FACULTY OF ENGINEERING AND APPLIED SCIENCE

ENGR4950U

Final Engineering Capstone Design Report

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G16-5-4 Electric Garden Tractor

Capstone Systems Design for Mechanical,
Automotive, Mechatronics and Manufacturing Engineering I
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Supervising Professor: Dr. Greg Rohrauer P.Eng

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Executive Summary

Between 2016 to 2025 the electric lawn mower market in the United States is expected to reach an absolute growth of 92% [1]. This research project is the "Electric Garden Tractor" and highlights the development of a retrofit conversion kit which converts an Internal Combustion Engine (ICE) lawn tractor to fully electric. The objective is to fabricate a conversion kit that is capable of mowing a moderately sized property which may take up to 3 hours. The electric garden tractor must keep the same functionality as its predecessor while requiring minimal fabrication and easy assembly. The target demographic for the conversion kit are customers that value their carbon footprint, green initiatives and novel DIY solutions.

As a society the safety and conservation of the environment needs to be prioritized. Canada and the US have implemented and continuously updated regulations and standards for the emissions of nonroad engines since 1994 [2]. It is expected that these standards will continue to become more stringent and require off road engines to produce less emissions. Electric solutions are of great importance to meet the current and future standards.

The design began by removing the original ICE components while retaining the variator drive system. The remaining tractor components and chassis were then restored.

An ME-1004 Brushed DC motor was selected to replace the original Kohler K241QS internal combustion engine. The motor provided adequate power and had identical shaft dimensions compared to the original engine meaning fabrication of an adapter to the drivetrain was unnecessary.

Modern Lithium ion battery technology was selected for their compact size, weight and power output capabilities. The conversion kit used 10 cell batteries taken from a 2016 Hyundai Ioniq.

Supporting components such as the Battery Management System (BMS) were selected to protect the battery from overcharging and discharging. Furthermore, an adequate cooling system was incorporated to keep components near optimal operating temperatures.

Preliminary concept designs were generated utilizing pictures of the restoration process. It was deemed that positioning the batteries vertically would yield better packaging and cooling. A motor mount was generated using CAD to position the motor shaft in the exact same position and orientation as the original Kohler engine.

Analysis was completed on both the motor mount and battery tray. Max torque was supplied to the prototype mound which resulted in minimal deflection. The battery tray was simulated to hold the 80lbs weight of batteries and deflected minimally.

Lastly, all fabricated components and subsystems were wired together. Final tests were conducted to ensure that all components are working together as intended and fine tuning of the tractor was done using an external laptop connected to the Alltrax motor controller.

Design Problem Definition and Objectives

Problem Definition

This capstone project performed an analysis and built a proof of concept to prove modern electric motors and batteries are suitable for converting residential lawn garden tractors into greener, more user friendly and possibly cheaper alternatives to conventional ICE lawn tractors. The electric tractor consists of many different subsystems which work seamlessly together to achieve the original ICE motor and configuration functions.

Literature Survey

The creation of a viable electric tractor has been attempted many times in the past century. The first potential attempt at electrifying a tractor was created by the Zimmermann company in 1894, in Germany. [3] However, the end result offered little benefit over existing solutions and the product seemingly ended. In 1968, General Electric began development of the Electrak electric garden tractor. [4] However, this product line also failed just a few years later. Largely due to inadequate power and battery life offered at the time. Despite this, the Electrak retained a niche following, with both a dedicated mailing list and owners club. [5] In recent years, the advancement of battery and electric motor technology has allowed a number of electric garden tractors to be produced commercially, to a point of relative market saturation. However, the majority of these options are relatively expensive with retail prices ranging from $3000 to $7000. Furthermore, many of the electric garden tractors on the market today are focused purely on grass cutting, and relatively incapable of more demanding tasks. [Table 1]

Previous Conversions

As the trend towards replacing internal combustion engines with electric systems continues, it comes as little surprise that projects similar to this have already been done. For example, in 2020, an electric conversion was done on a John Deere 214 series tractor. [6] This conversion utilized a brushed motor at 36 V, three AGM batteries, and did not utilize any kind of motor controller. While the end result was a capable machine, the motor would have been able to run at a higher power 48 V, giving a substantial increase to power. Furthermore, the AGM batteries which were utilized left much to be desired with regards to the run time of the tractor, as the capacity, as well as the depth of discharge, is significantly less than lithium ion batteries. Furthermore, without a motor controller, this particular conversion may not be operating at an ideal efficiency.

Emissions

When considering the environmental impacts of emissions from internal combustion engines, most arguments generally tend to discuss the outputs of cars. However, small engines, such as those utilized in lawn mowers, and garden tractors, are significantly less efficient than those in vehicles meant for transportation. According to the government of Canada, running a lawn mower for just one hour will produce as much air pollution as driving 480 km. [7] This creates a strange situation, in which someone may use an electric vehicle with the intention of limiting their emissions, only to produce more emissions in one day cutting their lawn, then the entire week of driving.

Battery Technology

For the purpose of this project, it is intended to utilize lithium ion batteries. Based on research, lithium ion based batteries are widely utilized in electric vehicles, as they provide a much faster charge and discharge rate compared to older technologies, such as lead acid. Furthermore, the volumetric energy density of lithium ion batteries is significantly higher than older technologies at close to 250 Wh/kg. There is interest from many industries to push this density higher, towards 500 Wh/kg. [8] This indicates that lithium ion batteries still have a long development lifespan, and will likely continue to be utilized in electric vehicles for the foreseeable future. As the current trend of these vehicles becoming more popular continues, the amount of discarded lithium ion batteries available on the market will also likely see an increase.

Motor Technology

When considering the motor technology currently available on the market, targeted specifically for motors of an appropriate power and size for this project, the primary point of consideration becomes brushed versus brushless motors. Brushed motors are much cheaper to construct, can be rebuilt, do not require expensive motor controllers, and do not require a controller for a fixed speed. However, these motors are also inefficient at certain power ranges, require maintenance, and are often bulkier than a brushless motor of the same power. Brushless motors require minimal maintenance, operate with high efficiency at most speeds under their rated load, and generate significantly less electric noise. [9] However, brushless motors are significantly more expensive, and generally require an additional expensive motor controller in order to function. Ultimately, the decision regarding motor technology comes down to a cost benefit analysis.

Noise Comparison

A consequence of retrofitting an existing internal combustion engine based lawn tractor to utilize an electric motor is a potential significant reduction in noise. Given the nature of internal combustion engines, they produce significant amounts of noise while in operation. This noise can range anywhere between 86.5 to 96.4 dBA. Moreover, when the cutting blades are in operation, this range can increase anywhere from 1.2 to 7.9 dBA. [10] This level of noise is significant enough that it necessitates hearing protection for those exposed to it with regularity. An electric motor, however, produces significantly less noise, as there is no combustion and expansion of fuel, only the noise produced by mechanical vibrations. By reducing the noise of a lawn tractor, the overall safety of the vehicle may increase. As the reduced noise allows a user to be more aware of their surroundings.

Economic and Market Analysis

After conducting an in depth market analysis and competitor research. It became apparent that most low end electric garden tractors provide a 48 volt system while the more expensive tractors provide a 56 volt system. In addition they provide fast charging capabilities and use lithium-ion batteries. These batteries on average deliver 60 Amps per hour with around 2 kwH of power. This implies that more expensive garden tractors can run from 1 to 1.5 hours on a single charge. Equaling a lawn mowing coverage of just 1 to 1.5 Acres of land. Therefore, the minimum objective of this capstone project is to develop a conversion kit that delivers current or exceeds industry standards.

Retail Options

The market is currently becoming saturated with new electrified versions of the garden tractors ranging in size and capabilities offered from all major big box stores. Manufacturers such as Ryobi, Cub Cadet, Craftsman and Ego all have designed their first electrified models of their garden tractor / garden lawn mowers from their gasoline powered line up. These prices range from the mid three thousand to the high end seven thousand Canadian dollars. While their gas powered counterparts are half that price.

	Ryobi [11,12]		Cub Cadet [13,14,15]			Craftsman [16,17]		Ego [18]
	30" 50 Ah	42" 75 Ah	XT1 LT42E	CC 30E	ZT1 42E	E150 30"	E225 42"	Power+ 42"
Model #	RY48131	RY48ZTR 100CAN	33ABA7E S596	33AA27J D80	34ABA2C S596	CMXGR AM11300 49	CMXGR AM20330 1	ZT4204L
System	48 Volt,	48 Volt	56 Volt	56 Volt	56 Volt	56 Volt	56 Volt	56 Volt

Output	DC							
Motor	3 Brushless Motors	4 Brushless Motors	1 Brushless Motor	1 Brushless Motor	2 Brushless Motors			4 Brushless Motors
Batteries	50 Amps / Hour	75 Amps / Hour	60 Amps / Hour	30 Amps / Hour	60 Amps / Hour			60 Amps / Hour
Watt Hours			3000 Wh	1500 Wh	3000 Wh	1500 Wh	2250 Wh	
Battery Type	Lead Acid	Lead Acid (Lpc12-75 , Lpc12-10 0)	Lithium - Ion	Lithium - Ion	Lithium - Ion	Lithium - Ion	Lithium - Ion	Lithium - Ion
Run Time	1 Hour = 1 Acre per Charge	1.5 Hours = 3 Acre per Charge	1.5 Hours = 2 Acre per Charge	1 Hour = 1 Acre per Charge	1.5 Hours = 2 Acre per Charge	1 Hour = 1 Acre per Charge	1 Hour = 1 Acre per Charge	
Charge Outlet	120 Volt	120 Volt	120 Volt	120 Volt	120 Volt	120 Volt	120 Volt	120 Volt
Fast Charger	No	No	Included	Included	Included	Included	Included	Included
Charge Time	7 Hours	12 Hours	4 Hours	4 Hours	4 Hours	4 Hours	4 Hours	2 Hours
Deck Type	Mid Mounted	Mid Mounted	Mid Mounted	Mid Mounted	Mid Mounted	Mid Mounted	Mid Mounted	Mid Mounted
Deck Size	30 Inch	42 Inch	42 Inch	30 Inch	42 Inch	30 Inch	42 Inch	42 Inch
# of Cutting Blades	2 Blades	2 Blades	2 Blades	1 Blade	2 Blades	1 Blade	2 Blades	
Cutting Height	1.5 - 4.5 Inch	1.5 - 4.5 Inch	1 - 4 Inch	1.5 - 4 Inch	1 - 4.5 Inch			1.5 - 4.5 Inch
Turning Radius	16 Inch	Zero Turn'	16 Inch	18 Inch		18 Inch	5 Inch *	
Weight						350 lbs	590 lbs	
Forward Speed	5 Mph	7 Mph	5.5 Mph	4 Mph	6 Mph	5 Mph	6 Mph	8 Mph
Reverse Speed	3 Mph	4 Mph	3 Mph	2 Mph	3 Mph	2.5 Mph	3 Mph	

Warranty	3 Years w/ 1 year on battery	4 Years w/ 1 year on battery	3 Years unlimited hours, 5 Years frame, 5 Years Front Axle and 4 Years Battery	3 Years unlimited hours, 3 Years frame, 3 Years Front Axle, 3 Years Deck Shell and 4 Years Battery	3 Years unlimited hours, Frame Limited lifetime, Deck Shell Limited Lifetime, 4 Years Battery	3 Year Limited Warranty and 3 Year Battery Warranty	3 Year limited warranty	5 Year tool, battery and warranty
Price	$ 3,298 CAD	$ 5,498 CAD	$6,299 CAD	$4, 499 CAD	$6,999 CAD	$3,287 CAD	$4,425 CAD	$6,999 CAD

Table [1]: Retail Competitors

Battery types

The market standard for current electric garden tractors is lithium-ion (Li-Ion) batteries although some competitors, including Ryobi, still use deep cycle lead-acid batteries. The battery types used by various competitors can be observed in Table [1]. Lithium-ion batteries were determined to be the best fit for this project.

The main benefit lithium-ion batteries have over other battery types is their high cell voltage capabilities. Fewer cells are required to produce the same amount of charge and as a result these batteries weigh less compared to other battery types. Other major benefits include a large cycle life with the ability to withstand deep cycling and a low self-discharge rate [19]. Together these benefits allow for a battery which is able to run for an extended period of time.

The main issue with lithium-ion batteries is their high cost especially for high power applications. Other shortcomings include their ability to degrade at higher temperatures and lose capacity when overcharged [19]. These drawbacks can be minimized by implementing adequate cooling systems and battery management systems to prevent over charging and discharging.

Lead-acid, nickel-cadmium, nickel-iron and nickel metal hydride battery options were explored but were found to have shortcomings. Lead-acid batteries are less expensive however they have low cycle life, low energy density and poor charge retention with a moderate energy efficiency of roughly 70%[19]. These batteries are good at starting a car but they are poor at running electric vehicles.

The main issue with nickel-cadmium batteries is known as "memory effect". This type of battery loses capacity when charged after being partially discharged. Nickel-cadmium also has lower cell voltages. Nickel-iron and nickel metal hydride batteries both have low cell voltages and high self discharge which make them less optimal to run an electric vehicle over an extended period of time [19]. These batteries can be substituted but would perform substandard to a lithium-ion battery option. A comparison of secondary (rechargeable) battery types can be seen in Table [2] below.

	Pros	Cons	Capacity (Wh/kg) [20]	Nominal Cell Voltage (V) [20]
Lead-Acid [19]	- Most popular and most used - Have been around for a century - Available in different forms and capacity sizes - Used primarily as starting lighting and ignition - Electrical efficiency 75-85% - Least expensive - Deep cycle is available but is heavier and bulkier	- Low cycle life - Low energy density - Poor charge retention - Not suitable for fast charging - Must be stored in a charged state - Regular maintenance required - Heavy and bulky - Very toxic	30.0 - 50.0	2.00

Lithium-Ion (Li-Ion) [19]	- High cell voltage - Fewer cells required - Very high energy density (approximately 4x larger than lead-acid) - Large cycle life - Very low self-discharge rate - Deep cycling - Low weight - Fast charging possible - Withstand extreme temperatures - Low maintenance	- Expensive - Degrades at higher temperatures - Capacity loss when overcharged -Degradation below certain voltage	100 - 250	3.70
Nickel-Cadmium (NiCd) [19]	- Old technology - Long life, reliable and sturdy - Able to withstand higher discharge rates and temperatures - Good shelf life - More expensive than lead-acid - Second to lead-acid in low temp performance - Low discharge rate - Low maintenance	- "Memory effect" - Lose capacity when discharged partially then recharged - Restoring lost capacity is expensive - Damaged when overcharged - Low cell voltage - Cadmium toxic	45.0-80.0	1.20
Nickel Iron (NiFe) [19]	- Less expensive than NiCd - Good durability - Long cycling - Long-standing life - Remain uncharged for a long time - Deep cycling is possible - Can be overcharged without damage	- Low power and energy density - High self-discharge - Expensive - Very heavy and bulky - Low cell voltage	60.0	1.20
Nickel Metal Hydride (NiMH) [19]	- Less expensive than NiCd - Robust - Withstand overcharge - Deep cycling - Can remain uncharged for a long time - Long cycling - Very long lifetime - Higher specific energy and energy density than NiCd	- Low cell voltage - Very heavy and bulky - Low reactivity (slow charge and discharge) - Low energy density - Large self-discharge rate	60.0-120	1.20

Table [2]: Battery Types

Electric motors - Preliminary Research

In order for this electric conversion kit to be attractable for the consumer. It must also have the adequate performance capabilities to perform the tasks intended to do. Therefore, as previously mentioned in this report. The new Brushed DC Motor must have a minimum power output equivalent to the original Kohler K241QS engine or more. A minimum target of 8 kW of power at a speed greater than 3,000 rpm. Additionally, in order to keep manufacturing costs to a minimum. A similar or same size output shaft was to be outfitted by the motor supplier. To allow a direct fit to the existing Variable Drive Transmission of the tractor.

Research was conducted to find the most suitable DC motor available on the market. However, only 'Motenergy' had powerful enough brushed DC motors that were able to conform to our specifications, size restrictions and budget. The table below summarizes all important criteria for five different 'Motenergy' motors when compared to the original ICE engine.

	Current John Deer 210		Target Specification	Supplier - Motenergy Brush - Type Permanent Magnet DC Motor				
Model	Kohler K241	Model	Target Outputs	ME-1004 [21]	ME-1003 [22]	ME-1602 [23]	ME-0909 [24]	ME-0708 [25]
Voltage	N/A	Voltage	48 - 56 V	24-48 V	12 - 72 V	24-48 V	12-48 V	24-48 V
Power	10Hp= 7.457 kW	Power	Min ~ 8 kW, Max ~10 kW	8kW continuous @ 48V, 16 kW for 1 min @ 48 V	11.5kW continuous, 20 kW peak for 30 seconds @ 72 V	6.4Kw continuous @ 48 V, 16 Kw for 1 min @ 48 V	4.8Kw continuous, 15 Kw for 30 seconds	4.8Kw continuous and 15 Kw for 1 min
Speed	3,600 rpm	Speed	Above 3,000 rpm	3360 rpm @ 48V	3700 rpm @ 72V	3360 rpm @ 48 V	3,984 rpm @ 48 V (83 rpm per volt)	3360 rpm @ 48V
Motor Size	4.68"x4.33" x 3.38"	Motor Size		8" Outer Diameter, 6.4" Long	8" Outer Diameter, 7.42" Long	8" Outer Diameter, 6.4" Long	6.88" Outer Diameter, 6.29" Long	8" Outer Diameter, 5.5" long
Shaft Size	1"	Shaft Size	1"	1" x 3.1", ¼" key shaft	⅞" x 1-⅝", 3/16" key	⅞" x 2.3", 3/16" key shaft	⅞" x 1-⅝", 3/16" key	⅞" x 1-⅝", 3/16" key
Weight	118 lbs	Weight	Max 40lbs	30 lbs	36 lbs	30 lbs	24.1 lbs	28 lbs
Amps	N/A	Amps	200amps continuous	200amps continuous	200amps continuous	200amps continuous	N/A	100amps continuous and 300 amps for 1 min
#of Brushes	N/A	#of Brushes	2+> # of Brushes	Double Brush	Double Brush	Double Brush	N/A	N/A

Price	N/A	Price	<$800 USD	$585 USD	$680 USD	$550 USD	$428 USD	$535 USD

Table [3]: Electric motors

Problem Definition Statement

Battery Life

The battery life and range is one of the most important aspects of this conversion kit. The customer expects to mow their moderately sized property which may take up to 3 hours. The battery will be required to power the electric motor with sufficient energy to perform garden tasks and stay within safe operating temperatures. The tractor is expected to also perform in winter conditions to snowplow a residential property. Thus, batteries utilized must be sufficient to power the systems in a variety of temperature range and operating conditions.

Motor Requirements

The electric motor and batteries provided in this kit must satisfy consumer requirements. Such as overall tractor power, battery life, charging capabilities, use of external attachments, noise and safety. The final product must at least meet the current power requirements set forth by the current gasoline engine. The electric motor must have enough power output to propel the garden tractor, mow the lawn, pull trailers and be able to operate a snowblower attachment in the winter. The goal is to provide the consumer a garden tractor that can compete directly with traditional gasoline powered tractors.

Motor Controller Requirements

The motor controller which will be implemented must be capable of withstanding the voltage and current output of the batteries, ensuring that it does not fail during use. The batteries will output a nominal voltage of 72 V, and have an estimated maximum discharge rate close to 5 C, about 400 A. The motor controller must be able to handle these as peak inputs, as well as continuously handling 200 A.

Battery and Thermal Management

In order for this project to be a viable option, the electric converted tractor must have an acceptable service life. In order to maximize the service life, care must be taken to ensure that the batteries and motor, and other electrical components do not reach temperatures which would cause degradation. Lithium Ion batteries will generally lose significant performance when reaching temperatures above 60℃, and even run the risk of combustion as they reach temperatures greater than this. Furthermore, the lithium ion batteries have a depth of discharge of approximately 80%. Meaning that discharging them below this amount will result in degradation of the cells over time. The objective regarding this issue then, is to implement cooling solutions for the electrical components, as well as a battery management system to prolong the lifespan of the batteries.

Auxiliary Systems

The original John Deere lawn tractor included some auxiliary components such as lights, and a horn. These systems will need to be adapted to the new electric system. With the original system voltage being a 12 V system powering the lights and horn. A DC to DC converter will be required to change these auxiliary systems from the higher nominal battery voltage. Some additional auxiliary systems such as a cooling system and charging for electronics via a usb port are some systems that will need to be powered as well.

Safety Systems

The conversion kit must also account for the original factory safety systems. The original gasoline version included safety switches to ensure the vehicle is in a safe configuration before starting. The seat also activated a safety switch to ensure the operator was in a safe position when operating the lawn tractor. A safety switch was wired in parallel with the seat switch to ensure the PTO was not engaged. All of these switches should be adapted to the electric conversion to retain and improve the safety of the lawn tractor. Additionally, a temperature sensor will be incorporated in the fan circuit to ensure the fans will cool the electronic components when needed in operation.

Charging

The charging options included in this conversion kit must be compatible with any residential or public setting. A Level 1 charger for basic home charging is the minimum requirement as these chargers are directly connected to 120V wall outlets but charge slowly [26]. Charge times must be competitive with other available market options. Fast charging will not be included because it was not required by the customer however the option may be available in the future. Since the conversion kit will use batteries salvaged from older vehicles and new purchased batteries various charging options were explored.

Mechanical Function

Regarding the mechanical function of the retrofitted John Deere 210 garden tractor, very little will change with regards to the end functionality. This is largely in part due to the original drivetrain remaining in place, with only the gasoline engine and fuel tank being replaced with an electric motor which has comparable, if not more power, and batteries.

Weight

Weight is an important factor when attempting to ensure that the chassis still functions as it was originally designed. Furthermore, to simplify the process of speccing out an electric motor with similar power to the original internal combustion engine, the change in weight from the internal combustion engine, fuel tank, and additional fittings versus the electric motor, batteries, and additional electronic components must be considered. If the later weight is significantly less than the original weight, then this can be easily fixed by adding weights to the tractor. If the electronic components are significantly heavier than the internal combustion engine and supporting components, it could require significant modifications in order to retain original functionality.

Wiring and Electronics

Regarding the electronics and wiring of this project, it is of significant importance that all electrical components are off the shelf, and either readily available, or interchangeable. For example, the batteries in this project are from an electric vehicle. Which could easily be changed out for alternate batteries if they were not available. When considering the wiring solutions for the electrical systems, it is very important that the design is simple, and easy to understand, so as to be repeatable.

Part Availability and Cost

Keeping the end user in mind, this retrofit utilizes as many off the shelf components as possible, keeping fabrication minimal. The only components which require fabrication are brackets which will be utilized to mount the components to the tractor. Furthermore, as the components which will be utilized are off the shelf, and not proprietary, they can be easily swapped and interchanged for other components of similar specifications if availability requires it, with minimal modifications. Assuming one were to attempt this project without having any of the components on hand, it would cost an approximate $5,908.61 CAD. However, in the more likely and intended case that the end consumer already owns a garden tractor which they will retrofit, this estimate drops to $4,908.61 CAD.

For a thorough breakdown of the cost to perform this retrofit, as well as the cost of individual components, a complete bill of materials is given further below in the report.

Criteria for Success

The primary criteria for which success will be judged on the creation of a proof of concept electric garden tractor. The tractor will be able to perform all regular lawn cutting duties and as well as be able to use additional lawn implements such as snowplows and landscaping tools. The electric garden tractor needs to be able to perform all original tasks of the gasoline version. The conversion will require sufficient battery life to mow a moderate to large residential lawn. The electric motor must also perform at the level of the gasoline motor or exceed its performance. During operation the garden tractor must have safety features implemented to ensure the operator is safe at all times. Maintenance, weight and noise should also be reduced to improve the user experience in owning and operating a lawn tractor. The overall cost of the conversion should also be comparable to current electric garden tractors available at major retailers.

Project Objectives

The project objective is to produce a proof of concept to ensure that this electric lawn tractor kit has:

i) More run time than competitors
ii) Same functionality
iii) Minimal fabrication
iv) Easy assembly

The tractor provided for this project was manufactured in 1975. However, the John Deere 210 lineup was proceduced from 1975 to 1987. These garden tractors were well known for their exceptional robustness and durability when it came to performing its tasks in the field or garden.

Motor and Drivetrain

When designing the electric conversion kit for this tractor. The main objective was to retain all its minimum designed functionalities and performances as compared to its gasoline counterpart. This means that the electric garden tractor must be able to mow the lawn, pull trailers, plow the snow, hoe the ground, etc. While also having a minimum power output as the original Kohler K241QS engine or more. This was a single cylinder, air cooled system design with a power output of 10hp running at 3600 rpm. This translates to 7,457 W or 7.5 kW of power. Since, the power output of gasoline engines is measured by a unit called Horsepower.

Electric motors are measured in a unit called Watts. Therefore, in order to have a minimum baseline for the new DC electric motor. They both must be converted to use the same unit of power.

Originally, this 0.4L gasoline engine power output was then sent to a four speed gear transmission and variator drive with 4 forward fears, and one reverse called a variator drive system. This transmission allowed the motor to run at a constant rpm. While the engagement speed of the tractor can be adjusted through the use of the clutch pedal. [27] This configuration is optimal for cutting grass, as it retains the engine's high rpm between 2,800 and 3,200. However, in order to keep overall costs and fabrication to a minimum. The tractor's variator drive system for this conversion will not be altered in design and will retain its original purpose. The electric DC motor drive shaft will be positioned in the same orientation as the original Kohler engine.

Battery

In order to provide enough energy capacity to fuel the DC motor. It was chosen that the latest available battery technology is to be utilized. Extensive research was conducted to evaluate all different types of batteries available in the market. (See Economic and Market Analysis for more in depth comparison analysis) It was chosen that lithium-ion batteries would be the best fit for this project. Mainly due to their high cell voltage capabilities and reduced weight due to having fewer cells to produce the same amount of charge. Additionally, they are able to withstand deep cycling and have a low self-discharge rate. Some shortcomings of using lithium-ion batteries is their ability to degrade at higher temperatures and lose their capacity when overcharged.Therefore, an integrated cooling system with fans and duct work will be designed to help cool both the DC motor and the batteries.

Weight Analysis

Furthermore, the weight of the original Kohler K241QS engine is 53 kg. [27] With a fuel tank of 13.2L, [28] assuming a gasoline density of 0.72 kg/L, and increasing the estimate in order to account for fittings, hoses, as well as the weight of the fuel tank itself, gives an approximate weight of 75 kg for the gasoline system.

When considering the weight of the electric system, the ME1004 electric motor has a weight of 14 kg. [29] The battery modules which will be utilized for the purpose of this retrofit are two refurbished 2016 Hyundai Ioniq 10 cell battery packs, with a weight of 17.5 kg each. [29] The motor controller will add a further weight of 1.74 kg. [30] These three components will make up the vast majority of the weight of the final electrical system, at 50.74 kg, however, assuming an additional 10kg of weight for additional electrical components and brackets will put the weight at approximately 60 kg, which is still less than the original weight of the gasoline fueled system. Therefore, the change in weight between the two systems will be extremely minimal, and will not significantly affect the mechanical function.

House of Quality

House of Quality is one of the main methods used in a QFD (Quality Function Deployment) system intended to provide a detailed quality design scope for the product and its business market. It is a quality control tool developed in achieving customer satisfaction and a business strategy to outperform current competitor products found on the market. [31]

Both ‘Customer Requirements’ and ‘Problem Definition’ points were researched and investigated to figure out customer needs and wants. The Problem Definition outlined the technical characteristics and design obstacles needed to be addressed. Based on the findings a House of Quality was developed as shown in Figure 14 below. This house of quality is organized into six major sections.

All customer requirements that have been addressed are outlined on the left hand side column in descending order of importance. While, all the ‘Problem Definition’ points have been addressed on the top horizontal column named ‘Functional Requirements’. These are points that are controllable in the design stage of the project in order to help achieve customer satisfaction.
The middle portion of the House of Quality is a relationship matrix that correlates how strong a customer's satisfaction is affected by the given functional requirement. Whereas, the top triangle portion is the ‘Expanded House of Quality’. It is a matrix used to identify the interactions between different functional requirements and how they work together as one whole system. [31]
The column on the right side of the House of Quality is a relationship matrix that ranks each customer requirement by current market competitors. This allows us to visually see what current customers are prioritizing and helps us rank our product against current competitor products. Lastly, the bottom column on the House of Quality calculates the importance of each Problem Definition/‘Functional Requirement’ relative to each other. This helps the team relocate time, resources and helps prioritize which functional requirements will ensure most customer requirements will be met once completed. Additionally, a visual matrix was added to track the importance and resource distribution of current competitors compared to our ranking functional requirements.

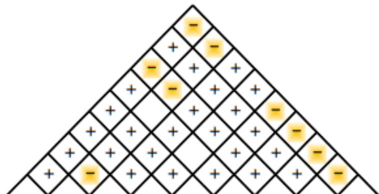
House of Quality

Project: Electric Garden Tractor
Revision: 1
Date: 2021-09-24

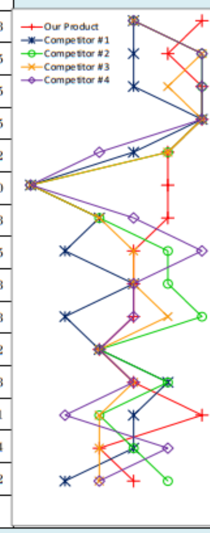
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

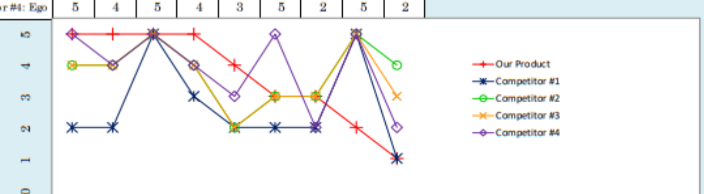


Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Battery Life	Motor Requirements	Safety Equipment	Mechanical Function	Part Availability	Charging Requirements	Operating Temperature / Conditions /	Wiring / Electronics	Weight / Size	Our Product	Competitor #1: Ryobi	Competitor #2: Cub Cadet	Competitor #3: Craftsman	Competitor #4: EGO	Row #
					Column #	1	2	3	4	5	6	7	8	9						
					Direction of Improvement	▲	◇	◇	◇	▲	◇	◇	▼	▼	Customer Competitive Assesment (0 = Worst, 5 = Best)					
1		8%	10	10	Basic Functionality Unchanged	●	●	○	●	○		○	▽	▽	5	3	3	3	3	1
2		8%	10	9	Power Requirement	●	●	○	●	●	●	▽	▽	○	4	3	5	5	5	2
3		8%	10	10	Battery Requirement	●	●	●	●	●	●	●	●	●	5	3	5	4	5	3
4		8%	10	10	User Safety	○	○	●	●	●	▽	▽	●	○	5	5	5	5	5	4
5		8%	9	8	Easy to Assemble/Reproduce/Operate	○	○	●	●	●	○		●	▽	4	3	4	4	2	5
6		7%	8	8	Uses Standard Parts and Methods	●	●	●	●	●	○	○	●	▽	4	0	0	0	0	6
7		7%	8	10	Recyclable & Reusable/Sustainable	○	▽	▽	▽	●	▽	▽	▽	▽	4	2	2	2	3	7
8		7%	8	7	Charging	●		●		●	●	●	●	○	3	1	4	3	5	8
9		7%	8	6	Maintenance	○	○	●	●	●	▽	●	▽	▽	3	3	4	3	3	9
10		6%	7	7	Robustness	●	●	●	●	●	▽	●	●	●	3	1	5	4	3	10
11		6%	7	3	Noise		○	○	●	▽		▽		▽	2	2	2	2	2	11
12		6%	7	7	Resistant to Corrosion and Elements	●	●	●	●	○	●	○	●	●	3	4	4	3	3	12
13		6%	7	6	Cost Efficiency	●	●	●	●	●	●	●	●	●	5	3	2	2	1	13
14		5%	6	5	Additional Creature Comforts	○		○	▽	○		○	●	○	2	3	3	2	4	14
15		3%	4	2	Attractivness	○	○	○	○	●	○		○	○	3	1	4	2	2	15
16																				16



	Battery Life	Motor Requirements	Safety Equipment	Mechanical Function	Part Availability	Charging Requirements	Operating Temperature / Conditions / Cooling	Wiring / Electronics	Weight / Size
Target									
Max Relationship	9	9	9	9	9	9	9	9	9
Technical Importance Rating	620.17	548.74	659.66	725.21	736.97	398.32	410.08	584.87	372.27
Relative Weight	12%	11%	13%	14%	15%	8%	8%	12%	7%
Weight Chart									
Our Product	5	5	5	5	4	3	3	2	1
Competitor #1: Ryobi	2	2	5	3	2	2	2	5	1
Competitor #2: Cub Cadet	4	4	5	4	2	3	3	5	4
Competitor #3: Craftsman	4	4	5	4	2	3	3	5	3
Competitor #4: Ego	5	4	5	4	3	5	2	5	2

Technical Competitive Assessment (0 = Worst, 5 = Best)



Column #	1	2	3	4	5	6	7	8	9

Design Process

Mechanically the design and operation of this garden tractor will not be drastically altered. The main purpose of this conversion is to be both simple to replicate for the average user and easy to operate. This means that no complex systems or fabrication is to be implemented into this conversion kit. Mainly to keep the project simple and be cost effective.

This electric garden tractor will utilize five main components and sixteen supporting components in order to be fully functional. The five main components include; John Deere 210 Chassis, Hyundai Ioniq Lithium Ion Batteries, Motenergy ME-1004 DC Brushed Motor, Alltrax SR72500 Speed Controller and a stand alone 1500W switching power supply. Whereas the supporting components include fuses, diodes, wires. As well larger components such as DC to DC converter, cooling fans, BMS (Battery Management Systems), etc.

When generating possible design solutions for this tractor. Attractiveness and visual presentation of the overall tractor was taken into consideration. The main goal was to find a solution where all the components are able to fit within the tractor's subframe and hood. In order to keep the tractor looking original. Moreover, since our group had no physical access to the tractor chassis to conduct measurements and tests for fitment. Extensive online research and assistance from the supervising professor was given. As previously mentioned, Dr. Greg Rohrauer has donated his own John Deere 210 chassis for the purpose of this project. As well, he is currently restoring both the chassis and the body panels of the tractor before sending it to the University lab for assembly and component testing.

Since this tractor is currently 47 years old. No CAD models of the tractor nor the chassis have ever been released or generated by John Deere. Therefore, the initial concept generation of the tractor and its packaged components are illustrated in the following figure below;

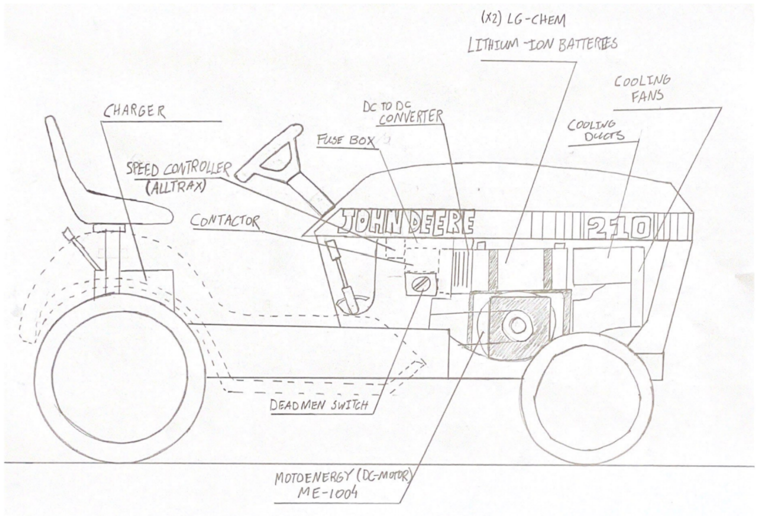


Figure [1]: Sketch of Finished Tractor with Possible Configuration or Sub Systems

In the case of this project, the vast majority of components are off the shelf, and do not require custom fabrication. However, many of these components will require mounting solutions in order to remain stationary relative to the chassis of the tractor. Due to the nature of many of these mounts, the forces which they will need to overcome are little more than the simple gravitational force of the components which they support. While, some of them may have no significant loading at all. In the case of the motor mount, the stress produced by the torque of the motor must be considered. Finite Element Analysis and CAD models will be further discussed in section 4. Detailed Design Documentation of this report.

Horizontal Battery Configuration Design Concept

Concept generations were conducted when the John Deere Chassis was fully restored and repainted to determine the available space for conducting this project. Additionally, the Hyundai Ioniq Lithium Ion batteries for this project were obtained and were test fitted horizontally underneath the hood to check for fitment and clearance issues.

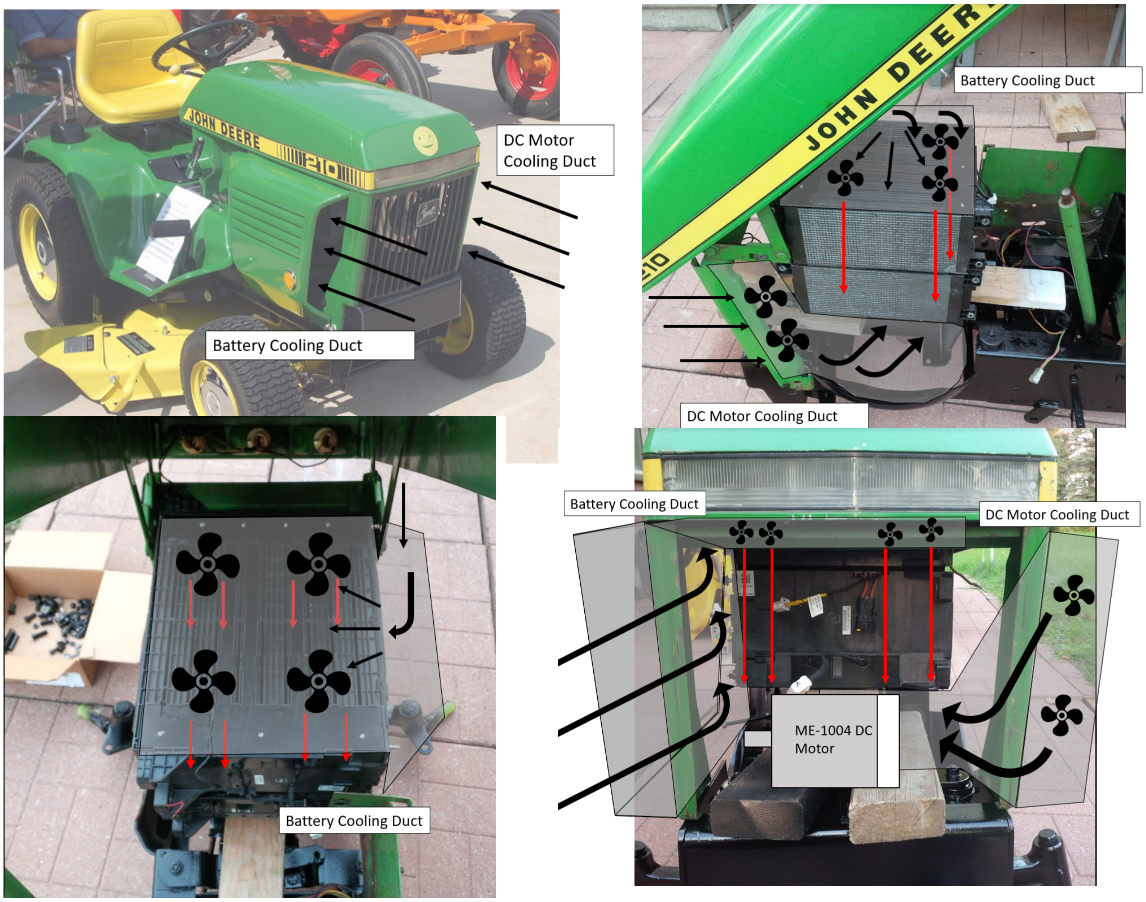


Figure [2]: Horizontal Battery Configuration Overlay

It was determined that this configuration was feasible in terms of packaging of the main components. The batteries in this layout had enough room for the hood and hood latches to close without interference. However, it was determined that creating cooling solutions for the batteries would pose a greater challenge. Hyundai Lithium Battery packs come with pre-designed cooling slots for the air to pass through. In this orientation, thin low profile cooling fans would need to be placed on top of the batteries to force air downwards through both batteries. Additionally, a more complicated cooling duct system would have to be fabricated which would go against our initial design goal of keeping fabrication to a minimum.

The John Deere 210 originally was designed with a single front grille and two side intakes to provide adequate cooling and air intake for the gasoline engine to utilize. However, when conducting this concept generation layout. It became evident for the purpose of this electric conversion. The two side intakes would be utilized again to help cool the batteries and the DC motor separately. While the front grille section would be then used as a ventilation outlet area for the exhaust heat produced from the DC motor to escape. A visual representation of this concept layout and cooling proposal is seen above in figure 2.

Vertical Battery Configuration Design Concept

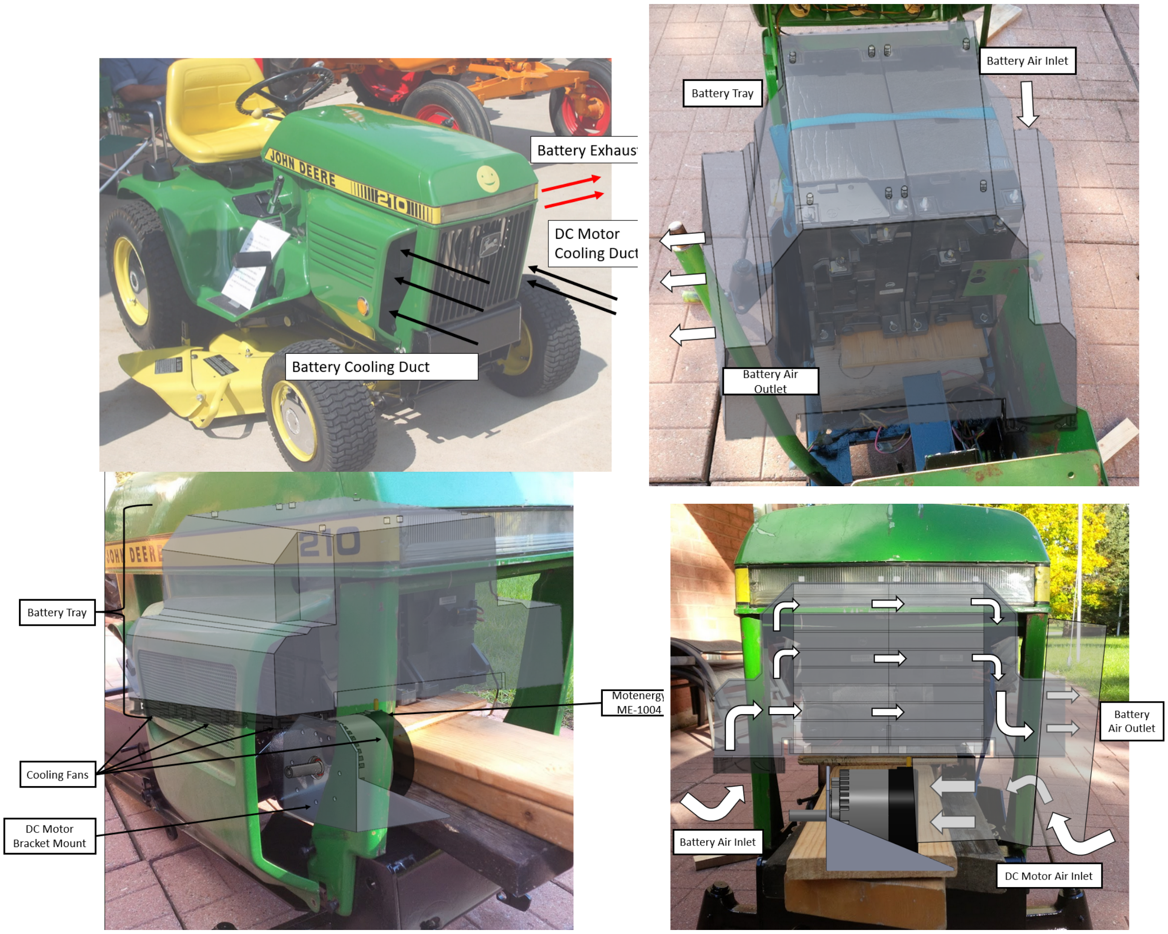


Figure [3]: Vertical Battery Configuration Overlay

The third concept generation was a development on the basis of the previous one. This concept was intended to find an alternative battery layout that would allow a simpler design of the cooling system for the two lithium ion battery packs. With the help of Dr. Greg Rohrauer, both batteries were placed in a vertical orientation and were tested again for clearance and fitment issues. It was seen that this orientation would also be deemed feasible and has enough clearance on all sides to package the batteries inside the hood compartment of this tractor model. Using the side intakes as previously explored in the previous concept design. They both would be used to cool down the batteries and the DC motor separately. The grille in the front would be used to ventilate the heat exhaust generated by the motor.

Figure [3] shows a design depiction of the battery tray and its battery shroud designed to flow the cooling air from the outside air through the specifically designed battery cooling slits in each module. The exhaust would then be pushed out from the side of the shroud on the opposite side through the already designed mesh vent on the intake vent of the tractor body panel.

Figure [3] depicts the flow of air for the battery and motor subassemblies. Both the battery and motor will have fresh air supplied from the outside environment. The battery assembly is then cooled as fresh air flows from one side of the tractor to the other. Three fans intake fresh air which then flows across the warm batteries. Heat from these batteries is then dissipated, and the exhaust air exits out the opposite side of the tractor. The DC motor is then cooled as the air enters the front of the tractor, travels across the motor, and exits at the bottom of the tractor. As mentioned above a mix of positive air pressure, filters, and mesh on the inlets and outlets will be used to help keep dust and grass clippings from entering these subassemblies.

The Decision Process - Battery Configuration

Both concept designs generated for this project yielded feasible battery configurations to proceed with. However, given the limited space available and the constrained mounting position for the DC Motor to fit and work alongside the Variable Drive System. Only the orientation of the battery placement posed an issue in regards to fitment clearance, cooling capabilities for both the battery and the DC Motor, ease of manufacturability of the battery tray/shroud, complexity of the final assembly and lastly appearance of the layout.

Therefore, in order to accurately score and choose the appropriate concept design to proceed with. Pugh's Decision Matrix was utilized. This qualitative decision making tool helped choose the appropriate concept design by establishing a list of design criteria for comparison with relative importance weightings. For which the weighted criteria is then evaluated against the concepts to see which design concept achieves the highest score. [32]

Issue: Choose a Battery and Motor Mount Layout Configuration		Original Internal Gasoline Engine Layout	Horizontal Battery Configuration Design Concept	Vertical Battery Configuration Design Concept
Fitment Clearance	35	Datum (Reference)	1	1
Cooling Capabilities	33		-1	1
Ease of Manufacturability	20		0	1
Complexity of the Final Assembly	7		1	0
Appearance	5		1	1
		Total	2	3
		Weighted Total	14	93

Table [4]: Pugh's Decision Matrix

The decision matrix unveiled that the vertical battery layout was a more favorable design. A less complex cooling duct design would be needed to be fabricated and a simpler flat battery tray would be used to secure both batteries and the cooling shroud together. A vertical battery layout design would also provide a better cooling performance to the batteries then the latter design. Most importantly this configuration, as tested, will be able to fit underneath the cowl and hood of the John Deere tractor. Thus, making this conversion kit both functional and original looking in design.

Final Design

I. Motor Mount

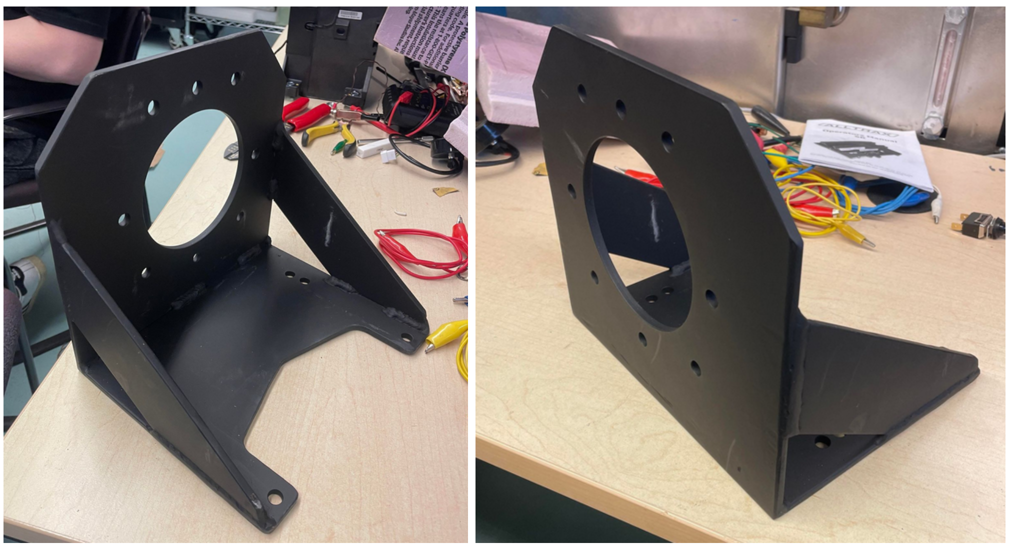


Figure [4]: Final Motor Mount Views

The motor mount design will be essential for the functionality and longevity of the electric tractor conversion. The preliminary design was revised slightly during the fabrication process. The corner cutouts on the sides of the mount were added to allow better access for hard to reach bolts as well as provide drainage of any dirt and debris that may make its way onto the motor mount. The base plate of the motor mount was cut out to accommodate the terminal on the electric motor. Many revisions were made to reduce the overall height of the mount while maintaining the original position of the shaft. The base plate holes correspond to the bolt location on the chassis. The motor mount was fabricated out of ¼ inch steel and welded together. The front plate of the motor mount holds two bolts patterns. The first bolt pattern attaches the electric motor to the motor mount. The other front bolt pattern attaches the clutch plate assembly to the tractor. A small hole was needed to be drilled into the clutch plate to ensure access to the motor mount bolts.

II. Electronics Tray (Top)

The top electronics tray was fabricated to mount all of the larger components required to drive and charge the electric tractor. The three major components housed in the top electronics tray were the battery charger, DC to DC converter and as well as the alltrax motor controller. Packing concerns were a major design goal to overcome. The tray is designed to bolt into the original internal tray bolt locations. Bolt patterns for the DC to DC converter and Alltrax motor controller where drilled and threaded inserts were added into each of the corresponding holes to attach these devices securely to the original battery tray location. For the charger, an alternative solution was deemed suitable due to the limited space below the top tray. A strap was designed to hold the charger down along rubber spaces to ensure secure fit and reduce vibration. This reduced the number of threaded inserts needed below the top tray to hold the charger down. A large ventilation hole was cut for the alltrax motor controller air cooling and careful consideration was made to also expose the charger fan to ensure good cooling. A large cutout in the front plate and rear of the electronics tray ensured space for routing wiring to this tray and below to the bottom electronics tray. The material selected for the tray was 14 gauge steel to match the existing bent sheet metal on the tractor. The tray was then primed and painted for final assembly. Matte black was selected to match the underhood color scheme.

Figure [5]: Electronics Tray (Top)

III. Electronics Tray (Bottom)

Similar to the top electronics tray, a separate tray was fabricated to hold all the other necessary components that did not have space on the top tray. Components such as the 12v battery, contactors, dial shunt, relays and fuses. By mounting all the electronic components this allows for more organized wiring and safety of the system while underway. The bottom tray was designed to hold all the components bolted together onto the tray to be then installed, this simplifies installation of the various components by allowing the user to install the components outside the vehicle. The tray was designed to be flat. To allow any dirt and debris to drain off the tray. The material selected for the tray was 14 gauge steel to match the existing bent sheet metal on the tractor. The tray was then primed and painted for final assembly. Matte black was selected to match the underhood color scheme. Mounting of the tray required the drilling of one additional hole to the body of the tractor. The remaining mounting locations use previously drilled holes from the factory for mounts or components no longer required for the electric conversion.

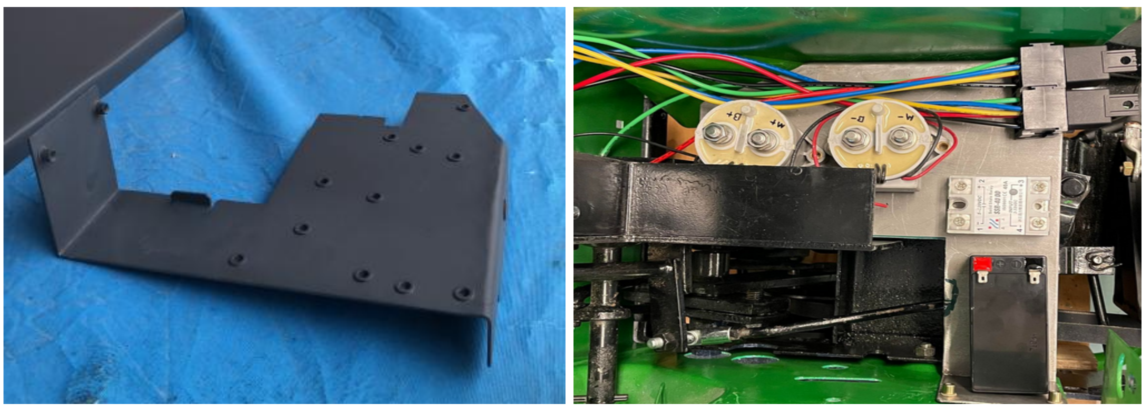


Figure [6]: Electronics Tray (Bottom)

IV. Battery Tray and Mount

The battery tray was revised from preliminary designs. An oversight of the preliminary design was the bathtub silhouette. This original design would hold dirt and debris in the tray along with the batteries. Dirt and debris can cause issues in long term situations for wear and tear. The final design the tray was flipped 180 degrees where the bathtub walls of the design would be repurposed for stiffening and strengthening the tray for the heavy batteries. The original chassis of the John Deere used large ⅜ bolts to attach the motor mounting plate to the chassis. These bolts would be repurposed to bolt the frame/ mount of the battery tray to the chassis. Threaded inserts were used to attach the batteries securely to the battery tray while the tractor is in motion. The tray of the battery tray was fabricated out of 14 gauge steel to match what was original from the factor. The tray mount was fabricated out of 1/8x1x1 angle iron, welded into the appropriate shape. Notches where necessary to be cut into the mount to allow for clearance of the threaded inserts as the tray sat on the mount.

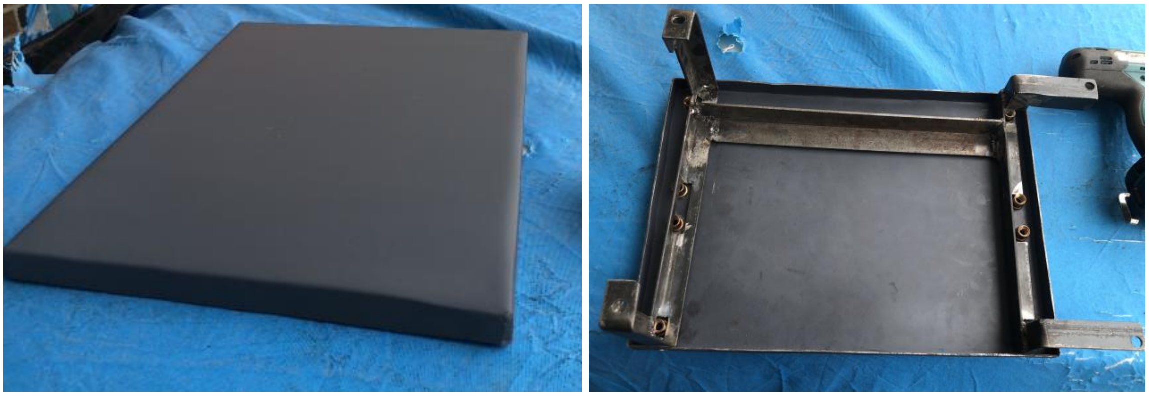


Figure [7]: Battery Tray (Top View) and (Bottom View)

V. Overall Tractor Design

The overall tractor design from the exterior has not changed. It still retains the recognizable visual elements from the original 1975 design. The classic green yellow and black color scheme were retained. Apart from the additional holes drilled to mount the component trays and the minimal metal fitting to ensure everything was seated. The tractor is able to be fully restored back to the original design with the ICE. All the newly designed and fabricated components can be bolted onto any similar John Deere tractor with a variator drive transmission. The electronics trays neatly rest behind the steering column in the main control section in the middle of the tractor, sheltered from the elements from the original hood without any fitment issues. The batteries and motor reside in the space that previously held the ICE and its supporting components. The mounts for the motor and battery tray mount onto the original factory locations. Therefore, retaining the minimal metal work goal that allows this conversion to be undertaken by any DIY enthusiast.

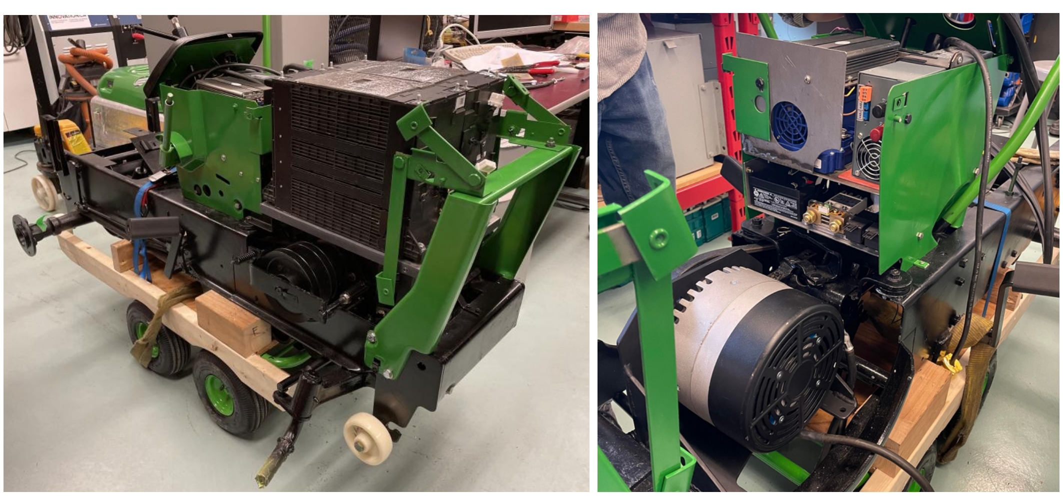


Figure [8]: Internal Assembled Components Isometric Views

Figure [9]: Internal Assembled Components Test Fitment

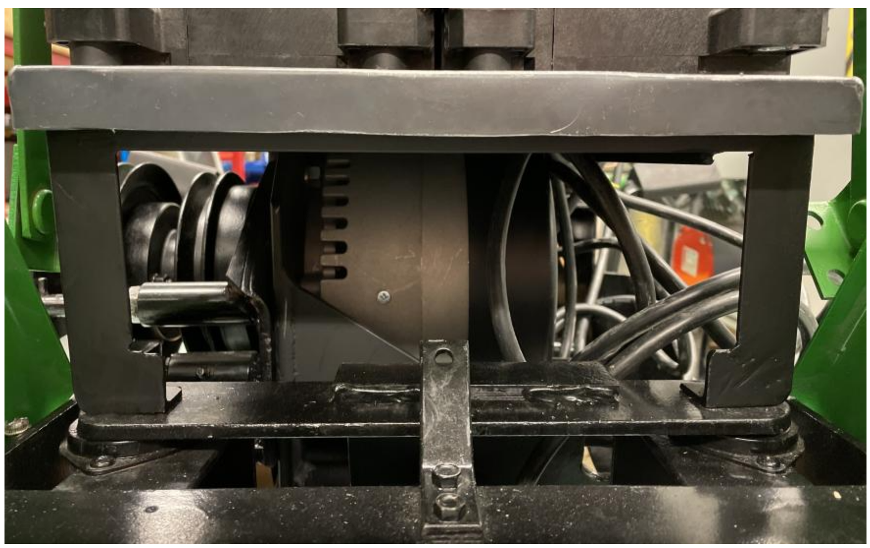


Figure [10]: Motor Mount and Battery Tray Test Fitment

Tractor Wiring Schematic

Another major concept generation for this project is the design of the overall wiring schematic for this garden tractor. The original John Deere 210 came equipped with just a handful of wires and safety switches that were run on a 12V system in order to start the gasoline motor. Whereas for this project, two separate voltage systems will be used. A 48V system will be used to power the DC motor and the alltrax motor controller. A 12V system from a DC to DC converter will be used to power all tractor safety switches and auxiliary components such as the headlights and its cooling system.

AllTrax Wiring Schematic

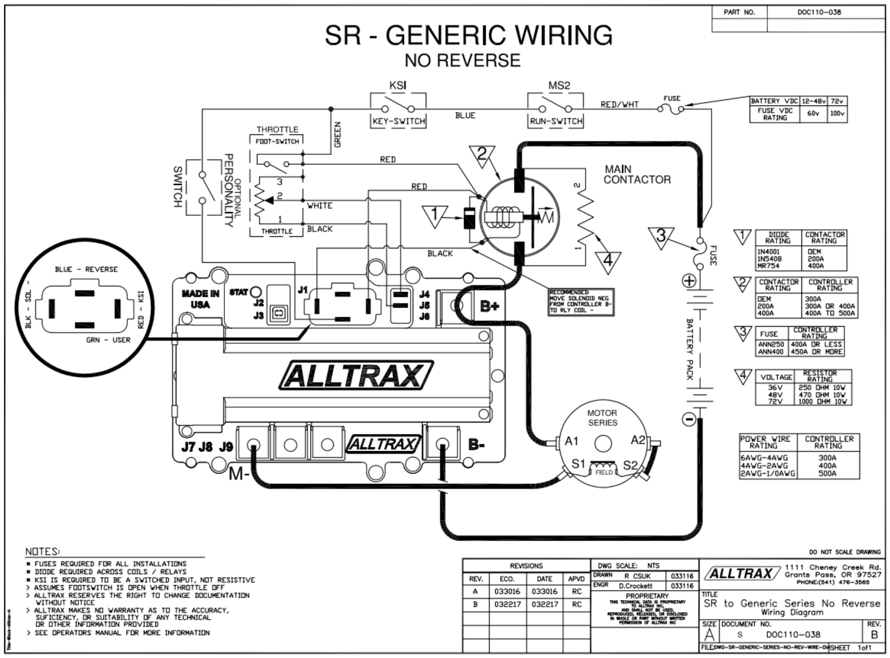


Figure [11]: Alltrax SR72500 Wiring Schematic

The Alltrax SR72500 was selected to be the optimal speed controller for the purpose of this project. This speed controller is capable of running a system voltage between 12-72V at a continuous amperage of 200 with a peak value of 500 Amps. This Alltrax speed controller will be primarily responsible for adjusting the voltage appropriately at different battery loads to provide a more consistent power output to the DC motor.

With the decision to proceed with this speed controller. A preliminary circuit diagram of the motor and the overall wiring of the system was provided by Alltrax for our project. The company also included suggestions for parts such as the diode, fuses, resistors and wire gauge needed to properly assemble and wire the speed controller to the rest of the main components.

The wiring schematic provided by Alltrax gave a fundamental understanding of how to wire the batteries, DC motor, speed controller, main contactor, personality switch and the throttle running at the desired 48V system voltage. However, this schematic did not include any 12 volt supporting systems and safety features. Therefore, this schematic was then used as a baseline to further develop the overall tractor schematic.

John Deere 210 Wiring Schematic

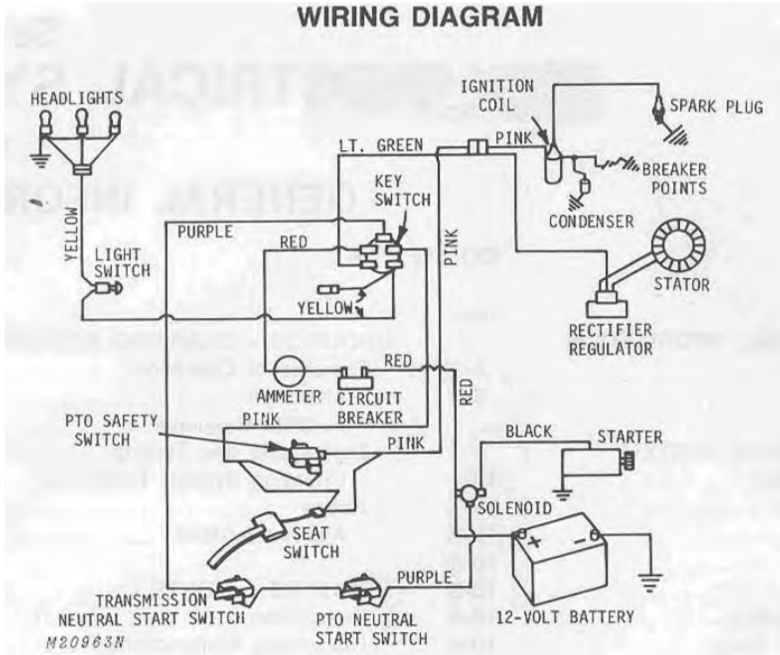


Figure [12]: Original John Deere 210 Wiring Schematic

Originally the John Deere 210 had a simple wiring circuit designed to start and operate a gasoline engine using a lead acid 12V system. This tractor was equipped with safety switches that allowed safe operation for the user. For this project the original safety switches such as the Transmission Neutral Start Switch, PTO Neutral Start Switch, Seat Switch and the PTO Safety Switch will be used to power the key switch using a 12V system. The purpose of utilizing the original safety switches is to prevent the tractor from turning on while the tractor is in gear or if the user is not sitting on the driver seat.

An original circuit schematic was found in the John Deere 210 Service Manual. This diagram gave insight on how the key switch is connected to the safety switches and was used in the development of the overall schematic.

a) Wiring Schematic Revision #1

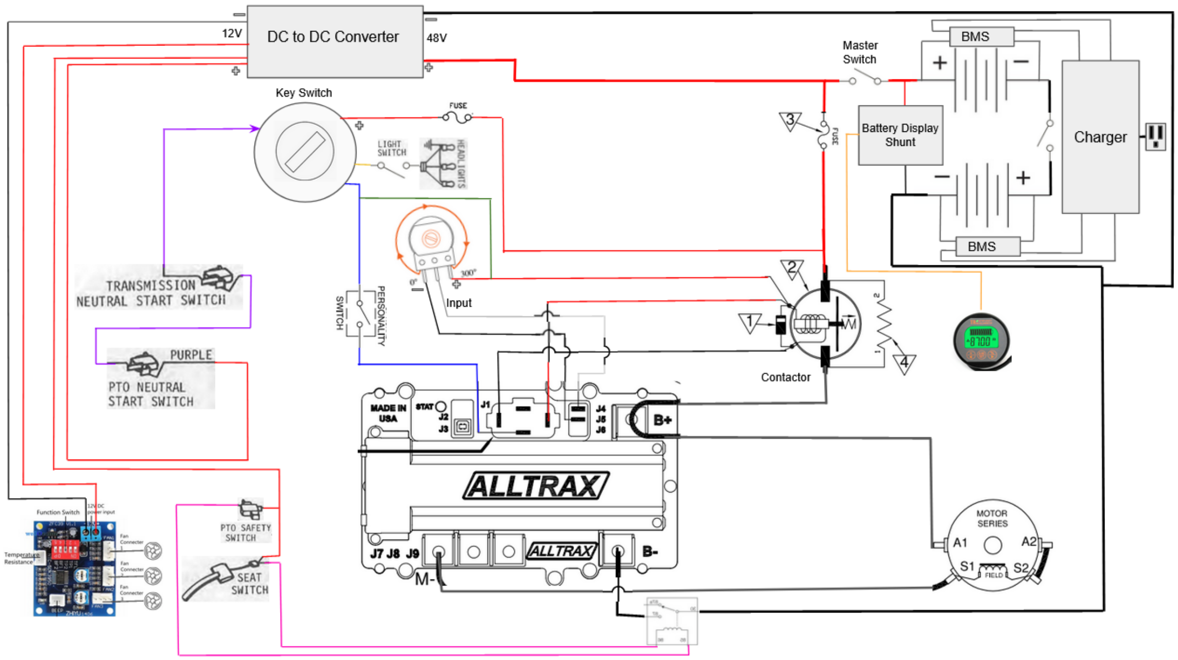


Figure [13]: Preliminary Overall Wiring Schematic

The circuit diagram above is a preliminary overall wiring schematic that combines all aspects of both the Alltrax and the original John Deere circuit diagram together. The John Deere tractor originally included safety switches to ensure safe operation and starting of the garden tractor. These parts must also be included in the new wiring schematic to ensure the conversion is safe. Components such as the DC to DC converter and the BMS charging system were also added compared to the Alltrax diagram to ensure that the auxiliary systems such as cooling fans and lights have power. This conversion kit will be running at two different voltage systems. (i.e 12V and 48V). To run the DC motor and the Alltrax system the 48V system will be used. While all the other auxiliary components and safety switches will run under a 12V system. This voltage will be converted from the 48V system using a DC to DC converter. A combination of switches, relays, fuses, diodes and resistors will be used to prevent malfunctions, increase safety and design a reliable and robust overall system.

b) Wiring Schematic Revision #2

Unfortunately, the preliminary circuit diagram was not feasible and flawed. This circuit diagram would not function as intended and would damage the motor controller and battery unit. Therefore, an updated revision of the circuit diagram was designed to capture all the errors seen in the preliminary design and make the electric tractor operational and safe as originally intended.

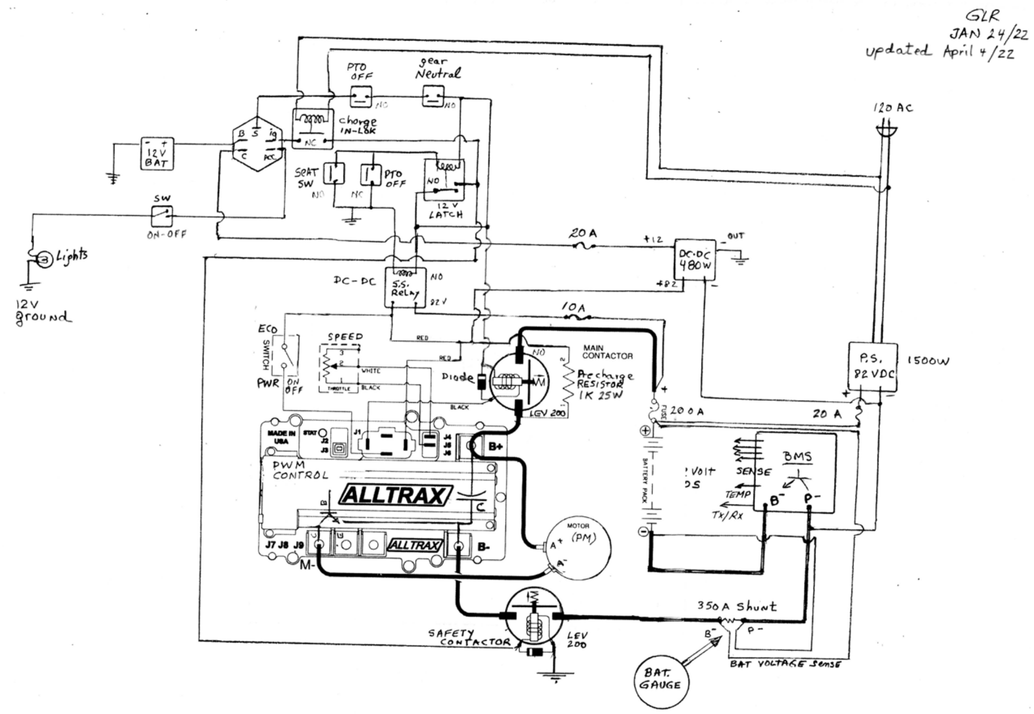


Figure [14]: Updated Circuit Diagram

After conducting multiple design review meetings with the group and Dr. Greg Rohrauer. The above schematic was developed based upon the preliminary circuit design. Major changes include the addition of;

1. Latching Relay

Initially, the original circuit diagram had two switches to control the sequence of ignition for the system. To engage the starter, both the PTO switch and the gear neutral switch had to be in the off position. In conjunction, with the seat switch and PTO off switch used to cut off ignition to the engine.

The updated circuit diagram duplicated the same system, except we ran the switches through the latching relay. The first relay is a charger interlock. If the charger is connected nothing works because it can't put a 12V signal into the system. This ensures that you cannot turn on the tractor while it is plugged into the wall.

The PTO switch found on the top low voltage circuit is normally open and the PTO next to the seat switch is normally closed. They are opposite in operation. Moreover, the drive gear has to be in neutral and PTO disengaged in the off position in order to turn the key to the start position. After these two conditions are met. The coil on the relay will be energized. Additional condition is that either you are sitting on the seat so the seat switch is closed or the second PTO switch is closed. This means you don't have to be in the seat to have the tractor running or to start the tractor as long as the PTO switch is off. Once the system is running and the relay is energized, it will latch. Meaning that the switch will remain open. If you get off the seat then this will automatically de-energize the latch relay and the system shuts down.

2. Solid State Relay - SSR-40 DD Solid State Relay

A Solid State Relay was added to the overall circuit diagram to prevent the system from arcing when the system turns on. Since the overall system voltage will be close to 80V. The currently optioned 12V relays found in the system are not intended to handle the huge influx of current during start up. Therefore, as a safety precaution. One SSR-40 DD Solid State Relay will be the main relay combining the high voltage and low voltage systems together in this tractor.

3. Stand Alone Power Supply - 1500W Switching Power Supply AC-DC SMPS

Eliminating the use of the iCharger 4010Duo. A stand alone power supply will be used to convert AC provided grid electricity to DC electricity for the lithium ion batteries to store. Therefore, a 1500W Switching Power Supply AC-DC SMPS was optioned for its versatility, size and customization of desired output charging voltages. This component will set the charging voltage just right so it will not overcharge the lithium-ion batteries. As well, not to over stress the Heltec Battery Management System with its task of balancing each cell individually.

4. BMS - Heltec Automation Smart Active BMS (24S 2A 200A)

By now optioning to use a stand alone power supply unit, instead of the iCharger 4010Duo. An external Battery Management System (BMS) will need to be added to ensure safe and equal charging of its lithium ion cells within the battery pack. The Heltec Automation Smart Active BMS is capable of overseeing up to 24 cells at once. Additionally, by selecting this alternative system. Both the lithium ion batteries will not have to be wired in parallel. Furthermore, this new BMS will have an integrated cellphone interface capability for better monitoring of cell charging and tunning purposes. This BMS does not dissipate any energy and is highly efficient. It transfers the charge from one cell to another once the previous cell is sufficiently charged.

5. DC-DC converter - Cllena DC 40V-90V to 12V Converter Voltage Regulator Reducer

A more powerful DC to DC converter was selected with an addition of a built-in safety on-off switch. The reasoning for optioning the Cllena DC 40V-90V to 12V Converter was mostly due to the fact that DC to DC converters when wired up to the main operating circuit will have current leakage, even if the whole system is turned off because its drawing of 80V from the battery all the time. However, this DC to DC converter has a safety on-off switch to cut the power and current supply from the main battery if needed. This switch would be turned on when handling any internal components of the tractor as seen during installation, removal or replacement.

6. Second 'Safety Disconnect' Contactor - LEV 200

Good practice suggests that it is customary to add an additional contactor to isolate both the positive and negative sides of the battery as a safety precaution. Once operation of the tractor is complete. The overall circuit should be switched off using a resistor. Initially a single main contactor was decided to be used, upon whose duty was to keep the operating and precharge circuit functioning. However, due to the high current it could weld the contactor wire shut together and as a result. Meaning that the overall system could run indefinitely. To combat this problem, a second 'Safety Disconnect' contactor will be added to separate the smaller pre-charge contactor for the pre-charge resistor.

The Alltrax SR72500 motor controller uses DC link capacitors. Which will provide a leakage current in the system. Leakage of current over time will get worse due to capacitor age and temperature. As a result it will discharge the main battery. By adding the second 'Safety Disconnect' contactor between the Alltrax motor controller and the lithium ion batteries. This adds an additional layer of protection for the batteries as well safer handling of components during installation, removal or replacement.

Certain wiring design was also changed due to foreseeable 'short circuit' design flaws captured from the original circuit diagram. The goal of updating the circuit diagram was to correctly eliminate circuit issues and thus add additional safety features to the tractor and for the end user.

Analyze and Select a Solution

Functional analysis

In the initial design of the wiring schematic, the full battery voltage of 72 V was fed into the contactor control board. When testing with one battery, this setup performed perfectly as intended. However, an oversight made was that the control board of the contactor is only rated for a maximum of 36 V. When doubling the voltage output with both batteries in series, the control board of the contactor burned up almost immediately, causing system failure. In order to remedy this, the wiring diagram was revised, instead giving the contactor 12V power from the auxiliary battery. After this change was made, the drive circuit functioned as intended.

Following these alterations, and finalization of the circuit, wire ends were all labeled as to where they go, to simplify the transition to the tractor. Once all components were mounted and wired up inside the chassis, the final prototype functioned as intended. With the DC motor only operating when powered on. When the throttle is increased the rear wheels receive power through the transmission.

Industrial design/Ergonomics

The original 1975 John Deere 210 tractor utilized for this project did not have a built-in seat safety switch. In order to ensure that the rider is properly seated during operation. This is considered a safety oversight, as allowing the tractor to operate without a user poses immense risk. In order to rectify this problem, a limit switch was added to the seat which allows the current to pass through when depressed by the weight of a rider. This in turn is added to the ignition circuit, meaning that the tractor will not power on when there is no rider present.

Furthermore, with regards to the mounting of components. Great care was taken to ensure that the assembly and disassembly of the kit is relatively simple, with easy access to all bolts which must be fastened in order to properly seat components.

Prototyping Plan

1. Restore Tractor Chassis

The restoration of the chassis is the first step of the prototyping process. The provided chassis for this project required restoration in order to have a suitable foundation to build upon. Degradation of items such as rubber bushings and paint over the years required restoration back to its original state. This included the removal of the original drivetrain components such as the motor and all associated subsystems for the ICE. Both the starter motor and lead acid battery were removed in order to provide additional available space for the conversion.

The general preparation of chassis was to accept electrical drivetrain components including clearancing and removing unnecessary components, restoring of components, painting , rust proofing, structural integrity, seals and replacing bearing bushings are just a handful of components changed in order to fully restore this 42 year old tractor.

2. Restore Drivetrain Components

The John Deere tractor was selected due to its desired transmission and drivetrain configuration along with its robust chassis. The variator drive is an efficient transmission when paired to an electric motor to the drivetrain compared to alternate methods such as hydrostatic transmission. The variator drive is the major component that connects the electric powertrain conversion to the original ICE. Restoring and ensuring that the variator drive and its supporting components such as axles, differential, brakes and steering components are in working order. Will ensure that the chassis and drivetrain are ready to accept the prototype conversion.

3. Research and Calculation of Prototype Component Specifications

Selection of the right electrical components is imperative for safe operation. There is a fine balance between the cost of the components and what space is available for this conversion. The success of the electric tractor depends on how well the conversion balances runtime, power and usability.

The amount of electrical power the tractor can carry will depend on the battery. How long it will run will largely depend on the electric motor and the loads experienced during operation. The successful interaction between each system will determine how convenient and well developed this product will be for the customer. The success rating of this project will be determined by the customer willingness to use/reuse the tractor.

The battery for this project was provided by the Professor. This affected the decision making process and early prototype design configurations. However, in the end the provided LG Chem Lithium Ion Batteries positively affected this project by satisfying many of the desired criteria and significantly reducing the budget for this project. Moreover, these battery packs are small enough to have no fitment issues underneath the hood. Thus, keeping the tractor look original as possible.

Consequently, the DC motor selected was chosen primarily due to its performance characteristics. Compared to the original ICE motor fitted in the John Deere tractor. The ME-1004 DC motor was selected due to having its normal operating performance parameters comparable to the original kohler engine.

It was also determined that a Motor Controller would be needed to control the available power from the lithium batteries to the motor in a safe and efficient method. The rating of the motor controller was determined based on the amount of current and voltage both the battery and DC motor will be using. Incorrect selection would result in the tractor being inoperable or cause other systems to break.

Component mounting brackets were custom developed using CAD software. This allowed for precise packaging and fitment of all components of the tractor. Any 12V systems and related components to support the main powertrain were bought 'off the shelf' to keep both costs and complexity of the project to a minimum. At this stage a fully developed electrical diagram was completed to see how each component communicated with each other.

4. Order and Receive Parts

Once the analysis of the component has been completed, the next step of the process was to order the parts needed. This step required some time. As many of these components come from international suppliers and international shipping was used. The motor controller was made and shipped from the United States. However, the majority of the components including the DC Motor shipped from China. During this step, researching adequate and readily available components was crucial. The COVID pandemic had increased the shipping times longer for everyone around the globe. A Bill of Materials (BOM) was made and utilized to track all components and their status.

5. Fabrication of Components and Preliminary Test Tit

All components will need to be mounted securely to the chassis for the conversion. Things such as the battery need ample support to ensure they are not damaged during operation which can lead to a short circuit or even a fire. Special considerations must be made for the motor to ensure it is strong and secure enough due to the foreseen operation stresses.

a. Brackets Mounts and hardware:
   i. Fit batteries: mounts, tray and supporting hardware
   ii. Fit electric motor: mounts, brackets, supporting components
   iii. Fit BMS system: mounts, brackets
   iv. Fit Charging system: mounts, brackets
   v. Fit DC-DC converter
   vi. Fit accessories

b. Wiring of major system components

c. Wiring of supporting accessories

6. Bench Test All Component for Functionality

Once all the components are received, appropriate fabrication of all necessary brackets is completed. The next step is to ensure that all components are in functional condition. Some components such as the batteries and contactors are second hand. However, before final assembly all parts are tested for their functionality within operating specification. Once all the parts are tested and operating as per specification. A preliminary bench test of all the overall components is completed. This ensures that all parts are accurately connected and compatible with each other. If there are any issues present. This step will allow for easier troubleshooting.

7. Test , Refine and Revise

Once all the parts are compatible with each other and working as designed. The next step is to assemble the tractor. Any refinements and revisions with all the components fitted to the chassis can be made. Careful analysis of any clearancing issues or chafing issues should be identified and eliminated.

8. Final major component assembly

Once all the components have been tested and fitted to the chassis and refined for the final component assembly. Wiring of the tractor will be cleaned up and prepared for final delivery to the customer.

9. Test drive / delivery

Final drive and operating tests will be performed to ensure the electric tractor is functioning at designed parameters and will be a safe product for the customer. If any issues occur, immediate action will be taken to address the problem and a re-test will be conducted.

Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis also more commonly known as FMEA. Is an analytical methodology used to expose potential problems that have been considered and addressed during the product development process.[33] FMEA is divided into two groups, Design FMEA (DFMEA) and Process FMEA (PFMEA). For this project, an electric garden tractor is to be developed and thus the appropriate methodology used should be the Design FMEA (DFMEA). [34]

Design Failure Mode and Effects Analysis explores all possibilities of all possible product failures caused by inherent design, material properties, tolerances, interference with other components and the various operating environments. This tool provides a structured approach to identifying and prioritizing these failure modes, taking appropriate action to prevent and detect such failures. [35]A standardized ranking system is put in place to determine the severity of failures and the likelihood of occurrence and their detection. Lastly, a Risk Priority Number (RPN) is assigned to each failure mode to rank its importance in the overall design.

	(DESIGN) FAILURE MODE AND EFFECTS ANALYSIS					
Item:	Electric Garden Tractor	Responsibility:	G16-5-4	FMEA #:		
Model:	Electric John Deere 210	Prepared by:	G16-5-4	Page :	1 of 1	
Core Team:	K. Boreczek, B. Chen, M. Chase, J. Bartley			FMEA Date:	18/2/2022	Rev 1

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	RPN	Recommended Action(s)	Responsibility	Action Results: Actions Taken	Sev	Occ	Det	RPN
Turning on the ignition switch	No electrical power	Inoperable tractor	8		Lithium Ion Battery Empty	2	Battery Gauge	1	16	Implement Charging Light	Karol, Bryan					0
			7		Safety Contactor disengaged	2	None	8	112	Implement System Check Light	Mitchell, Jacob					0
			7		Main Contactor disengaged	2	None	8	112	Implement System Check Light	Mitchell, Jacob					0
			8		Alltrax system - Damaged	4	None	9	288	Implement System Check Light	Mitchell, Jacob					0
			7		DC-DC Converter - Off	2	Light on/off on DC-DC	2	28	Implement System Check Light	Mitchell, Jacob					0
			7		DC-DC Converter - Damaged	4	Visual - Fuse damage indication	2	56	Implement System Check Light	Mitchell, Jacob					0
			7		DC-DC Converter 20 Amp fuse blown	5	Visual - Fuse damage indication	2	70	Implement System Check Light	Mitchell, Jacob					0
			8		Steady State Relay - Off	4	None	7	224	Implement System Check Light	Mitchell, Jacob					0
			8		Steady State Relay - Damaged	2	None	8	128	Implement System Check Light	Mitchell, Jacob					0

			7		12V Latch Relay - Opened	4	None	7	196	Implement System Check Light	Mitchell, Jacob					0
			6		PTO Switch - Off	2	None	3	36	None	None					0
			7		Gear Neutral Switch - Off	2	Visual Lever Position	2	28	None	None					0
			4		Charge In-Lock Relay - Closed	2	Visual Charging Plug Location	2	16	Implement Charging Light	Karol, Bryan					0
			4		Seat Safety Switch - Off	2	Visual Seat Position	2	16	Implement System Check Light	Mitchell, Jacob					0
Charging Lithium Ion Batteries	No electrical power	Inoperable tractor	2		No power from power outlet source	3	Alternative Plug Outlet	2	12	Implement Charging Light	Karol, Bryan					0
			6		Power Supply - Damaged	2	None	8	96	Implement Charging Light	Karol, Bryan					0
			6		BMS - Damaged	2	None	9	108	None	None					0
			3		Charge In-Lock Relay - Closed	2	Visual Charging Plug Location	2	12	Implement Charging Light	Karol, Bryan					0
	Short Circuit	Inoperable tractor, fire hazard	6		Power Supply - Damaged	2	None	8	96	Implement Charging Light	Karol, Bryan					0
			6		BMS - Damaged	2	None	9	108	Implement System Check Light	Mitchell, Jacob					0
	Overheating	Fire hazard	6		BMS - Damaged	2	None	9	108	None	None					
DC Motor	No electrical power	Inoperable tractor	8		Alltrax system - Damaged	4	None	9	288	Implement System Check Light	Mitchell, Jacob					0
	Short Circuit	Inoperable tractor, fire hazard	9		Short Circuit within the DC Motor	4	None	7	252	None	None					0

Severity Rankings			
Ranking	Effect	Design FMEA Severity	Process FMEA Severity
10	Hazardous-no warning	affects safe operation without warning	may endanger machine or operator without warning
9	Hazardous- w/ warning	affects safe operation with warning	may endanger machine or operator with warning
8	Very High	makes product inoperable	major disruption in operations (100% scrap)
7	High	makes product operable at reduced performance (customer dissatisfaction)	minor disruption in operations (may require sorting and some scrap)
6	Moderate	results in customer discomfort	minor disruption in operations (no sorting but some scrap)
5	Low	results in comfort and convenience at a reduced level	minor disruption in operations (portion may require rework)
4	Very Low	results in dissatisfication by most customers.	minor disruption in operations (some sorting and portion may require rework)
3	Minor	results in dissatisfication by average customer.	minor disruption (some rework but little affect on production rate)
2	Very Minor	results in dissatisfication by few customers.	minor disruption (minimal affect on production rate)
1	None	No effect	No effect

Figure [15]: Severity Ranking [36]

Occurrence Rankings				
Ranking	Effect	Failure Rates	Percent Defective	Cpk
10	Extremely High	> 1 in 2	50%	Cpk < 0.33
9	Very High	1 in 3	33%	Cpk ~ 0.5
8	Very High	1 in 8	10-15%	Cpk ~ 0.75
7	High	1 in 20	5%	
6	Marginal	1 in 100	1%	
5	Marginal	1 in 400	0.25%	Cpk ~ 1
4	Unlikely	1 in 2000	0.05%	
3	Low	1 in 15,000	0.007%	Cpk > 1.33
2	Very Low	1 in 150,000	0.0007%	Cpk > 1.5
1	Remote	< 1 in 1,500,000	0.000007%	Cpk > 1.67

Figure [16]: Occurrence Ranking [36]

Detection Rankings			
Ranking	Effect	Design FMEA Detection	Process FMEA Detection
10	Absolute uncertainty	No chance that design control will detect cause mechanism and subsequent failure.	No known process control to detect cause mechanism and subsequent failure.
9	Very remote	Very remote chance that design control will detect cause mechanism and subsequent failure.	
8	Remote	Remote chance that design control will detect cause mechanism and subsequent failure.	Remote chance that process control to detect cause mechanism and subsequent failure.
7	Very Low	Very low chance that design control will detect cause mechanism and subsequent failure.	
6	Low	Low chance that design control will detect cause mechanism and subsequent failure.	Low chance that process control to detect cause mechanism and subsequent failure.
5	Moderate	Moderate chance that design control will detect cause mechanism and subsequent failure.	
4	Moderately High	Moderately high chance that design control will detect cause mechanism and subsequent failure.	
3	High	very remote chance that design control will detect cause mechanism and subsequent failure.	High chance that process control to detect cause mechanism and subsequent failure.
2	Very High	Very high chance that design control will detect cause mechanism and subsequent failure.	
1	Almost Certain	Design control will almost certainly detect cause mechanism and subsequent failure.	Current control almost certain to detect cause mechanism and failure mode.

Figure [17]: Detection Ranking [36]

Detailed Design Documentation

CAD Model and Engineering Drawings

A CAD model of the tractor was created for fitment and visual purposes as well as FEA. The main components included: the tractor chassis, the motor mount, top electronics tray, bottom electronics tray, and battery tray assembly.

I. Base Tractor Chassis

Since no CAD model existed of the John Deere 210 tractor from 1975 a new model was created. Measurements of the chassis were taken and converted to the model seen in *figure [18]* below. The chassis CAD model acted as an environment where new components were checked for fitment and visual purposes.

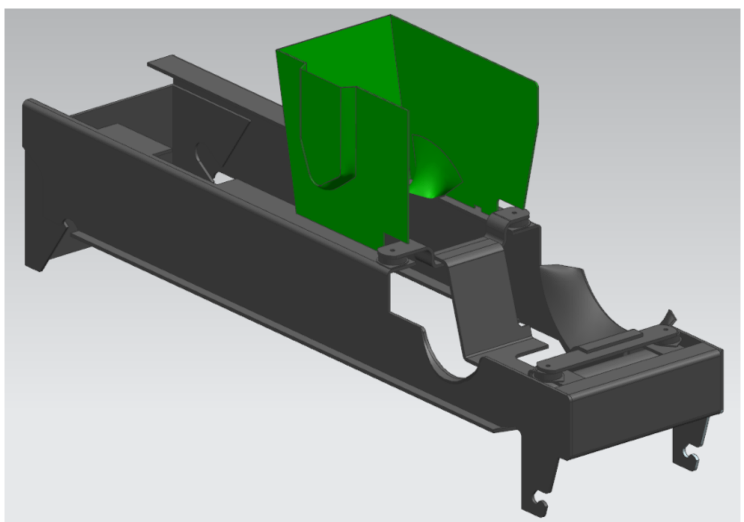


Figure [18]: Tractor Chassis CAD Model

II. Motor Mount

A motor mount was created on CAD software using ¼ inch steel and the design was changed from initial concept drawings. The side supports were reduced in size to allow for easier access and installation of bolts. At the same time the bolt locations securing the motor to the mount were moved to slightly off center. Furthermore the overall height of the mount was reduced to allow for more battery space. The model and corresponding dimensional drawings can be seen in *figure [19]* and *figure [20]* below.

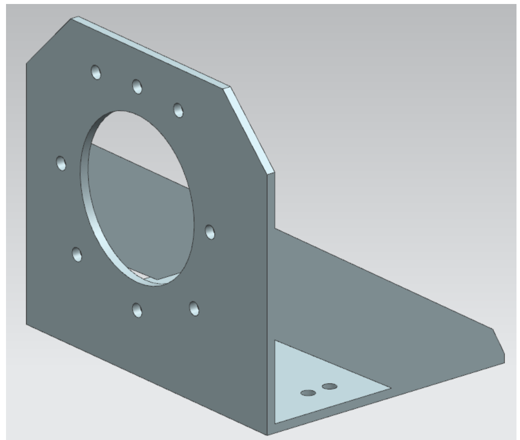


Figure [19]: Motor Mount CAD Model

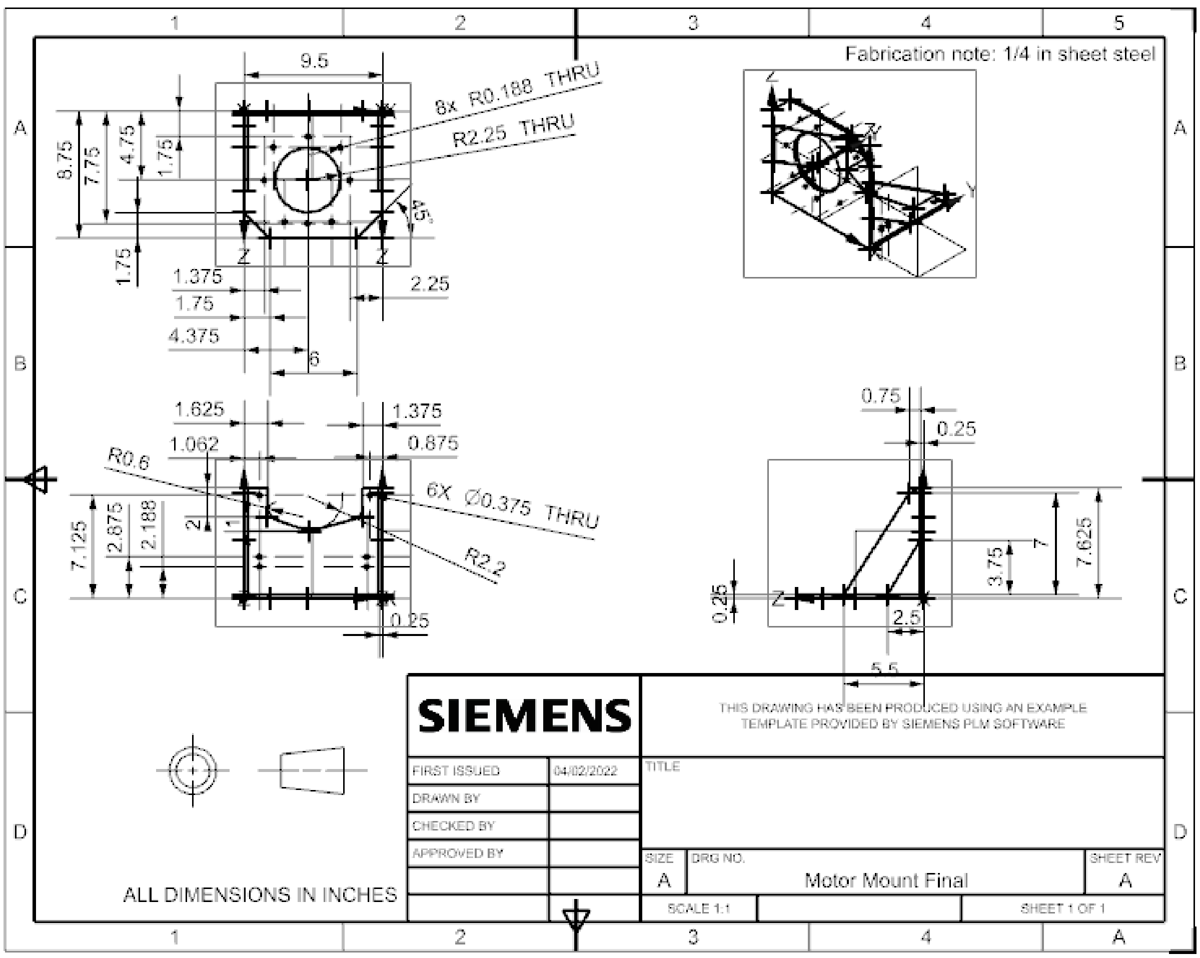


Figure [20]: Motor Mount Engineering Drawing

III. Electronic Tray (Top)

The electronics tray assembly consisted of two separate trays both housed in the center console of the tractor. The top tray was designed to bolt into the original tray's bolt locations. The design and dimensions can be seen in *figure [21] and figure [22]* below.

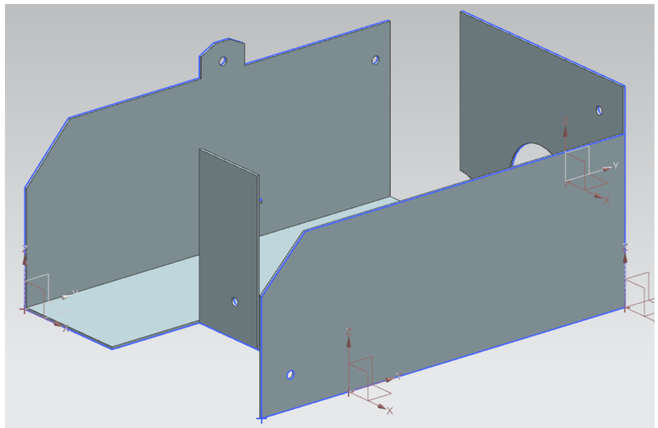


Figure [21]: Top Electronics Tray CAD Model

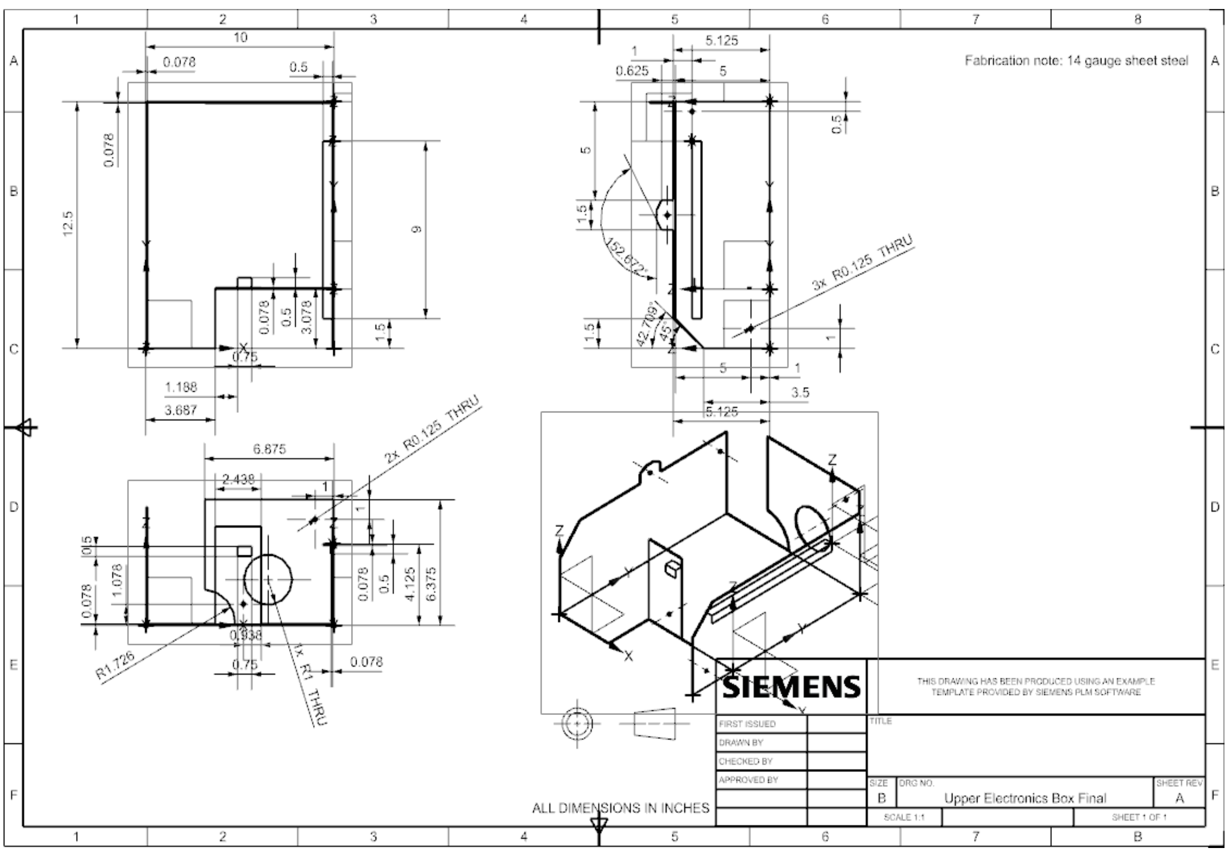


Figure [22]: Top Electronics Tray Engineering Drawing

IV. Electronic Tray (Bottom)

The bottom electronics tray is located around the steering column and is secured to the tractor via 3 bolt locations. The smaller electrical components are secured to the top face of the tray. The CAD model and dimensional drawing can be seen in *figure [23]* and *figure [24]* below.

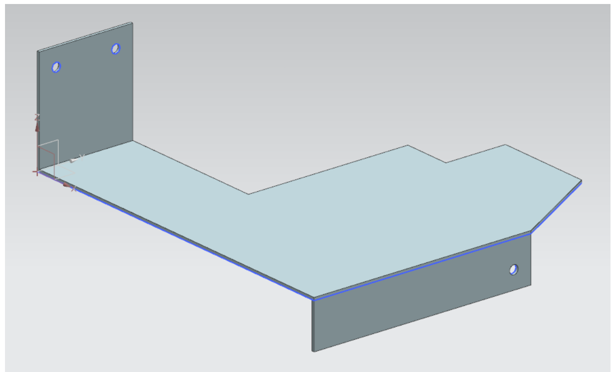


Figure [23]: Lower Electronics Tray CAD Model

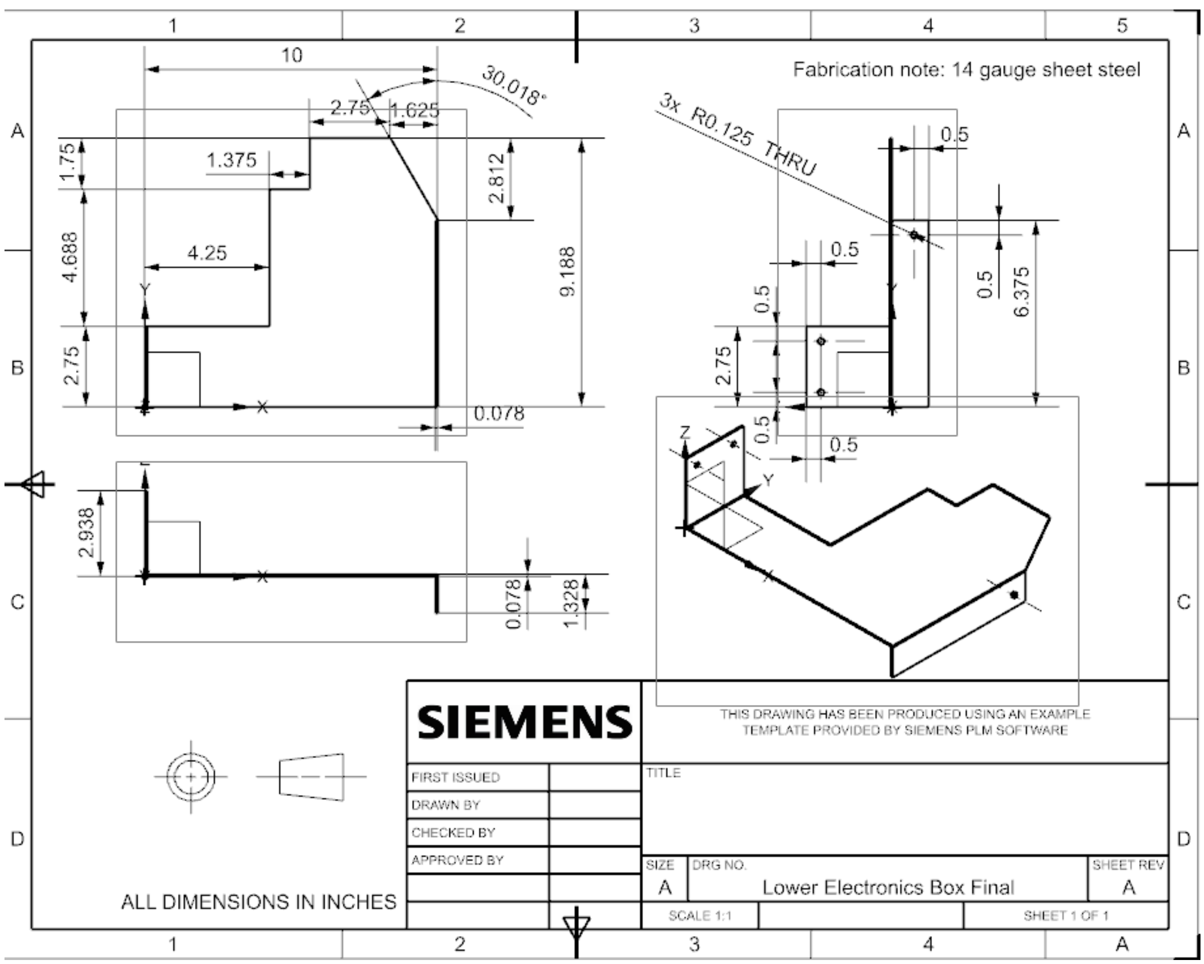


Figure [24]: Lower Electronics Tray Engineering Drawing

V. Battery Tray

The battery tray assembly consisted of 2 components: the tray itself and a mount to secure and position the tray over the motor mount. The tray 17.25”x11.875” tray was constructed of 14 gauge steel. The tray way constrained so that the bottom of the tray was in contact with the top of the mounts and centered on the mount. The tray assembly and engineering drawing can be found in *figure [25]* and *figure [26]* below.

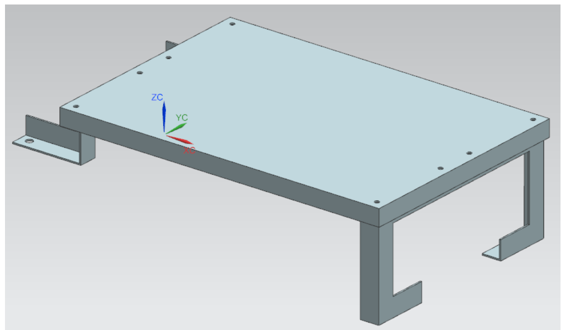


Figure [25]: Battery Tray Assembly CAD Model

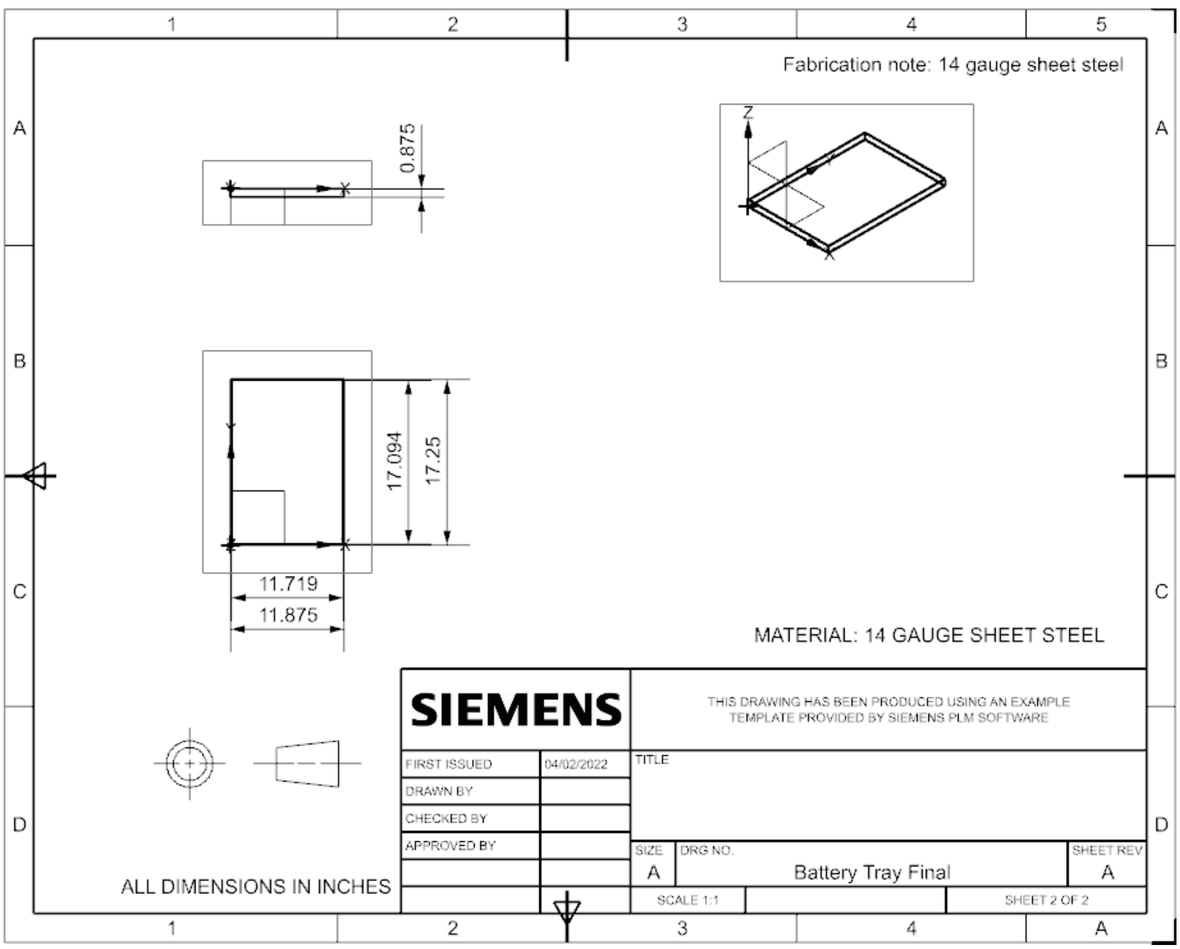


Figure [26]: Battery Tray Engineering Drawing

VI. Overall Tractor Chassis

After the fabricated components were created they were assembled using the chassis as a base component. The chassis was constrained so that it was fixed in the environment. This made assembly easier. The remaining components were introduced to the environment and using a variety of constraints (touch, align, concentric, distance) the parts were placed in their respective positions. *Figure [27] (a)* depicts the fully assembled tractor while *figure [27] (b)* shows an exploded view of the assembly.

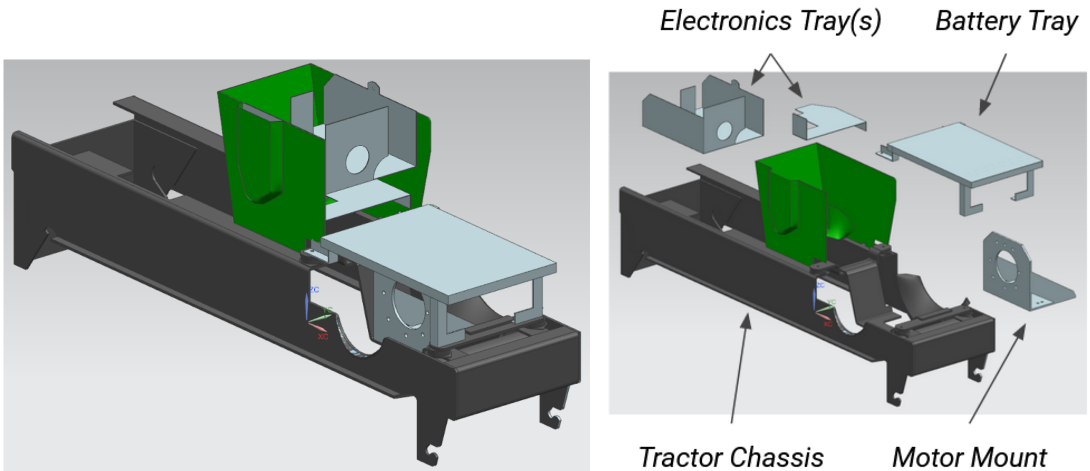


Figure [27]: (a) Tractor Assembly, (b) Tractor Assembly Exploded View

Finite Element Analysis

Finite element analysis was conducted on all fabricated components to ensure they could withstand their expected loads. The worst case scenario was simulated for each component.

I. Motor Mount

The motor mount was of primary interest because it would need to withstand the most intense load. The worst case scenario was simulated in the event the electric motor was at full torque, approximately 25 Nm. The motor mount and all other components were made of sheet steel of varying gauges. The mount was constrained at the 4 bolt locations securing it to the chassis and the torsional load was applied to the bolt pattern that would mount the electric motor to the mount. From this simulation it was discovered that the displacement of the mount was negligible as a max displacement of 7.38×10^{-4}in occurred along the top of the mount.

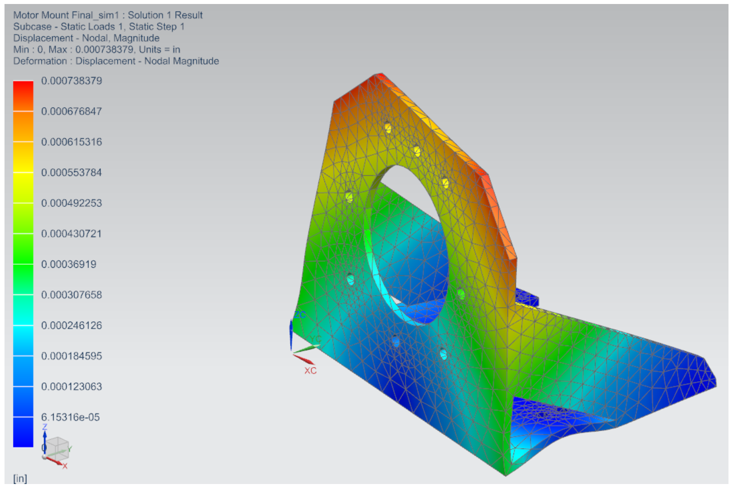


Figure [28]: Motor Mount FEA

II. Electronic Tray (Top)

The remaining components including the electronics trays, and battery tray were simulated with distributed loads acting as the weight of the components they would expect to experience. The top electronics tray used fixed constraints at the 4 bolt locations which secured it to the chassis. The top tray held the heavier electronic components which together weighed approximately 40lbs. In the simulation a distributed load of 40 lbs was applied to the tray and a max deflection of 5.65×10^{-3} in was experienced.

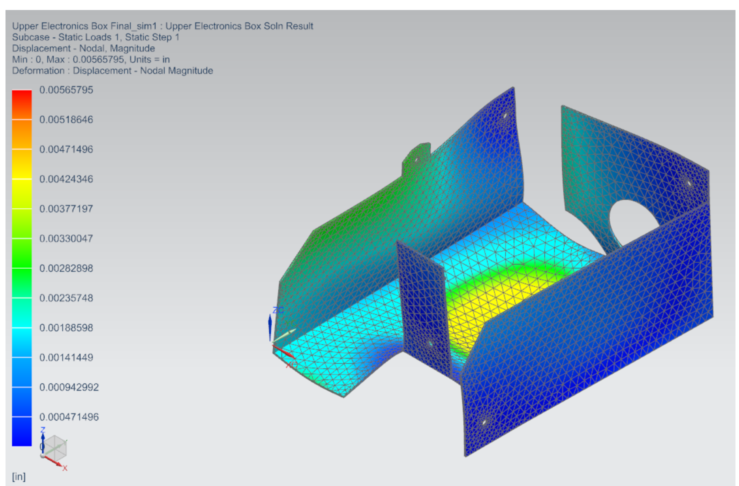


Figure [29]: Top Electronics Tray FEA

III. Electronic Tray (Bottom)

The bottom electronics tray held the smaller and lighter electric components. The simulation used 3 fixed constraints at the bolt locations securing the tray to the chassis. A distributed load of 30 lbf was applied along the face of the tray where the components rested. A maximum deflection of 7.13×10^{-2} in was experienced.

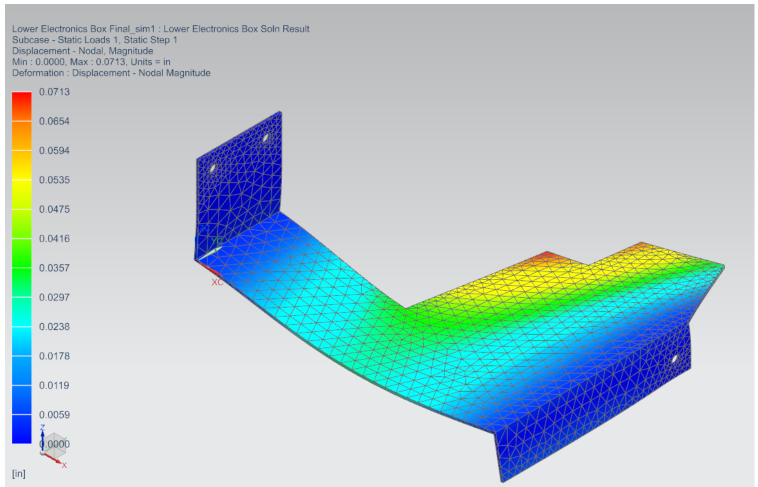


Figure [30]: Bottom Electronics Tray FEA

IV. Battery Tray

The battery tray was expected to hold 2 lithium ion batteries as well as the BMS. Together these components weighed approximately 80lbs. The battery tray and its mount were assembled using CAD software and the assembly was constrained at the 4 bolt locations of the mounts which secured the assembly to the chassis. The battery tray and mounts were secured to each other using welding features. A distributed load of 80 lbf was applied to the top of the tray. The results yielded minimal displacement with a max deflection of 2.69x10^-2 occurring near the center of the tray.

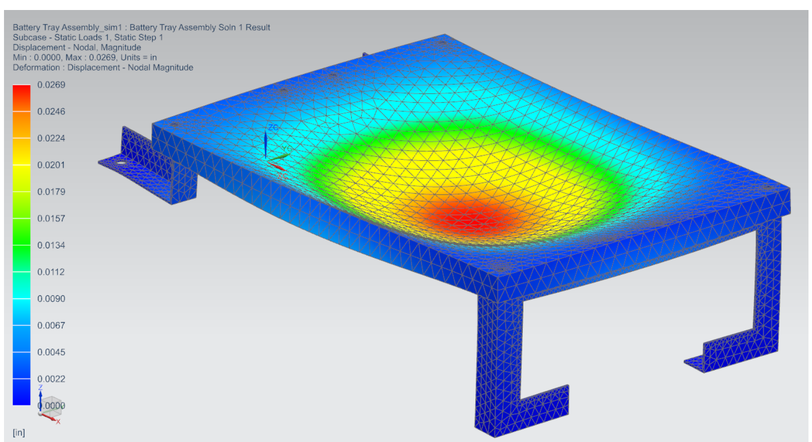


Figure [31]: Battery Tray Assembly FEA

The FEA results showed minimal deflection for all fabricated components. It was concluded that these steel components would withstand their expected loads as the tractor functioned.

Laboratory Tests

Once all the components and tractor chassis were brought up to the Universities laboratory. Laboratory testing was able to be conducted. During this time, all components were first tested to see if they work as intended. It was imperative to check before doing bench testing. If a faulty component was shipped then immediate action would have to be taken to replace it.

Initially, the overall wiring schematic of the tractor was generated. This gave a good insight and understanding on how to perform the first bench test wiring of the tractor. It was determined that wiring all the components in the tractor would be more difficult to work within the limited space available and would provide troubleshooting problems.

The first bench test was conducted using spare wires and a single battery to verify that the wiring schematic generated holds true. It was seen that some minor modifications to the schematic had to be done. However, the first base bench test was successful. Next step was to add the second battery in a series configuration. With an increase in voltage, the Alltrax Motor Controller had to be further tuned with a computer. Once, the main circuit was working properly. The third step was to create a bench test of the 12V wiring system / Ignition system.

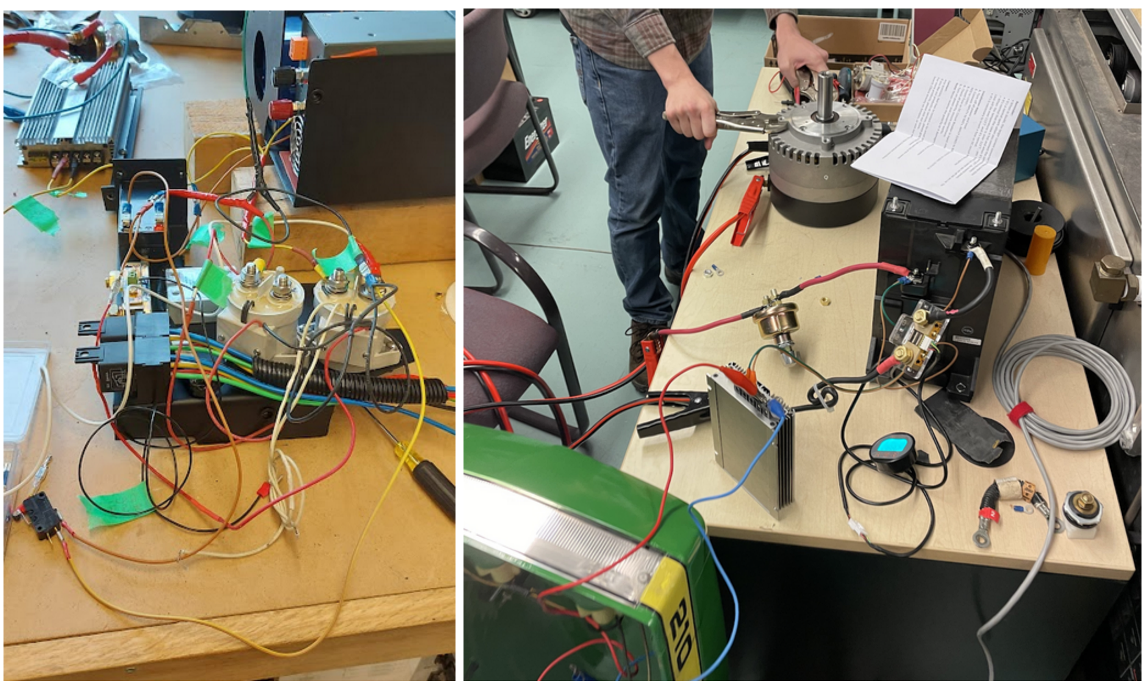


Figure [32]: Wiring Bench Testing

Once all bench test wiring was working and completed. All the components were then installed into the tractor chassis and new appropriate size wiring was made. All the components were then wired in the exact same way as previously bench tested. Finally, the tractor was fully wired and assembled for conducting a test run. The tractor chassis was lifted on a specially designed dolly. Which allowed the tractor wheels to hang in the air with no load. The first dry run was conducted at low current. It was seen that the axle and wheels were turning as predicted. More current was then added to the system to meet the calculated demands the tractor will encounter in the field.

Bill of Materials

Table [5]: Main Components

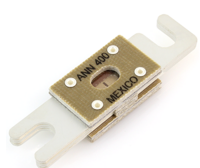
Component	**Description**	**Qty**	**Cost**
John Deere 210 Chassis 	- John Deere 210 - Model Year: 1975 - Chassis weight: 224 Kg - Steel Frame - Price ~ $1,000 CAD approx.	1	$1,000 CAD
Hyundai Ioniq Lithium Ion Batteries [37] 	- (x2) LG Chem Lithium Ion Batteries - 6'Wx11'Hx15.5'L - 40 lbs (each) - Number of Cells: 10 (each) - Nominal Capacity: 78 Ah (each) - Nominal Voltage: 37 V (each) - Price: $621 USD (each)	2	$1597.08 CAD
Motenergy ME-1004 DC Brushed Motor [38] 	- System Voltage: 24-48V - Power: 8 kW continuous at 48V, 16 kW for 1 min at 48V - Speed: 3360 rpm at 48V - Shaft Size: 1" x 3.1", ¼" key shaft - Weight: 30 lbs - 200 Amps continuous - Double Brushed - Price: $605 USD	1	$777.34 CAD
Alltrax SR72500 Speed Controller [39]	The speed controller will be responsible to adjust the voltage appropriately at different battery loads and provide a more consistent power output to the DC	1	$944.37 CAD

	Motor. It will allow the motor to operate in the region of 60 to 100 amps to increase its efficiency while allowing for the option to increase the current as power demands increase. The speed controller will also allow for fine tuning the voltage and current of the whole system in order to reduce the overall operating temperatures. (i.e DC Motor and Batteries) - System Voltage: 12-72 V - 500 Amps Peak - 200 Amps continuous - Price: 735 USD		
1500W ZJIVNV Switching Power Supply 	- Output Voltage: 48V - Output Current: 31.25A - Input Voltage: 110 VAC or 220 VAC - Output Power: 1500 W - Output Frequency: Above 24 KHz - Price: $58.99 USD	1	$74.30 CAD
Predicted Total	**With donated components: $1,796.01 CAD** **Without donated components: $4, 393.09 CAD**		

Table [6]: Supporting Systems

Component	**Description**	**Qty**	**Cost**
Cllena DC 40V-90V to 12V DC to DC Converter	- Input Voltage: 40V-90V - Output Voltage: 12V (Non-adjustable) - Output Current: 10A - Output Power: 120 W - Price: 26.99 USD	1	$33.99 CAD

			
Heltec Automation Smart Active Battery Management System (BMS) 	- Active balance mode - Maximum discharge Current: 200A - Balance Current (MAX): 24S 2A - Single Voltage Range: 1 -5 V - Number of temperature sensors: 2 - Supported Bluetooth function - Price: $199 USD	1	$250.63 CAD
Contactor [40] 	- TE Tyco Kilovac LEV200 - Nominal Voltage: 48 V - Pickup Voltage: 38 V - Max Voltage: 60 V - Dropout Voltage: 2-7 V - Coil Resistance: 145 Ohms - Rated Current: 500 Amps - 86.36mmx77.72mmx 60.45mm - Price: $107.19 USD	2	$270 CAD
Speed Potentiometer (Rotary Throttle w/ Switch) [41] 	Adjust the engine rpm at the given speed setting. By sending enough current to both the main contactor and the speed controller. - 5K Ohm Throttle Potentiometer - Price ~ $13 USD	1	$16.70 CAD
Speed Setting Switch (Turtle and Rabbit Mode) [42]	Switch used to set the tractor in a preloaded speed setting for easier usage, increased efficiency and more control of	1	$20.69 CAD

	the motor and battery consumption. - Off (Turtle Speed) - On (Rabbit Speed) - Price: $16.10 USD		
Diode on Main Contactor [43] 	- Diode Rating: MR754 - Silicon 6 Amp, 400V standard recovery - Forward Voltage Max: 1.25 V - Price: $1.23 - $1.89 CAD	1	$1.23 CAD
Fuse [44] 	- EATON's Bussmann Series ANN400 - Current Rating: 400 Amps - Nominal Voltage Rating: 125 V - Open link element - allows visibility through a mica window - Price: $17.65 USD	1	$22.68 CAD
Resistor on Main Contactor [45] 	- 1000 Ohm 10W - Type: WireWound Power Resistor - Tolerance: 5% - 1.88'L x 0.38'W x 0.36'H - Price: $1.05 USD	1	$1.35 CAD
Main Circuit Power Wire 	- Power Wire Rating: 2 AWG-170WG - Price ~ $3 USD per foot	~5 ft	$57.82 CAD
Multi-Display Gauge [46]	- QWORK Battery Monitor Voltmeter and Ammeter - LCD Display of battery information (Voltage, current, consumed power and battery capacity) - Voltage range: 8-80 V - Current range: 0-500 A - 13 ft cable	1	$125.02 CAD

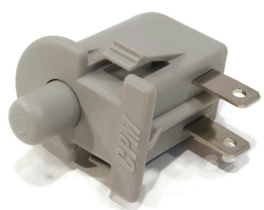
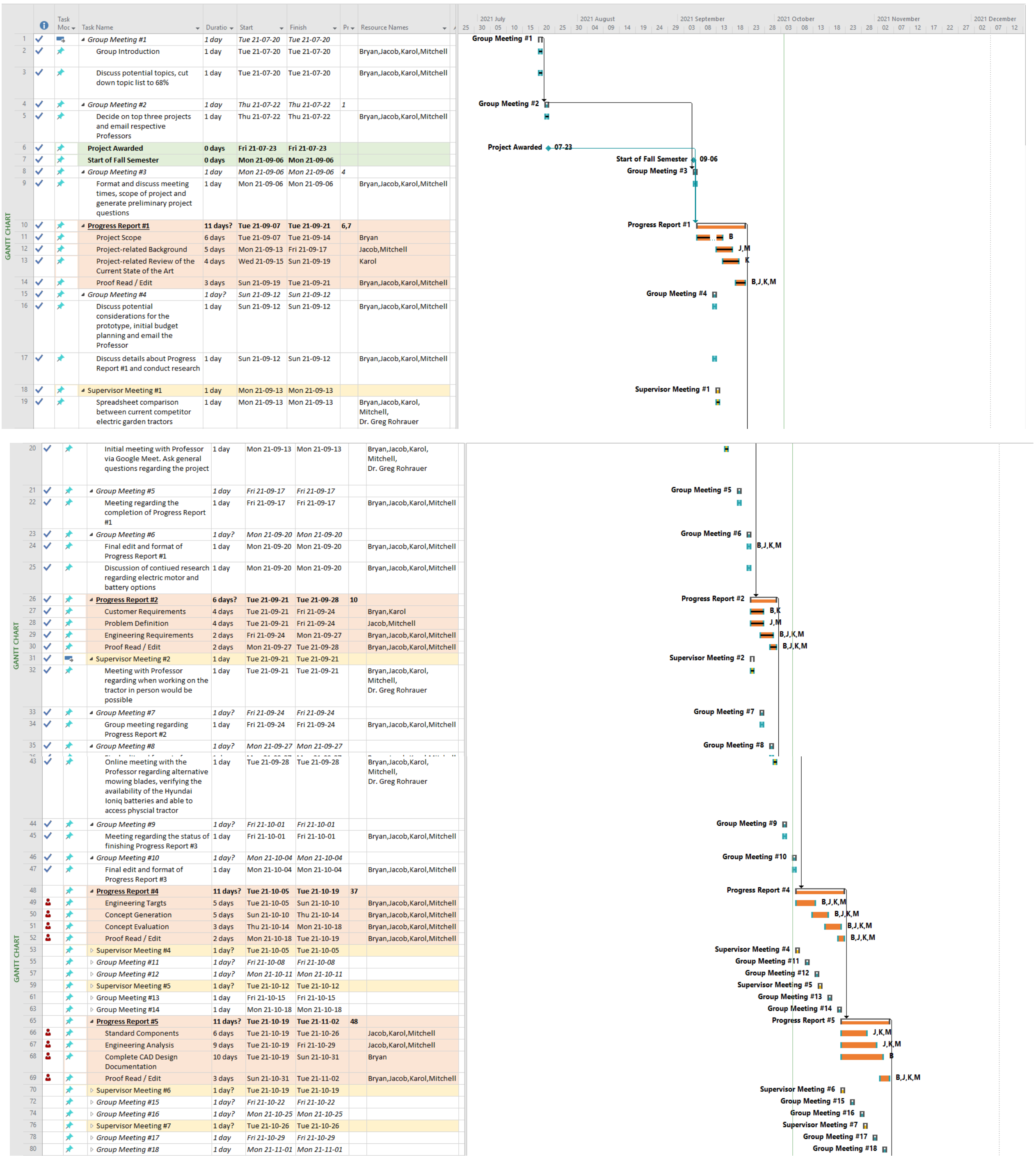
	- Diameter: 2.3’ - Weight: 400 grams - Price: $97.30 USD		
Momentary switch [47] 	- Interlock Seat Switch - 2 position - 2 terminals - 1”x1 ⅝’x1 ⅜” - On/Off position - $11.99 USD - Used on competitor tractors - Momentary switch	1	$15.41 CAD
12V Auxiliary wiring components and accessories	- Terminals - Wire - Solder - Flux - Fuses - Junction box - Crimp connectors - 3d printing filament - Usb port - ~350$ CAD		$350 CAD
Raw Materials	- aluminum plate 8 gauge - -¼ steel plate		$350 CAD
Total	**$ 1,515.52 CAD**		

Table [7]: Overall Cost Summation

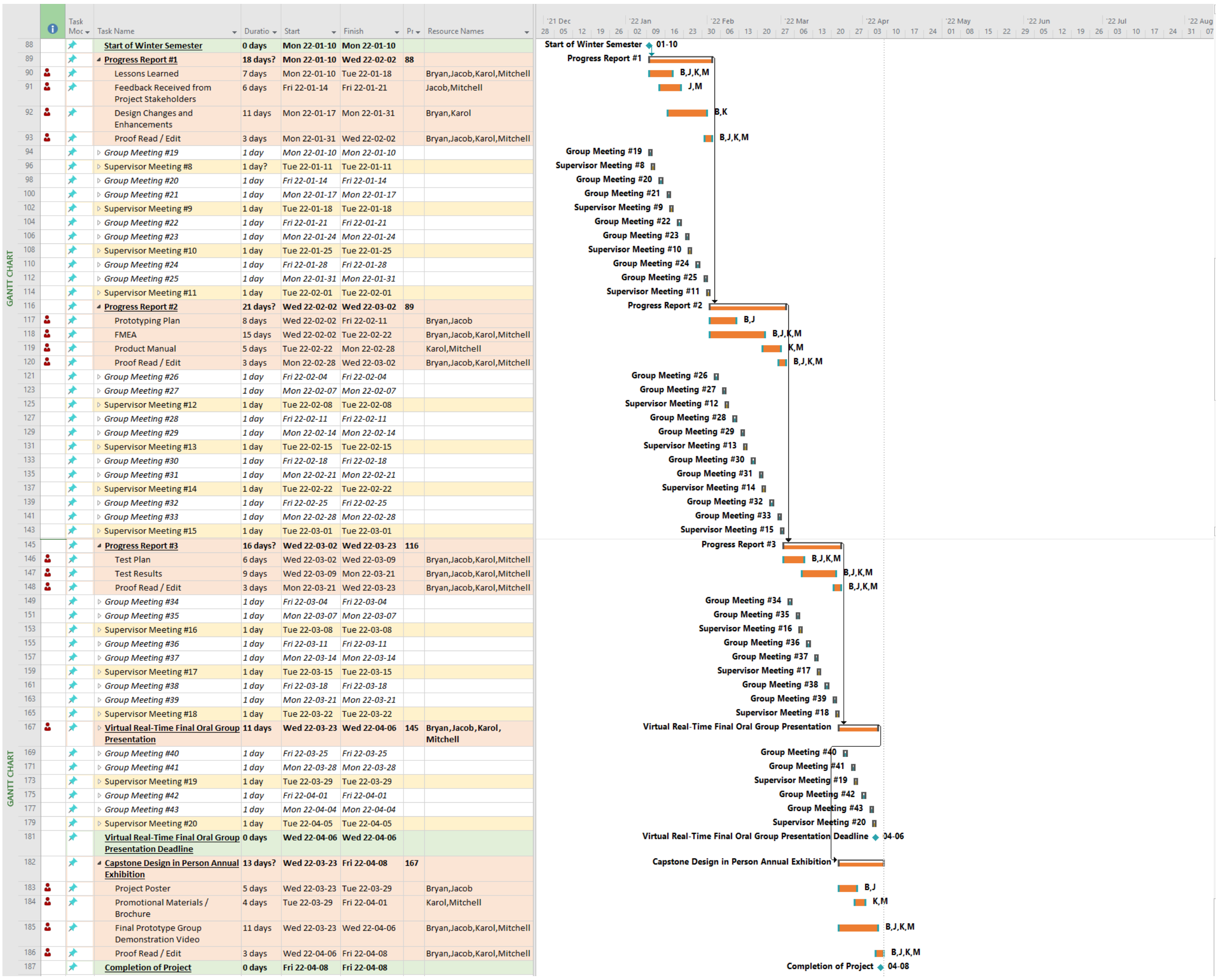
Tractor System(s)	Cost Summation
Main Components	**With donated components: $1,796.01 CAD** **Without donated components: $4, 393.09 CAD**
Supporting Systems	**$ 1,515.52 CAD**
Total Cost	**With donated components: $3,311.53 CAD** **Without donated components: $5,908.61 CAD**

Fall Semester Gantt Chart



	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Group Meeting #1	1 day	Tue 21-07-20	Tue 21-07-20		
2	Group Introduction	1 day	Tue 21-07-20	Tue 21-07-20		Bryan,Jacob,Karol,Mitchell
3	Discuss potential topics, cut down topic list to 68%	1 day	Tue 21-07-20	Tue 21-07-20		Bryan,Jacob,Karol,Mitchell
4	Group Meeting #2	1 day	Thu 21-07-22	Thu 21-07-22	1	
5	Decide on top three projects and email respective Professors	1 day	Thu 21-07-22	Thu 21-07-22		Bryan,Jacob,Karol,Mitchell
6	**Project Awarded**	**0 days**	**Fri 21-07-23**	**Fri 21-07-23**		
7	**Start of Fall Semester**	**0 days**	**Mon 21-09-06**	**Mon 21-09-06**		
8	Group Meeting #3	1 day	Mon 21-09-06	Mon 21-09-06	4	
9	Format and discuss meeting times, scope of project and generate preliminary project questions	1 day	Mon 21-09-06	Mon 21-09-06		Bryan,Jacob,Karol,Mitchell
10	**Progress Report #1**	**11 days?**	**Tue 21-09-07**	**Tue 21-09-21**	**6,7**	
11	Project Scope	6 days	Tue 21-09-07	Tue 21-09-14		Bryan
12	Project-related Background	5 days	Mon 21-09-13	Fri 21-09-17		Jacob,Mitchell
13	Project-related Review of the Current State of the Art	4 days	Wed 21-09-15	Sun 21-09-19		Karol
14	Proof Read / Edit	3 days	Sun 21-09-19	Tue 21-09-21		Bryan,Jacob,Karol,Mitchell
15	Group Meeting #4	1 day?	Sun 21-09-12	Sun 21-09-12		
16	Discuss potential considerations for the prototype, initial budget planning and email the Professor	1 day	Sun 21-09-12	Sun 21-09-12		Bryan,Jacob,Karol,Mitchell
17	Discuss details about Progress Report #1 and conduct research	1 day	Sun 21-09-12	Sun 21-09-12		Bryan,Jacob,Karol,Mitchell
18	Supervisor Meeting #1	1 day	Mon 21-09-13	Mon 21-09-13		
19	Spreadsheet comparison between current competitor electric garden tractors	1 day	Mon 21-09-13	Mon 21-09-13		Bryan,Jacob,Karol, Mitchell, Dr. Greg Rohrauer
20	Initial meeting with Professor via Google Meet. Ask general questions regarding the project	1 day	Mon 21-09-13	Mon 21-09-13		Bryan,Jacob,Karol, Mitchell, Dr. Greg Rohrauer
21	Group Meeting #5	1 day	Fri 21-09-17	Fri 21-09-17		
22	Meeting regarding the completion of Progress Report #1	1 day	Fri 21-09-17	Fri 21-09-17		Bryan,Jacob,Karol,Mitchell
23	Group Meeting #6	1 day?	Mon 21-09-20	Mon 21-09-20		
24	Final edit and format of Progress Report #1	1 day	Mon 21-09-20	Mon 21-09-20		Bryan,Jacob,Karol,Mitchell
25	Discussion of contiued research regarding electric motor and battery options	1 day	Mon 21-09-20	Mon 21-09-20		Bryan,Jacob,Karol,Mitchell
26	**Progress Report #2**	**6 days?**	**Tue 21-09-21**	**Tue 21-09-28**	**10**	
27	Customer Requirements	4 days	Tue 21-09-21	Fri 21-09-24		Bryan,Karol
28	Problem Definition	4 days	Tue 21-09-21	Fri 21-09-24		Jacob,Mitchell
29	Engineering Requirements	2 days	Fri 21-09-24	Mon 21-09-27		Bryan,Jacob,Karol,Mitchell
30	Proof Read / Edit	2 days	Mon 21-09-27	Tue 21-09-28		Bryan,Jacob,Karol,Mitchell
31	Supervisor Meeting #2	1 day	Tue 21-09-21	Tue 21-09-21		
32	Meeting with Professor regarding when working on the tractor in person would be possible	1 day	Tue 21-09-21	Tue 21-09-21		Bryan,Jacob,Karol, Mitchell, Dr. Greg Rohrauer
33	Group Meeting #7	1 day?	Fri 21-09-24	Fri 21-09-24		
34	Group meeting regarding Progress Report #2	1 day	Fri 21-09-24	Fri 21-09-24		Bryan,Jacob,Karol,Mitchell
35	Group Meeting #8	1 day?	Mon 21-09-27	Mon 21-09-27		
43	Online meeting with the Professor regarding alternative mowing blades, verifying the availability of the Hyundai Ioniq batteries and able to access physcial tractor	1 day	Tue 21-09-28	Tue 21-09-28		Bryan,Jacob,Karol, Mitchell, Dr. Greg Rohrauer
44	Group Meeting #9	1 day?	Fri 21-10-01	Fri 21-10-01		
45	Meeting regarding the status of finishing Progress Report #3	1 day	Fri 21-10-01	Fri 21-10-01		Bryan,Jacob,Karol,Mitchell
46	Group Meeting #10	1 day?	Mon 21-10-04	Mon 21-10-04		
47	Final edit and format of Progress Report #3	1 day	Mon 21-10-04	Mon 21-10-04		Bryan,Jacob,Karol,Mitchell
48	**Progress Report #4**	**11 days?**	**Tue 21-10-05**	**Tue 21-10-19**	**37**	
49	Engineering Targts	5 days	Tue 21-10-05	Sun 21-10-10		Bryan,Jacob,Karol,Mitchell
50	Concept Generation	5 days	Sun 21-10-10	Thu 21-10-14		Bryan,Jacob,Karol,Mitchell
51	Concept Evaluation	3 days	Thu 21-10-14	Mon 21-10-18		Bryan,Jacob,Karol,Mitchell
52	Proof Read / Edit	2 days	Mon 21-10-18	Tue 21-10-19		Bryan,Jacob,Karol,Mitchell
53	Supervisor Meeting #4	1 day?	Tue 21-10-05	Tue 21-10-05		
55	Group Meeting #11	1 day?	Fri 21-10-08	Fri 21-10-08		
57	Group Meeting #12	1 day?	Mon 21-10-11	Mon 21-10-11		
59	Supervisor Meeting #5	1 day?	Tue 21-10-12	Tue 21-10-12		
61	Group Meeting #13	1 day	Fri 21-10-15	Fri 21-10-15		
63	Group Meeting #14	1 day	Mon 21-10-18	Mon 21-10-18		
65	**Progress Report #5**	**11 days?**	**Tue 21-10-19**	**Tue 21-11-02**	**48**	
66	Standard Components	6 days	Tue 21-10-19	Tue 21-10-26		Jacob,Karol,Mitchell
67	Engineering Analysis	9 days	Tue 21-10-19	Fri 21-10-29		Jacob,Karol,Mitchell
68	Complete CAD Design Documentation	10 days	Tue 21-10-19	Sun 21-10-31		Bryan
69	Proof Read / Edit	3 days	Sun 21-10-31	Tue 21-11-02		Bryan,Jacob,Karol,Mitchell
70	Supervisor Meeting #6	1 day?	Tue 21-10-19	Tue 21-10-19		
72	Group Meeting #15	1 day?	Fri 21-10-22	Fri 21-10-22		
74	Group Meeting #16	1 day?	Mon 21-10-25	Mon 21-10-25		
76	Supervisor Meeting #7	1 day?	Tue 21-10-26	Tue 21-10-26		
78	Group Meeting #17	1 day	Fri 21-10-29	Fri 21-10-29		
80	Group Meeting #18	1 day	Mon 21-11-01	Mon 21-11-01		

Winter Semester Gantt Chart



ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
88	**Start of Winter Semester**	**0 days**	**Mon 22-01-10**	**Mon 22-01-10**		
89	**Progress Report #1**	**18 days?**	**Mon 22-01-10**	**Wed 22-02-02**	**88**	
90	Lessons Learned	7 days	Mon 22-01-10	Tue 22-01-18		Bryan,Jacob,Karol,Mitchell
91	Feedback Received from Project Stakeholders	6 days	Fri 22-01-14	Fri 22-01-21		Jacob,Mitchell
92	Design Changes and Enhancements	11 days	Mon 22-01-17	Mon 22-01-31		Bryan,Karol
93	Proof Read / Edit	3 days	Mon 22-01-31	Wed 22-02-02		Bryan,Jacob,Karol,Mitchell
94	*Group Meeting #19*	*1 day*	*Mon 22-01-10*	*Mon 22-01-10*		
96	Supervisor Meeting #8	1 day?	Tue 22-01-11	Tue 22-01-11		
98	*Group Meeting #20*	*1 day*	*Fri 22-01-14*	*Fri 22-01-14*		
100	*Group Meeting #21*	*1 day*	*Mon 22-01-17*	*Mon 22-01-17*		
102	Supervisor Meeting #9	1 day	Tue 22-01-18	Tue 22-01-18		
104	*Group Meeting #22*	*1 day*	*Fri 22-01-21*	*Fri 22-01-21*		
106	*Group Meeting #23*	*1 day*	*Mon 22-01-24*	*Mon 22-01-24*		
108	Supervisor Meeting #10	1 day	Tue 22-01-25	Tue 22-01-25		
110	*Group Meeting #24*	*1 day*	*Fri 22-01-28*	*Fri 22-01-28*		
112	*Group Meeting #25*	*1 day*	*Mon 22-01-31*	*Mon 22-01-31*		
114	Supervisor Meeting #11	1 day	Tue 22-02-01	Tue 22-02-01		
116	**Progress Report #2**	**21 days?**	**Wed 22-02-02**	**Wed 22-03-02**	**89**	
117	Prototyping Plan	8 days	Wed 22-02-02	Fri 22-02-11		Bryan,Jacob
118	FMEA	15 days	Wed 22-02-02	Tue 22-02-22		Bryan,Jacob,Karol,Mitchell
119	Product Manual	5 days	Tue 22-02-22	Mon 22-02-28		Karol,Mitchell
120	Proof Read / Edit	3 days	Mon 22-02-28	Wed 22-03-02		Bryan,Jacob,Karol,Mitchell
121	*Group Meeting #26*	*1 day*	*Fri 22-02-04*	*Fri 22-02-04*		
123	*Group Meeting #27*	*1 day*	*Mon 22-02-07*	*Mon 22-02-07*		
125	Supervisor Meeting #12	1 day	Tue 22-02-08	Tue 22-02-08		
127	*Group Meeting #28*	*1 day*	*Fri 22-02-11*	*Fri 22-02-11*		
129	*Group Meeting #29*	*1 day*	*Mon 22-02-14*	*Mon 22-02-14*		
131	Supervisor Meeting #13	1 day	Tue 22-02-15	Tue 22-02-15		
133	*Group Meeting #30*	*1 day*	*Fri 22-02-18*	*Fri 22-02-18*		
135	*Group Meeting #31*	*1 day*	*Mon 22-02-21*	*Mon 22-02-21*		
137	Supervisor Meeting #14	1 day	Tue 22-02-22	Tue 22-02-22		
139	*Group Meeting #32*	*1 day*	*Fri 22-02-25*	*Fri 22-02-25*		
141	*Group Meeting #33*	*1 day*	*Mon 22-02-28*	*Mon 22-02-28*		
143	Supervisor Meeting #15	1 day	Tue 22-03-01	Tue 22-03-01		
145	**Progress Report #3**	**16 days?**	**Wed 22-03-02**	**Wed 22-03-23**	**116**	
146	Test Plan	6 days	Wed 22-03-02	Wed 22-03-09		Bryan,Jacob,Karol,Mitchell
147	Test Results	9 days	Wed 22-03-09	Mon 22-03-21		Bryan,Jacob,Karol,Mitchell
148	Proof Read / Edit	3 days	Mon 22-03-21	Wed 22-03-23		Bryan,Jacob,Karol,Mitchell
149	*Group Meeting #34*	*1 day*	*Fri 22-03-04*	*Fri 22-03-04*		
151	*Group Meeting #35*	*1 day*	*Mon 22-03-07*	*Mon 22-03-07*		
153	Supervisor Meeting #16	1 day	Tue 22-03-08	Tue 22-03-08		
155	*Group Meeting #36*	*1 day*	*Fri 22-03-11*	*Fri 22-03-11*		
157	*Group Meeting #37*	*1 day*	*Mon 22-03-14*	*Mon 22-03-14*		
159	Supervisor Meeting #17	1 day	Tue 22-03-15	Tue 22-03-15		
161	*Group Meeting #38*	*1 day*	*Fri 22-03-18*	*Fri 22-03-18*		
163	*Group Meeting #39*	*1 day*	*Mon 22-03-21*	*Mon 22-03-21*		
165	Supervisor Meeting #18	1 day	Tue 22-03-22	Tue 22-03-22		
167	**Virtual Real-Time Final Oral Group Presentation**	**11 days**	**Wed 22-03-23**	**Wed 22-04-06**	**145**	**Bryan,Jacob,Karol, Mitchell**
169	*Group Meeting #40*	*1 day*	*Fri 22-03-25*	*Fri 22-03-25*		
171	*Group Meeting #41*	*1 day*	*Mon 22-03-28*	*Mon 22-03-28*		
173	Supervisor Meeting #19	1 day	Tue 22-03-29	Tue 22-03-29		
175	*Group Meeting #42*	*1 day*	*Fri 22-04-01*	*Fri 22-04-01*		
177	*Group Meeting #43*	*1 day*	*Mon 22-04-04*	*Mon 22-04-04*		
179	Supervisor Meeting #20	1 day	Tue 22-04-05	Tue 22-04-05		
181	**Virtual Real-Time Final Oral Group Presentation Deadline**	**0 days**	**Wed 22-04-06**	**Wed 22-04-06**		
182	**Capstone Design in Person Annual Exhibition**	**13 days?**	**Wed 22-03-23**	**Fri 22-04-08**	**167**	
183	Project Poster	5 days	Wed 22-03-23	Tue 22-03-29		Bryan,Jacob
184	Promotional Materials / Brochure	4 days	Tue 22-03-29	Fri 22-04-01		Karol,Mitchell
185	Final Prototype Group Demonstration Video	11 days	Wed 22-03-23	Wed 22-04-06		Bryan,Jacob,Karol,Mitchell
186	Proof Read / Edit	3 days	Wed 22-04-06	Fri 22-04-08		Bryan,Jacob,Karol,Mitchell
187	**Completion of Project**	**0 days**	**Fri 22-04-08**	**Fri 22-04-08**		

Figure[33]: Capstone Project Timeline

Ethical Considerations

Ethical considerations define the moral principles that govern a product's specifications and abilities. Ethical considerations governed every step of the design process from the initial design to end of life including marketing. Both the positive and negative impacts the products could have on the public, employees, investors and clients were reviewed. Key topics included environmental considerations, job minimization and marketing considerations.

One major ethical consideration is the elimination of fossil fuels. As discussed above, these protect both the environment and the public by eliminating hazardous fuels. At the same time the electricity charging the tractor may come from nonrenewable resources.

Another environmental consideration is the proper recycling of the original ICE engine and other components. The target demographic is the public who already own an old ICE chassis and who are required to discard the original ICE components. These components must be properly discarded to protect the environment.

The elimination of fossil fuel use comes at a price. The electric garden tractor may replace garden tractors that run on fossil fuels and associated jobs. This may be considered controversial marketing as it potentially affects the livelihood of the working class. At the same time the product will create new jobs that can replace those which were lost.

Accurate marketing of the product and its abilities is a key ethical issue. The product must be advertised such that the consumer is aware of the possible variation in specifications and performance, such as run time, that may occur due to the various different battery options and other parts.

For example, the conversion kit may supply new components but will prioritize using recycled products including batteries. Reusing old lithium ion batteries leaves a small chance that the customer may receive a product that is not 100% optimal even after vigorous testing and checking of battery health. The conversion kit must have fall backs for customers whose products don’t perform to expectations.

Safety Considerations

Throughout the design process the safety of the public and environment were considered paramount. The electric garden tractor is safe for both the environment and the population. The World Health Organization attributes an estimated 4.2 million deaths every year from outdoor air pollution. By eliminating the gasoline engine there is a decrease in use of fossil fuels, emission of carbon dioxide and other air pollutants into the environment.

In general electric powered lawn mowers are more quiet than gas powered mowers and the reduction in noise is safer for the user. The typical electric lawnmower emits approximately 75 decibels while gas mowers emit approximately 95 decibels. In comparison this would be similar to a washing machine and a motorcycle. The U.S Centers for Disease Control warns that 85 decibels can contribute to hearing loss.

As a final safety precaution the intended user has specified that charging and storage of the electric garden tractor will be in an outdoor shed location, not attached to their main residence, in order to prevent major damage in case of unforeseen failure.

Regulatory and Compliance

Both the United States and Canada have implemented and continuously updated regulations and standards for the emissions of nonroad engines. Nonroad engines can be defined as all internal combustion engines with the exception of motor vehicles engines, stationary engines or engines which remain in a single location for over 12 months, engines used in aircrafts and engines only used for competition. In 2003 this definition was added upon to include all diesel powered engines with some exceptions. The exemptions are applied to regulated applications including farm tractors and diesel lawn tractors [48].

The first USA federal emission standards for nonroad diesel engines, also known as Tier 1, were adopted in 1994. More stringent standards were phased in between 2000 to 2008 and are known as Tire 2 and Tier 3 standards. In 2004 the standards were again updated, Tier 4, and phased in from 2008 to 2015 [48]. The newest Tier 4 standards require a substantial reduction of emissions including nitrous oxide, particulate matter (also called particle pollution) and hydrocarbons. Carbon Dioxide emissions remained unchanged from previous tiers (Tier 3 standards). These new standards required that emissions of particulate matter and nitrogen oxide be further reduced by around 90% [48]. Table [4] below contains the Tier 4 emission standards for engines up to 560kW.

Tier 4 emission standards—Engines up to 560 kW, g/kWh (g/bhp-hr)

Engine Power	Year	CO	NMHC	$NMHC+NO_x$	NO_x	PM
kW < 8 (hp < 11)	2008	8.0 (6.0)	-	7.5 (5.6)	-	0.4[a] (0.3)
8 ≤ kW < 19 (11 ≤ hp < 25)	2008	6.6 (4.9)	-	7.5 (5.6)	-	0.4 (0.3)
19 ≤ kW < 37 (25 ≤ hp < 50)	2008	5.5 (4.1)	-	7.5 (5.6)	-	0.3 (0.22)
	2013	5.5 (4.1)	-	4.7 (3.5)	-	0.03 (0.022)
37 ≤ kW < 56 (50 ≤ hp < 75)	2008	5.0 (3.7)	-	4.7 (3.5)	-	0.3[b] (0.22)
	2013	5.0 (3.7)	-	4.7 (3.5)	-	0.03 (0.022)
56 ≤ kW < 130 (75 ≤ hp < 175)	2012-2014[c]	5.0 (3.7)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)
130 ≤ kW ≤ 560 (175 ≤ hp ≤ 750)	2011-2014[d]	3.5 (2.6)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)

a - hand-startable, air-cooled, DI engines may be certified to Tier 2 standards through 2009 and to an optional PM standard of 0.6 g/kWh starting in 2010
b - 0.4 g/kWh (Tier 2) if manufacturer complies with the 0.03 g/kWh standard from 2012
c - PM/CO: full compliance from 2012; NOx/HC: Option 1 (if banked Tier 2 credits used)—50% engines must comply in 2012-2013; Option 2 (if no Tier 2 credits claimed)—25% engines must comply in 2012-2014, with full compliance from 2014.12.31
d - PM/CO: full compliance from 2011; NOx/HC: 50% engines must comply in 2011-2013

Table [8]: USA Nonroad Engine Emission Standards [48]

Tier 4 standards not only affect engines, they also affect diesel fuels. The new standards mandated that nonroad diesel fuels must see a reduction in sulfur contents [48].

Since 1994 emission standards have become more strict in order to reduce emissions. It is expected that these standards will continue to update and require off road engines to produce less emissions using cleaner fuel. These strict standards highlight the need for electric garden tractors today and in the future.

Conclusions

This capstone project produced a proof of concept which showcased that modern electric motors and batteries are suitable for converting ICE lawn tractors, which run on harmful fossil fuels, into greener, more user friendly and potentially cheaper alternatives.

The criteria for success was to design a solution with a larger run time than its competitors (1 to 1.5 hours on a single charge) while maintaining the same functionality. The conversion kit was also expected to require minimal fabrication and easy assembly.

The design incorporated major components including; John Deere 210 Chassis, Hyundai Ioniq Lithium Ion Batteries, Motenergy ME-1004 DC Brushed Motor, Alltrax SR72500 Speed Controller and 1500W ZJIVNV Switching Power Supply.

The original chases required minimal alterations and provided a strong base for its components. A majority of the parts used in the conversion kit were standard off the shelf components and were readily available from retailers. The few parts which required custom fabrication were easy to manufacture.

The safety and auxiliary features including lights also remained unchanged from the original design. Safety features included the key switch and seat switch.

The run time of the tractor is estimated at 173 minutes in an ideal scenario and approximately 55.2 minutes in a real world grass cutting scenario. Charge time was approximated at 79.4 minutes from completely drained batteries and 63.5 minutes when the depth of discharge is limited to 80%. Both the run time and charge times are competitive with lawn tractors currently on the market.

Overall the functionality of the garden tractor remained unchanged compared to the original ICE design and provided a greener alternative.

Acknowledgments

We would like to thank Dr. Greg Rohrauer, Professor at Ontario Tech University for his supplies, workspace, expertise, evaluation of our work and continuous guidance throughout the entirety of the project. We would also like to thank Alltrax for the donation of a speed controller, schematic templates of the design and expertise.

References

Including books, technical journals, patents.

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N__PRODUCT_GROUP_aud-1217348015026:pla-302699771693&gclid=Cj0KCQjwm9yJBhDTARIsABKIcGbtnNNckbOMtlbJIqpjc_QxIsKxS1tyVlMAcWN21_OnI8_9CPC0VOMaAgE4EALw_wcB&gclsrc=aw.ds

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Appendices

Appendix J1: Overall Project Meeting Log

Jul 20, 2021

Group met to initially discuss topics
Cut down list to 68%

Jul 22, 2021

Group met to discuss topics discussed
Tier list made of high interest topics

Delegated profs to email

Bryan: greg, yulei

Karol: kiani, yuping

Note: email profs and cc all members to the email. Apply with the form. Get signature to email to dr: remon pop iliev

5th person potential?

Sep 6, 2021

Group met to discuss in person meetings, preliminary thoughts on the scope of the project.
Planned in person meeting for September 7, 2021.
Emailed professor regarding preliminary questions regarding the scope of the project.

Sep 7, 2021

Met in person on campus
Looked at the sirc classroom

Sep 12, 2021

Online meeting regarding potential considerations for the prototype, initial budget planning, sent an email to the professor regarding a meeting at his earliest convenience. Discussed initial gantt chart. Regular meeting times are set for Monday 12:30pm, Tuesday 11am-2pm, and Friday 2:15pm.
Discussed details about the project scope, background, and state of the industry. Plan to have all research completed by the 15th.

Sep 13, 2021

Brief online meeting at noon, spreadsheet comparison between various modern electric tractors created, plan to add DIY options. Later meeting with professor planned, briefly discussed what questions would need to be asked.

Met with professor in the afternoon via google meets, asked questions regarding scope of the project - received confirmation that there the objective is to market something similar to a retrofit kit, we will not be receiving the initially expected E15 tractor, but a different John Deere 210 tractor will be provided instead.

Sep 17, 2021

Online meeting at 2:15 regarding project report 1, edited existing paragraphs to be ready for final submission, prepared a final format for the report, and outlined what was required before submission.

Furthermore, had a discussion regarding electric motors, whether or not to utilize a brushless speed controller motor, and what kind of power is required.

Sep 20, 2021

Online meeting at 12:30 regarding finishing of project report 1, majority of the report finished by this date, brief discussion of what topics still need to be covered, and how to format them for the final report. The meeting then ended with group members taking a break, and researching and writing on required topics.

Second meeting held at 7:30 regarding final touches required for the report before submission. All topics are aggregated, read over, and formatted. References are checked. Progress report 1 is ready for submission.

Sep 21, 2021

Online meeting at 11am with the professor regarding when working on the tractor in person would be possible.

Following the professor's departure from the meeting, the group has a discussion on how to approach project report 2.

Sep 24, 2021

Group meeting at 3pm, regarding requirements for project report 2. Topics covered include battery life vs fuel capacity, weather resistance, electric motor vs original engine, customer requirements, ease of assembly. Rough idea of the format for the report is decided upon. House of quality drafted.

Sep 27, 2021

Group meeting at 12:30pm regarding progress report 1, majority of work finished by this time, with the remainder being highlighted.

Second group meeting at 7pm to proofread, add figure numbers and references, and proofread the final draft for submission.

Sep 28, 2021

Meeting at 11am with the professor regarding a few topics, including alternative blades, verifying the availability of the Hyundai Ioniq battery pack, and where/when we would be able to access the physical tractor. Hyundai Ioniq battery pack is not available, but similar albeit slightly smaller Hyundai batteries will be provided. Optimistic case, physical access in one week, realistic case, two to three weeks.

Oct 1, 2021

Group meeting at 3:15pm regarding an email received from the professor about the physical tractor being ready in a few weeks, and pictures of the total assembly.

Began work on project report 3, initial jot notes about which topics will be covered, and some early paragraphs written out.

Oct 4, 2021

Group meeting at 12:30 to consolidate content for project report 3, unfinished sections are highlighted. A second group meeting planned for 8pm to go prepare project report 3 for submission.

Group meeting at 8pm in which project report 3 is completed, proofread, and edited for final submission. Questions to ask the supervising professor are discussed following the completion of the report.

Oct 5, 2021
Group meeting with the professor at 11 to ask questions regarding the project, including battery life, tractor availability, where to find technical specifications for the batteries, motor controllers, BMS systems. Furthermore, feedback on project report 1 was received, technical details were good, but tone of the report needs to be shifted to an audience that understands the technical details.

Oct 8, 2021
Group meeting at 3:15 regarding project report 4, report was broken down into sections, and required research was discussed. In particular, the need for pictures and measurements of components in order to create engineering drawings and models of the tractor.

Oct 12, 2021
Group meeting at 11am regarding project report 4, research on components was done, such as the motor controller. An email was sent out to Alltrax regarding the possibility of a sponsorship, as well as their input on what motor controller is recommended for this project.

Oct 15, 2021
Group meeting at 3:30pm regarding the response from Alltrax, and project report 4. Alltrax has sent several circuit schematics, and recommended motor controllers. Furthermore, they have offered to donate a motor controller to the project. Project report 4 drawings were then discussed, as well as the necessary calculations.

Oct 18, 2021
Group meeting at 12:30 regarding project report 4, report is finished and finalized by the end of the meeting.

Oct 19, 2021
Group meeting with professor regarding direction of the project. In particular, the decision to order the ME1004 motor and SR72500 motor controller was made. Professor said that battery mounting locations would be considered over the following week, and pictures taken to be relayed to us.

Oct 25, 2021
Brief group meeting at 7pm regarding project report 5, what is required, what components we already have access to, what components still require speccing and ordering. What CAD and FEM is required.

Oct 26, 2021

Meeting with the professor at 11am, it was decided that batteries will be mounted vertically, as this will greatly simplify the cooling systems. More pictures of the chassis will be taken and sent to group members.

Oct 29, 2021

Meeting with group at 3pm regarding project report 5. Subheadings are created, required tasks are considered. Email sent to professor requesting pictures of chassis from multiple angles with some kind of measuring scale included, as well as picture of vertically mounted batteries.

Nov 1, 2021

Group meeting at 7pm regarding finishing project report 5. Meeting lasts several hours, after which point, project report 5 is completed. Of particular note is the finalized run time equations, FEA analysis, CAD of mounts, shrouds, etc. Additionally, projections of the component layout were created by overlaying CAD images over the tractor chassis.

Nov 2, 2021

Meeting with professor regarding the status of the tractor, motor and controller both shipped and in transit, tractor restoration near complete, professor only needs to sandblast the mower deck and reassemble the tractor. Also discussed the requirements, and what to expect for the presentation power point and final report.

Nov 7, 2021

Group meeting at 7pm regarding the formatting for the powerpoint presentation, and what sections are important, and must be included. By the end of this meeting, the majority of the powerpoint is completed, and all group members have chosen which slides they would like to present during the presentation.

Nov 8, 2021

Group meeting at 7pm regarding drafting the speaker notes to be submitted along with the power point. By the end of this meeting, the speaker notes are completed, and multiple practice presentations are done in order to ensure that the presentation time is close to the ten minute mark. Additionally, power point is touched up, ensuring figure numbers and references are accurate.

Nov 9, 2021

Group meeting with supervising professor at 12pm, discussing the presentation, some aspects to touch on for the final report, as well as the status of the physical tractor. Majority of the tractor components have been rebuilt, and are ready to place back into the chassis. Still waiting on sandblasting the mower deck.

Nov 12, 2021

Group meeting at 7pm regarding the final report, and what topics and tasks need to be worked on. Sections defined, and distributed across group members.

Nov 15, 2021

Group meeting to continue discussing and working on the final report. Furthermore, practice of the presentation is done, and some sections are cut from the script in order to bring the total presentation time to 10 minutes.

Nov 16, 2021

Group meeting at 7pm to work on the final report. Progress made on consolidating previous project report information into more finalized forms for use in the report.

Nov 19, 2021

Group meeting at 7pm to go over and figure out many of the calculations which the final report requires. By the end of this meeting, the run time of the tractor at different amperages was finalized, and some preliminary heat loss calculations are done.

Nov 23, 2021

Group meeting at 12pm with the professor regarding the state of the project, asking for help on how to go about heat loss calculations. By the end of this meeting, clarification and insight was given on how to go about the calculations.

A second group meeting at 7pm to practice the presentation, as well as trim some of the content was done, in which the final presentation time was 9 minutes and 45 seconds.

Jan 12, 2022

Group meeting regarding setting up regular meetings for the semester, the current school COVID policies and how they will affect the in person construction of the tractor. By the end of this meeting, an email is sent out to the professor regarding these issues. Regular meetings with professor scheduled for wednesday at 2pm

Jan 19, 2022

Group meeting with professor at 2pm regarding the direction the project should take for the semester, where and when group members will be working on the tractor in person.

Jan 25, 2022

Group meeting regarding HVAC calculations for duct work, looking at storage units which may provide an alternative work area during the COVID restrictions, and going over content needed to be discussed with the professor in the next meeting to complete project report #1.

Jan 26, 2022

Group meeting with professor at 2pm. In this meeting, the possibility of utilizing the on campus lab for tractor workstation after the 31st is discussed, as well as the alternative solution of renting a storage unit if on campus work is not possible. HVAC calculations are discussed with the professor, as well as the updated circuit diagram.

Second group meeting at 8pm regarding progress report 1, and what needs to be done for each section. Research into HVAC calculations is done. Another group meeting is scheduled for 2pm friday.

Jan 28, 2022

Group meeting at 2pm, regarding purchasing parts among group members, by the end of this meeting, solid state relay, dc/dc converter, and battery display meter are purchased. Additionally, work is done on HVAC calculations to cool the motor.

Feb 2, 2022

Group meeting with professor regarding hvac calculations, professor confirms that the calculations look good. Discussion is had on the possibility of the school going on strike, and how this may delay working on the tractor in person.

Feb 9, 2022

Group meeting to discuss project report 2, and what is needed for each given section. Unable to meet with the professor at our usual time this day, and the school going on strike the following day means we will be unable to receive correspondence from the professor during this time.

Feb 18, 2022

Brief group meeting to discuss plans for work over the reading week. Some initial work on project report 2 sections is completed.

Feb 23, 2022

Group work session for project report 2. Prototyping plan, FMEA, and operating manual are all worked on. Additionally, with the strike coming to a close, plans for the following week are made, as it is likely group members will be bogged down with postponed midterms and assignments following the school reopening.

Mar 2, 2022

Group meeting with professor regarding getting lab access to work on tractor. By the end of the meeting, information for getting access cards is given to the professor. Tractor to be delivered to campus by following week.

Mar 7, 2022

Group meeting regarding HVAC calculations. By the end of this meeting, the majority of first principles calculations are completed for the cooling of the motor.

Mar 9, 2022

Group meeting with professor regarding HVAC calculations, prox card access to lab, and when the tractor will be on campus. First principles calculations are deemed satisfactory, but need testing data to finalize. Information regarding prox card access is sent to the ACE office.

Mar 16, 2022

Group meeting with professor regarding test plan, when we will meet in person, and confirming that we have received ACE access. By the end of this meeting, it was decided that the tractor could be on campus on sunday. Planned testing includes motor airflow, battery discharge and charge rate, and internal resistance.

Mar 20, 2022

In person group meeting with professor at 5pm. During this meeting, the tractor and related components are relocated to the on campus work space. Measurements of core chassis components are taken. Electrical components are bench tested to verify their functionality, as well as build an idea of what the final circuit will look like. By the end of this meeting, plans for mounting brackets for various components are put in place

. Mar 21, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell begins work on a final CAD model of the chassis using concrete measurements.

Mar 23, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, preliminary designs for the electronics mounting tray are done, as well as an initial bench test of the drive circuit.

Mar 25, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, the frame of the electronics mounting tray is done, and construction of the finalized drive circuit begins.

Mar 28, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, the bolt hole locations on the electronics mounting tray are tapped and finalized. Wires for the finalized circuit are laid out and labeled.

Mar 30, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, a second electronics tray is devised to be located under the main electronics tray, and clearance issues noted and planned for.

Apr 1, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, the lower level electronics tray is completed, test fit, and tapped for bolt hole locations.

Apr 2, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, fabrication on the battery tray mounting system has begun. A mistake in the wiring diagram accidentally results in a broken contactor and solid state relay. Solid state relay is replaced with a contactor. Drive circuit completed otherwise.

Apr 5, 2022

In person group meeting to work on tractor. Brain and Karol focus on constructing mounts, Jacob focuses on the wiring of the tractor, and Mitchell continues work on a final CAD model of the chassis using concrete measurements. By the end of this meeting, all mounting brackets, CAD models, as well as main circuits are completed. With this, all components are mounted inside the chassis of the tractor, and video footage of the rear tractor wheels being powered by the DC motor is taken.

Apr 6, 2022

In person group meeting to prepare for presentation. Body panels of the tractor are fit into place, and video footage of a final product is taken to be shown in the presentation. Powerpoint slides are then rehearsed, and presented later in the day.

Apr 7, 2022

In person group meeting to clean up the final design for the exhibition day. Keyswitch, battery gauge, and light switches are wired in. Additionally, the final report is drafted and prepared for submission.

Apr 8, 2022

Exhibition day. Group meets at 7am to prepare the tractor for the move to the exhibition space. Exhibition presentation from 9am-4pm

Appendix J2: Motor Calculations for Tuning and Graphs

Table [9]: Motor Efficiency, power draw, and run time at given amperage

Motor Voltage (V)	Motor Amperage (A)	Efficiency	Power Draw (W)	Battery Capacity (Wh)	Run time (h)	Run time (min)		Motor Power (W)
48	10	0.6	800	4837.5	6.046875	362.8125		480
48	20	0.81	1185.185185	4837.5	4.081640625	244.8984375		960
48	30	0.86	1674.418605	4837.5	2.8890625	173.34375		1440
48	40	0.9	2133.333333	4837.5	2.267578125	136.0546875		1920
48	50	0.9	2666.666667	4837.5	1.8140625	108.84375		2400

48	60	0.91	3164.835165	4837.5	1.528515625	91.7109375		2880
48	70	0.9	3733.333333	4837.5	1.295758929	77.74553571		3360
48	80	0.91	4219.78022	4837.5	1.146386719	68.78320313		3840
48	90	0.91	4747.252747	4837.5	1.019010417	61.140625		4320
48	100	0.91	5274.725275	4837.5	0.917109375	55.0265625		4800
48	110	0.9	5866.666667	4837.5	0.8245738636	49.47443182		5280
48	120	0.89	6471.910112	4837.5	0.7474609375	44.84765625		5760
48	130	0.89	7011.235955	4837.5	0.6899639423	41.39783654		6240
48	140	0.88	7636.363636	4837.5	0.6334821429	38.00892857		6720
48	150	0.87	8275.862069	4837.5	0.58453125	35.071875		7200
48	160	0.87	8827.586207	4837.5	0.5479980469	32.87988281		7680
48	170	0.86	9488.372093	4837.5	0.5098345588	30.59007353		8160
48	180	0.86	10046.51163	4837.5	0.4815104167	28.890625		8640
48	190	0.85	10729.41176	4837.5	0.4508634868	27.05180921		9120
48	200	0.85	11294.11765	4837.5	0.4283203125	25.69921875		9600

Figure [21]: Motor Power Draw vs Run Time

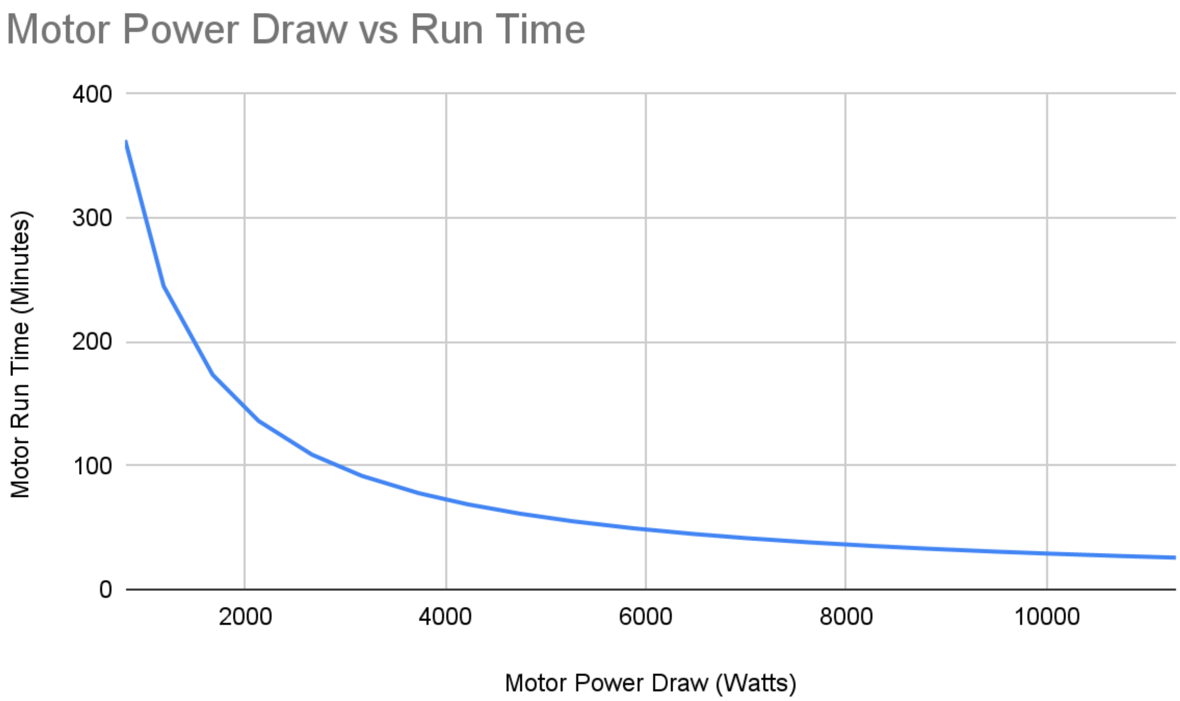
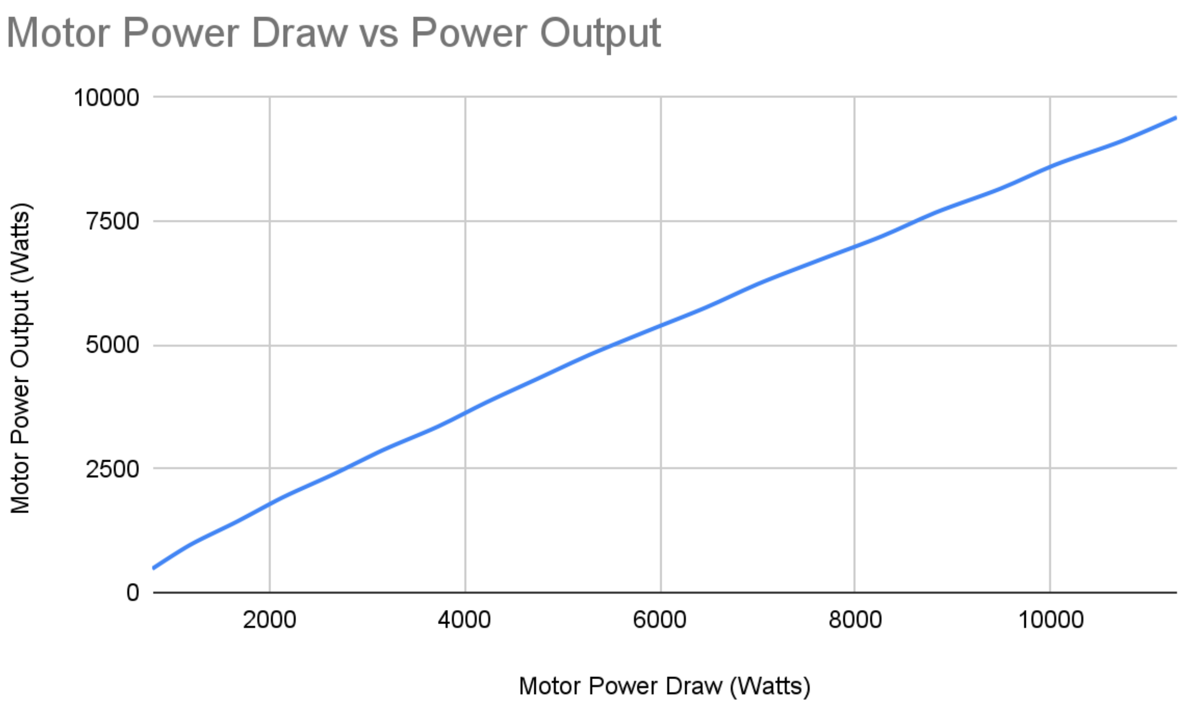


Figure [22]: Motor Power Draw vs Power Output


Motor Power Draw vs Power Output
10000
7500
5000
2500
0
2000
4000
6000
8000
10000
Motor Power Output (Watts)
Motor Power Draw (Watts)

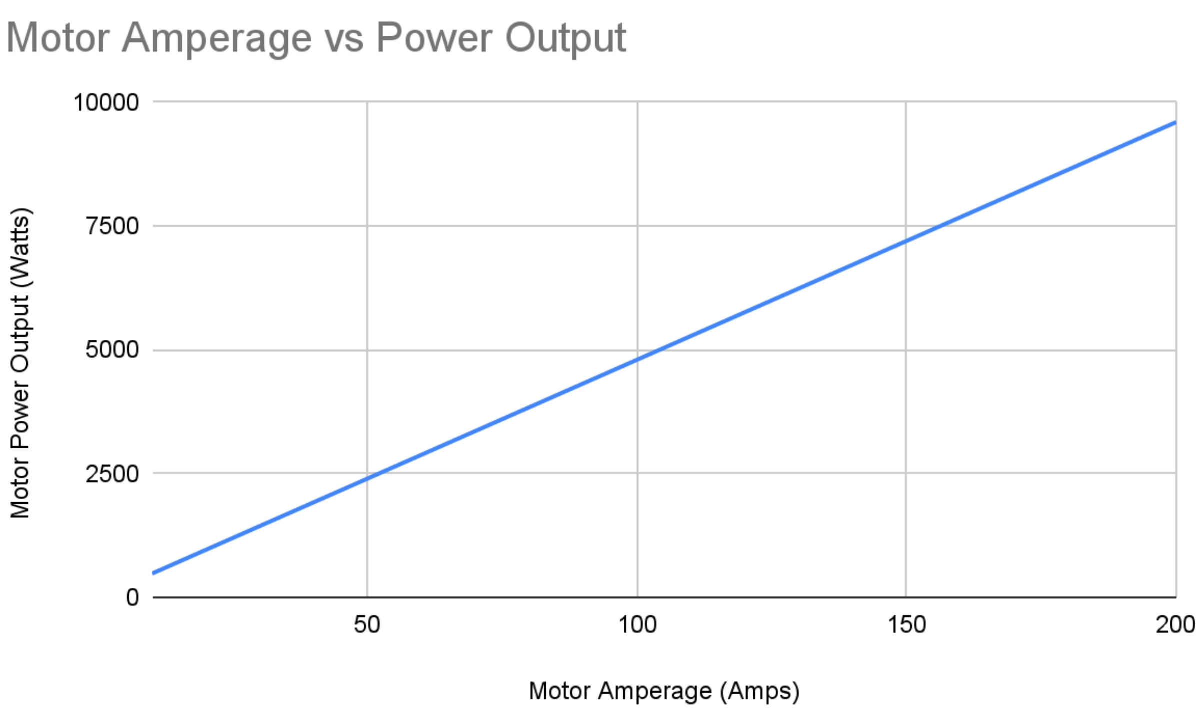

Motor Amperage vs Power Output
10000
7500
5000
2500
0
50
100
150
200
Motor Power Output (Watts)
Motor Amperage (Amps)

Figure [23]: Motor Amperage vs Power Output

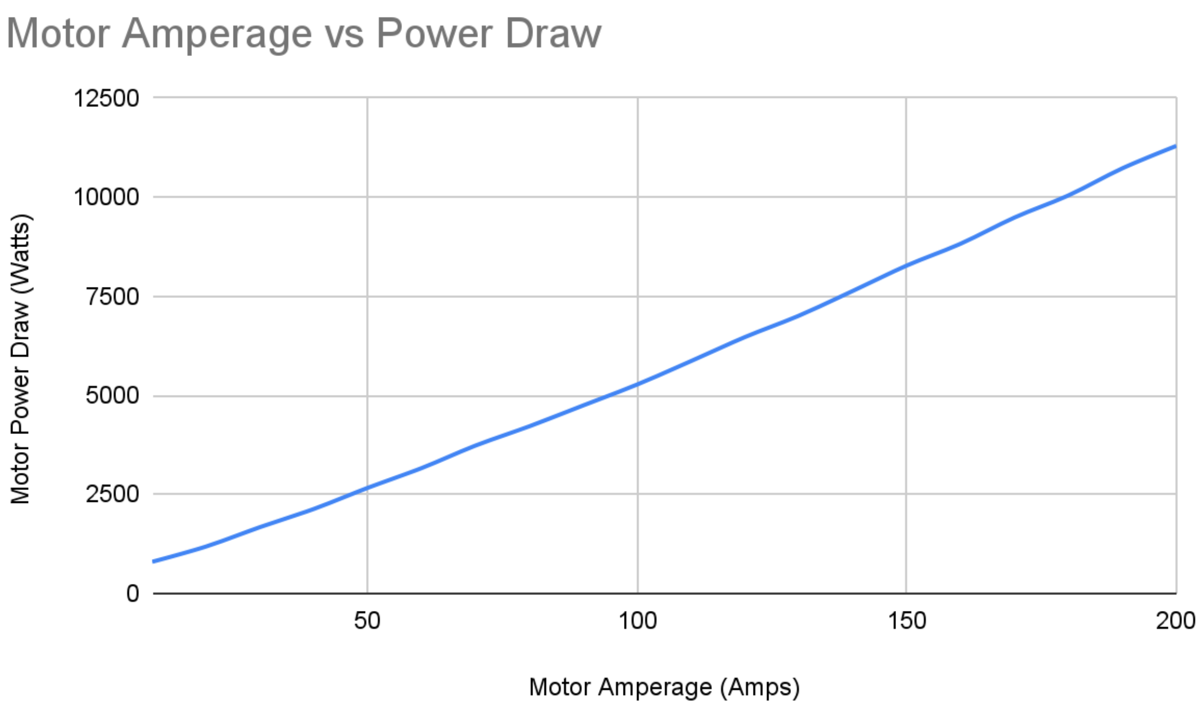


Figure [24]: Motor Amperage vs Power Draw

Appendix J3: Battery Cooling Calculations

Amperage to Motor (A)	Battery Amperage Draw	Internal Resistance (Ohm)	Power Loss (W)	Cp (J/kg*K)	p (kg/m^3)	Pr	T,ambient (C)	T,motor max (C)	m	equivalent vol/s	equivalent CFM
10	6.666666667	0.01	0.4444444444	1007	1.127	0.706	40	60	0.00002206774799	0.00001958096538	0.04148971593
20	13.33333333	0.01	1.777777778	1007	1.127	0.706	40	60	0.00008827099195	0.00007832386153	0.1659588637
30	20	0.01	4	1007	1.127	0.706	40	60	0.0001986097319	0.0001762286884	0.3734074434
40	26.66666667	0.01	7.111111111	1007	1.127	0.706	40	60	0.0003530	0.0003132954461	0.6638354549

									839678		
50	33.33333333	0.01	11.11111111	1007	1.127	0.706	40	60	0.000551693697	0.0004895241346	1.037242898
60	40	0.01	16	1007	1.127	0.706	40	60	0.0007944389275	0.0007049147538	1.493629773
70	46.66666667	0.01	21.77777778	1007	1.127	0.706	40	60	0.001081319651	0.0009594673038	2.032996081
80	53.33333333	0.01	28.44444444	1007	1.127	0.706	40	60	0.001412335871	0.001253181784	2.65534182
90	60	0.01	36	1007	1.127	0.706	40	60	0.001787487587	0.001586058196	3.36066699
100	66.66666667	0.01	44.44444444	1007	1.127	0.706	40	60	0.002206774799	0.001958096538	4.148971593
110	73.33333333	0.01	53.77777778	1007	1.127	0.706	40	60	0.002670197506	0.002369296811	5.020255628
120	80	0.01	64	1007	1.127	0.706	40	60	0.00317775571	0.002819659015	5.974519094
130	86.66666667	0.01	75.11111111	1007	1.127	0.706	40	60	0.00372944941	0.00330918315	7.011761992
140	93.33333333	0.01	87.11111111	1007	1.127	0.706	40	60	0.004325278605	0.003837869215	8.131984322
150	100	0.01	100	1007	1.127	0.706	40	60	0.004965243297	0.004405717211	9.335186084
160	106.6666667	0.01	113.7777778	1007	1.127	0.706	40	60	0.005649343484	0.005012727138	10.62136728
170	113.3333333	0.01	128.4444444	1007	1.127	0.706	40	60	0.006377579168	0.005658898996	11.9905279
180	120	0.01	144	1007	1.127	0.706	40	60	0.007	0.0063442	13.44266

									149950348	32784	796
190	126.6666667	0.01	160.4444444	1007	1.127	0.706	40	60	0.007966457023	0.007068728503	14.97778745
200	133.3333333	0.01	177.7777778	1007	1.127	0.706	40	60	0.008827099195	0.007832386153	16.59588637

Appendix J4: DC Motor Cooling Calculations

Motor Voltage (V)	Motor Amperage (A)	Efficiency	Power Draw (W)	Motor Power (W)	Heat Loss (W)	Cp (J/kg*K)	p (kg/m^3)	Pr	T,ambient (C)	T,motor max (C)	m (kg/s)	equivalent vol/s	equivalent CFM
48	10	0.6	800	480	320	1007	1.127	0.706	40	72.5	0.009777709877	0.008675873893	18.38313567
48	20	0.81	1185.185185	960	225.1851852	1007	1.127	0.706	40	72.5	0.006880610654	0.006105244591	12.93628066
48	30	0.86	1674.418605	1440	234.4186047	1007	1.127	0.706	40	72.5	0.007162740956	0.006355582038	13.46671567
48	40	0.9	2133.333333	1920	213.3333333	1007	1.127	0.706	40	72.5	0.006518473251	0.005783915928	12.25542378
48	50	0.9	2666.666667	2400	266.6666667	1007	1.127	0.706	40	72.5	0.008148091564	0.007229894911	15.31927973
48	60	0.91	3164.835165	2880	284.8351648	1007	1.127	0.706	40	72.5	0.008703236264	0.007722481157	16.36301087
48	70	0.9	3733.333333	3360	373.3333333	1007	1.127	0.706	40	72.5	0.01140732819	0.01012185287	21.44699162
48	80	0.91	4219.78022	3840	379.7802198	1007	1.127	0.706	40	72.5	0.01160431502	0.01029664154	21.81734783
48	90	0.91	4747.252747	4320	427.2527473	1007	1.127	0.706	40	72.5	0.0130548544	0.01158372174	24.54451631
48	100	0.91	5274.725275	4800	474.7252747	1007	1.127	0.706	40	72.5	0.01450539377	0.01287080193	27.27168479
48	110	0.9	5866.666667	5280	586.6666667	1007	1.127	0.706	40	72.5	0.01792580144	0.0159057688	33.7024154
48	120	0.89	6471.910112	5760	711.9101124	1007	1.127	0.706	40	72.5	0.02175265793	0.01930138237	40.89731307
48	130	0.89	7011.23	6240	771.235	1007	1.127	0.706	40	72.5	0.02356	0.02090	44.3054

			5955		9551						537942	98309	2249
48	140	0.88	7636.363636	6720	916.3636364	1007	1.127	0.706	40	72.5	0.02799980556	0.02484454797	52.64261579
48	150	0.87	8275.862069	7200	1075.862069	1007	1.127	0.706	40	72.5	0.03287333493	0.02916888636	61.80536994
48	160	0.87	8827.586207	7680	1147.586207	1007	1.127	0.706	40	72.5	0.03506489059	0.03111347879	65.92572793
48	170	0.86	9488.372093	8160	1328.372093	1007	1.127	0.706	40	72.5	0.04058886542	0.03601496488	76.31138878
48	180	0.86	10046.51163	8640	1406.511628	1007	1.127	0.706	40	72.5	0.04297644574	0.03813349223	80.80029401
48	190	0.85	10729.41176	9120	1609.411765	1007	1.127	0.706	40	72.5	0.04917612909	0.04363454222	92.45635883
48	200	0.85	11294.11765	9600	1694.117647	1007	1.127	0.706	40	72.5	0.05176434641	0.04593109708	97.32248298