Solar Powered Automated Rapid Transit Ascendant Network (SPARTAN) Superway :

Wayside Power and Distribution

San José State University

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ME 195A: Senior Design I, Section 4

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I Abstract

During the Fall 2019 semester, the Wayside Power and Distribution team has researched, designed and began the prototyping the full-scale, third rail system. Research completed assessed the various design options available to successfully produce a low cost and effective design. The research concluded a composite, wayside third rail system would be most effective to transfer power to 'bogie' cars. Multiple designs were produced and thoroughly considered using different principles of execution. The selected project design will avoid unnecessary mechanical complexities to provide a powerful, reliable power transfer system by using multiple sliding shoe contacts.

The tasks described above were accomplished by focusing the team's attention on organized documentation and communication. A team Google Drive cloud storage was created at the beginning of the semester, enabling the team to document and organize the work. Tasks were assigned to each member so that each individual has a clear understanding of their obligations to the team. Two weekly team meetings kept the team members on track with research and design work. When issues arose the team communicated and resolved the problem at hand through clear communications and explanations.

Upon completion of designs, the team will move forward with prototyping the full-scale, third rail system to ensure any unforeseen design consequences can be quickly resolved. Fabrication and assembly is expected to continue from December 2019 to the end of April 2020.

II Acknowledgements

The Wayside Power Team would like to express its greatest gratitude to Dr. Burford Furman for design guidance and mentorship on the Solar Powered Automated Transportation Ascendant Network (SPARTAN) Superway project.

The team would like to give a sincere thanks to Ron Swenson for providing insight, a facility location, and project construction tools and resources necessary for the success of the SPARTAN Superway project.

The team would like to give a special thanks to the following organizations and companies for insight on designs and industry developments and standards on sliding conducting shoe material properties. Special thanks to Mike Perkins for helping this team select a suitable current collector shoe. Thank you to Mersen for providing insight on industry standards and cost pertaining to realistic conductor shoe material wear.

Mike Perkins from Helwig Carbon	Mersen	Valley Transportation Authority

Special thanks to Husain Bootwala for assistance on electrical design pertaining to ideas for an energy storage reserve and power supply systems.

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IV Executive Summary

The purpose of this report is to document and provide information for future work on SPARTAN Superway Wayside Power and Distribution. It includes design, materials, implementation, proposed solutions, actions, and resolutions.

IV-I Existing Problems

Common electric third rail systems span the entirety of the rail system leading to expensive wayside power systems. Last year's team integrated a supercapacitor and battery combination with wayside rails to charge the power module at drop off stations to reduce costs. The existing current pickup mechanism does not provide sufficient pressure for the conductor shoe to make constant contact with the rail. This can cause electrical wear through arcing and increase electrical resistance. Additionally, there are two pivot points on the current collector mounting arm shown in figure 1 below that inhibit stability for the conductor shoe and rail contact. The conductive rail shown in figure 2 is made of thin aluminum which is not ideal for conductivity. Moreover, the insulator brackets shown in figure 2 that hold the rail in place are made of 3D printed PLA. Plastic is not a suitable insulator for the required current loads nor strong enough for the required pressure and loads from the current collector shoe. Guarding contact from the third rail must also be addressed as there is no safety guard that covers the third rail. Currently, a carbon brush is used for the current collector shoe material which does not tolerate high use wear over time. Increased wear and damage can also occur to the shoe and mounting arm as the current collector meets the third rail ascension ramp.

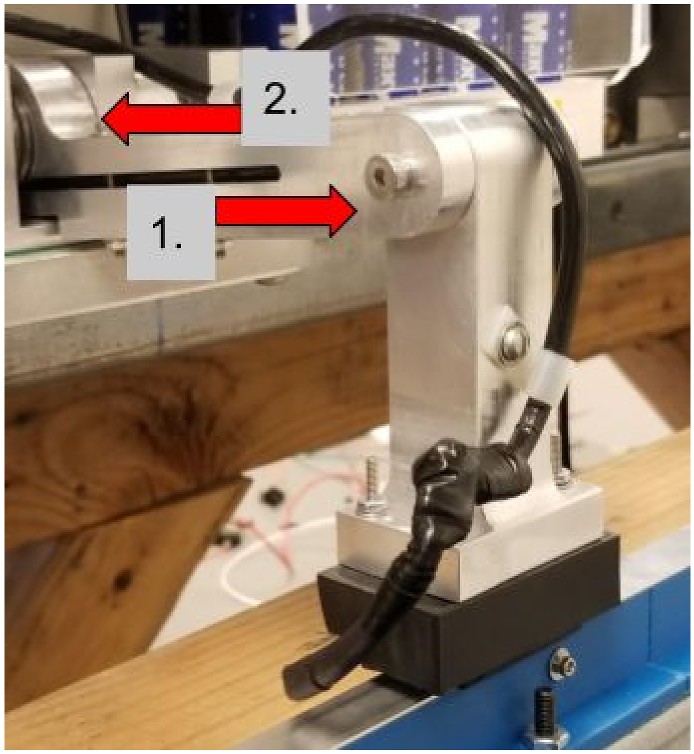

Figure 1. Existing current collector arm: [1] & [2] Pivot points

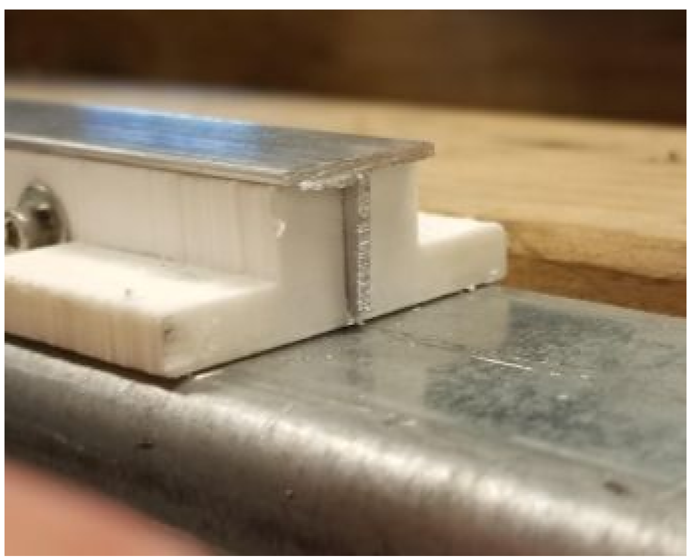
Figure 2. Existing aluminum rail and PLA insulated bracket

IV-II Possible Solutions

The existing design problems were reviewed and researched to find solutions that include commercially available parts and recent technology. The current collector shoe must have sufficient pressure to conduct current efficiently and minimize wear of the collector shoe. Options include linear springs with spring rates matched to collector shoe pressure specifications, pneumatic solenoids or linear actuators to control shoe pressure. Additionally, to ensure stable constant contact with the third rail the collector shoe mechanism must have limited mobility. The mechanism should also be able to withstand uneven rail joints and imperfections in the third rail. Installing multiple spring reinforced collector shoes along with linear actuators on a rigid mount would ensure constant contact without electrical interruption. The third rail should provide high wear endurance, minimal electrical resistance, and low cost.

Composite rails that use and aluminum base capped with stainless steel are commonly used in typical electric third rail train systems. These rails provide the solution to rail wear, conductivity and cost that is needed. Proper standoff brackets and electric insulators are needed to ensure the isolation of the electric rail from the system. Additionally, safety guards should be installed to cover the third rail from accidental contact by maintenance crews or passengers. Ensuring sufficient electrical current transfer from the third to the power module will require modern composite shoe materials. Carbon-metal composites have high electrical throughput and long lasting wear characteristics while minimizing noise and providing contact lubrication.

IV-III Current Work and Recommendations

Currently the team is focusing on design, manufacturing, and acquisition of materials. A 30 foot guideway is in the process of being built, shown in figure 3 below. More design work for the shoe mechanism including linear actuators, bogie mounting brackets, spring backed multi-collector shoe integration, and safety guards is in progress. A third rail consisting of a 2 inch by ¼ inch stainless steel bar bolted to a 2 inch by 1 inch aluminum bar shown in figure 4 will be used and will represent the commercially available composite rails used in industry shown in figure 5. Polyester insulator standoffs bolted to standoff brackets plan to used to ensure electrical isolation for the third rail shown in figure 6. A lexan plastic shield will be installed to block the rail from accidental contact. Additionally, voltage/current meters will be installed to display the current at the rail and after the collector shoe to verify the current transfer through the system pending project progress. Future work includes contacting vendors for composite conductor shoes, implementing current designs, testing, applicable redesign, and final testing.

Figure 3. 30 foot prototype guideway

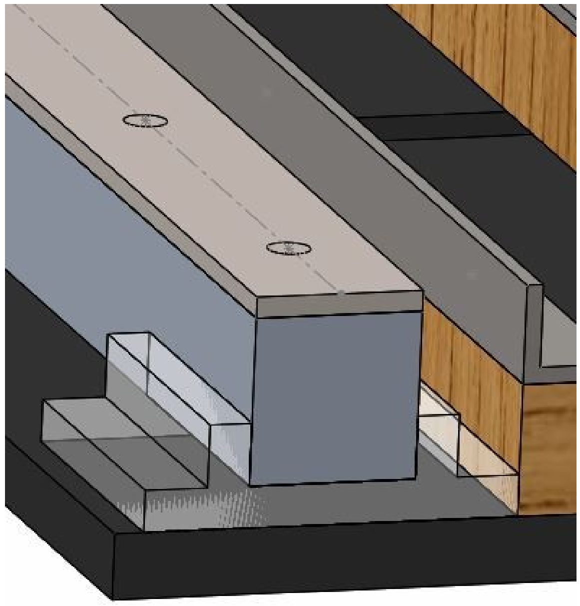

Figure 4. Designed steel capped aluminum rail

Figure 5. Commercially available steel capped aluminum rail
(https://www.transtech.com/electrification-products/transit-wayside/28-third-rail.html)

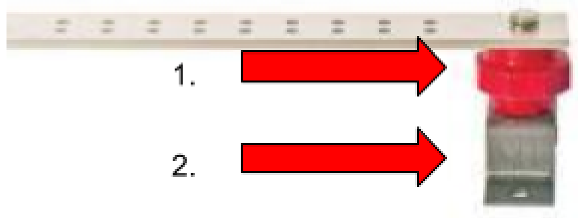

Figure 6. Commercially available insulators: [1] polyester standoff insulator, [2] steel standoff bracket

1.1 Introduction and Project Description

The current urban environment suffers from a multitude of issues. Transportation is one of the largest contributors to greenhouse gas emissions and traffic congestion in urban areas is dreadful and so the SPARTAN Superway addresses these problems. According to the U.S. Energy Information Administration, in 2018 over 45% of the United States CO_2 emissions were due to the burning of petroleum fuels (EIA, 2019, p.1). Combustion transportation vehicles are dependent on petroleum fuels, causing the largest emission of CO_2 in the U.S. As reported by the United States Environmental Protection Agency transportation ranks as the highest contributor of greenhouse gas emissions, over industrial, electrical, agriculture, commercial and residential (EPA, 2018, p. 1). Because of the extent to which transportation vehicles affect the environment, solutions must be thought out to minimize the use of carbon dioxide (CO_2) producing vehicles.

In addition to the environmental effects of transportation, urban environments suffer from traffic congestion. According to the Mercury News, the average person in the Bay Area spends about 59.5 minutes each day commuting (Baldassari, 2018, p. 1). That is about 465 days of commuting over the person's lifetime (Baldassari, 2018, p. 1). Imagine, if you will, if there was a way to reduce traffic congestion and thereby give people back time. This way they're able to spend more time with their families and loved ones.

The SPARTAN Superway addresses both the environmental and traffic congestion issue. It is doing so by engineering a solar-powered automated rapid transit ascendant network (SPARTAN) system for urban areas. Solar panels are used as a source of clean and renewable energy which generates electricity for the network of pod cars. Thus there is no greenhouse gas emitted into the atmosphere. This helps reduce the carbon footprint of future users of the SPARTAN Superway.

In addition to mitigating some of the causes of climate change, the SPARTAN Superway will relieve traffic congestion because of its elevated guideway design. The Superway is an Automated Transit Network (ATN). ATN is transit mode under Automated Guideway Transit

(AGT) (Furman et al., 2014, p.7). In ATN, the stations are off-line which provides the capability to travel to the final destination without intermediate stops and transfers (Furman et al., 2014, p.7). The service is not scheduled and thus available on demand, similar to a taxi (Furman et al., 2014, p.7). Passengers have the choice of traveling alone or with companions (Furman et al., 2014, p.7). Because the system is automated, it has the capability to run 24 hours a day and seven days a week (Furman et al., 2014, p.7). The ATN system has a small, narrow and light guidway that is usually elevated (Furman et al., 2014, p.7).

According to the Silicon Valley Business Journal, the South Bay ranks fifth most congested region in the United States (Hall, 2017, p. 1). The SPARTAN Superway will first be implemented in South Bay and globally in the future. Figure 7 depicts what the elevated guideway system will look like in downtown San Jose.

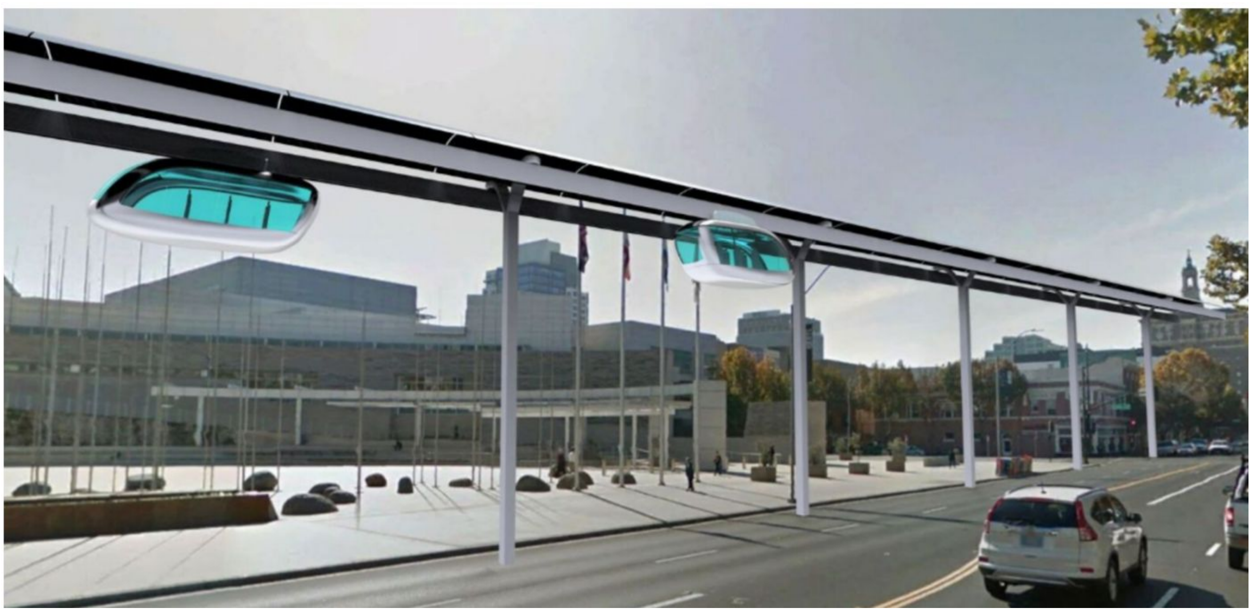

Figure 7. Image of what the SPARTAN Superway pod car network could look like in downtown San Jose. Adapted from “Spartan Superway Archive”, by B. Furman (2018), Spartan Superway Archive. Retrieved from https://drive.google.com/drive/u/1/folders/0B0Mc4v35mJaSUXNNUUszck5GSjg .

From a socioeconomic standpoint, the SPARTAN Superway has the capability to make commuters lives more fulfilling. The Superway pod car design is meant to transport fewer passengers in each pod. Since the system is elevated the guidway has the capability to branch out with less limitations and thus increasing the routes. In this way, the final destinations are more targeted and passengers are dropped off closer to their destinations. This makes Superway attractive to passengers and will encourage them to use the system. Superway passengers will experience reduced travel times. The passengers will be free from road rage and aggravation during their daily commutes. The regional air quality will improve as a result of less people commuting with combustion vehicles. Time, happiness and health will be given back to the SPARTAN Superway passengers. In order to make this system work it needs an effective power system. The Wayside Team charges the power module for the SPARTAN Superway system.

Today's rails use costly and inefficient wayside power systems that span the entirety of the guideways. This team will only be changing the pods power system to a substation power system to make the system efficient and inexpensive.

1.2 Objectives

Wayside Power and Distribution Team strives to design and manufacture a full scale third rail power system prototype to distribute power to a moving 'bogie' at power substations spread out necessary intervals. The third rail power system will pick up power from a stationary conductor using a conductor shoe and transfer power to a module provided by the power module team. The conductor shoe will be in contact with the power rail while the bogie is traversing the length of substations, including both arrival and departure. The conductor shoe system will integrate with the power module via an interface made in collaboration with the Power Module Team. Current and voltage requirements have been agreed upon with the Power Module Team according to their required specifications. Off-the-shelf components and materials will be preferentially used where reasonable when beneficial and affordable.

To achieve said objectives the team will produce deliverables to present the success level of the project. The deliverables are as follows:

1. Conductor Rail/Third Rail: A durable, composite, and conductive rail to distribute power to the individual bogies.

2. Conductor Shoe: A graphite sliding contact on the ‘bogies’ that will slide along the third rail to charge the power module system
3. Conductor Shoe Arm Mechanism: A mechanism that will lower the conductor shoe onto the third rail and apply optimal pressure to ensure proper contact pressure between the third rail and the conductor shoe. The mechanism will utilize linear actuators to provide vertical motion to lift and lower the shoe. Additionally, springs will be installed to provide shock absorption on a multi-shoe mechanism.
4. Presence sensor: To sense presence of the bogie so the fixed rail is powered only when power transfer is necessary to ensure safety.
5. Wear Analysis: A material analysis on different composite stainless steel and aluminum third rails and graphite conductor shoes to seek materials with sufficient conductivity and durability. Develop wear life cycle testing and understanding of contact forces and pressures to feed to mechanical design team.
6. Insulators and Grounding: Find appropriate insulators and grounding to prevent harm to any individuals making contact with the system and prevent any electrical current from straying from the system.
7. Ensure Safety: Deliver a mechanically and electrically safe system that will prevent individuals from injury. These safety mechanisms will include sensors and barriers.
8. Working in Conjunction with Power Module Team: Determine how long will the power rail and collector shoe will need to stay in contact to charge the capacitors and batteries sufficiently.
9. Power Distribution: A system to transfer power to the bogie power module which will include the third rail and any other additional parts and systems.
10. ‘Bogie’ and Third Rail System Demonstration: A completed, functioning product that will properly demonstrate the distribution of power from the third rail to the ‘bogie’ to the ‘power module’.
11. Monitor and display current and voltage input from rail and output from conductor shoe.

As development progresses the objectives have been adapted in various manners to maintain progress and as developments are made the objectives have been updated to meet newer and more well defined project demands. Furthermore, finding the right sponsors willing to assist and provide information regarding third rail systems will rapidly accelerate development of this project. Developing a successful system will rely on completion of the deliverables in swift and objective means.

1.3 Structure of the Project

To ensure success developing a third rail system the many tasks ranging from product research and development, company outreach, presentations, and document proofreading are divided among the team to create a productive environment.

Although team roles are divided into specifics, the work covered by individual team members is not restricted to his or her particular roles. Dividing work ensures discrepancies do not occur because a particular team member will get the final decision. Additionally, division of labor prevents unnecessary redundancies in work. However, some roles overlap to ensure duties are executed accordingly to excellent standards. The main team roles are as follows:

Table 1. Roles Assigned to Individual Members

Team Roles	
Team Managers	
Project Manager	Alex
Asst. Project Manager	Shane
Editors	
Grammar/ Spell-Check	Melody, Alex (secondary)
Format	Shane
Consistency	Alex
CAD	
Lead Drafter	Reynaldo
2nd Lead Drafter	Alex
Asst. Drafter	Waylon, Melody
Additional Roles	
Company Outreach	Waylon

In descending order, the duties of the team roles are as follows. Project manager and assistant project manager work together to keep the team on task to follow the schedule setup in the gantt chart produced earlier during the semester. Project managers will also organize the team in duties, scheduling, and help prevent team conflicts. Editors on the team will revise and proofread any documents and presentations produced by the team to create consistent and professional materials accurately reflection work completed at the SPARTAN project. Any members working on computer aided drafting (CAD) will work on producing any CAD materials necessary to produce a refined project. Lead CAD drafters will also help review CAD documents to ensure units, dimensions, and formatting are consistent across all CAD documentation. Additional roles like company outreach are tasked with reaching out to companies and organizations of interest through calls, emails, and any other means necessary.

Furthermore, as development has progressed the team has slowly divided into sub-teams to solve different problems the team faces including development of an electrical system, a smart control system, and physical product manufacturing. Although nonspecific the sub-teams enable focus on particular tasks and allow certain team members to be specialized experts for necessary tasks. The sub-teams overlap, but generally appear as follows:

Table 2. Sub-Team Division and Areas of Focus for Individual Team Members

Electrical Systems	Control Systems	Product Manufacturing
Waylon	Waylon	Shane
Melody	Melody	Melody
	Alex	Alex
		Reynaldo

At the current state of development the electrical and control systems are being developed in conjunction in order to produce a system that can monitor and control the power distribution system in a safe manner. This will be achieved by having team members in this sub-team focus on programming microcontrollers and sensors.

Product manufacturing is unlike electrical and control systems given that the development is more focused on producing necessities that include a rail system and the third rail power system. This means product manufacturing must machine, assemble, and CAD parts produced for the full scale prototype project. Machining includes any work at makerspace, the central shop, and SPARTAN facility.

2.1 State-of-the-Art/Literature Review

2.1.1 Examples of ATN Technology

Personal rapid transit (PRT) was the term most commonly used before the automated transportation network (ATN) concept. This is a new way of describing a specific mode of transportation that uses dedicated guideways with automated vehicles to deliver passengers to non-scheduled offline stations. The development of ATN technology is driving new

In 1975 a PRT system was built in Morgantown, West Virginia to overcome bus traffic that transported students between three West Virginia University campuses (Reaney & Young, 2004). The fully automated system can operate in three modes: demand, schedule, and circulation. Demand mode provides non-stop origin to destination travel while schedule and demand are similar to typical shuttle or tram systems. Each car can hold 20 passengers and is equipped with electrical pickups on both sides that connect to electrified rails on the guideway. The guideway also contains magnetic induction loops that connect to the car's location system and include glycol circulation pipes that melt snow and ice.

Masdar City in Abu Dhabi is a car-free city that uses CyberCab PRT for mobility. Autonomous electric vehicles travel at ground level using magnetic strips for navigation feedback and operate using Lithium-Phosphate batteries that provide 60 kilometers of travel on a 1.5 hour charge ("The world's first Personal Rapid Transit system: Masdar City," 2010).

Skycube is another PRT system that operates in Suncheon, South Korea. This system operates above grade with pods that hold 10 passengers (Choi, 2015). The vehicle captive guideway is bi-directional and uses a third-rail current collection system. Each pod has a minimum four second headway and operate using distributed asynchronous control systems. The Skycube operates similar to a tram station

The world's largest ATN system contract was announced by Ultra-Fairwood in July 2017 (Stone, 2017). The proposed all-electric network will include 75 miles of track, 115 station, and use a fleet of 1,745 vehicles. This system uses both PRT and group rapid transit (GRT) systems. The PRT system which includes both at and above grade passenger vehicles that hold six to 30 passengers with a total daily count of 1.64 million passenger trips. The six person capacity PRT system transports riders anywhere within the track without stopping at intermediate stations by using off-line stations. Conversely, the 30-passenger GRT system operates as a shuttle system with fixed stops.

2.1.2 ATN at SJSU

Since 2012, several wayside power distribution projects have been completed for SPARTAN Superway. In 2017, a team provided a power distribution system for the half-scale bogie guideway. This team used a commercial current collector shoe rated at 50-60 amps with a spring assisted four-bar mechanism to transfer current from a copper strip on the guideway to the bogie power module (Pham & Hsiung, 2017). Safety considerations included using a fourth-rail system that includes a ground rail and powered rail to isolate current from the track rails as well as covering the conductive rails in PVC pipe to protect against high voltage hazards. Last year, the 2018 wayside power team built a current collector shoe device and a super capacitor battery pack power module. A passive current collector mechanism delivered up to 1.5kW to the supercapacitors that could be charged in two minutes and run two 48V motors at two mph for 50 feet (Coaquira, Lau-Donald, & Winters, 2019).

2.1.3 Wayside Power Technology

New technology in third rail power components has influenced the Superway wayside power team's design. Composite third rails provide lower costs and longevity, composite materials for current collector shoes reduce noise with lower electrical resistance, and individual sprung collector shoes can provide more consistent electrical contact reducing voltage fluctuation and heat accumulation.

The conductive third rail for typical tram stations consists of a steel I-beam which has proven reliability for rail systems. Another conductive rail type consists of a steel I-beam with aluminum extrusions riveted or bolted to the web of the steel. The composite rail provides lower electrical resistance compared to standard steel rails through the aluminum ballast (Forman, 2012). Further advances in rail technology include the aluminum/stainless steel (ALSS) rail which consists of a co-extruded aluminum rail and stainless steel cap that are crimped and welded together. This configuration minimizes electrical resistance therefore increasing energy savings, provides longer service life, and has a 50% lower installation cost compared to steel rails (Forman, 2012).

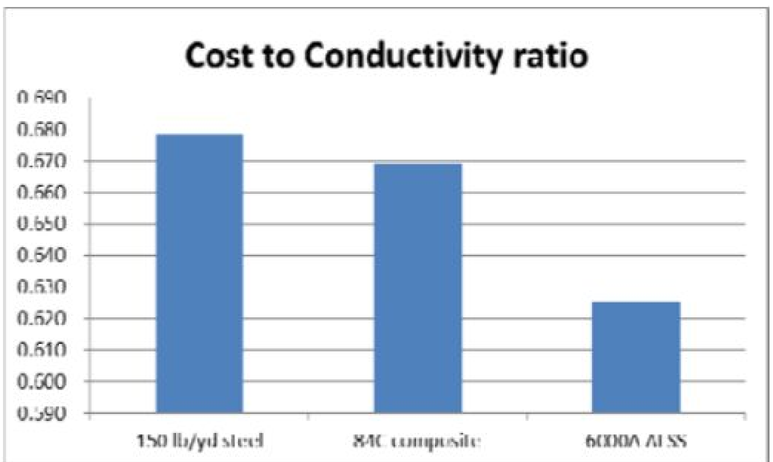

Figure 8. Comparison of cost to conductivity ratio of ALSS vs traditional steel vs 84C composite (Forman 2012)

The conductor shoe material used on most electric third rail systems is made of steel, cast-iron or bronze. These can damage conductor rails causing higher wear rate and maintenance costs because they are high mass and high friction coefficient metals. Conductor shoes made with copper-graphite composite materials (CGCMs) provide high wear resistance, lower density, self lubrication, low sliding noise, and allow higher electrical conductivity compared to stand alone metals (He & Manory, 2001).

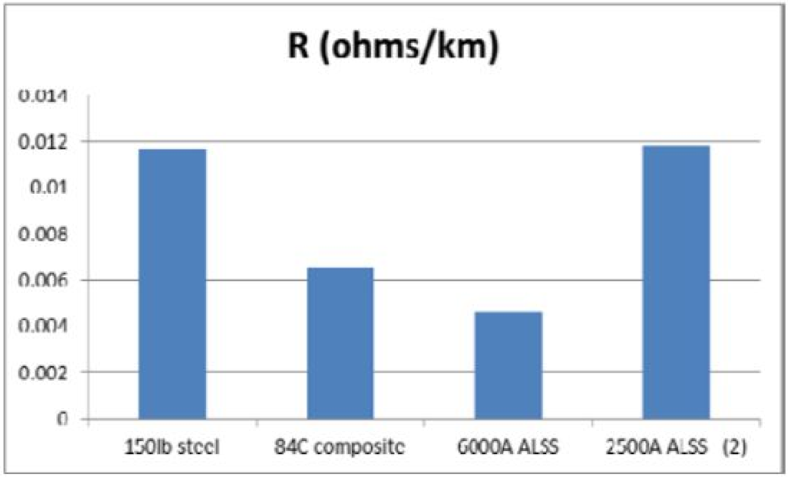

Figure 9. Comparison of resistivity of 6000A ALSS vs 2500A ALSS vs traditional steel vs 84C composite (Forman 2012)

Conductor rails are not perfectly straight or level and will have joint connections with uneven separation. Typically third rail conductor systems include multiple shoes to make sure the electrical contact is not lost over imperfections in the rails. The installation of additional shoe mounts increases mass and costs of a third rail system. To overcome the rail imperfections a conductor shoe mount can contain multiple shoes with multiple electrical connections on a bus bar with each shoe backed with an individual spring (US Patent No. 8727085B2, 2014).

3.1 Design Solution

3.1.1 Design Specifications

This semester this team focused on producing a prototype that will be able to scale into the final design in the spring. The final design will incorporate the power module team's design, but the prototype will not. Both prototype and full scale demonstrations will use a provisional bogie and rail track that does not represent the final Superway design. They will only serve as a receptacle for the hardware and to exhibit proof of concept. The bogie will carry a power dissipator, the shoe mechanism, and various sensors. The bogie will be rolled along the track to determine its performance.

Table 3.Track and Power Specifications

Track and Bogie Specifications				
Description	**1/5th Scale**		**Full Scale**	
	Specification	**Units**	**Specification**	**Units**
Track length	2	m	10	m
Velocity of pod car	0.2	m/s	1	m/s
Current output of third rail	30 (in losses)	A	33.3	A
Supply voltage	12	V	36	V
Current collector shoe force	40	N	100-150	N
Power needed for motor	3	W	110	W

Table 4. Full Scale Electrical Specifications

Full Scale: Electrical Specifications			
Component	**Property**	**Specification**	**Units**
Third Rail			
	Voltage	36	V
	Current	30-70	A
Charger			
	Voltage	36	V
	Current	33	A
	Power	1200	W

3.1.2 Prime Design

To get to the current design, various well researched and adapted iterations of wayside power system have been considered. This project design is divided into two sections; the current collector design and the wayside power track.

3.1.2.1 Current Collector

First, the team considered the contact types suitable for this projects current collector design.

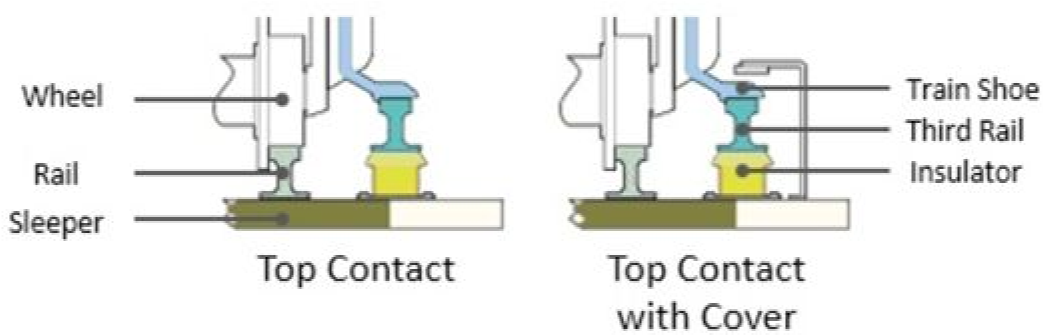

Figure 10. Current collector contact type

After considering various options, the team concluded a top down contact with cover would be most suitable for this product design. There are two main considerations, force applied and safety, helped determine the contact type. When trying to keep the current collector intact with the wayside power the mechanism requires sufficient force to support the collector to intact to the rail. The top contact gives a gravitational force advantage for maintaining contact on the collector surfaces. The second consideration, a cover will provide safety on the wayside power since it will cover the third rail, making it difficult for uninformed individuals to touch the live rail.

Next, this team designed a mechanism appropriate for application on a bogie current collector system. Reviewing last year's team current collector, it is apparent the arm mechanism of the current collector is unnecessarily complex and fallible. The reaching arm is ineffective because it creates uncertainty in which the arm will have different angles causing the mechanism to miss the wayside power track. The means to overcome this problem is by designing the current collector to be exactly on top of the wayside track such that the mechanism will not have to reach out from the bogie.

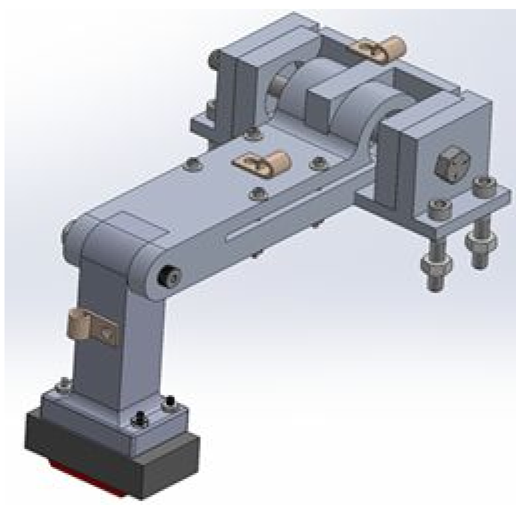

Figure 11. Last year team current collector

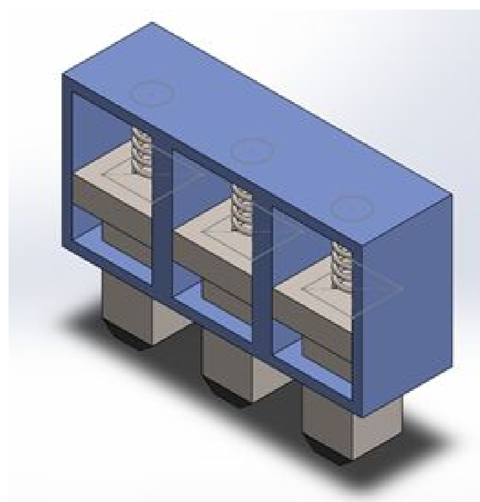

Figure 12. Our new current collector design

The new current collector design will provide stability on uneven terrain. Stability is achieved using three conductor shoes that are spaced evenly to maintain contact on uneven terrain. The design will help to ensure the conductor shoe will always remain in contact with the wayside power track. The spring on each of the conductor shoe will help to maintain the conductor shoe in horizontal direction depends on the track.

3.1.2.2 Wayside Power Track

The full scale wayside power track will be 10 meters long and made of wooden planks. The design of wayside power track is divided into two sections; the track for the bogie itself and the wayside power design.

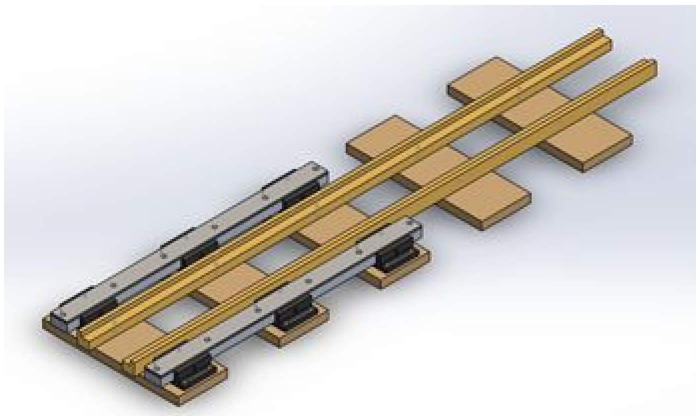

Figure 13. Full Assembly of Wayside Power

The design of the track will be L-shaped to help the wheel of the bogie to keep moving straight on the track and to prevent derailing. The rail system uses wood planks as the base material for the track because wood is easy to fabricate and cost effective. Additionally, wood planks have enough yield strength to maintain the load throughout the track. Further analysis of wood planks will be discussed in the analysis section.

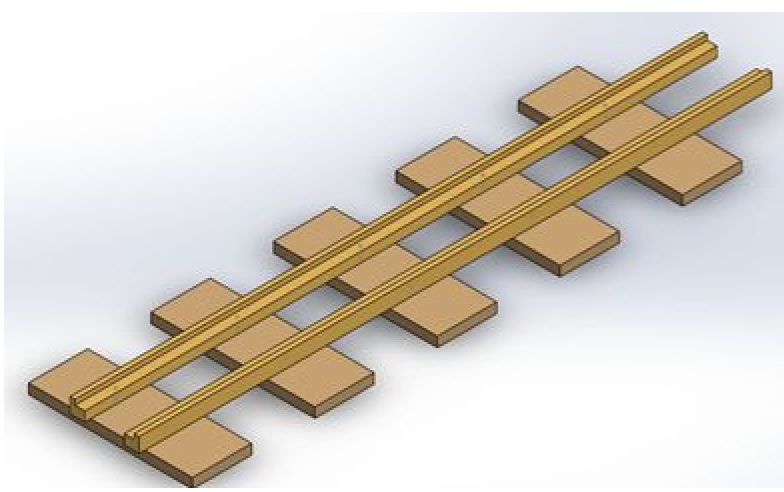

Figure 14. Wooden Rail Assembly

A wood bracket will be used below the tracks to maintain the track above the ground about waist high. Raising the track to waist level will help decrease physical stress and difficulty of work on the track by eliminating the need to bend over or sit on the ground when working on the project. The wood brackets also suspend the conductor rails and respective insulation by the track.

For the conductor rail, the placement of the aluminum bar and stainless steel bar being used is of utmost importance. The effective conductivity of ALSS third rail also brings risk with poor placement. To avoid these problems the aluminum bar will be below the stainless steel plate.

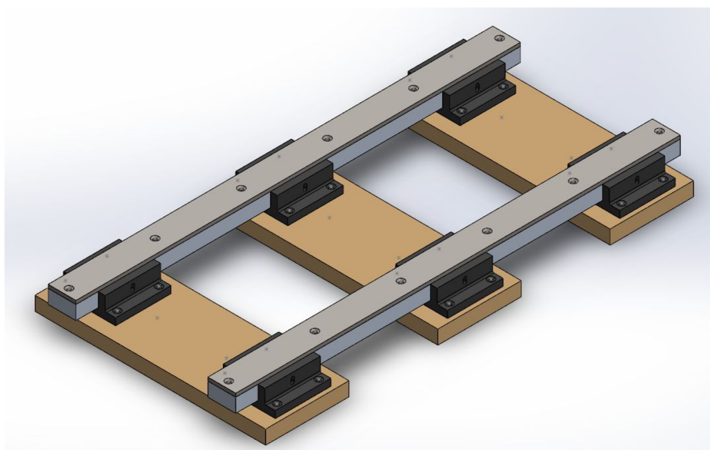

Figure 15. Conductor Rail Assembly with Insulation

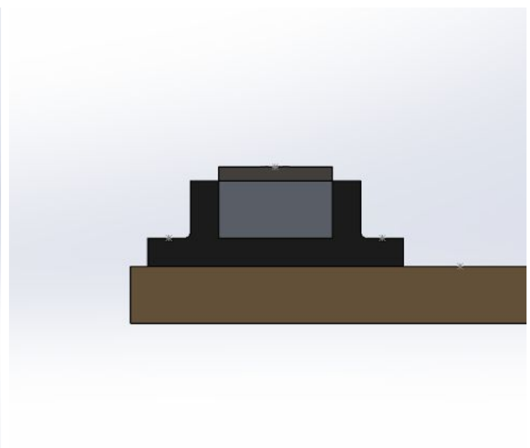

Figure 16. Front View of the 3rd Rail

The conductor rail will be held together by bolting the stainless steel bar on top of aluminum bar in a countersunk hole. Additionally, insulation brackets will be used to help to insulate the conductor rail and hold the third rail in place. The bracket will be bolted through the aluminum bar and wooden rail. For this design the third rail is isolated as much as possible and covered on contact surfaces using insulation for electrical safety. Additional details of the design drawings can be found in the appendix.

3.1.3 Supporting Analysis and Experimental Validation

3.1.3.1 Supporting Analysis

The energy storage system, which is based on supercapacitors, has proven to be a somewhat obscure topic, however this team aims to provide a reliable power transfer system. For this project design, the team is concerned with the power transfer efficiency of the track and shoe. To minimize the voltage drop, the track must have a low resistance. Using approximate dimensions for 316 stainless steel, the calculations below show there will only be a maximum voltage drop of 0.0138 V.

$$I = P / V_{charger} \quad \textbf{(1)}$$

$$R_{total} = \rho_{steel} * \frac{L}{A_{steel}} + \rho_{aluminum} * \frac{L}{A_{aluminum}} \quad \textbf{(2)}$$

$$V_{track} = I * R_{total} \quad \textbf{(3)}$$

Where, P is power of the charger, $V_{charger}$ is the output voltage of the charger, V_{track} is the voltage drop after the track, I is the current flowing through the track, R is the resistance of the track at certain length L, A is the cross-sectional area of the track, and rho is the resistivity of the material.

In this example calculation, the maximum expected track length of 10 m is used and the resistivities of the steel and aluminum is shown.

Table 5. Cross Sectional Area and Resistivity

Cross Sectional Area	
A_steel	**A_aluminum**
0.0270967 m2	0.00193548 m2
Resistivity	
ρ_steel	**ρ_aluminum**
7.496 * 10^-7 Ohm * m	2.65 * 10^-8 Ohm * m

$$I = \frac{1200\ W}{36\ V} = 33.3\ A \quad \textbf{(4)}$$

$$R_{total} = \frac{(7.496*10^{-7}\,Ohm\ m)(10\ m)}{(.0271\ m^2)} + \frac{(2.65*10^{-8}\ Ohm\ m)(10\ m)}{(.00194\ m^2)} = 0.0004136\ Ohm \quad \textbf{(5)}$$

$$V_{track} = (33.3\ A) * (0.0004136\ Ohm) = 0.01379\ V \quad \textbf{(6)}$$

3.1.3.2 Experimental Validation

Experimental validation is currently in its infancy for much of the development, however much of the experimental validation work is currently targeted at electrical control systems. The experimentation will be completed using the 1/5th scale prototype. Using a smaller scale prototype will decrease material cost from testing various aluminums and steels that may potentially corrode from stray current or wear damage. Furthermore, smaller composite rail samples expands the number of samples tested for the electrical system. As production progresses, the team will continue to run various electrical tests on the materials using the rapid prototype project that will be completed later during the winter recess.

3.1.3.3 Finite Element Analysis (FEA) of the Track

To prove the design can maintain loads from the bogie and not fracture or bend, a Finite Element Analysis (FEA) was performed on the wayside power track. Solidworks 2018 Student Edition was used to help perform analysis on the track and simulate the project. The Solidworks simulations are completed under the assumption of static conditions, fixtures on every wooden bracket base, and 500 N force throughout the track.

Beginning with the analysis of the von Mises stress on the track the results of the analysis are as follows:

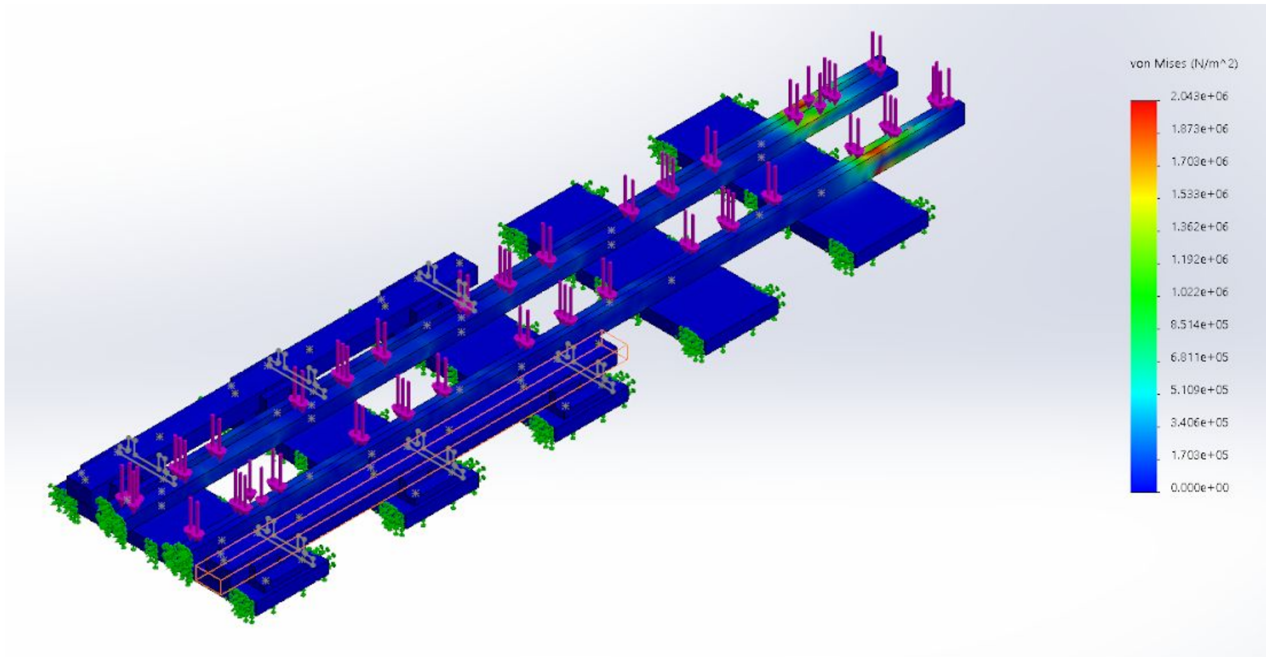

Figure 17. Von Mises stress analysis of the track

On the simulation, blue area means that it is the minimum stress while red means the maximum stress. The results indicate that the design has a relatively low stress concentrations with some green to red zones at the end of the tracks indicating the maximum stress at those locations. The maximum stress on the track is 2.043 MPa while the minimum stress is close to 0MPa.

Further analysis using Solidworks simulation on the bending or displacement of our track was performed . The results of the analysis are shown as below:

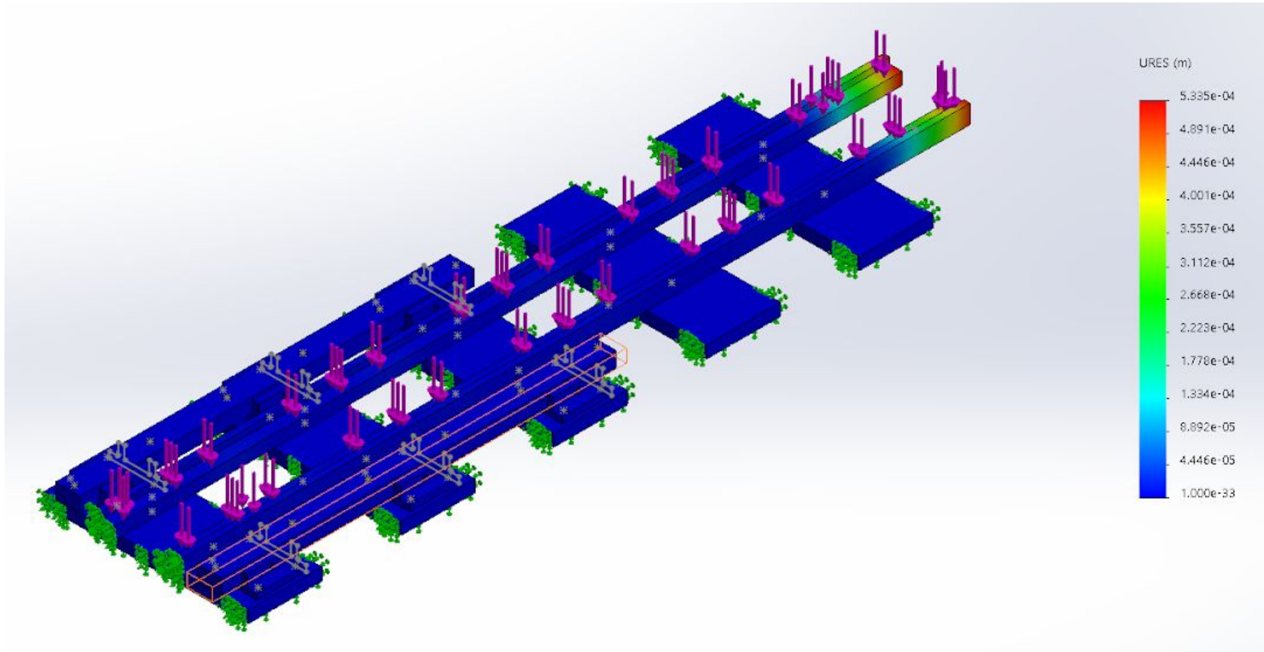

Figure 18. Displacement analysis of the track

Based on the result, the displacements are negligibly small, which means the rigid track will not bend in an unacceptable manner. The maximum displacement found using the simulation is 0.5335 mm and the minimum displacement is also close to 0mm.

To approve the design, a Factor of Safety (FoS) analysis was performed throughout the track. The equation for FoS is Yield Strength divided by von Mises stress. The results of the simulation on the Factor of Safety is shown below:

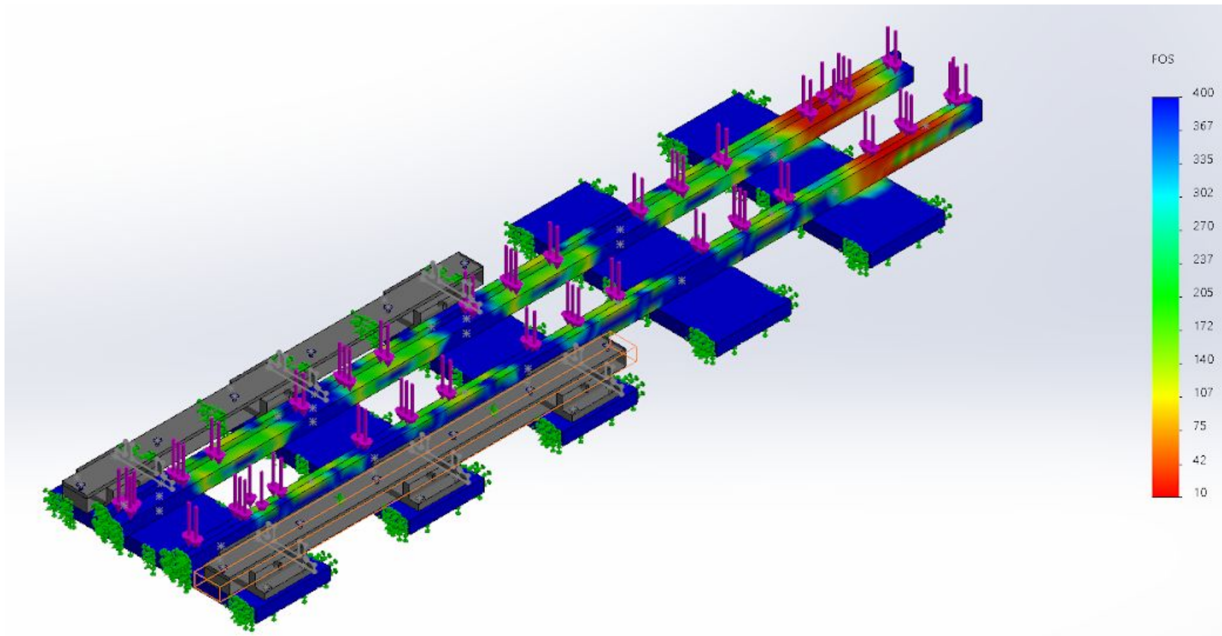

Figure 19. Factor of Safety of the track by using FEA

The results show there are high factor of safety throughout the track. The lowest factor of safety exists at the end of the track. According to the simulation, the lowest factor of safety on the track is 9.8 while the maximum is more than 400. All of these results show the design of the track will have minimum bend at the tip of the track making it confidently safe to use.

3.1.4 Plans for Fabrication

As the team continues to finalize design specifications and solutions it is of utmost importance to know the next steps of fabrication following the design process. To keep the team on track to producing the prime design concept into a working prototype the team has created a schedule and rapid prototype deliverables. The steps of fabrication for the prime design include rapid-prototyping, material selecting and purchasing, material fabrication, assembly, testing, and troubleshooting.

The first step for fabrication, rapid prototyping enables the team to test design concepts at early stages to avoid potentially, unforeseen technical problems. Designing a rapid prototype forces the team to consider realistic means of production and fabrication that can be frequently neglected. Initially the team intended to produce a complete rapid prototyping test, however after careful consideration and constraints in budgeting and time the team moved to produce an extremely small rapid prototype. The rapid prototype will be used to test the composite rail design, electrical systems, and sensor systems.

Phase two of the project, material selecting and purchasing, began with materials for the full-scale prototype rail system. The team selected appropriate materials to build a rail system fit for the bogie system adapted from last year's team. Material selection will also include insulators, metals for the composite rail, sliding conductor shoes, and structural materials.

Phase three of the project, material fabrication and assembly, will first be completed by building the standard rail system to hold the bogie car in place. Upon completion of the rail system the team will move to fabrication the composite aluminum stainless steel used for the conductive third rail system. The fabrication will be completed at the central shop and makerspace; the fabrication includes cutting and potentially steel crimping if possible. Installation of the parts into the prime design prototype will require assembly of insulators and the shoe mechanism in the completing stages.

The final phase of the project, testing and troubleshooting will be important for the team to collect data and prove the functionality of the produced prototype third rail system. Furthermore, the testing phase will be used to troubleshoot and repair any unforeseen design flaws or errors.

4.1 Conclusions and Next Steps

In the next phase, the Wayside team will be focusing on manufacturing and testing. During winter break, the team will continue to work on the one-fifth scale prototype and test it. By the end of Spring 2020, the final prototype will be completed. The most critical months will be between February and March as this will be the time where most of the manufacturing will be completed. Since the team will rely on unfamiliar machinery there will be mistakes and unexpected errors. The earlier manufacturing starts the more time there will be to correct these blunders. Testing will fine tune the operation of the design for public demonstration. With the finished wayside power system, Superway will be able to power its podcars.

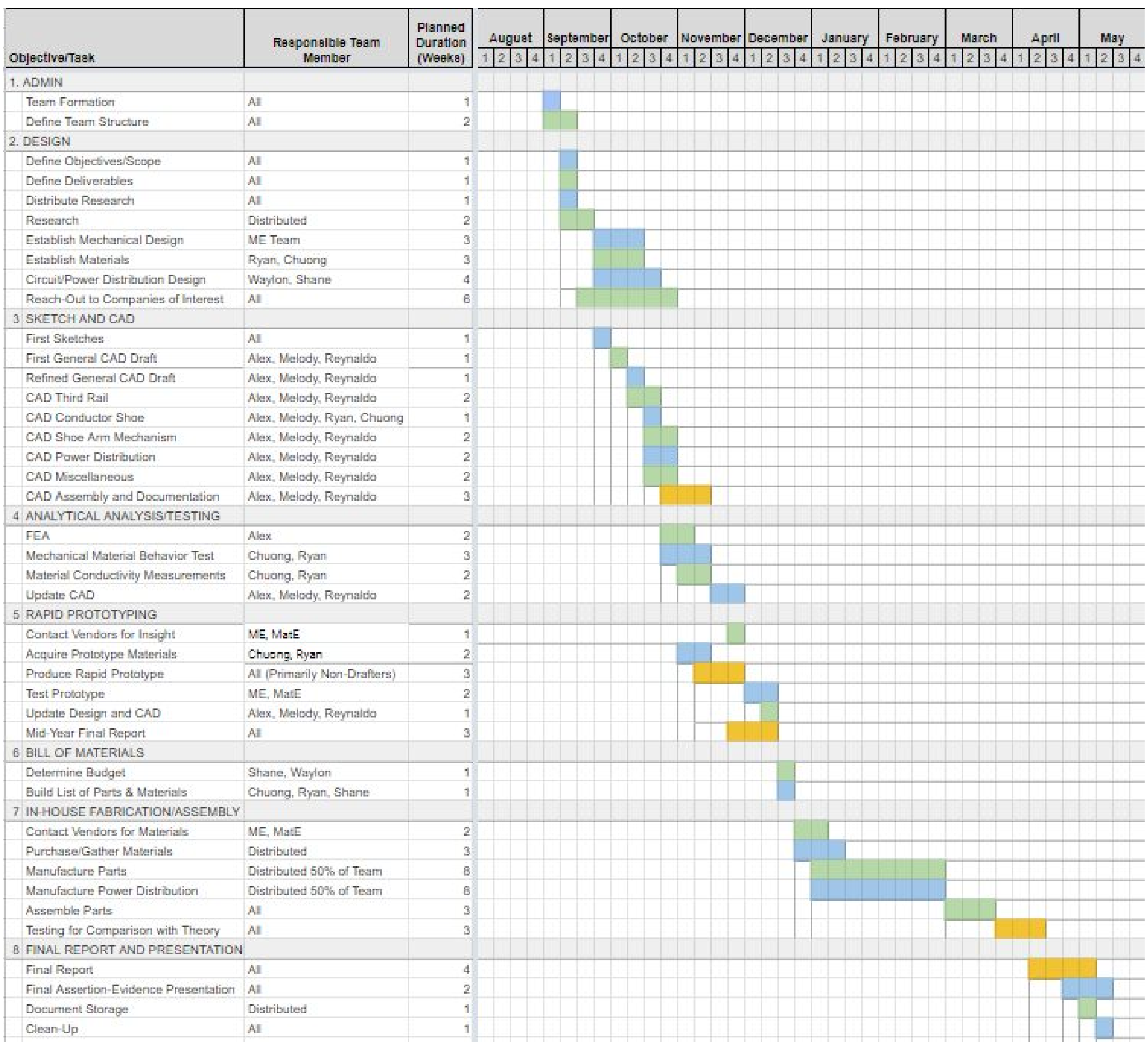

Figure 20: Gantt Chart of Wayside Power Team

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Appendices

Detailed Specifications, Calculations and Analyses

Table 3. Project Specifications for Different Scales

Track and Bogie Specifications				
Description	**1/5th Scale**		**Full Scale**	
	Specification	**Units**	**Specification**	**Units**
Track length	2	m	10	m
Velocity of pod car	0.2	m/s	1	m/s
Current output of third rail	30 (in losses)	A	33.3	A
Supply voltage	12	V	36	V
Current collector shoe force	40	N	100-150	N
Power needed for motor	3	W	110	W

Table 4. Full Scale Electrical Specifications

Full Scale: Electrical Specifications			
Component	**Property**	**Specification**	**Units**
Third Rail			
	Voltage	36	V
	Current	30-70	A
Charger			
	Voltage	36	V
	Current	33	A
	Power	1200	W

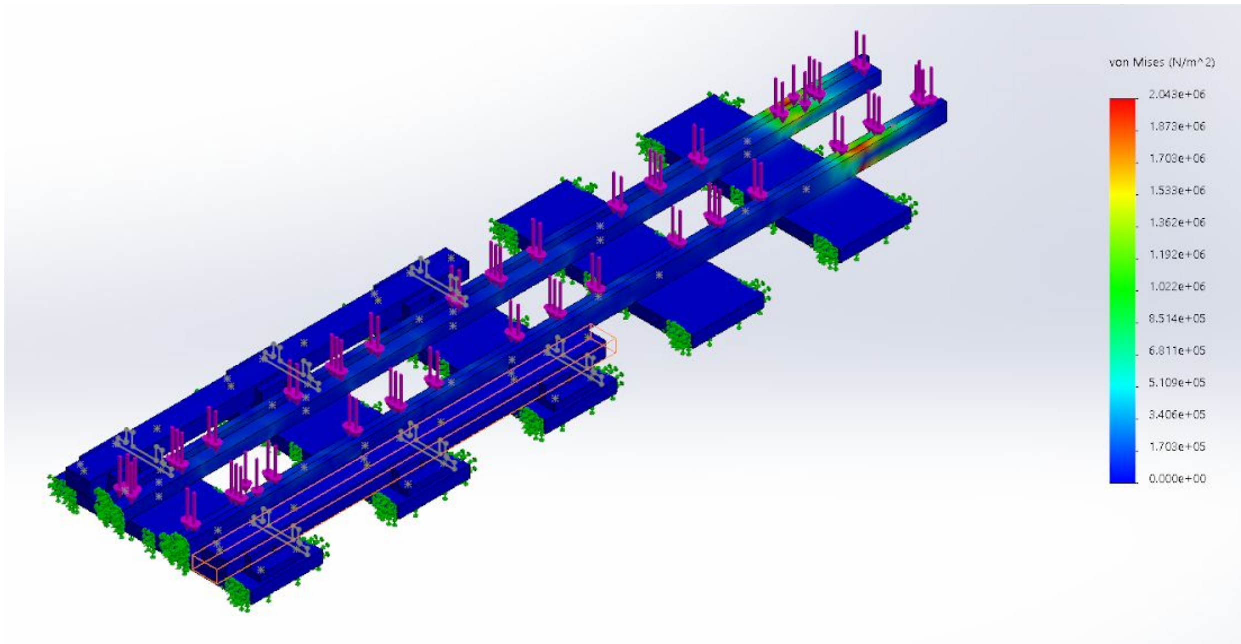


Figure 17. Von Mises stress analysis of the track

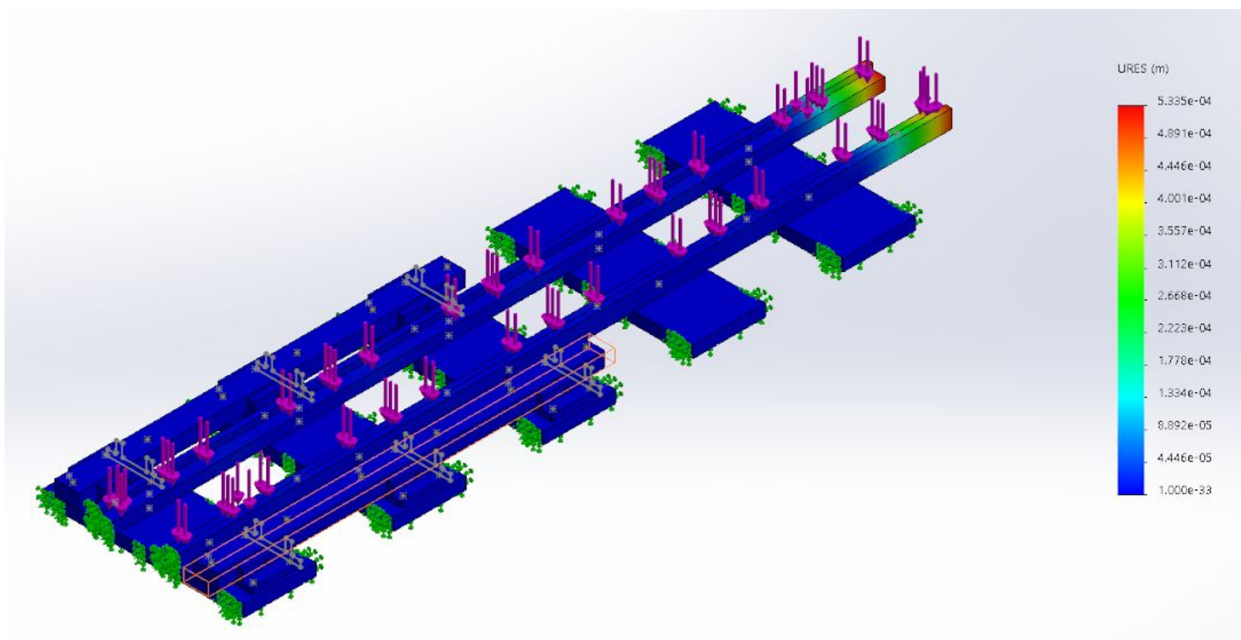


Figure 18. Displacement analysis of the track

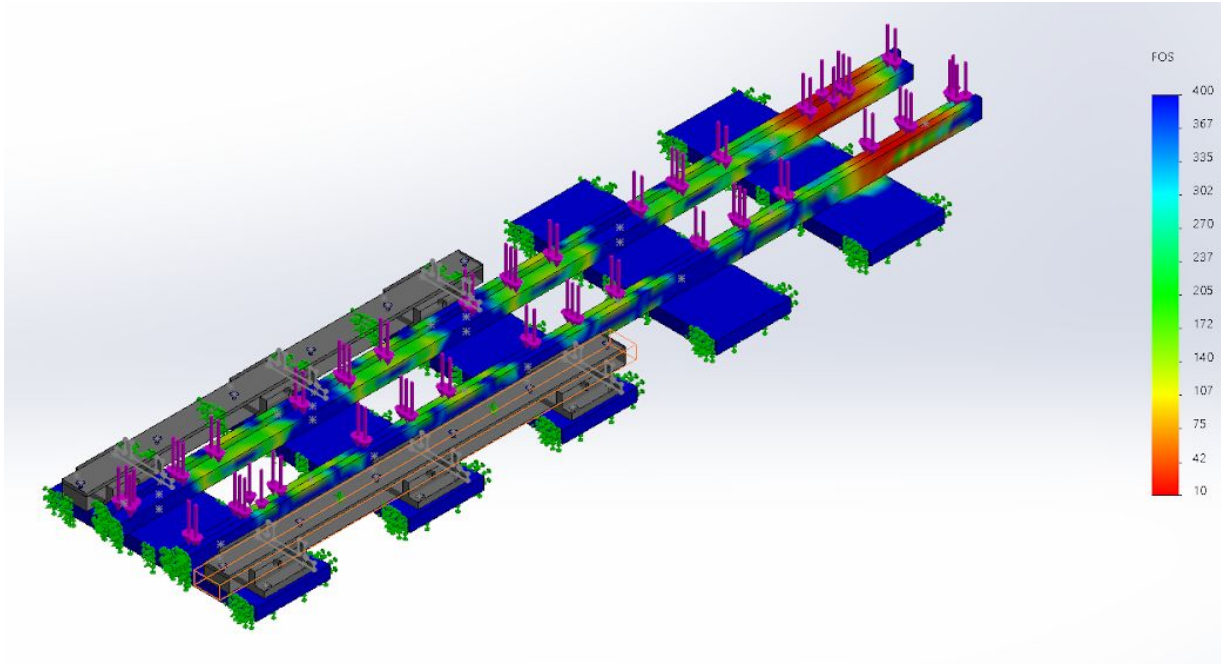


Figure 19. Factor of Safety of the track by using FEA

Table 6. Results for Analyses of bogie wheel diameter design

VEHICLE	Spec	Unit
m_vehicle, m1	4	kg
wheel outer diameter, d1	69	mm
wheel mass, md1	0.1134	kg/pc
number of wheels, n1	2	pc
rolling friction coefficient between wheel and floor, mu1	0.001	

Table 7. Additional Results from Analyses of bogie wheel diameter

	Spec	Unit
RPM	55.39	rad/min
Torque	25	Nm
Power	150	W

Calculations for finding the necessary spring force needed to support the sliding shoe mechanism:

$$6\ (PSI) = \frac{Needed\ Spring\ Force}{1.1\ in * 1.5\ in} = 9.9\ lbs \approx 44.0\ N$$

$$4\ (PSI) = \frac{Needed\ Spring\ Force}{1.1\ in * 1.5\ in} = 6.6\ lbs \approx 29.4\ N$$

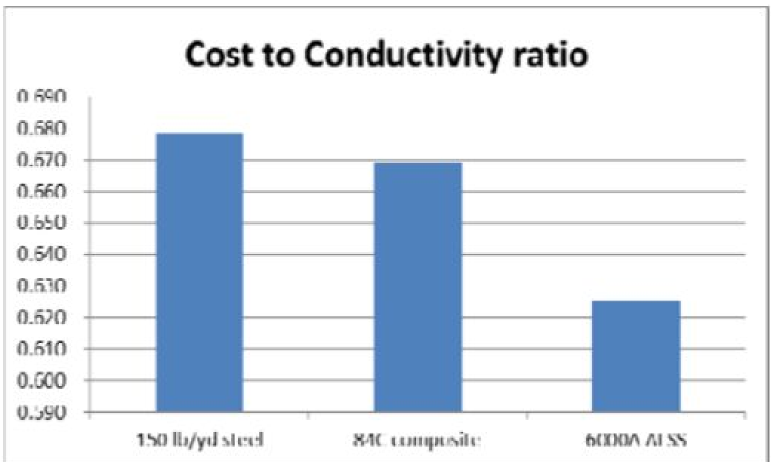


Figure 7. Comparison of cost to conductivity ratio of ALSS vs traditional steel vs 84C composite (Forman 2012)

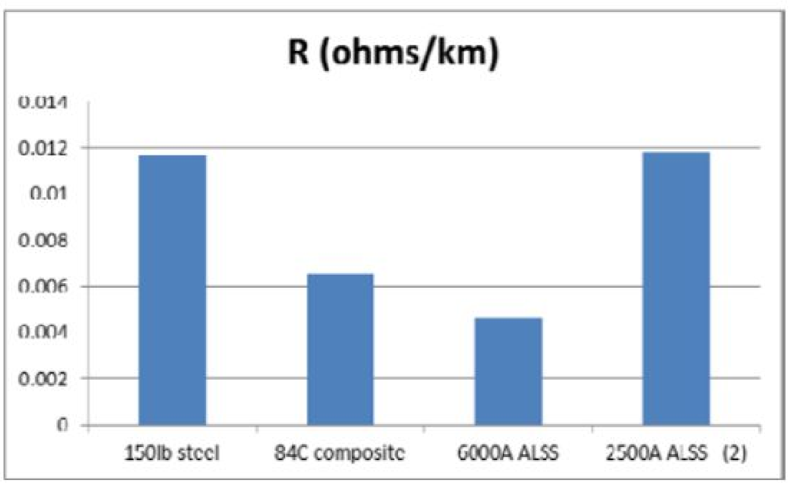


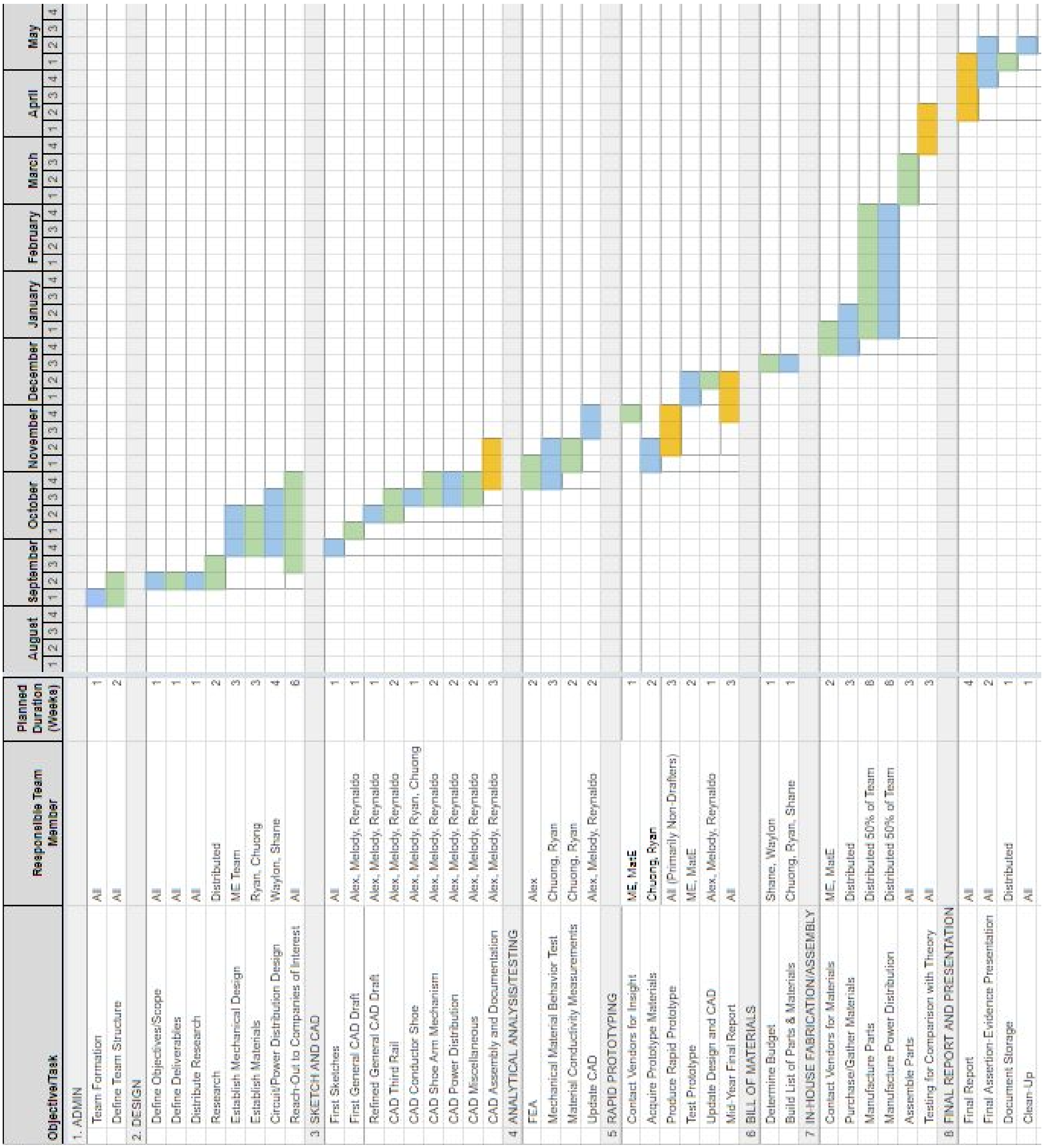
Figure 8. Comparison of resistivity of 6000A ALSS vs 2500A ALSS vs traditional steel vs 84C composite (Forman 2012)

Bill of Material (BoM)

Part No.	Item Name	Description	Unit	Quantity		Cost	
				Needed	Purchased	Per Unit	Total
1/5 Scale							
F412	1" X 2" 6061-T6511 Aluminum Flat	Third rail base	ft	40			$72.96
F5142	1/4" X 2" 304 Stainless Steel Flat	Third rail top	ft	40			$45.90
		Rail track angle wood	ft	12			$0.00
202093850	MDF (Common: 1/4 in. x 2 ft. x 4 ft.; Actual: 0.216 in. x 23.75 in. x 47.75 in.)	Rail track wood	2 x 4 ft	12		$7.49	$0.00
91263A562	Zinc-Plated Alloy Steel Hex Drive Flat Head 1/4"-20, 1" Long	Screws third rail cap to steel base	25 Pack	1		$9.02	$0.00
90011A153	Slotted Decorative Rounded Head Wood, Zinc-Plated Steel, No 6 Size, 1" Long	Screws bracket to rail tie	100 Pack	1		$4.01	$0.00
91247A555	Medium-Strength Grade 5 Steel Hex Head, Zinc-Plated, 1/4"-20 Thread Size, 3-1/4" Long	Screws third rail to bracket	25 Pack	1		$6.71	$0.00
		Screws to secure rail track to rail tie					$0.00
95462A029	Medium-Strength Steel Hex Nut Grade 5, Zinc-Plated, 1/4"-20 Thread Size	Nut third rail to bracket	100 Pack	1		$4.88	$0.00
		Bogie box					$0.00
		Wheels					$0.00
		Motor					$0.00
Full Scale							
	Saw Horses	BURRO BRAND 21-in W x 29-in H Wood Saw Horse (1,000-lb Capacity)	1	4		$21.98	$87.92
	Track wood base plate	2 ' x 6" Douglas Fir	1	6		$6.94	$41.64
	track wood for wheels	1' x 4' x 10' White wood	1	6		$6.77	$40.62
1100-A1	Standoff Insulator	1" x 1" insulated standoff	1	22		$4.01	$88.22
scbkt-3	Bracket	Stainless mounting bracket for ground bar	1	22		$5.75	$126.50

For most updated BoM visit: tinyurl.com/ues3yjn

Gantt Chart



For most updated Gantt Chart visit: tinyurl.com/r5ao7fu