of the weeds. The Robo-Weeder's many functions are controlled by six DC gear motors. The central unit controlling the electronics located on the Robo-Weeder is an Arduino Mega microcontroller which in turn sends signal to three Roboclaw motor controllers. The Robo-Weeder is designed to be operated by a user that is in close proximity to the robot allowing for quick corrections in weeding mechanism. The ability to manipulate auger speed and ground contact coupled with a much smaller size and reduced cost than its market competition makes the Robo-Weeder an ideal addition to organic farms.

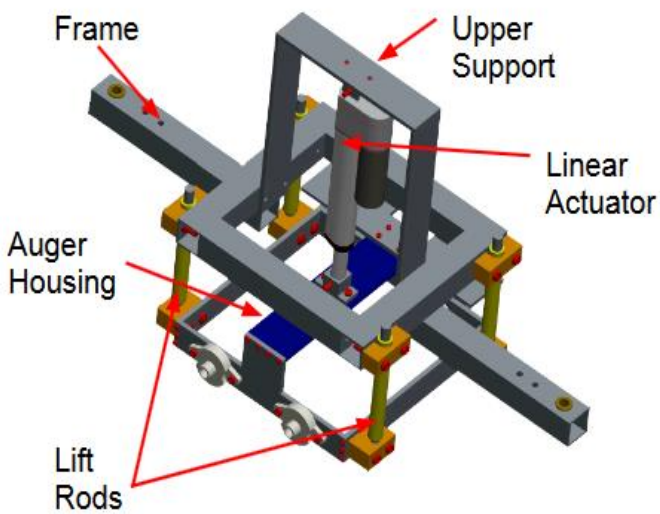
Appendix A

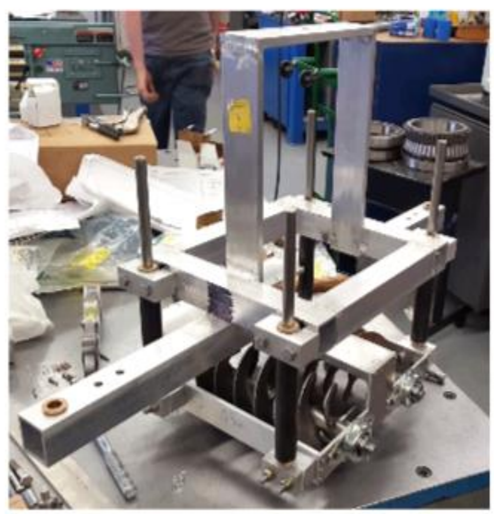


Full assembly of Robo-Weeder with subassembly labels.

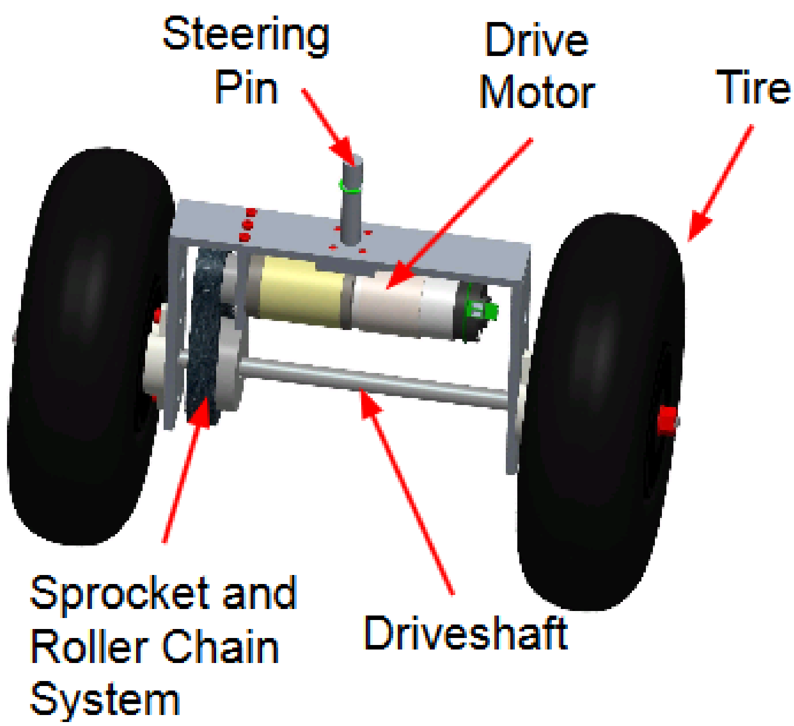


Frame and lift subassembly connected to auger housing, with labels.

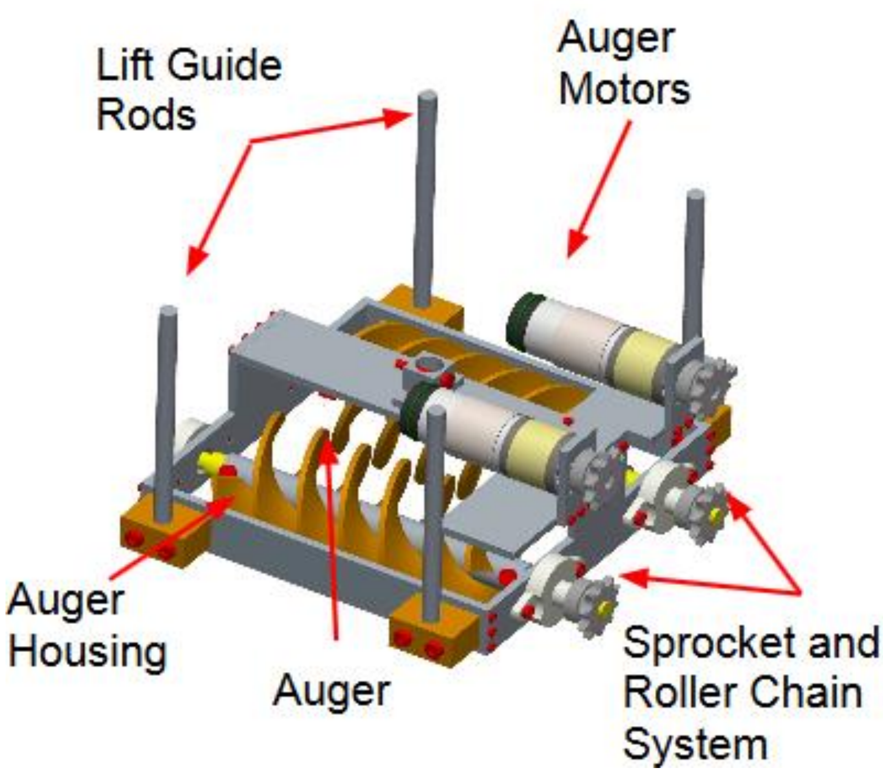




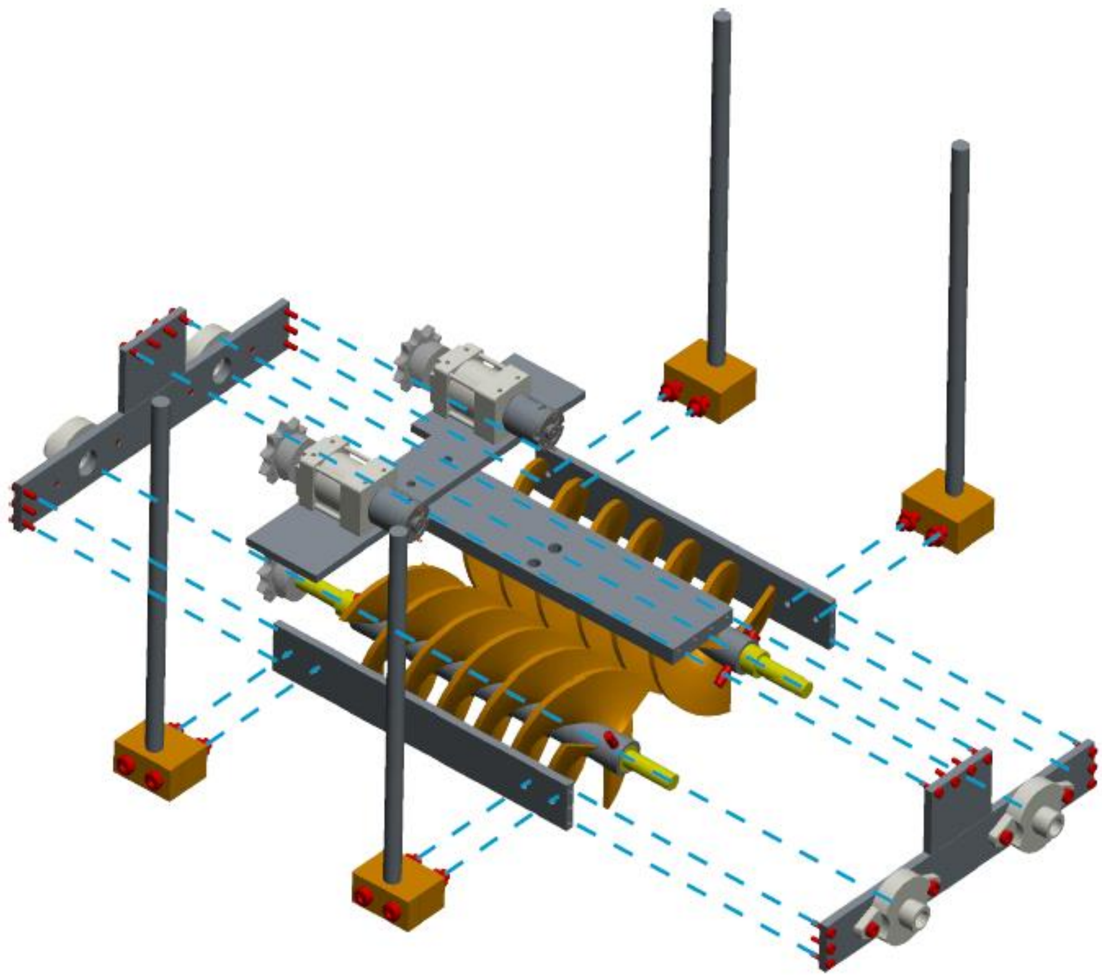
CAD and actual Robo-Weeder with frame and lift subassembly connected to auger housing.



Drive subassembly with labels.

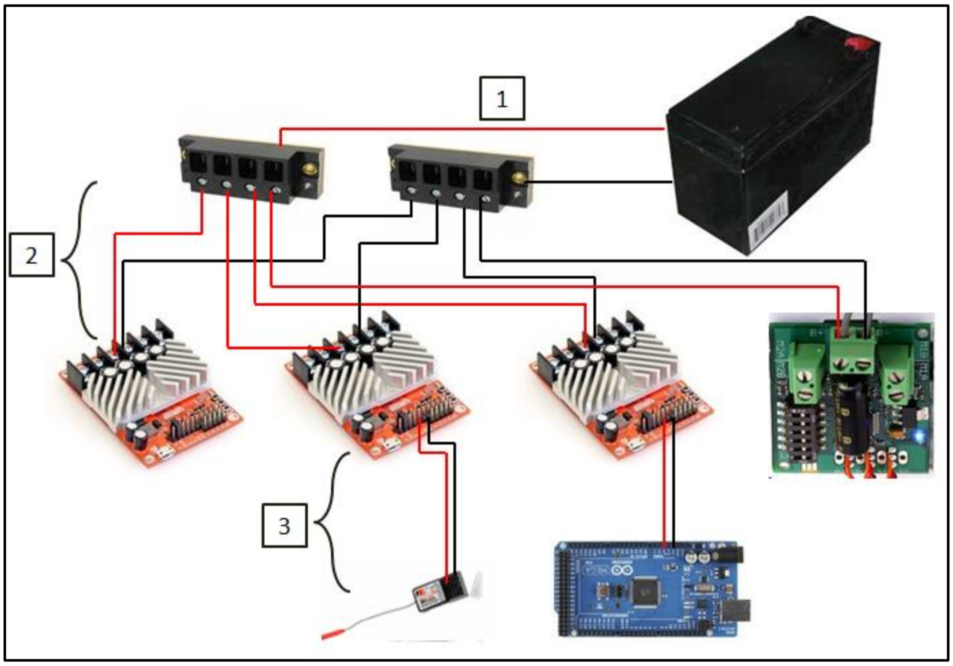


Auger subassembly with labels.

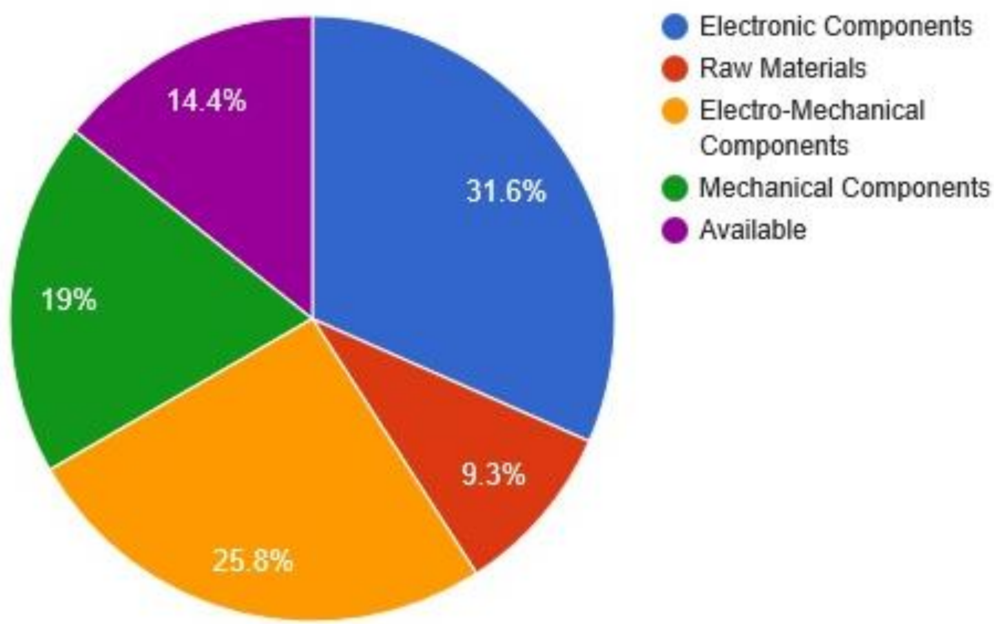


Auger Subassembly Exploded View.

Appendix B



Power connection between electrical components



Pie Chart of Robo-Weeder cost.

Team 11 - Robo Weeder	
Total Funds:	3,000.00
Running Balance:	405.93

Ordered Items					
Vendor	Item Description	Part Number	Quantity	Price	Total Cost
Robot Shop	Arduino Mega 2560 Microcontroller	RB-RIk-03	1	34.99	34.99
Robot Shop	Radiolink Transmitter and Receiver	RB-Ard-33	1	36.81	36.81
Bloom MFG	Auger Flighting - Right Hand	528	1	61.00	61.00
Bloom MFG	Auger Flighting - Left Hand	528L	1	61.00	61.00
McMaster	Material - AL Flat Bar and Tubing, Steel Rod and Tube	N/A	-	120.00	120.00
Northern Tool	10" Pneumatic Tire/Wheel	2252	2	9.99	19.98
Amazon	12V 30A DC Universal Power Supply 360W	S-360-12	1	23.97	23.97
Amazon	Heavy Duty Power Cord - 6 Feet	N/A	1	9.99	9.99
Amazon	16 Pack 2800 mAh Rechargable Batteries w/ Charger	N/A	1	39.99	39.99
Robotshop	PG188 Gearmotor - No Encoder (Steering)	am-2193a	1	79.00	79.00
Robotshop	PG71 Gearmotor w/ encoder (Drive)	am-2971	1	89.00	89.00
Andy Mark	Absolute Encoder w/ Cable	am-2899	1	45.00	45.00
Pololu	Roboclaw Motor Controller 45A continuous	2397	2	169.95	339.90
McMaster	Materials - 304 Stainless Rod and Flatbar	N/A	-	35.63	35.63
Grainger	1/2 Flange Bearing	4X727	2	21.22	42.44
Robot Shop	Arduino Mega 2560 Microcontroller	RB-RIk-03	1	34.99	34.99
Amazon	1/2 Brass Steering Bushing	EXEF081008	2	8.99	17.98
McMaster	1/2 Chain & 1/2 Sprockets	N/A	-	73.90	73.90
Amazon	FlySky FS-T6 2.4ghz Digital Transmitter	N/A	1	49.99	49.99
Andy Mark	PG188 Gearmotor - No Encoder (Steering)	am-2193a	1	79.00	79.00
Andy Mark	PG71 Gearmotor w/ encoder (Drive)	am-2971	1	89.00	89.00
Andy Mark	Absolute Encoder w/ Cable	am-2899	1	45.00	45.00
Andy Mark	Optical Encoder Kit	am-3132	2	42.00	84.00
Banebots	DC Motor - RS540 - 12V	M5-RS540-12	2	4.37	8.74
Banebots	P60 Gearbox: Standard, 104:1, for RS500 motor	P60S-554-5	2	67.95	135.90
polulu	Roboclaw Motor Controller 30A continuous	2396	1	124.00	124.00
Firgelli	Linear Actuator		1	119.99	119.99
Firgelli	Mounting Bracket		2	7.00	14.00
Dimension	Sabertooth 5A Motor Driver		1	59.99	59.99
McMaster	Nuts/Bolts/Materials/Sprockets/Chain/		-	272.89	272.89
Grainger	1/2 Flange Bearing	4X727	6	21.22	127.32
Digikey	Power Wire/Connectors		-	194.08	194.08
Vellaman	Electrical Housing	G378	1	24.60	24.60
				Total	2,594.07

Total breakdown of Robo-Weeder's individual component cost.

Appendix C

Process or input	Failure Mode	Failure Effect	SEV	Cause	PROB	Control	DET	RPN	Preventive Measures	Responsibility
Augers	Stops from tangled debris	Stalling of Motor	8	Large amount of debis present	3	Auger design prevents tangling	4	96	Ensure field is free of large debris items to include rocks and roots.	Operator
		Bending of Flighting	5	Large amount of debis present	3	High strength materials prevent failure	4	60		
DC Motors	Burns Up	Loss of function	8	Over Loading	3	Over Design	7	168	Ensure proper alignment	Operator
		Loss of function	8	Bearing Wear	2	Accurate Alignment	7	112	Clean bearings	Operator
Roller Chain	Derailing from sprocket	Loss of Drive/Weeding	6	Chain too loose	4	Proper spacing of sprockets.	2	48	Install a chain tensioner	Operator
	Link Breakage	Loss of Drive/Weeding	6	Over Loading	2	Over Design of Chain	8	96	Operate as intended	Operator
Tires	Flat Tire	Insufficient ground clearance	5	Wear, Age, Puncture	7	No Control	1	35	Remove debris items	Operator
	Lock Nut Failure	Loss of Drive	3	Wear	3	Locking compound on threads	5	45	Remove debris items	Operator

Failure Modes and Effects Analysis