Abstract

This project is to develop an alternative energy transportation vehicle. According to potential customer surveys safety, affordability, and reliability are the top customer preferences. With this in mind, safety, affordability, and reliability will be the major design parameters to maximize public appeal.

1.0 Introduction

There is a continuously growing need for a change in the way Americans travel. The U.S. consumes nearly 25% of the world’s oil and 67% of that is used for transportation. Furthermore, experts expect fossil fuels to be depleted within the next generation’s lifetime\(^3\). Census information from the Federal Highway Administration reports 63.9% of
miles driven by vehicles in 2004 were on urban streets and the Bureau of Transportation Statistics reports that almost 40% of all car trips have only the driver in the vehicle.

The primary focus of this project is the reduction of oil dependency and consumption through an alternate form of transportation. Furthermore, compact electric cars already exist that address parking, emissions, and fuel issues. These vehicles are comparable to full size cars in cost, but do not meet all the comforts, and capabilities consumers are accustomed to. This project will address the fuel and parking issues but will also focus on producing a vehicle that includes heating and air conditioning, a passenger seat, more cargo area, and a weatherproof cabin at a more reasonable price.

1.1 Initial Needs Statement

There is a need for an alternatively powered, intra-community vehicle. The vehicle will address the problems of pollution, oil dependency, parking space, and oil consumption. The vehicle needs to be safe and comfortable with a good suspension and climate control. The vehicle should be functional for errands and transportation with 2 passengers and a well-designed cargo area. The vehicle should also be able to maintain a speed of 25-30 mph and travel at least 20 miles. Lastly, the vehicle should be affordable and easy to maintain, while aesthetically pleasing to the customer.

2.0 Customer Needs Assessment

Potential customer needs were determined by surveying a sample of people including retirement home residents and workers, industrial complex workers, and university students and faculty. College students, faculty and staff were determined to be the major focus group. There are college campuses all over the country, so a large market exists for potential customers interested in small campus vehicles. First, a list of questions was compiled that would elicit customer preferences to maximize marketability; the questions helped to determine selling points such as the amount of cargo space, performance expectations, and aesthetics of the vehicle. Also, focus groups were established to address areas such as inclement weather capabilities, convertible passenger seat, and cargo space. Since this project is being designed and built in a college town by college students, observations and interviews of college students and faculty and staff were easy to conduct.

Individuals surveyed consisted mostly of college students, Ohio University faculty and staff, and residents of the Athens area. One important area addressed by the interviews was the features of the vehicle the customers felt were the most important. To determine the relative importance of each feature, customers were asked to rate six aspects of the vehicle on a scale from one to ten, one being the lowest and ten being the highest. The six aspects that were asked were comforts (i.e. A/C, music, and cup holders), safety, affordability, reliability, performance, and vehicle appearance. Customer importance
averages are shown in Table 1, listed from most important at the top to least important at the bottom.

<table>
<thead>
<tr>
<th>Results from Customer Interviews (conducted with 64 people)</th>
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<tbody>
<tr>
<td>Affordability</td>
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<td>Safety</td>
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<tr>
<td>Maintenance/Reliability</td>
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<tr>
<td>Vehicle Appearance</td>
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<tr>
<td>Performance</td>
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</table>

**Table 1:** Interview results of important vehicle characteristics

These averages indicate that affordability is the most important aspect, second in importance is safety, and third is reliability. Furthermore, interviewees indicated vehicle appearance ranked higher than vehicle performance.

As affordability was the primary concern, customer input was sought on acceptable price ranges for such a vehicle. First round interviews were compiled into a bar graph with results from 56 people. After further consideration a leasing option provided by the university would address the affordability issue in the future.

Another important decision is whether one or two seats would be best for this vehicle’s application. In the interviews customers were asked whether they would want side-by-side seating (if a second seat was to be added,) or tandem. Only one person out of 64 interviews wanted to see a vehicle with tandem seats. All others that were interviewed indicated that they would prefer side-by-side seats, similar to those in a standard car. To
gauge customer behavior versus preference, drivers, passengers and cargo needs were observed in different parts of campus at different times. All in all, 561 cars were observed. After compiling the data 72% of the cars observed had only a driver, 23.9% had a passenger with them, and only 4% of the cars had two or more passengers. This indicates that there is no definitive need for a second seat, which would reduce the overall size of the vehicle and save on parking space and cost.

3.0 Revised Needs Statement and Target Specifications

There is a need for a compact, neighborhood electric vehicle (NEV) that will be marketable for intra-campus and intra-community travel in a varying climate. The vehicle must address the problems of oil dependency, oil consumption, parking, and money spent on gas. It must be reliable, safe, aesthetically appealing, weatherproof and capable of being used all year. The vehicle must also meet state regulations and follow FMVSS 500 and NEV America’s standards.

Cost

- After conducting interviews in the Athens/Ohio University campus area, 30 people out of 56 said they would spend 5000 dollars or less for an intra-campus compact electric vehicle. This vehicle must not cost greater than 5000 dollars retail.

- A second option for future models will be leasing the vehicle; this would maximize sales and provide a way for students to have a vehicle that interests them only for a limited time.

Steering

- For maneuverability purposes, the vehicle must have a turn radius of 10 ft or less. This number was found as competitive when benchmarking current production NEV specifications. Additionally, the vehicle must be able to negotiate a turn with a radius of 12 ft at 10 mph. This speed corresponds to a typical speed during a parking operation, which requires a maximization of turning ability.

Parking

- As a means of addressing the limited availability of parking spaces in college towns, the footprint of the vehicle should be minimized to maximize opportunities for parking. The vehicle should have a maximum footprint of 3.75 feet wide by 8.5 feet long to allow the vehicle to park perpendicular to the curb. It would also permit three such vehicles to park in the aforesaid manner in one parallel parking space. While these dimensions do not satisfy the worst case scenario in Athens, Ohio, where the parking space dimensions
measure 7 feet wide and 23 feet long, they do still satisfy parking space dimensions in other cities where parking is at a premium, such as in Columbus or Bowling Green, Ohio.

*NEV specifications (as stated in Article 49CFR 571.110, FMVSS 500, and NEV America Technical Specifications)*

**Weather**

- This vehicle must be able to encounter 2 inches of standing water at 20 mph and continue operating without malfunction.
- This vehicle must be able to operate in temperatures ranging from 32-104 °F without malfunction.
- The human body begins to sweat at a core temperature of 99 °F, so this vehicle must maintain a temperature of 72 °F between the seat and the passenger in extreme temperatures up to 115 °F.

**Weather Proof**

- More than 90% of the potential customers interviewed said they would want to be able to drive the vehicle in rainy and light snow conditions. Therefore the vehicle should be able to drive in the rain without water entering the vehicle, unless a window or vent is opened by the user.

**Tires**

- The Digest of Ohio Motor Vehicle Laws requires that all tires on passenger vehicles have a minimum tread depth of 1/16 of an inch.
- All other tire requirement must comply with Title 49 Transportation of the Code of Federal Regulations parts 571.109 and 571.110.

**Odometer and Speedometer**

- In accordance with NEV America standards, an odometer and a speedometer must be present and have an accuracy of ±5%.

**Acceleration**

- The vehicle should be able to accelerate from 0 to 20 mph in 6.0 seconds or less when operated with a minimum payload of 332 pounds, and starting with the battery at a 50% state of charge.

**Top Speed**
• The vehicle should have a minimum top speed of 20 mph when loaded with a payload of 332 pounds and starting with the battery at a 50% state of charge.

• The vehicle top speed shall not exceed 25 mph when tested in accordance with 49 CFR 571.500.

Range

• The vehicle should have a minimum 25 mile range when operated at constant top speed with a payload of 332 pounds, and starting with the battery at a 100% state of charge.

High Speed Grade

• The vehicle should achieve a minimum sustainable speed of 20 mph when loaded with a payload of 332 pounds on a 6% grade, starting with the battery at 50% state of charge.

Low Speed Grade

• The vehicle should be capable of starting and ascending a 25% grade when loaded with a payload of 332 pounds and starting with the battery at a 50% state of charge.

Rated Payload

• The vehicle shall have a minimum payload of at least 400 pounds.

Cargo

• According to potential customer interviews, cargo capacity should be 8 cubic feet. This would ensure an entire grocery cart of cargo could fit inside.

Charger

• Charger must not require a neutral connection.

• Charger must not use the frame of the vehicle as a ground (frame voltage must not exceed 5 mA when connected to charger).

• Fans in charging unit must be 240V.

• Charger must achieve a full charge in less than 12 hours.
• Chargers must run on 208 to 240V, 60Hz AC with a tolerance of ±10 percent and a maximum power of 40A.

• Chargers must have a true power factor value of ≥0.95 with a total harmonic distortion value of ≤20 percent.

• Chargers must be able to determine when battery is at full charge and then maintain full charge while connected to the vehicle automatically.

• When charging, the main battery must be automatically disconnected from the propulsion circuit.

• The vehicle must not be non-operational when connected to the charger.

• Vehicle must contain a state of charge indicator.

• Method of charging main battery must be reviewed and approved by battery manufacturer.

• Charger cable must have provisions for positive retention when connected to vehicle to prevent inadvertent disconnection.

• Vehicle charging coupler must not be interchangeable with other electrical systems.

Brakes

• The vehicle must have a service brake for normal use. The vehicle also must have an alternate brake that is separate from the main braking system.

• If a hydraulic system is used for the service brake, the driver should be able to maintain the brake pedal height under a moderate force of 40 to 60 lbs for one minute.

• Non-power assisted systems should have 1/3 of the total pedal travel distance left with a force of 40 to 60 lbs applied.

• Power assisted systems should have 1/5 of pedal reserve left with a force of 15 to 20 lbs applied.

• The service brake should hold the vehicle still under any loading condition and on any grade of road.

• The secondary brake system should keep the vehicle stopped with only 2/3 of the actuator stroke used.
• All parts and fluids used for the braking system must meet the standards of the Ohio Department of Public Safety.

_Glass/Mirrors_

• All glass used on the vehicle must be safety glass.

• The vehicle must have a rear view mirror located to reflect an unobstructed view of the highway to the rear to the driver.

_Drive train_

• The vehicle's drive train must be able to meet the required performance specs.

• If the drive train makes use of a transmission, it must be automatic.

_Seat Belt_

• The vehicle shall have a Type 1 or Type 2 seat belt assembly conforming to Federal Motor Vehicle Safety Standard No. 209 (Section 571.209) at each seating position.

_Horn Specification_

• The vehicle shall have an electrically powered horn which may be operated by the driver of the vehicle.

_Lights_

• The vehicle must have two headlights that are either amber or white.

• The vehicle must have at least one taillight visible from 500 ft.

• There must always be two red lights plus one red light for brake indication on the rear of the vehicle, visible from 500 ft.

• There must be a rear license plate illuminator.

• There must be two red reflectors on the sides of the vehicle, as far to the rear as possible.

• The vehicle must have front and rear turn signals visible from at least 300 ft.

• The vehicle must also be equipped with emergency flashers that are able to run on a backup power supply for at least one hour without the main batteries.
4.0 External Search

Since the group is addressing the design problem through a neighborhood electric vehicle, significant research had to be done on existing electric vehicle technologies. With this topic in mind the group collected information from a variety of sources on the internet and at the library. To organize the research into the design problem, and more specifically the many components and systems of an electric vehicle, the group considered four main topics: the way an electric vehicle is powered, the way the power is transferred to a motive force, the way the vehicle responds to the force, and the way the vehicle is controlled. Applicable patents and regulations were also investigated.

Battery Power

Today’s hybrids typically utilize nickel metal hydride (NiMH) batteries. While these rechargeable batteries are similar to the nickel cadmium (NiCd) type, they have a hydride-absorbing alloy for the anode instead of cadmium, so it’s safer for the environment. Also, for the same size, NiMH batteries have two to three times the capacity. Vehicle batteries are now coming out that use lithium polymer technology. These batteries can have up to three times the energy density of NiMH and NiCd batteries and are less hazardous than lithium-ion batteries since the lithium is held in a solid composite rather than a solvent.

However, for the application of a personal transportation vehicle, a low-speed vehicle (LSV), none of these batteries are used. Normal lead-acid batteries are used instead. Since an LSV cannot exceed 25 mph, not as much voltage or energy is required so a typical set-up includes four to six 12V lead-acid batteries. These will produce 48 to 72 volts which should last for 30-40 miles and may take 10 to 11 hours for a full charge.

Since the group will not be building its own batteries, not many patents apply. Patents that were found relate to charging systems, regenerative systems, and control systems for the monitoring of battery status.

Climate Control

There are several factors to consider in regards to providing climate control for an electric vehicle. First, an NEV does not have excessive power as compared to an internal combustion (IC) engine. In addition, the electric engine does not provide any reject heat to warm the cabin, so a separate heating element is needed. However, the vehicle has a smaller cabin than a conventional automobile, and will need less energy to heat and cool it. Also, because of the size of the vehicle, saving space is an important concern.
Free-Piston Stirling coolers and Rankine cycle air conditioners have been considered to cool the vehicle. Both systems have desirable qualities as well as short-comings. The Rankine cycle, which is found in automobiles, has a faster pull down time than the Stirling cooler. In other words the Rankine can cool an already hot car in a shorter period of time. Once the inside temperature of the car reaches the desired temperature, the Stirling can match the ability of the Rankine to offset the heat leak\(^6\).

A Rankine cycle air conditioner requires much more space than a Stirling cooler, and must be sized larger compared to the load. A Rankine compressor is sized to around 250% of the load, where a Stirling can be sized to as little as 150% of the load\(^6\).

The typical use of a Rankine cycle cooler is to force air over coils and transmit the air into the cabin of the car. Wikipedia reports that most automobile A/C units use about 5 hp or 4 kW to accomplish this. A Stirling cooler can transmit heat in a number of ways. External heat exchangers are required for the cooler to operate and can range from cold plates to thermo siphons. Global Cooling’s M-100 Stirling cooler operates at around a maximum power draw of 60 Watts\(^6\).

An FPSC can be controlled to lift between 0 to 100% of its maximum capacity\(^6\). It does not need to cycle on and off. A Rankine compressor is normally designed to operate at one speed, and if it does have variable speeds it can only go slow enough so as to transmit sufficient oil to the moving parts.

To summarize the attributes of the two thermal cycles:

- **Compactness**
  - FPSC is small and can be mounted nearly anywhere
  - Rankine is relatively bulky

- **Cool down time**
  - Rankine is very fast with initial pull down
  - FPSC can match the Rankine in pull down after desired temperature is reached

- **Power**
  - Rankine typically uses 4 kW
  - The M-100 can use between 0% to 100% of 60 W

- **Reliability**
  - Rankine coolers break down over time because of wear from oil
  - Stirling coolers have yet to break down, even after being tested to run for 12000 hours

FPSCs are superior machines for using electric energy to remove heat; unfortunately they have a draw back in that they don’t have an innate ability to transfer heat over a large
area. This means a Stirling cooler must have a secondary system to transmit the heat from the hot source. This can be most efficiently done with a heat pipe.

A heat pipe is a remarkably efficient system that is also quite simple. The idea behind a heat pipe is that boiled fluids rise and condensed liquids fall with gravity. Fluids that go through a phase change carry extreme amounts of heat compared to a fluid that has not (on the order of 500 times or more). For this system which will operate in the vicinity of human comfort temperatures CO₂ is a great candidate for the working fluid. When CO₂ is brought to a high pressure, it will condense and evaporate at temperatures that make it ideal for air conditioning, or simply transferring heat.

To use the heat pipe in this application the cold head of an FPSC must be above the driver and both must be in contact with the heat pipe. The body heat of the driver will boil the CO₂ which will rise to the FPSC which will draw the heat from the gas. The gas will then condense and flow down the sides of the heat pipe. This process is continuous and the heat is transferred almost instantly through the pipe. Making the pipe out of copper will allow the heat to easily be transferred from the driver’s body by conduction through the walls of the pipe.

*Solar Power*

Solar powered automobiles are currently manufactured around the world. Europe has many different competitions with solar powered vehicles and some are even used for everyday transportation. Nuna II is a Dutch solar car that employs the ESA space technology. The car's shell is covered with triple-junction gallium-arsenide solar cells, developed for satellites. Nuna II also carries Maximum Power Point Trackers⁹. Often called the brain sport, successful solar car racing relies on more than just a fast car. Weather conditions will affect how much energy the car will be able to generate, and terrain and road condition will affect how much energy the car will require, particularly in cross-country racing. Taking all these factors into consideration, the group can determine how fast the car should travel¹¹.

This technology in solar power would enable the vehicle to achieve maximum range by energy regeneration, as well as provide some other comforts such as a heated cabin, radio, and brighter lights.

In further research, a recent technological breakthrough was found that combines solar power and battery power. The batteries help store the solar power and make it as efficient as possible. Also the batteries help when the vehicle needs more power than what the solar applications can give, such as climbing up a hill or passing on the road. There have been many development vehicles and some in production of this type. Typically the batteries can help the development of speeds from 10 – 60 MPH. This technology would help meet the acceleration, and speed requirements as stated in the NEV specifications.
**Human Power**

There are numerous existing devices that have converted human power into electrical power that people have made out of bikes and alternators. These devices have powered things such as TVs, chainsaws, air compressors, and musical equipment. A human powered generated does exist that includes the pedals and converter for about $800. These human power generators (HPGs) claim to be capable of producing 80 watts of electrical output. This may eliminate any power assist, as 80 watts is a small percentage of a motor’s capability, but human powered regeneration could be used to increase the range of our vehicle.

**Recharging Options**

Due to the fact that this vehicle is electric it must be recharged periodically. Ideally the batteries must be fully charged each time the driver enters the vehicle. Maintaining a full charge could be achieved by employing an electrical outlet plug for the vehicle when it is parked near a power source, so long as a patented plug specified for this purpose is not used; or regenerative power (i.e. solar panels, regenerative braking) is not in use. To avoid damaging the batteries by overcharging, the charger must sense when the battery is at 100% state of charge and maintain the full charge. Further research indicated that special fabrication would be needed for a regenerative energy system, thus increasing cost. All patents found that apply to recharging were very specific which would reduce the chance of infringing on them. This research indicates that the technology and resources for designing a system for this project does exist and is feasible.

There is an abundance of articles available concerning inductive charging and regenerative braking for the group’s application. Observing inductive charging articles online led the group to the conclusion that it might be possible to accomplish, but custom pieces would need to be fabricated and it would add a great deal of complication to a charging system design. Regenerative braking will necessitate the use some type of controller to prevent overcharging the batteries. It could be as simple as a voltage regulator but could also be employed to adjust the amount of braking force provided by the motor.

The majority of applicable patents issued are for inductive charging devices. The patents include external device design, internal core design, method of alignment and attachment and many other parameters. It would be feasible for the group to design our own inductive charging apparatus. Almost all of the patents dealing with regenerative braking systems concern devices to control the amount of power supplied to the charging system from the motors.

**Codes and Regulations**

Ohio vehicle code(XLV) states that head lights, tail lights, turn signals, seatbelts, safety glass, four-wheel brakes, reflectors, mirrors, street-rated tires, and an inspection by the
state highway patrol would certify a vehicle for legal road use. The following is a list of applicable standards.

Standard No. 101:

This standard specifies requirements for the location, identification, and illumination of motor vehicle controls and displays. The standard requires that essential controls be located within reach of the driver when the driver is restrained by a lap belt and upper torso restraint, and that certain controls mounted on the instrument panel be identified. The purpose of this standard is to ensure the accessibility and visibility of motor vehicle controls and displays and to facilitate their selection under daylight and nighttime conditions.

Standard No. 111:

This standard specifies requirements for the performance and location of inside and outside rearview mirrors on motor vehicles. The purpose of this standard is to reduce the number of deaths and injuries that occur when the driver of a motor vehicle does not have a clear and reasonably unobstructed view to the rear. The requirements for school buses were revised for driver visibility in front of and along both sides of school buses.

Standard No. 135:

This standard specifies equipment and performance requirements for service brakes and for parking brake systems. The purpose of this standard is to ensure safe braking performance under normal and emergency driving conditions.

Standard No. 202:

This standard specifies requirements for head restraints to reduce the frequency and severity of neck injury in rear-end and other collisions.

Standard No. 209:

This standard specifies requirements for seat belt assemblies. Seat belt assemblies are devices such as straps, webbing, or similar material, as well as to all necessary buckles and other fasteners and all hardware designed for installing the assembly in a motor vehicle, and to the installation, usage, and maintenance instructions for the assembly. The purpose of this standard is to ensure that the hardware of seat belt assemblies shall be designed to prevent attachment bolts and other parts from becoming disengaged from the vehicle while in service.

Part 531:
This part establishes average fuel economy standards for passenger automobiles. The purpose is to increase the fuel economy of passenger automobiles by establishing minimum levels of average fuel economy for passenger vehicles.

**Existing Electric Compact Vehicle Patents**

# 6859009 “Urban Transportation System”

An urban transportation system comprises a pool of rental urban vehicles. All having the same size and physical configuration and having a range of driving which is limited as compared to the range of vehicles that are powered by internal combustion engines. The system includes a computer-controlled mechanized facility for delivering, receiving, processing, servicing and storing the vehicles. Vehicles are automatically recharged while in storage. The system includes areas for on-street parking of the vehicles. There are also several features to combat theft of the vehicles. A user may obtain the most readily available vehicle from any place in the system and return the vehicle to any other place within the system.

**4.1 Benchmarking**

Benchmarking was conducted on a wide variety of vehicles including the GEM car, ParCar, Dynasty, Cart-Rite, B.I.G. man and the Feel Good Car. All of the vehicles qualified as NEVs and met the applicable federal regulations. With the exception of the legally mandated specifications, the vehicles had large differences in their dimensions, payload capacities, propulsion systems, extra features and prices. This benchmarking provided many examples for what is already available to the public such as cargo, seating, weatherproofing, and comfort options. Furthermore, this benchmarking helped to determine selling points and focus area of this project that would maximize customer satisfaction and sales. Finally, these vehicles also prove the project is feasible.

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**MAKE:** CART-RITE  
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MAKE: Dynasty Motorcar Corporation  
MODEL: 2006 IT Sedan  
PRICE: 14,500  
DRIVE: Front  
TRANS: Dana Spicer  

MAKE: Dynasty Motorcar Corporation  
MODEL: 2006 IT Utility  
PRICE: 14,500  
DRIVE: Front  
TRANS: Dana Spicer
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**MAKE:** Global Electric Motorcars
**MODEL:** 2006 e2
**PRICE:** $6,995
**DRIVE:** Front

**MAKE:** Global Electric Motorcars
**MODEL:** 2006 eS
**PRICE:** $7,995
**DRIVE:** Front
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<tr>
<td>ENGINE: 72 V Shunt GE Motor</td>
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<td>BATTERY: Lead Acid Trojan/Deka Gel</td>
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<tr>
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**Additional Specifications**

- **Engine**: 72 V Shunt GE Motor
- **Battery**: Lead Acid Trojan/Deka Gel
- **Voltage**: 72
- **Turn Radius**: 24'
- **Braking Dist**:
- **Charger**: 110 V On-Board Conductive
- **Time**: 6-8 hrs
- **Lease**: Yes

**Dimensions**

- **Weight**: 1120 lbs
- **Speed**: 25 mph or 15 mph
- **Range**: 35 Miles
- **Climb**:
- **Dimensions**: 8.25’x4.58’x5.83’
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Table 2: Benchmarked specifications of current market NEV’s

5.0 Concept Generation

5.1 Problem Clarification

The two energy problems for this project are vehicle performance and climate control. The problems are outlined in the following power flow diagrams.

| NEV PREFORMANCE |
|-----------------|-----------------|-----------------|------------------|
| Power Source    | Converter       | Power Transmission | Load             |
| Battery         | Electric motor  | Mechanical       | Power needed to meet performance specs |
| Possible supplemental power such as solar | Gears, chains, belts… | Losses from the system |
|                 |                 |                 | Can be an automatic transmission |

19
## HEATING/COOLING

<table>
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<th>Power Source</th>
<th>Converter</th>
<th>Power Transmission</th>
<th>Load</th>
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</thead>
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<td>Battery</td>
<td>Rankine cycle A/C</td>
<td>Forced air convection</td>
<td>Body heat</td>
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<td>Possible supplemental power such as solar</td>
<td>Heat pump</td>
<td>Cold plate w/ natural convection</td>
<td>Heat leak</td>
</tr>
<tr>
<td>Resistance heater</td>
<td>Radiator w/ natural convection</td>
<td>Pull down time</td>
<td></td>
</tr>
<tr>
<td>Free-Piston Stirling Cooler</td>
<td>Heat Pipe</td>
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**Table 3:** Power flow diagrams for vehicle performance and climate control

### 5.2 Concept Generation

The concepts for this vehicle were largely influenced by unique features that made the vehicle more desirable to the market. The customer requirements are the basis of the overall design, but these aspects will give the vehicle an edge over the competition.

The first step is defining the main selling points of the vehicle, indicated by customer surveys, and benchmarking.

- A footprint that allows for several vehicles to fit in a normal parking space
- A second seat that is removable or folds up
- A climate control system comparable to IC engine vehicles

The next step in concept generation was benchmarking to determine what is currently in the market and generate ideas that are original and innovative.

- In regard to parking, the vehicles can in fact park perpendicular to the sidewalk
- Only one vehicle had tandem seating; this would take the place of the cargo area when a second person is present
- There is no air conditioning in any of the vehicles benchmarked

Conceptual design took place at weekly meetings within the group. The team exchanged ideas and individuals took turns drawing their thoughts on a white board to show the alternate designs. Current conceptual design is as follows:

- The car should be seven feet long by four feet wide so it can fit into an Athens city parking space perpendicular to the curb
- A second seat that fits in the space provided by the current dimensions
Figure 2: Parking sketch (Todd Steigerwalt)

Figure 3: Second seat sketch (Todd Steigerwalt)

Figure 4: Second seat implementation sketch (Todd Steigerwalt)
These images show the latest conceptual design for the climate control chair. This chair will direct the cooling and heating energy into the driver. By not trying to control the temperature throughout the entire vehicle the power required and the time until the driver is comfortable will be reduced. The chair will be made of layers. The bottom layer is the steel frame that will support the chair and driver. The next layer is an aluminum sheet that will be on the back of the heat pipes. This sheet will protect the occupants if the heat
pipe were to burst, as well as withstand condensation from the surface of the heat pipe without corroding. The top metal layer will be a thin copper foil that will provide a large area for heat transfer between the body of the driver and the heat pipe. This layer will be soldered to the heat pipe directly to maximize conduction through the walls of the heat pipe and the seat. The right picture shows the placement of the cold source to allow for the natural convection inside the heat pipe. The cold area must be higher than the hot area (the driver). Condensed CO$_2$ will flow down by capillary action, while the evaporated CO$_2$ will flow up the center of the pipe.

![Figure 7: Climate control chair components](image)

These images show the intricate workings of the cooling system. The left picture shows the wrapped tubes that are soldered to a copper ring. This will fit over the cold head of the FPSC and allow for heat transfer to take place. The spiral shape will maximize the heat transfer by increasing the surface area exposed to the cold head. Furthermore, the system condensed CO$_2$ will not pool in the heat pipe. The right picture shows the individual layers of the climate control chair. The uppermost layer is on the left, next is the heat pipe which will be soldered to the top copper layer. Behind the copper plate is the aluminum back and the steel fram.
These pictures represent the options considered for covering the back of the seat with the coils. The overall shape of the seat, heat transfer surface area, manufacturability, and cost were considered in the design of each of these alternatives.

The two pictures above show the two options that were considered in covering the cool head of the FPSC. The one on the left would just be a solid ring with the CO₂ coils soldered to the outside, and the picture on the right indicates the coils wrapped directly around the cool head of the FPSC.

6.0 Concept Selection

6.1 Data and Calculations for Feasibility and Effectiveness Analysis

Designing and constructing a vehicle that conforms to NEV standards requires extensive consideration of feasibility. Since it is uncertain how the existing vehicles and components will be divided, the group approached feasibility from a worst-case scenario. This meant viewing the construction from a ground-up basis, where all components
would potentially have to be selected and purchased based on calculations and analyses. With the scope of the course, with time and cost in mind, the group was forced to analyze whether or not a NEV's performance specifications could be met.

*Vehicle Performance Calculations*

Calculations were performed based on the uncertainty of the final gross vehicle weight. Torque and power were calculated for varying masses for a variety of road conditions, including a zero percent grade, 6 percent grade, and 25 percent grade. Direct drive was assumed as further research is needed to specify a gear ratio. Initially, analysis for an acceleration of 0 to 20 mph in 6 seconds on a zero grade was done. Acceleration was assumed to be constant at 1.490 m/s².

![Torque vs. Time (zero slope)](image-url)

**Figure 10:** Torque required versus time for varied gross vehicle weight at zero grade

These calculations were based on the equation

\[ \tau_m = (r_w/N) [am + F_{drag} + F_{roll} + F_{slope}], \]

where the wheel radius is 6.5 inches (0.1651 meter) and the restrictive forces were calculated based on the formulas below.

\[ F_d = \frac{1}{2} \rho v^2 AC_d \]
where \( C_d = 0.5 \), \( \rho = 1.204 \text{ kg/m}^3 \), and \( A = 2.23 \text{ m}^2 \),

\[
F_r = mgC_r
\]  \hspace{1cm} (3)

where \( C_r = 0.015 \), and

\[
F_s = mg(slope).
\]  \hspace{1cm} (4)

At six seconds the torque and power requirements are as follows (2586 rpm):

- \( \tau_m(400\text{kg}) = 116.982 \text{ Nm (6.135 hp)} \)
- \( \tau_m(450\text{kg}) = 130.497 \text{ Nm (6.820 hp)} \)
- \( \tau_m(500\text{kg}) = 144.012 \text{ Nm (7.526 hp)} \)
- \( \tau_m(550\text{kg}) = 157.528 \text{ Nm (8.232 hp)} \)
- \( \tau_m(600\text{kg}) = 171.043 \text{ Nm (8.941 hp)} \)

Motor torque and power was then calculated at constant speed of 20 miles per hour and 6 percent grade (2586 rpm).

- \( \tau_m(400\text{kg}) = 155.841 \text{ Nm (8.144 hp)} \)
- \( \tau_m(450\text{kg}) = 174.214 \text{ Nm (9.104 hp)} \)
- \( \tau_m(500\text{kg}) = 192.586 \text{ Nm (10.064 hp)} \)
- \( \tau_m(550\text{kg}) = 210.960 \text{ Nm (11.024 hp)} \)
- \( \tau_m(600\text{kg}) = 229.332 \text{ Nm (11.988 hp)} \)

Finally, motor torque and power were calculated at constant speed of 15 miles per hour and 25 percent grade (1939 rpm).

- \( \tau_m(400\text{kg}) = 275.020 \text{ Nm (10.782 hp)} \)
- \( \tau_m(450\text{kg}) = 308.774 \text{ Nm (12.105 hp)} \)
- \( \tau_m(500\text{kg}) = 342.528 \text{ Nm (13.428 hp)} \)
- \( \tau_m(550\text{kg}) = 376.284 \text{ Nm (14.752 hp)} \)
- \( \tau_m(600\text{kg}) = 410.038 \text{ Nm (16.075 hp)} \)

**Cool Seat Feasibility Calculations**

Heat transfer and HVAC research indicates that the cool seat is in fact not feasible at this time. Reasons for which are as follows; ASHRAE indicates that an average sized man produces 150 watts\(^{14}\) while driving a car. An initial energy balance indicates that a 100 watt cooler will not provide adequate cooling for the passenger and the passenger will act as the heat sink until the internal temperature of the passenger reaches the ambient temperature. ASHRAE also states that internal temperatures above 43 °C are lethal.
\[
\Delta S = M - W - E + (R + C)
\]  

Above is an energy balance in W/m². Where \( S \) is the time rate of heat storage, \( M \) is the energy generated by the body’s metabolism, \( W \) is the mechanical work, \( E \) is the energy lost by sweating, and \((R+C)\) is the dry heat exchange with the environment. Our specs require that the passenger is kept comfortable, which implies that the passenger is not sweating. Furthermore, the passenger is not doing any work so those two terms go to zero. ASHRAE states that if the right side of the equation is positive then the average body temperature is rising. With \( M \) equaling 150 W/m² or more and \((R+C)\) equaling -100 W/m² at most, the right side of the equation will in fact be positive.

Further investigation indicates that a feeling of comfort can be accomplished by keeping the skin surface temperature within the comfortable range indicated by ASHREA. A comfortable skin temperature varies with ambient conditions, clothing, and activity level. In higher ambient temperatures, a comfortable skin temperature is less, and the inverse is true for cold ambient temperatures.

\[ t_{sk} = 35.7 - 0.0372M \]  

Above is the Fanger comfort equation where \( t_{sk} \) is the comfortable skin temperature and \( M \) is the metabolic rate. For a resting driving man \( M = 1.5 \). Indicating that \( t_{sk} = 36 \, ^\circ C \). Fanger comfort charts also exist which are a function of metabolic rate, clothing insulation, evaporative heat loss, skin temperature, air velocity, radiant temperature, ambient temperature, and vapor pressure. A chart does not exist for velocities greater than 1.5 m/s and ambient temperatures greater than 30 °C. However, a man in a suit in an office building with air velocity less than .1 m/s, and resting requires an ambient temperature of 23 °C (about 73 °F), one could conclude that a passenger in an ambient temperature of 45 °C, high humidity, a t-shirt, and not sweating, would require a much greater air velocity to feel comfortable.

The conduction coefficient \( k \) for a human is .3 W/mK, compared to copper or aluminum which have coefficients of 400 and 200 respectively. This indicates that the human body is a very bad conductor of heat, so drawing heat out of the back of the passenger is not capable of cooling the entire body. Furthermore, this sensation of extreme heat on the front of the body and cool on the back may be more uncomfortable and potentially dangerous.

\[ q = kA\frac{\Delta T}{t} \]  

Where \( k \) is .3 W/mK, \( A \) is .35m², and \( t \) is .003m. The above equation indicates the conduction of heat through the human body. If \( q = 100W \) then \( \Delta T \) is only 3 °C. This shows the surface between the cold seat and the human body can only reach 34 °C (93 °F) with the M100 Stirling Cooler.

We have considered cooling the seat and providing some forced air convection over the front half of the body. The seat could be designed as a finned heat exchanger within the
back of the seat to chill the air, and direct the cooled air back over the passenger. Although, a few problems arise from this method; the heat pipe would cause the moisture in the air to condense due to the hot and humid summer time conditions, which could lead to corrosion and mildew issues. However, this could be designed for and alleviated with simple drainage. If the velocity of the air was increased then less condensation would occur, but the exiting air would not be as cool. If the temperature of the heat exchanger was designed to stay above the dew point then, again, the air would not be cooled as much. This could be compensated for by increasing the velocity of the air and creating a wind chill, but this would require a much more powerful fan and the velocity would be so great that it would be an annoyance to the passenger. One must keep in mind that if an air velocity/temperature balance was achieved, the FPSC still only pulls 100 watts from the air. This means that the cooled air would warm back up nearly instantly, and again the energy balance above indicates that environment is not cooling down.

With an FPSC capable of drawing 300-400W, coatings on the windows that could reduce solar radiation, superior insulation, and a forced air system the cool seat theory may be feasible. However, these upgrades are very costly and would cause the cost of the project to exceed the cost goal. We have also considered radiant panels in the roof, but these panels use chilled water through a horizontal pipe, which would freeze in the winter and not allow for a heat pipe system. Also, they would require much more area than is available in the roof of the vehicle.

At this time we have decided to postpone the cool seat project until the technology becomes more powerful and inexpensive. We all know from personal experience that rolling the windows down in a car does provide some level of cooling, and that sitting on the metal bleachers at a football game does in fact make you feel colder even when the air temperature is reasonable. The theory still sounds promising, but it is not feasible to complete a system design within the schedule for this project, so we recommend pursuing it further as a Research and Development project, while our production climate control design team focuses on meeting the design specifications using conventionally available methods and systems.

**Heat Leak Calculations for Climate Control**

The heat leak is very important to the design of the vehicle. A cooling and heating system will depend on the power needed to balance the heat leak, and the design of the body of the vehicle may also be dictated by the potential heat.

The car was modeled as a rectangular box measuring 8.5 ft. by 4 ft. by 6 ft. These measurements were obtained by the revised dimensions for the parking requirements. The outside air was assumed to be 85 °F, and the inside temperature is 72 °F. All of these measurements were converted to metric units. Windows made of Pyrex glass was assumed to take up 3 cubic meters of the vehicle surface.

\[
q = \frac{\Delta T}{R_{total}}
\]  

(8)
Where $q$ is the heat in Watts, $\Delta T$ is the change in absolute temperature in Kelvin, and $R$ is the total thermal resistance in $K/W$.

$$\Delta T = (T_{\text{outside}} - T_{\text{inside}}) = 7.22K$$

$$R_{\text{total}} = \frac{L_{\text{glass}}}{K_{\text{glass}} \cdot A_{\text{glass}}} + \frac{L_{\text{ins}}}{K_{\text{ins}} \cdot A_{\text{ins}}}$$ \hspace{1cm} (9), (10)

$L$ is the thickness in meters, $K$ is the heat transfer coefficient in $W/m*K$, and $A$ is the area in meters squared. These values are separated for the window glass, and the insulation through the rest of the car body. The glass is assumed to be 0.25 inches (0.00635 m) thick and the insulation is assumed to be glass fiber ($K=0.038$ w/mK). The area of the insulation is the total area minus the area that is glass.

$$R_{\text{total}} = 0.00151 + 1.61 \cdot L_{\text{ins}}$$

$$q = \frac{7.22}{0.00151 + 1.61 \cdot L_{\text{ins}}}$$ \hspace{1cm} (11), (12)

With these assumptions the minimum thickness of the insulation is 1.7 inches. Another calculation is done with 5 inches of insulation and the heat loss is 35.05 Watts. A heating calculation with 5 inches of insulation, an outside temperature of 0 °C, and an inside temperature of 65 °C, yielded a heat loss of 89 Watts. Currently the group is researching heating options.

**Vehicle Stability Calculations**

Stability during cornering is a major safety and comfort concern. A lateral force is created during turning on the contact patch of the wheels and can be calculated as:

$$F_L = \frac{mv^2}{r},$$ \hspace{1cm} (13)

where $m$ is the mass of the vehicle, $v$ is the velocity, and $r$ is the radius of turn. To avoid rollover, the moment caused by the normal force must not be overcome by the moment of the centripetal force (neglecting dampening effects of the suspension system):

$$F_N t \geq F_L h,$$ \hspace{1cm} (14)

where $t$ is the lateral distance from the CG to the tire (half-tread) and $h$ is the vertical distance from the CG to the ground. This inequality can be re-written to solve for a safe turning radius for a given velocity:
Using the measured half-tread value of 1.875 feet, an estimated CG height of 2 feet, and a speed of 10 mph, the vehicle will not tip at a turn radius of 12 feet. Additionally, cornering at this speed would result in a G-force of just over one-half, which would not pose a threat to driver comfort. This was checked by negotiating a car around a turn with an approximate radius of 20 feet at approximately 13 mph.

Steering Calculations

To achieve the targeted turn radius, the angle of steer must be properly evaluated. This steer angle can be calculated by equation 13.

\[
\theta = -\tan^{-1}\left(\frac{w}{a/2}\right) \quad (17)
\]

where the wheelbase \( w \) is 4.417 feet, and the half axle length is 1.583 feet. With these parameters, the Ackerman angle is approximately 70° as measured from the front axle.

Suspension Calculations

For the double wishbone suspension system it is important to find a spring rate that is applicable for the design. A spring that is too stiff will result in too harsh a ride. A spring that is too soft will result in not absorbing the road irregularities. Wheel rate (WR) in lb./in. is calculated as follows

\[
WR = \frac{SW}{(4)(WT)} \quad (18)
\]
where $WT$ is total wheel travel (in.), and $SW$ is the sprung weight of corner (lb). The motion ratio (MR) takes into account the distances $d1$ and $d2$ as seen below. With a desired wheel travel of 5 inches and a $d2$ to be 11 inches and $d1$ to be 8 inches, the following parameters can be calculated. The Wheel rate is calculated to be 125 lb/in.

![Figure 1]

The motion ratio is calculated by Equation 16, which takes into account the distance from the lower spring mount to the A-arm pivot ($d1$), and the length of the lower arm from the inner pivot to the outer ball joint ($d2$)

$$MR = \left(\frac{d1}{d2}\right)^2$$  \hspace{1cm} (19)

The motion ratio becomes 0.529

Another important characteristic of the double wishbone setup is the angle correction factor (ACF). This factor accounts for the angle the spring takes on ($A$) as measured from vertical, as seen in Figure 9. The ACF is computed as follows

$$ACF = \cos(A)$$  \hspace{1cm} (20)

The geometry of the setup allows for the spring to be 34° from the vertical. This makes the ACF=0.829.

With the calculation of the wheel rate, motion ratio, and angle correction factor, the spring rate ($C$) can be calculated in units of lb/in.

$$C = \frac{WR}{(MR)(ACF)}$$  \hspace{1cm} (21)

The spring rate can be solved using the values above. From previous values the spring rate is 285 lb/in. The value is rounded up and the desired spring rate to be used on the front suspension is 300 lb/in.
With a maximum vertical load factor of $4g$ from a pothole to be applied to a wheel, the maximum spring deflection needed to be analyzed. The corner weight of the vehicle is 250 lbs, this led to an applied force of 1000 lbs to the wheel. With the layout of the suspension arms and damper the applied force to the spring is 1752 lbs, with a spring rate of 300 lb/in. This indicates a maximum spring deflection of 5.84 inches. A desired free length of at least 8 will accommodate for the worst case load, which will limit deflect to not more than 85% of the free length and prevent any damage to the spring. Calculations can be found in Appendix C.

The damping ratio to be used for the vehicle will be a common average value used in passenger cars. Therefore a ratio of 0.3 will be used for the prototype.

6.2 Concept Screening

Early concepts were screened during meetings and discussions. The discussions focused mainly on customer satisfaction and feasibility. The concepts were narrowed to three main sellable features:

- Second seating/cargo area
- Climate control system
- Parking issues with current parking system

The seat and the parking dimensions were determined by benchmarking. Most NEVs have at least two passengers, and are designed to be much smaller than automobiles. Air conditioning systems do not exist in any other NEV.

<table>
<thead>
<tr>
<th>Cargo</th>
<th>Interviews</th>
<th>Feasibility</th>
<th>Uniqueness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backpack</td>
<td></td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Distance</td>
<td>20 miles</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Tandem / side-side</td>
<td>Side by side</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Passengers</td>
<td>2 people</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Price Range</td>
<td>$5k - $10k</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comforts</th>
<th>Rank</th>
<th>Feasibility</th>
<th>Uniqueness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
A small NEV like this vehicle cannot spare the power required to run a regular Rankine air conditioner. Research indicates that the FPSC is the most promising cooling system for this vehicle. Using an FPSC for climate control in a vehicle is a new idea, and has not been done successfully. This feature could allow the vehicle to stand out from other NEVs. Another possibility is to use a high pressure carbon dioxide Rankine system. These types of air conditioners have several advantages over a fluorocarbon system. Preliminary research on the Rankine and FPSC are listed below.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Rankine (Fluorocarbon)</th>
<th>Stirling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>6 kg+ (Just For Compressor)</td>
<td>2.5 kg+ (FPSC Only)</td>
</tr>
<tr>
<td>Load Sizing</td>
<td>250% of Load</td>
<td>150% of Load</td>
</tr>
<tr>
<td>Mounting Options</td>
<td>Big And Bulky</td>
<td>Can Be Mounted Almost Anywhere</td>
</tr>
<tr>
<td>Starting Amps</td>
<td>Big Power Loss When Starting Up</td>
<td>0.05 Amps</td>
</tr>
<tr>
<td>Initial Pull Down</td>
<td>Very Good</td>
<td>Slow Initial Pull Down</td>
</tr>
<tr>
<td>Running Pull Down</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Working Temperature Range</td>
<td>Optimized For Small Range</td>
<td>Works Well In Wide Range of Temperatures</td>
</tr>
<tr>
<td>Efficiency</td>
<td>On/Off Cycle Losses</td>
<td>Matches Load To Use Between 0% and 100% Capacity</td>
</tr>
<tr>
<td>Reliability</td>
<td>Internal Oil Degrades Parts, Refrigerant Can Leak</td>
<td>Ran for 12000 Hours W/O Fail</td>
</tr>
<tr>
<td>Power Requirements</td>
<td>15 kW</td>
<td>60 W</td>
</tr>
<tr>
<td>Cost Effective</td>
<td>Modestly Inexpensive</td>
<td>Single M-100 Priced @ $12,500. A Hundred Units Cost $2000 Each</td>
</tr>
</tbody>
</table>
### Heating Options

<table>
<thead>
<tr>
<th>Environmental Friendly</th>
<th>Only Cooling, Using As A Heat Pump Very Difficult</th>
<th>Heating Appears Feasible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorocarbons Are Harmful To Environment, CO₂ Is Better.</td>
<td>No Refrigerant Needed. Uses Helium.</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Characteristic comparison of Rankine versus Stirling cooling

### 7.0 Final Design

The system level design of this vehicle consists of a frame, the collapsible second seat, batteries, steering, body panels on the door, zip-out windows, and suspension. Scope of this project has been to find a better solution for the steering and suspension as well as improve on weather proofing through some sort of door and body panels; also the second seat and cargo space. The following section will discuss each of these systems in greater detail, and the decision on how each system will be designed. These decisions were based off of FMEA, DFMA, mock-ups, benchmarking, and FEA analysis. This section will also show solid edge drawings for each of these parts.

![Figure 12: Final prototype design rendition](image_url)
This picture shows the vehicle at the final design with a full steering and suspension, with the doors on both sides, and zip-out windows for air circulation. Also shown in this picture is the second folding seat with two people to show how they would sit in the vehicle. The vehicle is designed for safety, maneuverability, and a small footprint, as well as to make room for a second seat and cargo.

Frame

For this project a skeleton or configuration was needed to show that all the systems would fit within the vehicle. The skeleton frame needed to support the systems stated in the business opportunity. These systems were a climate control seat for the driver, a second seat/ cargo area that could hold eight cubic feet of cargo, as well as the suspension, steering and a weather proofing enclosure of some sort. Initially the vehicle was given a footprint of seven by four feet, so if would be able to park perpendicular to the curb. This would enable more cars to fit in one spot. After solid edge models were completed and a solid edge 95th percentile person was added to the vehicle, it was decided that the frame was not long enough to accommodate the second seat.

In section 5 the iterations of the frame skeleton can be seen. It is easy to see that there is not enough space for the second seat. It was then decided based off of benchmarking on the width of parallel parking spaces around the country that the length could be extended to eight and a half feet.

<table>
<thead>
<tr>
<th>City</th>
<th>Width Dimension (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athens, OH</td>
<td>7.0</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>8.5</td>
</tr>
<tr>
<td>Bowling Green, OH</td>
<td>8.5</td>
</tr>
<tr>
<td>Cincinnati, OH</td>
<td>8.5</td>
</tr>
<tr>
<td>Ithaca, NY</td>
<td>8.5</td>
</tr>
<tr>
<td>Jersey City, NJ</td>
<td>8.5</td>
</tr>
<tr>
<td>Columbus, OH</td>
<td>9.0</td>
</tr>
<tr>
<td>Memphis, TN</td>
<td>8.5</td>
</tr>
<tr>
<td>Newport, RI</td>
<td>9.0</td>
</tr>
</tbody>
</table>

*Table 6: Benchmarked parking space dimensions*

Once the decision was made to make the frame longer, another solid edge model was created to accommodate two people. The basis of this original design was to provide space for the passengers and other components.

The final configuration design for the frame is shown in the next figure. This new design has many flat surfaces that would be easy to design jigs for manufacturing. One inch round tubing was used to show what the frame would look like, based of benchmarking and what stock is available.
**Figure 13:** Final frame configuration design with FPSC chair frame and 95\textsuperscript{th} male in the driver seat

**Figure 14:** Side view and base frame of final frame design

On the left, a side view of the vehicle and on the right is the base frame that has been designed for the vehicle. The current frame design, with respect to DFMA stated above, can be manufactured easily via jigs. There has also been a member added to the front of the frame six inches up from the base and five inches from the center of the axle will provide a mount for the steering. The suspension for this vehicle is a double A arm design. To mount this to the car, brackets will be welded to the frame for easy installation and bolts will attach the A arms to the brackets. In the current configuration, two bars come up from the frame to provide a mount for the FPSC chair. Currently, there
is space behind the driver’s seat for a passenger seat, addition of support members can be added to mount the chair depending on geometry.

FMEA analysis results for the frame is shown in the chart below.

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>SEV</th>
<th>Reason for Failure</th>
<th>OCC</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Impact</td>
<td>4</td>
<td>hit by car/run into wall</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Rear Impact</td>
<td>4</td>
<td>hit by car/run into wall</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Side Impact</td>
<td>5</td>
<td>hit by car/run into wall</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Welds Fail at joints</td>
<td>6</td>
<td>bad welding</td>
<td>7</td>
<td>42</td>
</tr>
<tr>
<td>Under Body Corrosion</td>
<td>2</td>
<td>salt, gravels, and water</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Roll Bars Collapse due to a roll</td>
<td>6</td>
<td>turn to hard and roll over</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>Axels Fracture</td>
<td>10</td>
<td>large pot hole</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Body Panels fall off</td>
<td>1</td>
<td>screws strip, impact</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Motor mounts break</td>
<td>5</td>
<td>bad welding, screws strip</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Bending due to over loading</td>
<td>3</td>
<td>too much weight</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 7: FMEA analysis of frame design

Frame design is not within the scope of the group’s project, therefore this design is simply to show a system level configuration indicating subsystem passenger positions. OK, so much of this content relative to the frame analysis needs to be moved to the Appendix and merely referenced here to show what was done to establish basic feasibility of your configuration.

Focusing on the worst failure modes, the highest RPN numbers are for the motor mounts braking at 50, the axel fracturing at 40, and the welds failing at the welding joints with 42. Without extensive testing and analysis, these RPN numbers will not be able to be changed greatly; however, there are things that could be done to help the safety of the frame.

Since the analysis of the axel is not in the scope of this vehicle, the current axel on the prototype will be used to test the other systems during the prototyping period. To make an axel safer and bring the RPN down the best thing to do would be have an overly high factor of safety when determining the diameter of the axel for the given stresses it would encounter.

The best way to avoid failure at the welds would be to employ a professional welding shop with the knowledge and experience to overcome such hazards. The material selection is also very import for the welding of the frame.
Choosing a material to completely suit the needs for the vehicle and the group is one of the biggest decisions that the group has faced. The selection of the material must satisfy many different requirements for the frame and body of the vehicle. The following table is the top four choices of materials for the project. Each metal was subjected to a decision matrix and a final overall score was obtained.

<table>
<thead>
<tr>
<th>Material</th>
<th>Machinability</th>
<th>Weldability</th>
<th>Formability</th>
<th>Wear</th>
<th>Cost</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Carbon Steel - 1045</td>
<td>Fair</td>
<td>Fair</td>
<td>Poor</td>
<td>Fair</td>
<td>Mid</td>
<td>4</td>
</tr>
<tr>
<td>Low Carbon Steel - A36</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td>Low Carbon Steel - 1015</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>Aluminum - AA6061-T6</td>
<td>Excellent</td>
<td>Fair</td>
<td>Excellent</td>
<td>Good</td>
<td>High</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 8: Material analysis for frame design

The low carbon steel 1015 and aluminum 6061-T6 received the same score from this vague decisions matrix so more analysis must be performed on the materials to make a better decision.

When developing our frame in SolidEdge, two different parts were made, the base frame and then the body frame. The base frame is what supports all of the weight of the vehicle and the design of it is very important. After many different designs the group decided on one specific frame configuration. This frame configuration was chosen because it fit all of the needs for the group and the project. It was slim enough to meet parking requirements, long enough to be able to accommodate two passengers, and strong enough to meet our project specifications. The finalized base frame configuration is shown in the picture below.
From this picture you can see that the group has chosen a very unique design using square pipe. The picture shown is eight and a half feet long by three and three fourths feet wide. The entire frame with the body attached can be seen in the later sections of the report.

For performing analysis on the frame and on the different materials selected, the frame was analyzed in Algor, an FEA computer program. The analysis was performed two different ways, the first way and the most detailed was by drawing the frame in Algor and then assigning all of the parameters in the program, setting the members as a hollow box, and changing them to the correct material. Loads were applied at each of the nodes with a magnitude of 35 lbs and 70 lbs. This simulated a distributed load across all of the connection points of three and six times the weight of the body of the vehicle. The figure is shown below. This level of analysis is all that was needed for are configuration design since we just wanted to show that the frame was strong and would not collapse under its own weight, much more design considerations and analysis will be done on the body/ car door of the vehicle in the next section.
In the figure, the red triangles are the fixed points of the frame simulating where the axels would be placed on the vehicle for zero deflection. A great amount of analysis was put into this program. The group tested three different materials, low carbon steels 1015-as-rolled, and A36, and the third material tested was AA-6061-T6. Test were performed with 2”x 2box shape with thickness of and 1/8”. The complete results table is shown below.

Based on the results from the FEA the best material for the group would be the low carbon 1015-as-rolled steel. This decision was based on the amount of deflection and stresses, cost, and the availability of the material. A sample of the deflection is shown in the figure below.
The main concern of the door frame was that it be safe. It had to be designed for the worst case scenario. To find what this would be, FMEA was performed.

<table>
<thead>
<tr>
<th>System</th>
<th>Subsystem</th>
<th>Component</th>
<th>Failure Mode</th>
<th>OCC</th>
<th>SEV</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>Door Frame</td>
<td>Door Frame</td>
<td>Yeilding due to impact</td>
<td>8</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Buckleing under persons weight</td>
<td>7</td>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>Body</td>
<td>Body Panels</td>
<td>Door Panels</td>
<td>Cracking</td>
<td>6</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erosion</td>
<td>8</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fracture</td>
<td>7</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sun Damage</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Leaking @ seams</td>
<td>7</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Leaking @ bolts</td>
<td>7</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>scratching finish</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Windows</td>
<td>windshield</td>
<td>cracking</td>
<td></td>
<td>5</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leaking</td>
<td></td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Door windows</td>
<td>cracking</td>
<td></td>
<td>5</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leaking</td>
<td></td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 10: FMEA door frame
Above is the FMEA analysis that was performed for the door frame. In red are the two largest RPN numbers found based on occurrence and severity. It was decided that the worst case would be a side impact on the door where a vehicle would hit it. Another concern was the weight of a person being supported on the door when a person would use it to get out of the vehicle.

To find what the worst case of a side impact would be, it was decided that the worst case would be the greatest force right before the vehicle started to slide due to a side impact. The dynamic loading after the vehicle starts to slide is beyond the understanding of an undergrad. That is why the greatest force right before that instance will be used for the worst case loading. To find this force it would be the normal force of the vehicle times the coefficient of static friction. For the weight of the vehicle one of the heavier benchmarked vehicles was used with a weight of 2450 lb. or 5390 kg. This would ensure that even if the end weight or the groups vehicle was less the loading would still be for the worst case. Even if the vehicle weighed less it would start to slide before the max force that the car was designed for before it even reached that force. It was found that the

\[
\text{Force} = \text{Normal Force} \times U_s
\]

The coefficient of static friction that was used is 1.0 for dry concrete. Wet concrete did not need to be taken into concern since the vehicle would start to slide on wet concrete before the force being designed for was reached. The normal force was found from the weight times gravity, and found to be 52,875.9 N. Therefore when multiplied by 1 = Us the worst case force for a side impact would be 52,900 newtons.

**Door Frame Design**

The door design of the vehicle has been one of the main focuses for this project the entire year. After struggling through a few different designs a final door frame and body panels was created. But to get a little bit of understand of how the design process came about, lets take a look at the process and steps that were performed to reach the final design level.

The very first door frame had very little detailed thought into the design. It was merely a lets draw something that fits into the vehicle frame to get some ideas flowing. The design is show below in Figure 17.
Not only are there some major manufacturing issues with this frame, safety issues like visibility also occur. This idea and design was scrapped immediately, but it was a step in the right direction.

The next design was drawn up with a lot more thought behind it and some FEA analysis was performed to see how the strength of the door held up. As stated previously in the report the worst case scenario for a side impact would be with a force of 52,900 N. With a quick conversion of Newton’s to pounds that translates to about 12,000 Lbs. This is the force in pounds of the worst case scenario, for the FEA testing a safety factor of 4 was applied making the analysis force equal to about 48,000 Lbs. Things to look for during the analysis were that the maximum shear stress did not exceed the Modulus of Elasticity for the type of material chosen. The material chosen during the analysis was AISI 1015 as-rolled steel which has a modulus of elasticity of 4.2768e9 lbf/ft². Any amount of shear above this would mean that a failure has occurred in the design. A snapshot of the first door design that had analysis performed is shown below in Figure 18.
Body panels were included in the design but no window was placed at this point yet. Also for the FEA analysis there is point in having a window in for a side impact crash because it gives very negligible support to the frame. Next the analysis was performed but turned out to be unsuccessful.
Looking where the arrow points in the image shown in Figure 19, a major stress point has occurred in the design. The red area there exceeded the modulus elasticity of the material, so a new design was implemented.

The new design had very little changes, a second bar running across the middle of the door frame and improvements made to the center support bar, is all that was added. The image is shown below in Figure 20, this shows the assembled version on the exploded image.

![Figure 21: exploded door](image)

The design was created this was to limit the amount of bending in the center area of the door frame. Analysis was then performed and came out successful, images are shown below in Figure 21.
Looking at the image it is clear that the design was successful. The maximum shear stress occurred was only $1.449042 \times 10^6$ lbf/ft$^2$. This is well under the required stress for the material chosen.

Some assumptions were made during the analysis. The first one being that every part of the frame touching the frame of the vehicle was considered to be fixed in the x, y, and z axis. Also the way the force was supplied to the frame was by 49 nodes. An image of how the analysis was set up using Algor can be seen in Figure 22.
In the image the red triangles represent the fixed nodes, and the blue arrows represent the nodes which have forces on them. The image only shows the top seven blue arrows but there are seven more rows underneath them all on the seven centered nodes. Each arrow, 49 of them, has a pound force value of 1000 lbs, making the total force on the door frame 49,000 lbs, 1,000 lbs more than the calculated force with a factor of safety of four. The same assumptions and ways the forces were divided up were used on all of the frames were analysis was performed.

The hinges for the doors will be regular door hinges. When looking at the cost for a special door hinge, the cost of a vertical door hinge set was at least $900. It was decided that money could be better spent on another aspect of the vehicle. Therefore normal piano hinges would work just fine for this application. These hinges would be ordered from a company like McMaster and would be normal detentions held in stock.
For weather proofing the vehicle there had to be some way for sealing the door from weather when it was closed. The solution that the group came up with and prototyped was a angle iron frame that the door would close into. This would also only add to the structural integrity having the door supported the entire way around. For this design 3/4in. x 3/4in. x 1/8in angle iron would be used. The material would be the same as the rest of the door frame for simplicity in ordering and welding. Below is the design that the door will close into.

Here you can see the angle iron and how it will enclose the door, then a simple rubber weather stripping would be glued in between to seal the door from any water leakage.
Figure 26: angle iron door frame and door closed

Figure 27: soft top window zipped up
To address the climate control design specification, a soft convertible top will be employed. This does not meet the design specifications to maintain a constant cabin temperature within the cabin. The soft top will allow for four season operation, however, the passenger will have limited climate control.

The top will provide excellent water protection, and the passengers can remove any combination of the five zip-out windows and/or top to obtain a more comfortable driving environment. In the winter months, the soft top will provide protection from snow and ice, but will provide a minimal amount of insulation.

The materiel selected for the cloth top is a four ply composite made of a PVC outer layer, an un-dyed 100% cotton sheeting backing fabric, a butyl rubber inner layer and a dyed Polyester/Cotton Sateen lining fabric. It can be ordered in bulk or manufactured to specific dimensions. The thread used to join the individual panels is a heavy-duty high tensile strength monofilament thread. A cross-section of the seams is indicated in the image below. The windows are made of a heavy duty clear vinyl. The windows are joined to the fabric top by water resistant zipper tape. The entire system will have seven windows; a zip out window on each side of the vehicle for the driver and rear passenger, a zip out back window, and two smaller non-removable windows in front of the zip out driver windows. The cloth top will be comprised of a top panel, two trim pieces for the
doors, and trim around the passenger windows and rear window. When completed, the
cloth top system will have two door covers and a larger cover for the rest of the vehicle.

The cloth top will join to the body be a flexible plastic piece that fits into a channel that
runs around the entire length of the top edge of the body. A cross-section of the joint is
indicated in the images below. Allow four inches extra on each length to form the seams.

When selecting materials for the weatherproofing of the vehicle, the group encountered
many less problems. After analyzing several different options for how the
weatherproofing was going to be applied, the decision was made to stay in line with the
options of a standard vehicle. Double-pained sheet metal would be used on the base,
body panels, doors and roof of the vehicle, and safety glass for all windows and
windshields. Although there are more desired applications such as, fiberglass, and soft
tops comparable to a Jeep Wrangler, when applying them to this project they did not fit
the needs as well as a traditional setup. The following table shows a condensed decision
matrix analysis of the different types of materials to be used for the weatherproofing.

<table>
<thead>
<tr>
<th></th>
<th>Workability</th>
<th>Durability</th>
<th>Cost</th>
<th>Waterproof</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite (fiberglass)</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Wood (balsa)</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Plastic (molded)</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Metal (steel)</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Metal (aluminum)</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

**Table 11: Body panel material decision matrix**

The metal chosen for the body panels, doors, and roofing would most likely be a light
weight material, such as AA 6061-T6 aluminum, or a different less expensive type of
sheet metal aluminum. Aluminum was chosen because of his extremely high formability
and wear resistance. Ordering sheet metal of this material would make it very easy to cut
to the desired shape and then mold, weld, and rivet into position.

*Second Seat*

A primary feature of this design is to include a second seat in the vehicle which is
capable of stowing away to create a moderate cargo area. The key features of the seat’s
design include being light-weight, able to store in a very small space, able to support a
95th percentile male passenger during normal operation and impact, and it also must include a seatbelt.

The seat is currently in the late stages of design. The design has been narrowed into two models pending process and final material selection.

The initial stages of this design began by looking at what collapsible seats were already on the market in passenger vehicles. A major source of information was extended cab pick-up trucks that contained folding rear seats. Although a good design, it immediately became clear that the seats, although not optimal by any means, were extremely over designed for our applications. They were designed for longer trips and more severe impacts than the MeCat vehicle would ever see. In addition the latching and hinging mechanisms were also very complex, as shown in Figure 18.(Show pictures of benchmark products)

This discovery led the group to begin coming up with its own design parameters, guidelines, and concepts. Original iterations showed a more complex system than exists in later iterations. As the design concept sharpened, a few key decisions were made concerning the seat. The seat was placed in a forward facing configuration, this allows for the “well” under the seat to house drive components, and allows some space under the front seat to be used as leg space. It was designed to fold up out of a lower panel; this prevented the system from having to support itself on the wall in the cargo configuration, and supporting the weight of the passenger on the hinge in the riding configuration. This, in turn, makes the hinge and latch design simpler. A simple hinge was designed around a bolt and bushings, as opposed to standard hinges or a torsion bar. This makes for simpler manufacturing and repair. To hold the seat in position in the riding configuration, a latch will hold the seat back to the wall. The decision was also made to attach the seatbelt directly to the frame through holes in the seat base panel to lessen the forces trying to pull the seat out of its mounts on the frame in a collision.

In keeping with the mission statement, another important aspect to consider is the aim to create an energy efficient electric vehicle. Inherent to the design of an energy efficient vehicle is the ability of the vehicle to accelerate and propel itself with the least resistance possible. A very good way to reduce motive resistance is to decrease the mass of the object being moved. Therefore all major components should be optimized for weight efficiency in the final model.
The back seat base structure itself is a larger piece, which places even more importance on efficient design for weight. By minimizing the weight of the piece through material selection and its geometry, the piece will contribute to an overall weight reduction of the vehicle in conjunction with other weight optimized components, which should intern raise the efficiency of the vehicle.

The part itself has certain required minimum geometries that must be met. The part must be able to fill the cavity completely to the side-walls in the rear of the vehicle. The Part must have a recessed cavity to allow the seat back to fold down into it. The part must also feature a flat, planar, relatively level top-surface and maintain this when the seat back is folded down flush. Another key feature is an underside mounting surface, designed to fit the frame mounting locations. Also the design must have holes for a seatbelt to pass through and mount to the frame. Many of these features can be seen in Figure 30.

![Figure 30: Basic seat design in passenger configuration, illustrating configuration and seat belt holes.](image)

It was quickly determined by the group that a metal part that fulfilled our needs would be extremely heavy. The discussion soon turned to other materials. As discussion went forward three key parameters were discussed, the part must be lightweight while withstanding basic crash impacts, it must be as inexpensive as possible, and it must also be easily produced. Cost restrictions immediately ruled out most high grade composites and advanced materials, such as carbon fiber. The most viable option was then determined to be investigating and choosing a heat moldable plastic suitable for our application.

The idea of a part consisting of both metal and plastic pieces was proposed and discussed. The group soon determined that a hybrid piece would require both plastic and metal-working stages in production which would cause production costs to skyrocket.
In addition to the basic parameters listed above, the final dimensions of the seat were given by the frame design, after the frame designer finished crafting a frame that was capable of holding a second person in the back, the footprint of the seat was laid out, (Figure 31) and final design iterations could begin. – please note that a minor change will be made to the trapezoids dimensions as soon as new dimensions are available to me.

![Figure 31: Basic seat base dimensions, cutouts will be made at the corners to accommodate frame bars.](image)

This is at least an attempt at making the design real, but it is unclear how you have optimized this with respect to loading (transferring them to the frame) and stresses.

After determining the footprint of the design a suitable mounting system had to be determined. In discussion with the frame designer the decision was made to install a ladder style support bar spanning across the rear seat cavity. This would allow maximum surface area of the seat to contact the frame while keeping weight reasonable. The decision was also made to use square bar stock on this ladder to further increase the contact area between the two parts. The two parts would be joined by inserting bolts through the frame members from the bottom directly into the seat plastic or female threaded mounting rivets embedded in the seat part. This design allows for the resistance of torsion about its mounting bars in both directions of the mounting plane. Much of the resistance to rotation perpendicular to the mounting plane will be resisted by the vertical support bars of the upper frame at the four corners of the seat base, there will be cutouts that wrap around the members and secure the base into position. This built in resistance to torsion will significantly lower the bending stress in the mounting bolts. By using basic hand calculations (pending) the size and number of bolts is still being determined. These bolts will be the main resistance to the shear forces applied in a collision. The members of the ladder would also provide key support to the weight of the passenger and
the threads of the bolts would keep the seat from rising on its mount. Required geometry for mounting can be seen in Figure 32.

![Figure 32: Required geometry for mounting.](image)

After choosing a desired geometry processes were considered to determine which operations could produce the best quality parts containing the necessary geometry. Discussion centered on injection molding and rotational molding. After conferring with an IT student and friend who has had experience forming plastic, it was determined that injection molding was the choice for the job. Injection molding is capable of producing complex geometries at a high rate with a great deal of accuracy and precision. Rotational molding although requiring a lesser initial investment, has certain characteristic flaws that influenced the decision. Rotational molding can cause uneven surface thickness and flaws in more complex geometries.

The basic structural design of the base piece is shown in figure 21 (wrong #). The structure is a thin walled shell with ribbing for structural support and mounting. Female threaded rivets will be installed along the ribs to accept bolts through the frame bars. The base also contains cutouts for the seat back to tuck into along with the necessary holes for the hinge bolt. This is the semi-final structural configuration. (How can it be final if it hasn't been analyzed?) Although some thicknesses may change through further analysis, the overall configuration and to a moderate extent, thickness of the members is somewhat set.

Initial FEA analysis was done on the seat design using ABS. The tests were promising and showed that the seat was well within the range of that plastic and others with similar strengths.
To perform the FEA, the bolt holes were constrained from rotation in all directions and displacement within the mounting plan. The bottom surfaces were constrained from rotating through the plane of mounting or displacement perpendicular to the mounting plane. Crash loads for 30mph were applied to the seat assembly by hand. The appropriate forces were then added to the model for analysis. Results can be seen in Figure 33.

Figure 33: Loading, stress and displacement plots.

Another key feature of the seat base is the cutout in which the top panel folds into. Not only is it necessary that it conceals the folding seat panel, it must also support itself well enough to be a stable load bearing surface for the cargo configuration.
The primary analysis of the seat base will be done using Algor FEA. The loading of a person sitting on the base will be checked for various materials, to get a feel for what is usable. From there, the list will be narrowed and all material aspects weighed for final selection. Another key FEA will be performed on the mounting bolts and hinge mounting holes for crash stresses. The current thinking is based around molded plastic, however if metal is required, aluminum will be high on the list; if necessary and feasible, a combination of metal and plastic may be used.

Considerations have also been given to value in particularly in regard to manufacturability. Whether the base is made from metal or plastic, it can be made in 4 steps (3 with a custom drill bit). All features are moldable/castable, except the hinge mounting and assembly holes. Finally insert mounting plugs in the mounting holes (or drill and tap if metal). Another key manufacturing consideration surrounds the hinge bolt. Interference was found with the hex heads that hold the bolt in place on the underside of the shell. This presented two problems, the interference, and how does one get the bolt in place to begin with? A hole was drilled in the side of the shell along with a matching groove to allow the bolt to slide in easily, and give clearance for the hex head. Another similar smaller groove is on the nut side. These grooves can be drilled and milled or molded, however the holes still need drilled. Figure 24.
Figure 35: Grooves and holes for assembly and bolt/nut clearance.

The seat back is then mounted by one long bolt. The bolt slides into a hole in the base shell, passes through a bushing, into the seat back, through another bushing, and is finally capped with a nut at the other end of the base piece. All mounting hardware is concealed inside the base shell. The seat back is constructed of a plastic shell that will hug a cushion.

Figure 36: Hinge assembly illustrated

Worst case shear testing of the bolt will be done to determine its proper diameter. The current design calls for ½” however this will be scaled to the nearest stock bolt that will match the requirements. Simple hand calculations will be performed to test the bolt; also
a small amount of FEA may be used to gain a better understanding of the how forces transmit through the assembly to the bolt so that a more accurate mathematical model can be created.

The holding latch for riding position will be selected based on its rating from the manufacturer weighed against the applied loads of a rear collision.

The seat will primarily consist of two cushions. Both cushions are exactly the same. One will be mounted to the base piece in the bottom of the cavity, the other on the seat back. The cushions will be glued into position if an adhesive is found strong enough in mock up and testing, or hardware can be put through the shell into the cushions. Another cushion will be mounted to the wall on the back of the vehicle to rest the head and provide support for impact. Cushion material is still under investigation pending comfort and impact testing. Materials under consideration include memory foam and vinyl or similar stretched and stapled over stuffing on a backing board.

Figure 37: Exploded view of final second seat design

-Dr. Kremer, the actual plastic being used will be chosen when I return. I did not want to include an incomplete decision as of now.
Climate Control

As discussed throughout the report thus far, we feel there is a definite need for a climate control system within the vehicle. The unit will be able to cool and heat the driver. After conducting extensive research and personal interviews, we found that direct contact with the seat would be the best way to transfer or remove heat from the occupant. (You have never given the data or the justification for this statement—that must be included in a design report!) After further study, we discovered that a heat pipe would best accomplish the desired effect.

Our first step to complete this heat pipe was to decide what would be the best material to construct the pipe out of. We created a chart comparing several different types of metals to each other. After weighing several factors such as pressure requirements, cost, availability, and thermal conductance, we found that copper would work best for our design.

<table>
<thead>
<tr>
<th>Material</th>
<th>Max Pressure</th>
<th>Tensile Strength</th>
<th>Cost/ft</th>
<th>Heat Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>psi</td>
<td>Ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>4800</td>
<td>40</td>
<td>$2.30</td>
<td>0.22</td>
</tr>
<tr>
<td>Copper</td>
<td>3200</td>
<td>10</td>
<td>$1.87</td>
<td>0.09</td>
</tr>
<tr>
<td>Nickel</td>
<td>5000</td>
<td>55</td>
<td>$10.59</td>
<td>0.13</td>
</tr>
<tr>
<td>Stainless</td>
<td>6000</td>
<td>40</td>
<td>$8.36</td>
<td>0.12</td>
</tr>
<tr>
<td>Steel</td>
<td>5200</td>
<td>30</td>
<td>$2.10</td>
<td>0.12</td>
</tr>
<tr>
<td>Titanium</td>
<td>3600</td>
<td>125</td>
<td>$53.31</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Table 12: Material analysis for heat pipe design

In addition to choosing the material, we also had to find the proper dimensions of the pipe, which are a function of the necessary pressure within the pipe and the volume of gas inside the pipe.

After deciding on copper tubing, we felt that the best way to transfer or withdraw heat from an object would be to design for the greatest exposed surface area as possible. Therefore, we determined that a thin sheet of material between the actual coils and the passenger would greatly increase the efficiency (I think you mean effectiveness) of the system. Once again, we compared several different types of metals and found that copper once again would be the best choice.

FMEA was also utilized to identify possible failure modes, as seen below.
<table>
<thead>
<tr>
<th>Part/Failure</th>
<th>Description</th>
<th>Severity (1-no effect, 5-bad)</th>
<th>Description</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPSC</td>
<td>Eletrical</td>
<td>4</td>
<td>Does not allow FPSC to run, not safety risk due to lack of exposure</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>4</td>
<td>Cause cooling system to run inefficiently or not at all, not dangerous</td>
<td>3</td>
</tr>
<tr>
<td>Copper Coils</td>
<td>Burst</td>
<td>5</td>
<td>Create leak of CO2, slightly harmful</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Clogging</td>
<td>3</td>
<td>Make the system inefficient due to the lack of flow of CO2, not dangerous</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Kinking</td>
<td>3</td>
<td>Make the system inefficient due to the lack of flow of CO2, not dangerous</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Wear</td>
<td>2</td>
<td>Create leak of CO2, initially harmful</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Exposure to outside elements creating corrosion</td>
<td></td>
<td>System may become inefficient, may potentially create leaks or unsafe</td>
<td>3</td>
</tr>
<tr>
<td>Ring around cool end of FPSC</td>
<td>Not permitting CO2 to reach cold head of FPSC</td>
<td>4</td>
<td>Make the system inefficient due to the CO2 not cooled to potential, not dangerous</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Wear</td>
<td>2</td>
<td>System may become inefficient, not dangerous</td>
<td>3</td>
</tr>
<tr>
<td>Valve for CO2 entry</td>
<td>Leak</td>
<td>4</td>
<td>System may become inefficient due to lack of pressure or amount of CO2, not dangerous</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Burst</td>
<td>5</td>
<td>Create leak of CO2, initially harmful</td>
<td>1</td>
</tr>
<tr>
<td>Structure (frame &amp; backing)</td>
<td>Too great of weight from passenger</td>
<td>3</td>
<td>May create kinks in tubing and cause inefficiency in the system, not dangerous</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Wear</td>
<td>2</td>
<td>Create corrosion in seating apparatus, not dangerous</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 13:** FMEA of climate control design

OK, but what about failure by not making the occupant comfortable enough.

In order to prove the feasibility of our project, we conducted several experiments in which the data would give us a better understanding of the capabilities of the idea and help us to optimize the final design. First, we wanted to know if direct contact with a cool surface would be sufficient enough to make the passenger comfortable. We simply placed a .030 inch thick copper sheet on top of a bag of ice and sat on it. (What conditions did you control in this test. If you had a very hot room and the approximate amount of body surface area exposed to the low temperature and the appropriate amount of insulation between you and the copper sheet that will be provided by the seat padding, then you could get a meaningful result.) The results of this test were minimal at best. Second, we tested the thermal conduction capabilities of the copper sheet when exposed to the cool head of the FPSC. We ran the sterling cooler with direct contact to the copper
sheet and placed a small amount of water around the cool head of the FPSC on the sheet of copper. The cooler was left to run for 3 minutes to simulate the time a typical vehicle cooling system would take to reach its minimum temperature. We found that the water had frozen forming a ring around the cool head two inches wide. This test indicates that the FPSC can develop freezing temperatures in the copper sheet out to two inches from the source of the cooler (i.e. heat pipe). This data can be correlated to the diameter of the bends in the heat pipe. (OK, then do it.) Finally, we tested the system with a heat load. We ran the cooler in direct contact with the copper sheet for three minutes with a teammate’s hand on the copper sheet. We placed a thermocouple between the hand and the copper sheet with the tip of the thermocouple two inches from the edge of the cool head. After three more minutes the thermocouple displayed a steady state temperature of about 53° F.

Some assumptions we made when testing this system is that the heat pipe would maintain a two degree temperature difference from the FPSC throughout the heat pipe. Furthermore, the FPSC we are using to prototype with only operates at 25% of capacity when powered by 110 V AC. We assumed that when the FPSC is operating at maximum capacity it will account for any ambient temperatures higher than the ambient temperature in which the tests were performed. (I do not understand this assumption, and therefore I cannot agree with it unless it is explained logically.) Finally, we assumed that when the FPSC is operating at maximum capacity, it will account for a larger heating element than a single human hand.

The results obtained from these tests do not prove feasibility with 100% certainty, however they do warrant further testing. After consulting Dr. Kremer about our results we have decided to build a full size model complete with a heat pipe and chair. The tentative design will include the FPSC, a variak to increase the capacity of the FPSC, and a complete frame to support the passenger and cooling system. We also will incorporate a second small coil in the heat pipe, so that we can add a chilled forced air system if supplementary cooling is necessary.

Due to the lack of benchmarking available for this system, we are focusing on feasibility testing. Feasibility testing is planned to be completed by April 5, 2007. At that time we will have performed several tests and compiled the data to make a final decision on whether or not to continue researching and developing this system.

Currently there is no final design, only conceptual design. The conceptual design is based on benchmarking, FMEA, and some FEA. Tentatively the conceptual design includes the FPSC mounted in the driver seat behind the driver’s head. A heat pipe is brazed to a copper sheet within the driver seat. The heat pipe is designed with a coil around the cool head of the FPSC, such that the FPSC can be removed easily for maintenance. The chair will be comprised of a square pipe frame and aluminum sheet that will support the cooling system and the passenger. The heat pipe will be constructed from 1/8th inch copper tubing that is rated for 3200 psi, this will account for the hydrostatic testing to 5 times the operating pressure of the system. The connections are brass flared fittings rated for 3500 psi, which is also safe for hydrostatic testing. The heat pipe will be between the
copper sheet and aluminum plate. This will help provide safety for the passenger in the event of the pipe bursting. To help provide comfort and maximize the cooling effect of the system, freezer gel packs have been benchmarked. These freezer packs are non-toxic and guaranteed not to leak if punctured. A mock-up of the system can constructed for under $200.

To address the climate control design specification, a soft convertible top will be employed. This does not meet the design specifications to maintain a constant cabin temperature, and four season comfort. The soft top will allow for four season operation, however, the passenger will have limited climate control.

The top will provide excellent water protection, and the passengers can remove any combination of the five windows and/or top to obtain a more comfortable driving environment. In the winter months, the soft top will provide protection from snow and ice, but will provide a minimal amount of insulation.

Steering

![Figure 38: Rack-and-Pinion](image)

After considering direct steering, recirculating ball steering, and rack-and-pinion steering, the team decided to use a rack-and-pinion steering system. This includes the rack-and-pinion assembly attached to tie rods at either end, which are in turn attached to steering arms attached to the spindles. Several factors contributed to the overall decision including benchmarking, customer feedback, heuristics, and mechanics.

Research was conducted into common steering mechanisms for a vehicle similar to the one the team is building. NEVs and SAE’s mini-Baja vehicles were considered
comparable, and every vehicle in these two categories utilize the rack-and-pinion system. It is also well known that the vast majority of production cars use rack-and-pinion steering systems. The recirculating ball system was dismissed after this analysis due to a lack of market presence and a known complexity that surpasses the other two systems. Feedback from potential customers was also examined. College students are considered a target demographic for the team’s vehicle, and when polled they commented that while steering response is important, they preferred the steering ease and feel associated with the cars they currently drive. This information also inclined the team to opt for the rack-and-pinion set-up.

To capture the team’s objective view on the possible steering systems, a decision matrix was set up that compared the steering options versus important factors. These factors included cost, manufacturability, reliability, repair ease, weight, steering ease, and steering response. When a consensus was reached on the weighting of the factors, reliability, cost, and steering ease came out as the most important. Each team member rated each of the factors for each steering system on a scale from one to three (three being the best), which were then multiplied by the weight and summed for each system.

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Manufacturability</th>
<th>Durability/Reliability</th>
<th>Repair Ease</th>
<th>Weight</th>
<th>Steering Ease</th>
<th>Steering Response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Rack and Pinion</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>With Weight</td>
<td>8</td>
<td>6</td>
<td>15</td>
<td>4</td>
<td>4</td>
<td>12</td>
<td>6</td>
<td>55</td>
</tr>
<tr>
<td>Direct Steer</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>With Weight</td>
<td>12</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>44</td>
</tr>
</tbody>
</table>

Table 14: Example of Team Rating System

When scores were averaged, the rack-and-pinion system edged out the direct steer system 53.8 points to 45.2 points.

Next the team considered the mechanics of the two steering systems and how they impact the vehicle’s performance. While the direct steering system provides a faster response when turning, it may result in a high rate of normal load transfer that would make the vehicle unstable and the driver uncomfortable. The higher steering ratio in a rack-and-pinion set-up would require a larger rotation of the steering wheel to execute the same turn and so reduce the rate of normal load transfer and rate of lateral force. This, in turn, would positively increase the feel of the steering and the driver’s comfort level. The rack-and-pinion also has two distinct advantages over the direct steering system in terms of tie rods. Rack-and-pinion set-ups employ shorter tie rods, making them less susceptible to breakage. Additionally, the tie rods in the rack-and-pinion system are in the same plane as the control arms to minimize toeing during suspension travel, whereas in a direct steering system the tie rods are at an angle to the control arms.

After the team settled on the rack-and-pinion steering system, it was decided that an Ackerman style steering arrangement would be employed in the vehicle. The Ackerman
concept is to have all four wheels rolling around a common point during a turn, requiring the inner front wheel to turn at a greater angle than the outer front wheel\(^2\).

![Figure 39: Ackerman Tire Geometry\(^1\)](image)

The idea is to reduce the slip angle so that the tires experience more pure rolling and thus require less force to steer. This would facilitate low-speed parking maneuvers where rolling friction dominates turning ability. To accomplish the Ackerman tire geometry, the steering arms are angled inwards to allow the tires to rotate at different rates. The size of the angle determines toe on turn in, and for zero toe it is referred to true Ackerman\(^8\). This translates to angling the steering arms so that a line drawn between both the kingpin and steering arm pivot points intersects with the center of the rear axle. It is this set-up that the team will utilize when establishing the steering arm angle\(^8\).

An FMEA analysis was conducted to investigate possible steering system failures. This analysis was of paramount concern, since any failure of the steering system would result in loss of control of the vehicle and jeopardize the safety of its passengers. From research into possible modes of failure and their occurrence both in production and mini-Baja vehicles, it was found that efforts should be focused on the tie rod ends and the joints which connect them. Excessive forces during hard cornering can break the tie rod ends, especially if weakened by rust and/or corrosion. These forces could also shear the joints that attach the rod ends, or the joints could loosen from vibration.

First the tie rod ends were analyzed. If the ends were to break, steering would not be possible, and at elevated vehicle speeds this could result in catastrophe, both to passengers of the vehicle and to surrounding vehicles and pedestrians. With this in mind, the severity was rated as 9. Taking into account a high factor of safety, knowledge of the magnitude of applied forces, and material used in industry, the probability of occurrence was rated as 4. The probability of detection was rated as 6 due to a possible inability to detect early fracture, especially when the fracture may occur because of fatigue. This results in an overall rating of 216. To avoid failure, the team ought to use a high-strength steel with good fatigue life that has proven acceptable in the automotive industry. It is also advised that these components are purchased instead of fabricated.

Next the joints that connected the tie rod ends were analyzed. Again, if the joints were to break, steering would not be possible, and dangerous or fatal accidents might occur. Taking the safety of the vehicle’s passengers to be of primary concern, the severity was again rated as 9. The joints may loosen regardless of fastening efforts. Additionally,
they may loosen after unpredictable durations of time from a lack of knowledge of vibrations that the vehicle will experience. Due to this nature the probability of occurrence was rated as 6. A loosening of the joint could be visibly detected and/or felt through loose steering, but a shearing of the joint could occur without warning. In light of this, the probability of detection was rated as 5. This results in an overall rating of 270. If the joints are to employ threads, the threading ought to be long and fine with a tight pitch with an accompanying locking mechanism. If ball joints are used, care should be taken to prevent seal leakage and ball wear. Again, it is advised that these joints be purchased from a reputable supplier to avoid fabrication errors.

**Suspension**

After determining that the vehicle needed to have independent wheel suspensions on the front, then the main suspension designs were considered. This included the MacPherson Strut, Double wishbone, and multi link suspension. The team decided upon the double wishbone setup after weighing the pros and cons of each different setup. This will include two control arms that are attached to the frame, a damper and spring, and a spindle that will connect the control arms to the wheel itself. One of the major factors in determining this was the benchmarking of similar small vehicles. These vehicles were also using double wishbone for their front suspension. Another important aspect was the wheel control with this setup. It provided better optimization of the wheel motion compared to the MacPherson.

The following chart shows how the team weighed several important aspects of the suspension system. These aspects were then rated against the different type of suspension setup. After the setups were rated, the sums of the weighted totals were calculated with the double wishbone setup having the highest total.

<table>
<thead>
<tr>
<th>Weight</th>
<th>Cost</th>
<th>Complexity</th>
<th>Control</th>
<th>Comfort</th>
<th>Manufacturability</th>
<th>Assembly</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MacPherson</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Double Wishbone</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Multi Link</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Weighted MacPherson</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>44</td>
</tr>
<tr>
<td>Weighted Double Wishbone</td>
<td>8</td>
<td>6</td>
<td>15</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>51</td>
</tr>
<tr>
<td>Weighted Multi Link</td>
<td>4</td>
<td>1</td>
<td>15</td>
<td>12</td>
<td>3</td>
<td>4</td>
<td>39</td>
</tr>
</tbody>
</table>

*Table 15: Team Suspension Rating*

The customer feedback was also an important role in helping to determine which suspension to go forward with. As the role of the driver, their main concern was with handling and comfort. This helped influence that decision as the double wishbone configuration allows for better handling and comfort as opposed to the other options. The multi link setup could theoretically have the best attributes but the cost and the complexity of the system made the team decide on the double wishbone.
After considering that this setup will add some weight to the overall vehicle and some additional complexity, the team felt that the benefits outweigh any negative characteristics that this may bring.

An FMEA analysis on the suspension system helps determine possible failures and the severity of those outcomes. Since suspension is important to overall control of the vehicle, a failure can cause unpredictable handling. This makes it important to consider all possibilities of failure.

First major component that would be suspect to failure is the shock absorber itself. If it is worn, then the vehicle would bounce more than normal after impact with a bump. This could also be caused by a broken mount for the shock as well. This would not make for a catastrophic failure but it would be undesirable for the driver. With this in mind it receives a 4 for severity. Given the fact that the shock will be purchased from a vendor, the probability of occurrence will be 4 as well. The worn shock will act differently than it used to so the driver may be able to feel a difference in handling. They may also see oil leaking out of the housing of the shock as well. This leads to a detection rating of 6. This gives an overall RPN of 96 for the damper component.

The springs could become fatigued and crack. This could lead to the car wandering on the road and causing the driver to have to constantly correct for the deviation of the path. This failure would not be too dangerous so it receives a severity rating of 5. If the proper springs are used for the given application and they are purchased from a reliable vendor the occurrence rating is a 5. Otherwise damage to the springs may result from too much deflection. It would be hard to see any damage before failure due to fatigue. The driver may notice handling differences. The detection rating will be a 4 for a spring. This leads to a RPN of 100 for the spring.

The control arms are important for keeping the wheels in contact with the road. If they were to break, it could lead to hazardous conditions as control would no longer be possible for the vehicle. This is cause for a severity rating of 9. The bushings at the body mounting points could also wear leading to loud squeaking or unwanted movement. Therefore, these component should be purchased from a reliable vendor. This would give a probability rating of 4. The only way these should fail would be from impact on a crash. The detection also receives a 4 due to the inability to see any fatigue damage on the arms. This gives the control arms a RPN of 144. Since this has the highest RPN’s of the suspension components, it is recommended that these be made of high strength steel that has been proven in automotive applications from a reliable vendor.

7.1 Design Drawings, Parts List and Bill of Materials

Please See Appendix E for Part List and Drawings, and Appendix D for A Full Cost Analysis.
7.2 How does it work?

System level

This NEV works like any other normal NEV. A person opens the doors using the lack on either side of the vehicle. Once you get in the car close the door and turn the car on using the key. Then like any other car, the accelerator is on the right and the brakes are on the left. There is a switch to change from forward to reverse. The steering is like any other rack and pinion steering. Right the wheel to the right and the car will turn to the right, same for the left. Turn the wheel to the left and the car will turn to the left. To get into the back seat, open it and rest it against the back and sit down. Once your have buckled your seat belt you are ready to drive. Next we will look into a more focused component level.

Angle Iron Door Frame

This frame is designed to enclose the door. In between the door and the angle iron frame is a rubber seal so that when the door is close water will not leak into the car. This frame will be attached to the car, and the hinges attached to the angle iron, and finally the door attached to the hinges. The door will open and close from the back, just like a regular car door. The hinges will be attached in the front. There will be nothing required of the customer but to replace the rubber seal around the door if it were to become worn out.

Figure 40: Angle iron and door frames sealed
Suspension

The suspension system allows the driver to pass over obstacles with very little shock loads transferred to the driver. It is meant to allow a comfortable ride and handle the various bumps that may occur with everyday driving. The suspension should be inspected every 10,000 miles to ensure proper function. This would be done by a trained technician. The customer can check the shock absorbers to see if there is any hydraulic fluid leaking from them from time to time. If they find a leaking shock, they should have it replaced immediately.

Steering

To operate the steering system of the vehicle, the user must rotate the steering wheel. If a right-hand turn is desired during the operation of the vehicle, the user is to rotate the steering wheel clockwise. If a left-hand turn is desired, the user is to rotate the steering wheel counter-clockwise. The tighter the desired turn (the smaller the desired turning radius), the greater the degree of steering wheel rotation is required. The steering wheel will lock after ¾ of a rotation in either the clockwise or counter-clockwise direction from a neutral steering position. This corresponds to 1-1/2 turns lock-to-lock.

The steering subsystem consists of the following items in order of user interaction to driving surface interaction:

Steering wheel
Steering column
Rack and pinion
Tie rods
Steering arms
Spindles
Tires

The steering wheel is rigidly attached to the steering column so that when the steering wheel is rotated, the steering column is equally rotated. The steering column is then in turn attached to the rack and pinion assembly. The rotation of the steering column causes an equal rotation of a round pinion gear in the assembly, which then causes a lateral left or right movement of an attached rack gear. The steel pinion and rack gears are sealed in a protective aluminum housing with flexible rubber boots at either end of the housing to accommodate rack movement. At each end of the rack a tie rod is connected, which transmits the left or right motion of the rack. The tie rod is then connected to a steering arm which is attached to the spindle that holds each front tire. Thus, when the tie rods move left or right by rack movement, they in turn push the steering arms left or right, respectively, which in turn pivot the tires left or right, respectively, for a left or right-handed turning maneuver.

The tie rod connections at the rack and pinion and at the steering arm should be checked every 10,000 miles.

A comprehensive check of the steering system should be immediately performed if the steering feels loose or operates erratically.

Soft Top

The operator can remove then entire cloth top system or they can leave the top on and just remove any combination of the five windows. The seams are all reinforced with an industrial strength flexible adhesive to ensure that the seams are waterproof. The windows can be removed by a zipper that runs the perimeter of each window; the zipper is overlapped by cloth trim pieces to prevent water leakage. Where the window meets the body, and where the cloth top meets the body there is a flexible plastic strip that holds the top and windows in place by tension. The cloth top attaches to the doors by an industrial strength Velcro that runs the perimeter of the doorframe. The entire top can be removed by unzipping all the windows and rolling them up and storing them, then removing the cloth top and rolling it up and storing it.

To install the top start by fitting the flexible plastic strip in the channel at the top of the windshield. Then stretch the top over the vehicle and fit the flexible plastic strip into the channel around the rear corners of the vehicle. Then fit the flexible plastic strip into the channel in front of the passenger windows. Zip the windows in first then attach the bottom of the window to the body with the flexible plastic strip. Attach the driver windows by attaching the Velcro edges first, then fitting the flexible plastic strip into the channel at the top of the body panel.
Door Hinge

The hinges designed for this system simply open wide, and close tightly together. A pin is used to keep the two separate wings of the frame in line. The outside of one of the wings will be welded to the angle iron of the door’s frame, while the other wing will be welded to the angle iron of the car’s frame. The door will be able to open more than 90 degrees and close tightly against the frame allowing no precipitation to enter.

7.3 How is it made?

Door Frame

The door frame of the vehicle comes together fairly easy, placing it in the simple jig that was created, and making sure that everything is secure before welding is the most difficult task. A way to improve on how the make sure the parts are secure in the jig is by placing the part correctly in the jig and then using welding magnets and c-clamps to increase stability.

![Figure 42: Picture of jig to be used for door frame welding](image)

Once all parts have been tack welded while in the jig, the frame can be removed from the jig, this is when welding is then completed. After welding is completed the only thing left to do is bolt on the body panels and then add seal around the panels and the inner rim of the frame which will be flush against the angle iron of the vehicles frame. A full part list and assembly diagram, along with part drawings with tolerances can be seen in Appendix E, at the end of the report.
This door frame was specifically designed for easy manufacturing. Any experienced manufacturing shop would easily be able to follow the assembly guidelines and create the frame with the correct tolerances. Cost of the door frame was based on a lot of 5000 parts. For materials alone the bar stock and sheet metal cost, $70.18 and $40.25 respectively, for the amount of material needed to create a pair of door frames. The total cost of the door frames with manufacturing and assembly cost is shown in detail in Appendix D Figure IV. The total cost comes to a value of $281.43 for a set of door frames with body panels. This is a very competitive price when compared to other replacement door prices out on the market.

**Angle Iron Door Frame**

Step one, cutting material
Cut DI1, DI2, DI3, DI4 to specified lengths.

Step two, using a jig
In lots of 5,000 a jig would be the fastest way to weld all the frame parts together. The four parts would be places into a jig using the law of threes to locate them. Then the four pieces of angle iron would be welded together. There would have to be two different jig, one for each side of the car since they have opposite geometries.

Step three, grinding
Depending on the quality of the welding, the welds would have to be ground down so that once a rubber seal was added, the door would close tightly for lease water penetration.

Step four, attaching the angle iron frame to the car
Once the car frames were finished there would have to be a step of welding the angle iron frame to the car. this would ensure a sound structure, only adding to the strength of the frame.

Step five, attached hinges.

**Suspension System**

The suspension assembly requires the vehicle frame to be elevated off the ground. First the control arms are attached to the frame brackets with connecting bolts and lock nuts to keep them in place. The knuckle is then attached to the control arms via the ball joint connections. After the knuckle is secured, the hub assembly is attached to the knuckle. The next step is to attach the shock absorber to the lower arm and the frame with the associated bolts and nuts. The wheel is then placed and bolted over the hub assembly. Finally the car can be lowered onto the wheels safely.
The following chart gives a breakdown of the total cost of the suspension subsystem including labor for assembly. The total is listed for mass lots of 5000 units to be produced.

Steering Assembly

The first step in the manufacture of the steering assembly is to fabricate the tie rods. 303 stainless steel round bar stock 6 feet in length and of 3/8” diameter is to be supplied by McMaster-Carr (part no. 8984K23) in lots of 5000 pieces. Each tie rod is to be cut to a length of 10-1/8” in the first step by a horizontal band saw with human labor. Next, both ends of the tie rod are to be finished off 1/16” by a CNC machine so that the total length is 10” +/- 0.005”. Finally the rod is to be threaded 3” from each end 3/8”-24-UNF-A on the same CNC machine to a length tolerance of +0.010/-0.000”. Two of the final rods are used for each steering assembly.

Figure 43: Assembly drawing of steering system

The only remaining fabrication items are to drill cotter pin holes for the clevis shoulder screws and ball joint studs. The zinc-plated low-carbon steel turnbuckle ball joints are 3.938” long with a 3/8”-24 internal and stud thread and boot dirt shield. They are
supplied by Midwest Control Products Corporation in lots of 5000 (part no. ESTX375). A 3/32” through-hole is to be drilled in the stud ½” from its end by a human-operated drill press using a jig. A 1/16” through-hole is to be drilled in the stud ½” from its end by a human-operated drill press using a jig. The alloy steel shoulder screws have a 3/8” shoulder diameter, 7/8” shoulder length and 5/16”-18 thread. They are supplied by McMaster-Carr (part no. 91259A623) in lots of 5000 pieces. A 1/16” through-hole is to be drilled in the stud ¼” from its end by a human-operated drill press using a jig.

The next step is to install the rack and pinion system into the vehicle. The 11” rack and pinion system has a billet aluminum casing and hardened steel gears, 4” of total travel, a 12:1 gear ratio and splined pinion input shaft. The system is supplied by Desert Karts in lots of 5000. The first installation procedure is to weld a mounting bracket to the frame to allow the rack and pinion to be bolted to the round frame cross-member. The rack and pinion is to be bolted to the bracket by two alloy steel screws 5/16” in shoulder diameter, 1-1/4” in shoulder length, and with ¼”-20 threading. The bolts are fastened with zinc-plated steel lock nuts 7/16” wide with nylon inserts and ¼”-20 threading. The shoulder screws (part no. 91259A585) and the lock nuts (part no. 90640A129) are supplied by McMaster-Carr in lots of 5000 pieces.

During or preceding the rack and pinion installation the tie rod subassembly is brought together. Screwed onto either end of each tie rod are zinc-plated steel lock nuts 9/16” wide with nylon inserts and 3/8”-24 threading. These lock nuts are also supplied by McMaster-Carr in lots of 5000 (part no. 90640A150). Once the lock nuts are on, one of the previously drilled turnbuckle ball joints are screwed onto one end of each of the tie rods. On the other end a turnbuckle clevis is screwed on. The zinc-plated, low-carbon steel clevises are 2.83” long with a 3/8” hole and 3/8”-24 internal thread and are supplied by Midwest Control Products Corporation in lots of 5000 (part no. TC375).

Once the tie rod subassembly is ready and the rack and pinion is installed, two of the tie rod subassemblies can be installed into the vehicle. First the clevis end of the subassembly is joined to the spherical rod end of the rack and pinion by the previously drilled shoulder screws of 3/8” shoulder diameter and 7/8” shoulder length. Once the screw is inserted through the eye of the clevis and rod end a zinc-plated steel castle nut is threaded on and tightened. 18-8 stainless steel cotter pins are then inserted into the through-holes of the screw. The ½” wide castle nuts of 5/16”-18 threading (part no. 95030A130) and the 1/16” diameter and ¾” long cotter pins (part no. 98401A413) are supplied by McMaster-Carr in lots of 5000.

Next the turnbuckle ball joint is joined to the steering arm of the tire’s spindle. The ball joint’s stud is placed into the hole of the steering arm and a zinc-plated steel castle nut is threaded onto the stud and tightened. 18-8 stainless steel cotter pins are then inserted into the through-holes of the screw. The 9/16” wide castle nuts of 3/8”-24 threading (part no. 95030A160) and the 3/32” diameter and ¾” long cotter pins (part no. 98401A442) are supplied by McMaster-Carr in lots of 5000. Once this operation is complete the steering assembly is nearly finished. The tie rods must be threaded into the clevises and ball joints on either end equally by aid of the turnbuckles until proper front tire alignment is
achieved. This should be complete under typical vehicle loading conditions. Once the correct alignment is attained the lock nuts previously threaded onto the tie rods are tightened to the turnbuckles of the clevises and the ball joints. The steering assembly is now complete.

*Soft Top*

The cloth top is made by cutting each cloth panel to the specified dimensions in the parts list above. The seams at each joint are formed by applying 1 inch of glue to the edge of the top panel and laying the top panel edge over the appropriate edge of the adjoining piece, fold the glued seam in such that the seam becomes four layers thick. Sew the seam using a reinforced zigzag stitch. The flexible plastic strip is attached in the same manner. Attach the zipper to the cloth top by gluing the zipper to the inside perimeter of each window, and sewing the seam with the same zigzag stitch. The opposite side of the zipper is attached to the clear plastic window in the same manner.

*Door Hinge*

The hinges selected to connect the door to the angle iron of our car’s frame is made from stainless steel. These hinges are known as surface-mount piano hinges with a tight clearance according to *McMaster-Carr*. We will need four hinges total, two for each door. The hinges are modified to the exact size by using a hacksaw to cut to the desired dimensions. It is imperative that the cuts are made straight so that the hinge remains square with the angle irons that it is to be welded against.

### 8.0 Conclusions

<table>
<thead>
<tr>
<th>Spec</th>
<th>Required</th>
<th>Prototype</th>
<th>Final Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering</td>
<td>10’ radius</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Suspension</td>
<td>More comfortable than the Hopper</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cargo space</td>
<td>8 ft^3</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Passengers</td>
<td>2 (including driver)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Water proofing</td>
<td>No leaks</td>
<td>Almost</td>
<td>Yes</td>
</tr>
</tbody>
</table>

As shown in the chart above, the design did meet the requirements set out for it. The prototype itself failed on a few requirements, mostly due to it being a different style vehicle to begin with. The final design parameters are all theoretical, but should still be accurate enough to make judgments on its ability to met the specifications.
The only environmental impact this design poses is from the batteries. Once the batteries no longer function they will have to be disposed of properly as per the manufacturer’s instructions. There are also indirect impacts to the environment. The electricity to charge the vehicle will most likely come from a power plant that burns fuels. The emission regulations and the actually percentage of the power needed to charge an individual vehicle make this concern minimal however.

There is already some political backing for NEVs. The NEV America program has set the national standards for NEVs, and has started testing fleets in city environments. In California, residence can claim a tax exemption if they drive a zero emission vehicle. In the future more tax benefit laws should be passed to encourage ZEV and NEV usage. There should also be vast penalties for driving oversized, inefficient vehicles in the near future since oil is becoming scarcer.

Searching US patents has yielded no specific intellectual property issues. There are patents for many specific NEV designs, battery technology, rack and pinion assemblies, suspension assemblies, charging apparatus, and so on. None of the patents are broad enough to conflict with the MeCAT vehicle design. Since we bought the steering and suspension, we have no issues with those systems. The overall frame design is incomplete and unique to our vehicle. The folding second seat is not a main feature of competing NEV models, and is not patented.

Relative to the specifications our vehicle has very little true value at this point. The steering met specifications but is not an outstanding design compared to other NEV models. The same can be said for the suspension as well. The folding second seat is mostly unique to our vehicle, and makes it stand out. The second seat still has a lot of redesign work to make it a real delighter for the MeCAT vehicle. The tandem seating is one of the more appealing aspects of the design that make the vehicle show some promise. The tandem profile distances the MeCAT from standard golf cart designs, and other competing NEVs. The thinner build of the NEV allows better parking options and a unique driving experience for the driver.

Overall this design is incomplete is not ready for production. The project should not be continued. The general concept for an NEV is a good idea as it has the potential to make the biggest impact on the energy situation. However, the design for this vehicle is no where near ready for production. Many systems for the vehicles have no been worked on yet, the systems that have been worked on all need more time and energy put into them. The major competitors on the NEV market would overwhelm the MeCAT vehicle after the design is finished. The vehicle does not have enough good features to bring it ahead of the competition. Finally, the cost of start up and production would greatly outweigh whatever money we could expect to get from MeCAT sales.
References


### Appendix A: FMEA Analysis Spreadsheets

<table>
<thead>
<tr>
<th>Subsystem Component</th>
<th>Potential Failure Mode and 5 Whys(^1)</th>
<th>Potential Effect of Failure(^2)</th>
<th>Probability of Occurrence of Failure(^3)</th>
<th>Current Controls for Detection/Prevention(^4)</th>
<th>Recommended Action(^5)</th>
<th>Person Responsible &amp; Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tie rods and tie rod ends that control vehicle steer</td>
<td>Loss of steering ability</td>
<td>Vehicle crash</td>
<td>9</td>
<td>Moderate</td>
<td>Visual check for fracture</td>
<td>Kevin - TBD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>6 216</td>
<td>Use high strength, high fatigue life steel accepted in industry</td>
</tr>
</tbody>
</table>

1. Why: Fracture from excessive fatigue
   Why: Corrosion and/or oxidation weakens material
   Why: Design overloads axially or in shear
   Why: Improper material strength/corrosion resistance
   Why: Misalignment increases stress

2. If the rods or ends were to break, steering would not be possible, and at elevated vehicle speeds this could result in catastrophe, both to passengers of the vehicle and to surrounding vehicles and pedestrians.

3. A high factor of safety is used, magnitude of applied forces is known, and material used in industry is known.

4. As fatigue and excessive stress are the primary failure modes, it would be difficult to visually check for initial fracture. With high strength steel and a generous factor of safety, failure could be prevented.

5. To avoid failure, the team ought to use a high-strength steel with good fatigue life that has proven acceptable in the automotive industry. The team should also purchase the rod ends to avoid fabrication errors and consequential stress concentrators.
<table>
<thead>
<tr>
<th>Subsystem Component</th>
<th>Potential Failure Mode and 5 Whys¹</th>
<th>Potential Effect of Failure²</th>
<th>Probability of Occurrence of Failure³</th>
<th>Current Controls for Detection/Prevention⁴</th>
<th>O</th>
<th>D</th>
<th>R</th>
<th>N</th>
<th>Recommended Action⁵</th>
<th>Person Responsible &amp; Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tie rod end joints</td>
<td>Loss of steering ability</td>
<td>Vehicle crash</td>
<td>9 Moderate</td>
<td>Loose/inconsistent steering ability, visual check for fracture</td>
<td>5</td>
<td>270</td>
<td>Long, fine, tight pitch threading with locking mechanism or ball joint seals</td>
<td>Kevin - TBD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Why: Fracture from excessive shear forces or
Why: Joints loosen and disconnect
Why: Vibrations from normal road surfaces or surface deviations
Why: Improper thread length, fastener, or ball joint seal and size
Why: Improper design and/or installation

2. If the joints were to break, steering would not be possible, and dangerous or fatal accidents might occur.
When the joints begin to break, steering would be very difficult and unresponsive.

3. The joints may loosen regardless of fastening efforts. Additionally, they may loosen after unpredictable durations of time from a lack of knowledge of vibrations that the vehicle will experience.

4. If the threads are long and/or tight enough, a loosening can be checked visually or with a qualitative analysis of steering ability. This analysis would also prove useful for worn or dirty ball joints.

5. If the joints are to employ threads, the threading ought to be long and fine with a tight pitch with an accompanying locking mechanism. If ball joints are used, care should be taken to prevent seal leakage and ball wear.
Again, it is advised that these joints be purchased from a reputable supplier to avoid fabrication errors.

---

### FMEA rating form for a single Failure / Hazard

<table>
<thead>
<tr>
<th>Category:</th>
<th>Identify subsystem and mode of operation</th>
<th>Potential Failure Mode and 5 Whys¹</th>
<th>Potential Effect of Failure²</th>
<th>Probability of Occurrence of Failure³</th>
<th>Current Controls for Detection/Prevention⁴</th>
<th>O</th>
<th>D</th>
<th>R</th>
<th>N</th>
<th>Recommended Action⁵</th>
<th>Person Responsible &amp; Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Arm</td>
<td>Loss of Control</td>
<td>Crash vehicle</td>
<td>9 Moderate</td>
<td>Visual check for fracture</td>
<td>4</td>
<td>144</td>
<td>Use high strength steel arms that have been proven in automotive industry</td>
<td>Justin Krumm - TBD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Why: Fracture from excessive fatigue
why: corrosion from salt and elements
Why Excessive forces applied from an impact
Why improper alignment increases stress
Why Disconnection from frame

2. A failure in the control arm could lead to complete loss of control of the vehicle making for a catastrophic failure

3. Due to the fact that these components are so important for the handling, a high factor of safety will be used and they will be purchased from a vendor.

4. It would be difficult to detect fatigue in these. However, a high strength material will be used with a high factor of safety to help prevent failure.

5. Use a generous factor of safety and use parts that have a good track record in the use of automobiles that show reliability and lifespan. Purchase the parts from a reliable vendor to prevent any fabrication errors.
<table>
<thead>
<tr>
<th>Subsystem Component</th>
<th>Potential Failure Mode and 5 Whys¹</th>
<th>Potential Effect of Failure²</th>
<th>Probability of Occurrence of Failure³</th>
<th>O C C</th>
<th>Detection/Prevention ⁴</th>
<th>D E T</th>
<th>R P N</th>
<th>Recommended Action¹</th>
<th>Person Responsible &amp; Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft top and windows</td>
<td>Does not provide water protection</td>
<td>Failure</td>
<td>9 Low</td>
<td>4</td>
<td>Quality Assurance check during manufacturing</td>
<td>2</td>
<td>72</td>
<td>Random Water Jet Testing During Manufacturing</td>
<td>Micah-6-1-07</td>
</tr>
</tbody>
</table>

1 Why: Weakend seams  
Why: Assembled incorrectly/UV damage  
Why: Seams are not shielded from the sun  
Why: Not enough extra material to cover the adhesive  
Why: Design of the seam is not effective  

2 If the seams were to fail the passenger/cargo would become damp. The passenger would become uncomfortable, thus failing to meet design specification  

3 The probability of leakage is low, due to the extra reinforcement by the adhesive, and the heavy duty vinyl  

4 Regular quality check to ensure associates are assembling tops correctly  
Random water jet testing, and applying tension to the top until seams fail  

5 To ensure product capability, specialty adhesives, threads, and vinyl should be used that are produced for this particular application

---

**Steering Bracket FMEA**

<table>
<thead>
<tr>
<th>Component</th>
<th>Potential Failure Mode and 5 Whys¹</th>
<th>Potential Failure Effect²</th>
<th>S E V</th>
<th>Probability of Failure Occurrence³</th>
<th>O C C</th>
<th>Detection/Prevention ⁴</th>
<th>D E T</th>
<th>R P N</th>
<th>Action⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering Bracket</td>
<td>Steering comes lose from frame</td>
<td>Loss of control</td>
<td>6</td>
<td>Fairly low</td>
<td>2</td>
<td>Weld break would be quick with little notice</td>
<td>1 0</td>
<td>1 2 0</td>
<td>Quality inspection of all welds</td>
</tr>
</tbody>
</table>

1 - 5 Whys  
Weld breaks  
Poor weld  
Welder did a bad job  
No inspection of welds  
No quality inspection set up  

2 - Failure Effect  
If the steering separates from the frame, the rack and
pinion would not operate properly and could result in a loss of control

<table>
<thead>
<tr>
<th>3 - Failure Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any typical weld should hold the bracket easily because the bracket should not be under high torque from the steering assembly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4 - Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>The weld will not give any warning as it will have a brittle failure. When the weld breaks it will snap all at once, giving no chance for prevention</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5 - Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>By inspecting each weld for quality, the probability of occurrence for this failure would drop to almost nothing</td>
</tr>
</tbody>
</table>
### FMEA rating form for a single Failure / Hazard

<table>
<thead>
<tr>
<th>Component Subsystem Component</th>
<th>Potential Failure Modes and 5 Whys</th>
<th>Potential Effect of Failure</th>
<th>SEV</th>
<th>Probability of Occurrence of Failure</th>
<th>QCC</th>
<th>Current Controls for Detection / Prevention</th>
<th>DET</th>
<th>RECOMMENDED ACTION</th>
<th>PERSON RESPONSIBLE</th>
<th>COMPLETION DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door Frame and Door Post</td>
<td>Door cracks or breaks in metal</td>
<td>Injuries passengers or damage to frame</td>
<td>9</td>
<td>Moderate</td>
<td>5</td>
<td>Defective Driving, Visual check for flaws</td>
<td>4</td>
<td>10/05</td>
<td>Paul Kulis</td>
<td>5/07</td>
</tr>
</tbody>
</table>

1. **Discuss root cause of the failure mode (based on the 5 whys)**
   - **Why:** Cracks because of impact on vehicle
   - **Why:** Bad Design cannot handle impact loads
   - **Why:** Frame experiences large fatigue
   - **Why:** Bad / incorrect welding at crucial spots
   - **Why:** Corrosion, Contact or Rusting

2. **Discuss/justify the severity rating (SEV)**
   If the door was the break or crack it could cause serious damage to the passengers inside the vehicle. If the door was to cave into the driver it could cause them to get severely injured which could also lead to a wreck. Also if the door frame or panels were to crack then the could be leaking of moisture into the cabin which could also cause a problem for the operator of the vehicle.

3. **Discuss/justify the rating for probability of occurrence (QCC)**
   The incidents listed above could happen quite often. There are hundreds of thousands side impact accidents everyday throughout the United States on a normal driving day. Also without the proper care taking of the vehicle rust also occurs quite often especially once the vehicle gets more and more exposure to the elements.

4. **Discuss/justify the rating for the probability of detecting a “failure imminent” condition and avoiding the failure (DET)**
   A lot of this depends on the operator of the vehicle and the care taker of the vehicle. If the person is a safe driver and stays aware of their surrounds then they can limit some accidents that are caused by carelessness. Also if the person is responsible and regularly washes and cleans the vehicle it would be easy to detect a crack in the body panels and or frame. A lot of the severity comes into play that you don’t have control of the other drivers out on the road.

5. **Make specific recommendation for action and include some discussion of the alternatives that were considered.**
   Multiple door frames and body panels were design, and put through a rigorous analysis of impacts. Many of the designs failed once the 48,000 lbs impact was placed on the center frame of the door. The final design frame passed the impact test easily and had no problems with the amount of shear stress added to simulate an impact.
Appendix B: DFMA Analyses

Justin Krumm

Component: Suspension System

Component: Double A-arm suspension (Upper and lower control arms, knuckles, coil-over shock absorbers)

Manufacturing Decisions:
  Purchase vs. Manufacturing
    Purchase
      Control Arms
      Coil-over Shocks
    Manufacture
      Knuckle

Features:
  Manufactured
  Standard hole sizes

Materials:
  Readily available cold rolled steel flat bar stock for the knuckle

Treatment:
  Corrosion protection for all suspension components

Plan for Application in Manufacturing Drawings and Plans:
  Manufacture
    Knuckle
      Band Saw, drill press, MIG welder

Assembly:
  Control arms first attached to frame
  Knuckle is connected to the control arms
  Shock is connected to lower arm and frame
  Same process is used on left and right side of vehicle

Kevin Fogarty

Component: Steering Assembly (rack-and-pinion, tie rods, tie rod ends, steering arms, joints, steering column)

Important Manufacturing Considerations:
  Purchase vs. Manufacture:
    Purchase
      Rack-and-pinion assembly
      Tie rod ends
      Joints
Bearing for steering column
U-joints for steering column

Manufacture
Tie rods
Steering arms

Features:
Manufactured
Straight edges, standard thread/hole sizes
Simple machinist skills required

Materials:
Readily available and inexpensive
1018 steel round tube stock for tie rods, flat bar stock for steering arms

Tie rods and steering arms
Free from incisions, grooves, indentations, large scratches
Sufficient threading on tie rod ends to allow for adjustments

Ball Joints
Female end to tie rod, heavy-duty and lubrication-free with standard thread sizes

Treatments:
Corrosion, rust protection for tie rods and steering arms

Plan for Application in Manufacturing Drawings and Plans:
Manufacture
Tie rods
Band saw, lathe
Steering arms
Band saw, drill press, table grinder

Assembled with system after suspension installation
Steering arm installed with suspension installation on spindle, king pin
Rack-and-pinion mounted first with bracket on frame cross beam
Tie rods and tie rod ends pre-assembled together
Assembly mentioned above installed on right and left sides

Todd Stiegerwalt

Component: Frame

In the main system of an NEV, the part that my group is designing for is the frame. The frame that is being designed is not what will be used for the final prototype, but it had to be designed to show that there was room for a second seat within the constraints of the project. In considerations for this frame there had to be space for the driver, the passenger, room for the engine and transmission, the batteries, the passenger/cargo. The basic dimensions for this frame were 4x7 feet until it was decided that it would not be long enough to also carry a second passenger. The dimensions of the frame were
extended to become 4x8.5 ft to make it longer. In the main report there is information to back this decision.

Things that need to be taken into consideration for building this frame would be where is the engine going to be? As of right now in the design the engine and transition would be placed under the area where the second seat and cargo go. This leaves a space or panel that would go in the back to get to this if it needed to be worked on. All the dimensions for this are in English units since we live in America. Therefore any bolt holes or measurements need to be the same, but that goes without saying. For the seat to make it easier to install it is going to be bolted right to the frame with two members crossing from left to right in the back.

As for the batteries there is ample room on the left and the right of the driver seat to fit them. This would give the car a good 50-50 weight distribution across the center of the vehicle. This would also mean a large zero gauge wire would have to run across the floor, but that could go under the seat and be out of the way. The drive seat is currently being designed by the team working on that aspect, and once they come up with a close to finally design it will be decided how it is going to be put in the car. Most likely a member will come up from the base to support the seat.

In the front of the car the steering components need enough room to get the full range of motion without the drivers feel getting in the way. How they would be mounted, would be determined by the steering assembly that is bought by the group. The same goes for the A-arms that the wheels will attach to.

For this project to stay within the scope we have chosen the majority of the work will be done to the frame from last year. Their needs to be a wider roll cage for better visibility, something that might not have been considered in the initial plans. Also the entire frame needs to be lengthened by about a foot to make room for the new steering that is going to be used. This should not be very hard just a few cuts, then new metal to be welded in. For the scope of the project the main point of designing a new frame was to show there was enough room for a second collapsible seat behind the frame, and this was accomplished.

The soft top will be manufactured and the raw materials will be purchased in bulk. The individual panels for the soft windows and vinyl top will be cut using large presses and dies. This will ensure that all pieces are exactly the same size. The only human labor will be in sewing the panels together.

Micah Snyder

Component: Soft Top

Component: Soft Top and Windows

Important Manufacturing Considerations:

- Purchase vs. Manufacturing:
  - Purchase/materials
    - 1000 yd spools of monofilament
    - 10’x 500’ rolls of 20 mil clear plastic
    - 10’x500’ rolls of soft top fabric
50 gallon drums of adhesive
100’ rolls of extruded termination stripping
Lots of 5000 stainless steel buttons
1”x50’ rolls of Velcro
500’ rolls of zipper

Manufacture (automated)
All necessary vinyl top pieces are cut from the same roll of fabric using a die and press

Assembly of soft top (human labor)
Sewing soft top, windows, and termination strip together
Waterproof all seams using adhesive and the prescribed seam
Apply snaps with appropriate machinery
Sew windows and door section together
Sew Velcro to the door section and reinforce with adhesive

Chris Baters

Component: Steering Bracket

Important Manufacturing Considerations:
Purchase vs. Manufacture:
Manufacture Bracket
Features:
Manufactured
Standard hole size, straight edges
Simple machinist skill required

Materials:
Readily available and inexpensive
A36 steel U-channel stock Bracket
Free from incisions, grooves, indentations, large scratches
Correct distance between holes and correct size of round cutout

Treatments:
Corrosion protection

Plan for Application in Manufacturing Drawing and Plans:
Manufacture Bracket
Cold saw, mill
Welded to frame before steering assembly installed
Paul Kuhr

Component: Door Frame

Important Manufacturing Considerations:

Purchase vs. Manufacture:

Purchase
- Bar Stock 1x1 inch. 1/8 in thick
- 1/16 inch sheet metal

Manufacture
- Cut stock to required length and size
- Drill holes in bar stock and sheet metals according to drawings
- Place cut pieces in specialized Jig
- Tack weld all joints
- Remove from Jig
- Finish welding
- Grind welds

Features:

Manufactured
- Drilling at standard hole size, strait edges
- Simple welding and jig work
- Simple welding and machinist skill required

Materials:
- Readily available and inexpensive
- AISI 1015 As-rolled square tube stock
- Low Carbon sheet metal steel

Treatments:
- Corrosion protection

Plan for Application in Manufacturing Drawing and Plans:

Assembly
- Assembly doors and attach to frame using requires hinges
- Add sealant to body panels
- Add rubber to inner lining of door frame
Appendix C: Hand Calculations

With worst case shock loading scenario such as a pothole, the affected wheel undergoes a load factor of Eq. 13.

With a corner weight of 250 lbs = 4 x 250 = 1000 lbs

\[
F = 1077 \text{ lbs}
\]

\[
\frac{F_1}{\sin 107} = \frac{F_2}{\sin 30} = \frac{F_3}{\sin 57}
\]

\[
F_3 = \frac{1077 \text{ lbs}}{\sin 57} = 1752 \text{ lbs}
\]

Worst Case Loading \( F_{\text{sprig}} = 1752 \text{ lbs} \)

With a Physical Spring Rate of 300 lbs/in.

\[
\text{Length of spring} > \frac{1752 \text{ lbs}}{300 \frac{\text{lbs}}{\text{in}}} = 5.87 \text{ in}
\]

Spring must be at least 6" in length to prevent binding with worst case loading.
Appendix D: Cost Analyses

Figure I

<table>
<thead>
<tr>
<th>Operation 1</th>
<th>Operation 2</th>
<th>Operation 3</th>
<th>Operation 4</th>
<th>Operation 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut round stock to length and thread</td>
<td>Drill holes in ball joint and shoulder screw</td>
<td>Install rack and pinion</td>
<td>Join tie rod w/ ball joint and clevis</td>
<td>Install tie rod subassemblies</td>
</tr>
<tr>
<td>a. total time to complete operation(s) in hours</td>
<td>0.25</td>
<td>0.25</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>b. labor rate for the operation</td>
<td>20</td>
<td>15</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>c. Labor cost = axb</td>
<td>5</td>
<td>3.75</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>d. basic overhead factor</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>e. Equipment factor</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>f. Special operation/tolerance factor</td>
<td>0.25</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>g. labor/overhead/equipment cost = cx(1+d+e+f)</td>
<td>$13.75</td>
<td>$10.31</td>
<td>$3.00</td>
<td>$3.00</td>
</tr>
<tr>
<td>h. purchased materials/components cost</td>
<td>$7.81</td>
<td>$8.00</td>
<td>$82.43</td>
<td>$11.16</td>
</tr>
<tr>
<td>Total</td>
<td>$147.84</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure II

<table>
<thead>
<tr>
<th>Operation 1</th>
<th>Operation 2</th>
<th>Operation 3</th>
<th>Operation 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attach control arms to frame</td>
<td>Connect knuckle to Control arms</td>
<td>Attach hub/wheel assembly to knuckle</td>
<td>Connect Shocks to lower arm and frame</td>
</tr>
<tr>
<td>a. total time to complete operation(s) in hours</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>b. labor rate for the operation</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>c. Labor cost = axb</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>d. basic overhead factor</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>e. Equipment factor</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Operation 1</td>
<td>Operation 2</td>
<td>Operation 3</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Cost Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. total time to complete</td>
<td>3 min per</td>
<td>3 min per</td>
<td>3 min per</td>
</tr>
<tr>
<td>operation(s) in hours</td>
<td>cut/ 20 cut</td>
<td>cut/ 8 cuts</td>
<td>weld/ 8</td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td>.5 hours</td>
<td>weld/ .4</td>
</tr>
<tr>
<td>b. labor rate for the</td>
<td>12 dollars</td>
<td>12 dollars</td>
<td>20 dollars</td>
</tr>
<tr>
<td>operation</td>
<td>an hour</td>
<td>an hour</td>
<td>an hour</td>
</tr>
<tr>
<td>c. Labor cost = axb</td>
<td>12</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>d. basic overhead factor</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>e. Equipment factor</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>f. Special operation/tolerance factor</td>
<td>0.25</td>
<td>.25</td>
<td>0</td>
</tr>
<tr>
<td>g. labor/overhead/equipment cost = cx(1+d+e+f)</td>
<td>$33.00</td>
<td>$16.50</td>
<td>$20.00</td>
</tr>
<tr>
<td>h. purchased materials/components cost</td>
<td>$41.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$153.88</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure IV

<table>
<thead>
<tr>
<th>No.</th>
<th>Part</th>
<th>Qty</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Canopy</td>
<td>1</td>
<td>2 yards</td>
<td>$31.98</td>
</tr>
<tr>
<td>2</td>
<td>Right side door</td>
<td>1</td>
<td>2 yards</td>
<td>$31.98</td>
</tr>
<tr>
<td>3</td>
<td>Left side door</td>
<td>1</td>
<td>2 yards</td>
<td>$31.98</td>
</tr>
<tr>
<td>4</td>
<td>Right side permanent window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>6</td>
<td>Left side permanent window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>7</td>
<td>Right side driver window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>8</td>
<td>Left side driver window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>9</td>
<td>Right side passenger window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>10</td>
<td>Left side passenger window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>11</td>
<td>Rear window</td>
<td>1</td>
<td>1 yard 20 mil clear vinyl</td>
<td>$8.95</td>
</tr>
<tr>
<td>12</td>
<td>Zipper</td>
<td>1</td>
<td>12 yards water resistant zipper tape</td>
<td>$9.95</td>
</tr>
<tr>
<td>13</td>
<td>Button</td>
<td>10</td>
<td>#20 brass snaps</td>
<td>$1.66</td>
</tr>
<tr>
<td>14</td>
<td>Adhesive</td>
<td>2</td>
<td>Still searching for products</td>
<td>???</td>
</tr>
<tr>
<td>15</td>
<td>Flexible plastic strip</td>
<td>1</td>
<td>Will have to be extruded</td>
<td>???</td>
</tr>
<tr>
<td>16</td>
<td>Thread</td>
<td>1</td>
<td>1 1000 yard spool monofilament</td>
<td>$17.90</td>
</tr>
</tbody>
</table>

**Subtotal** $161.48

---

Figure V

<table>
<thead>
<tr>
<th>No.</th>
<th>Part</th>
<th>Qty</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Canopy</td>
<td>1</td>
<td>2 yards</td>
<td>$31.98</td>
</tr>
<tr>
<td>2</td>
<td>Right side door</td>
<td>1</td>
<td>2 yards</td>
<td>$31.98</td>
</tr>
<tr>
<td>3</td>
<td>Left side door</td>
<td>1</td>
<td>2 yards</td>
<td>$31.98</td>
</tr>
<tr>
<td>4</td>
<td>Right side permanent window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>6</td>
<td>Left side permanent window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>7</td>
<td>Right side driver window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>8</td>
<td>Left side driver window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>9</td>
<td>Right side passenger window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>10</td>
<td>Left side passenger window</td>
<td>1</td>
<td>.5 yards 20 mil clear vinyl</td>
<td>$4.48</td>
</tr>
<tr>
<td>11</td>
<td>Rear window</td>
<td>1</td>
<td>1 yard 20 mil clear vinyl</td>
<td>$8.95</td>
</tr>
<tr>
<td>12</td>
<td>Zipper</td>
<td>1</td>
<td>12 yards water resistant zipper tape</td>
<td>$9.95</td>
</tr>
<tr>
<td>13</td>
<td>Button</td>
<td>10</td>
<td>#20 brass snaps</td>
<td>$1.66</td>
</tr>
<tr>
<td>14</td>
<td>Adhesive</td>
<td>2</td>
<td>Still searching for products</td>
<td>???</td>
</tr>
<tr>
<td>15</td>
<td>Flexible plastic strip</td>
<td>1</td>
<td>Will have to be extruded</td>
<td>???</td>
</tr>
<tr>
<td>16</td>
<td>Thread</td>
<td>1</td>
<td>1 1000 yard spool monofilament</td>
<td>$17.90</td>
</tr>
</tbody>
</table>

**Subtotal** $161.48
Appendix E: Door Frame Assembly and Parts List
### Door Part List Rubric Key

<table>
<thead>
<tr>
<th>Image Number</th>
<th>Part Number</th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P-D-01</td>
<td>Front Upper Angled Support</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>P-D-02</td>
<td>Top Upper Support</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>P-D-03</td>
<td>Rear Angled Support</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>P-D-04</td>
<td>Rear Middle Support</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>P-D-05</td>
<td>Rear Center Support</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>P-D-06</td>
<td>Rear Lower Bottom Support</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>P-D-07</td>
<td>Rear Lower Vertical Support</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>P-D-08</td>
<td>Front Middle Support</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>P-D-09</td>
<td>Front Vertical Support</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>P-D-10</td>
<td>Front Lower Bottom Support</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>P-D-11</td>
<td>Front Center Support</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>P-D-12</td>
<td>Rear Lower Panel</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>P-D-13</td>
<td>Front Lower Panel</td>
<td>1</td>
</tr>
<tr>
<td>14 - 21</td>
<td>P-D-14</td>
<td>Assembly Bolts</td>
<td>8</td>
</tr>
</tbody>
</table>

### Frame Assembly Detail

![Frame Assembly Diagram](image-url)
Part Drawings

P-D-01
RIGHT HAND VIEW

CUT AT A 48 DEG. ANGLE

40.4

GENERAL TOLERANCE = 0.025

P-D-02
RIGHT HAND VIEW

30.000

GENERAL TOLERANCE = 0.025
P-D-03
FRONT VIEW

CUT AT A 70.5 DEG ANGLE

GENERAL TOLERANCE -0.025

28.0

CUT AT A 70.5 DEG ANGLE

P-D-04
RIGHT HAND VIEW

30.000

GENERAL TOLERANCE -0.025
P-D-05
RIGHT HAND VIEW

DRILL HOLES
WITH 1/4 inch
HSS DRILL BIT

20

17.00

-1.200

GENERAL TOLERANCE -0.005

P-D-06
RIGHT HAND VIEW

29.000

GENERAL TOLERANCE -0.025
P-D-07
RIGHT HAND VIEW

DRILL HOLES
WITH 1/4 inch
HSS DRILL BIT

16.00

.20

.20

GENERAL TOLERANCE = 0.005

P-D-08
Top VIEW

30.00

CUT ANGLES
AT 72 DEG

GENERAL TOLERANCE = 0.025
P-D-09
RIGHT HAND VIEW

DRILL HOLES
WITH 1/4 inch
HSS DRILL BIT

17.00

20

1.200

GENERAL TOLERANCE = 0.005

P-D-10
TOP VIEW

CUT ANGLES
AT 72 DEG

29000

GENERAL TOLERANCE = 0.025
P-D-11
RIGHT HAND VIEW

DRILL HOLES
WITH 1/4 inch
HSS DRILL BIT

16.00

.20

.20

GENERAL TOLERANCE = 0.005

P-D-12
RIGHT HAND VIEW

DRILL HOLES WITH 1/4
inch HSS DRILL BIT

1.200

.5

18.000

30.000

GENERAL TOLERANCE = .005 IN
Part Drawing for Soft Top

All rounded corners are 2" radius unless otherwise specified.