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Team 17: Mobile GPS Payload

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Abstract

The project sponsor is the Air Force Research Lab's Advanced GPS Technology (AGT) Program, whose mission is to provide satellite navigation services in adverse conditions while reducing costs. The team is designing a mobile lab to allow AGT to test a GPS payload in various locations. The design goal is to provide a cost-effective, user-friendly, and transportable lab. The mobile lab must protect the test equipment, produce its own power, and house four technicians. The team is selecting several parts for the mobile lab. These parts include the trailer, heating and AC unit, generator, workstations, antenna mast, shielding, and floor plan. While selecting the parts of the mobile lab, the team considers cost, efficiency, ergonomics, and size. The design is a 40-ft. shipping container, transported to the test site on a flatbed trailer. The team is presenting a scaled 3D printed model as proof of concept for AGT, who is finally responsible for the lab's full-scale construction.

Keywords:

- Mobile
- Cost-effective
- User friendly

Acknowledgement

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Notation

GPS	Global Positioning System
AFRL	Air Force Research Lab
AGT	Advanced GPS Technologies
ESD	Electrostatic Discharge
ORDWG	On-Orbit Reprogrammable Digital Waveform Generator
A/C	Air Conditioning
RV	Recreational Vehicle
HVAC	Heating, Ventilation, and Air Conditioning
AHP	Analytical Hierarchy Process
FRP	Fiberglass Reinforced Panel
BIFMA	Business and Institutional Furniture Manufacturers Association
VDR	Virtual Design Review
ME	Mechanical Engineering
CAD	Computer-Aided Design
ECE	Electrical and Computer Engineering
EST	Eastern Standard Time
REBA	Rapid Entire Body Assessment
MSD	Musculoskeletal Disorder
RULA	Rapid Upper Limb Assessment

Chapter One: EML 4551C

1.1 Project Scope

1.1.1 Project description.

Design a mobile GPS lab for AFRL with the capability to test components of a position, navigation, and timing payload. The design will be: cost effective, user friendly, and as simple as possible.

1.1.2 Key goals.

- Design a self-sufficient mobile GPS lab that can perform the necessary functions to complete a successful mission.
- Make the interior design ergonomic for the drivers and test operators.
- Ensure equipment is undamaged during transport or testing.
- Keep overall design costs low.
- Provide AFRL with a complete design used to build the mobile lab.

1.1.3 Markets.

The primary market of the Mobile Lab is the Advanced GPS Technologies (AGT) Program of AFRL. Secondary markets may include other military and civilian research labs, medical labs, and educational labs.

1.1.4 Assumptions.

- The final product can include commercially available products.
- Most of the test equipment comes from the preexisting lab.
- The given weights and dimensions of test equipment are estimates.
- Team 17 will not build a full-scale model of the design.

- The lab technicians know how to setup all equipment.
- There is no requirement for the mobile to provide restroom facilities.

1.1.5 Stakeholders.

The primary user of this Mobile Lab will be AGT. Other potential users of the mobile lab are test groups within AFRL; particularly those in the Space Vehicles Directorate.

1.2 Customer Needs

The team gathered requirements and created need statements from the project scope and conversations with the sponsor. The customer needs statements are in four categories based on the subject of each statement.

1.2.1 Operator.

- The mobile lab is technician friendly.
- The interior provides ergonomic conditions for operators.
- The vehicle interior allows users ample test space.
- The lab has workstations for multiple operators.

1.2.2 Lab equipment.

- The vehicle allows for easy loading and unloading of lab equipment.
- Support the antennas required for operation.
- Lab equipment functions inside of the vehicle.
- The unit accommodates varying sizes of equipment.
- The equipment is undamaged in transit.
- There is proper control of electrostatic discharge (ESD).

1.2.3 Vehicle capabilities.

- The unit is capable of driving on unpaved roads.
- The unit transports all the desired equipment.
- The unit is self-sufficient.
- The vehicle has protection against intrusion.
- The vehicle can withstand various climates/environments.

1.2.4 Overall design.

- The mobile lab is versatile.
- The design provides the sponsor with a reasonably priced option.
- The design minimizes operational costs.

1.3 Functional Decomposition

The functional decomposition represents the processes necessary for the mobile lab. Arrows show the flow moving between functions, and progresses through the steps of operating the lab.

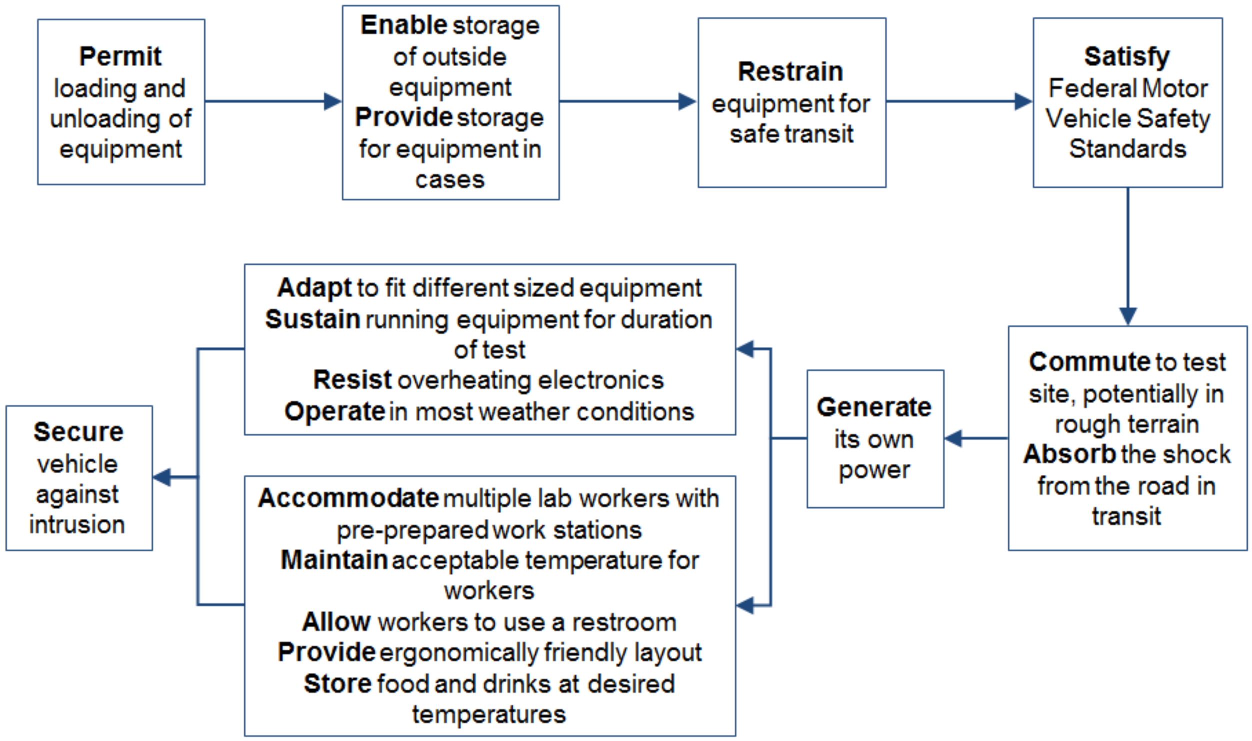


Figure 1. Functional decomposition of the mobile lab operation.

1.4 Target Summary

The targets were established by identifying the most important Customer Needs and Functions based on the overall goal of the mobile lab. Using these ranked functions, the team set targets to assist in selecting a concept and communicated with the sponsor to make sure all of the targets lead towards the goal. Appendix C contains a complete list of targets.

A few targets focus on the operators of the unit. The unit will operate at in New Mexico where it can be very hot during the day, reaching maximum temperatures of 90°F (March, 1989), and very cold in the evening, dropping down to 11°F (March, 1965). To keep the operators comfortable inside of the lab, the unit must able to maintain an interior temperature of 68-77°F. The number of operators needed in the mobile lab will vary depending on the necessary tests.

For the most extensive testing, the lab should have workstations that can accommodate up to three operators, given the equipment needed in the mobile lab. The three operators should be able to work simultaneously and have enough space to move around the lab when needed.

One of the established customer needs is to produce a design that is versatile; AGT anticipates being able to use this lab for years, and would like some versatility in the type of equipment tested. Most of the equipment used in testing will be in server racks that will roll in and out of the mobile lab. To meet the need, the lab should accommodate racks of varying heights, up to 6 feet.

AGT provided a list of equipment expected for testing in the initial use of the mobile lab. Shown below in table 1 is a list of that equipment. The lab must be able to securely carry all listed equipment to the testing location.

Table 1
List of Required Equipment for Testing on the Mobile Lab

Item	**Approximate Dimensions LxWxH (in.)**	**Approximate Weight**	**Quantity**
ORDWG-1	14 x 13 x 13	50 lbs	2
ORDWG-2	13 x 18 x 15	60 lbs	2
ORDWG-3	13 x 14 x 12	65 lbs	1
Antenna	Varied (need more details here)	varied	1-3
Server Rack(s)	~100U	varied	3+
Computers	varied	varied	5

Many of the electrical components dissipate heat. To prevent the equipment from overheating and damage, there must be cooling in the lab to keep running equipment at a temperature between 32 and 104°F. Another aspect of the desert environment is high wind speed. With that in mind, the mobile lab, which will include antennas located outside of the vehicle during testing, should be able to withstand winds up to 75 mph.

The lab must be self-sufficient, meaning that it can provide its own power for the duration of the test exercise, which, based on the information received by NAVFEST personnel, is an 8-hour session for 5 consecutive nights. Additionally, the lab will need at least 6kW of input power to be fully operational.

One of the most important considerations of this project is the cost. Non-recurring costs include the expenses of purchasing and customizing the vehicle. Recurring costs include expenses incurred when the vehicle is in operation and maintenance costs. The non-recurring costs of the design should be less than or equal to $150,000, and recurring costs from each deployment below $2,500.

1.5 Concept Generation

Concept generation for this project included ideas for the vehicle used to transport the mobile lab and ideas for the basic interior layout. The process began by team members proposing possible vehicles to be used to house the mobile lab. While the targets were considered when generating vehicle ideas, the proposed vehicles did not have to meet all of the targets. Several of the vehicle options could be modified, either by the manufacturer or after purchase, to meet the targets that they fail to satisfy. The team developed 5 vehicle concepts, which are outlined below in table 2, along with the targets met by the vehicle before any additional modifications.

Table 2
List of Major Targets Met for Each Concept

Concept	Interior temp.	Restroom	1-3 operators	Storage of racks up to 6'	Overall cost of $150,000	Deployment cost of $2,500
Motor Home	X	X	X	X	X	X
Camper Trailer	X	X	X	X	X	X
Enclosed Trailer			X	X	X	X
Shipping Container			X	X	X	X
Step Van			X	X	X	X

For the interior layout, concept generation was based off of input from the AGT team regarding the equipment used by each operator. The concepts consider location of critical equipment to test stations as well as movement of the operators within the lab space. Three interior layout concepts are discussed following the vehicle concept discussion.

1.5.1 Vehicle concepts.

The vehicle concepts are described below in further detail. Each vehicle is viewed in relation to how well it meets the proposed targets, as well as the pros and cons of each option. Additionally, a significant or unexpected benefit is highlighted to further emphasize the strengths of each concept.

1.5.1.1 Concept 1: motor home.

A motor home is an all-in-one vehicle that can transport up to 3 people and has towing capabilities. The vehicle comes with the option of heating and A/C, contains a restroom onboard, and is over 6'9" (99.997 percentile US male) in interior height. The total floor space will increase with pop outs as well. Negotiating with the manufacturer to purchase a model without the majority of the interior will reduce the cost of this vehicle. Additionally, having a model with minimal interior amenities allows for the addition of custom workstations for up to 3 lab workers.

The advantage of using a motorhome is that it satisfies all of the customer's needs. Additionally, there is no extra tow vehicle required, and there are no trailer driving skills or licenses required. Motorhomes contain plumbing for a bathroom, sink, and shower, and they feature heating and air conditioning capabilities. A few disadvantages include the costs of initial purchase and continued maintenance. Also, finding a gutted model and customizing the interior translates into higher labor costs and longer assembly time.

Figure 2. A basic layout of a motor home.

Table 3
A Pro and Con Comparison for the Motor Home

Pros	Cons
No tow vehicle required	Must customize gutted model
Can customize with lift	Expensive

A/C Established	Must maintain vehicle
Plumbing established	
Power established	

A motor home is an all-in-one vehicle that can transport up to 3 people and has towing capabilities. The vehicle comes with the option of heating and A/C, there is a restroom onboard, and is over 6’9” (99.997 percentile US male) in interior height. Negotiating with the manufacturer to purchase a model without the majority of the interior will reduce the cost of this vehicle.

1.5.1.2 Concept 2: camper trailer.

A camper trailer provides just about everything that the mobile lab would need. The camper trailer contains a built-in A/C system which can keep the team comfortable and the equipment cool. Additionally, camper trailers have at least one on board bathroom. This allows the test crew to have easy access to a restroom. Note that the camper is quite voluminous as well – the typical camper is 30 ft. long and at least 10 ft. wide. These features allow for ample workspace and storage area for the crew and supplies.

Camper trailers also come with a power generator. This generator comes in many different supply loads which can be interchangeable depending on the necessary power consumption. This allows for future flexibility as the design increases in detail. Campers are also well-suited for harsh weather conditions. Designed for outdoor adventures, campers can withstand the elements faced in a desert environment.

The key factor with the camping trailer is that it is relatively cheap considering everything that it includes. The average price of camping trailers found was around $30,000 dollars. This is well below the given budget which means there will be many leftover funds for renovations and for a vehicle to tow the trailer.

Figure 3. A camper trailer (top) and a sample camper trailer interior layout (bottom).

Table 4
A Pro and Con Comparison for the Camper Trailer

Pros	**Cons**
Equipped with ramp	Must customize gutted model
Tow vehicle can have 4x4	Additional cost of tow vehicle
A/C Established	
Plumbing established	
Power Established	

A camper is cheaper than an RV and has many of the same benefits. One important thing to take away is that a towing vehicle would be necessary. However, with an extra $120,000, purchasing a tow vehicle would be in budget.

1.5.1.3 Concept 3: enclosed trailer.

Using a basic enclosed trailer will require more modifications than a camper trailer or motorhome. The trailer is capable of meeting all targets. The consideration is whether the labor required to make this suitable is worth it.

Temperature control is possible with the addition of a heating and A/C unit. This is an available option in some models. Work stations would accommodate 3-4 occupants because various sizes ranging from 4ft x 8ft to 8.5ft x 53ft are available. Most trailers meet the height requirement of 6ft for equipment and some have an interior height of 6ft 7in. The trailers do not come with the ability to generate power, but it is possible to add a generator and/or solar panels with batteries. In addition, the trailer does not come standard with a restroom, but again, it is possible to install one. Enclosed trailers come standard with a ramp to aid in the loading and unloading of equipment.

The cost of use for each deployment would only include the cost of fuel for the tow vehicle and possibly a rental fee for the tow vehicle if the operators don't already have access to one. Due to the wide range in available sizing, prices vary between $1,200 and $30,000. That price does not include any extra features like HVAC or plumbing. Diamond Cargo company offers a restroom package for trailers for $3,000.

The advantages of using an enclosed trailer include, ease of acquisition, the wide range in sizing, customizability, and less maintenance over all self-propelled vehicles. If renting the tow vehicle, the only regular maintenance is checking tire pressures and greasing bearings. The disadvantage to choosing an enclosed trailer is that it will require more labor to meet all targets.

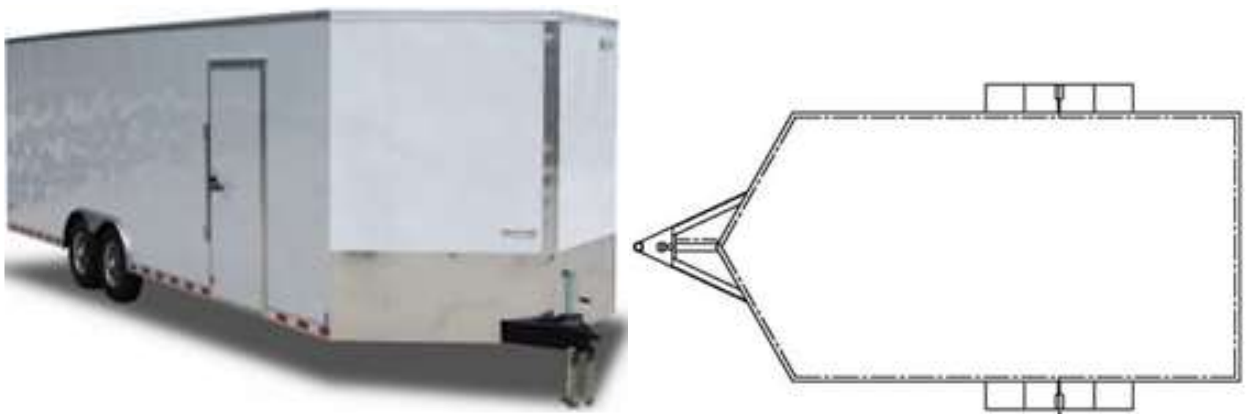


Figure 4. An enclosed trailer (left) and a simple top-down view (right).

Table 5
A Pro and Con Comparison for the Enclosed Trailer

Pros	Cons
Comes empty	No running water
Tow vehicle can have 4x4	Additional cost of tow vehicle
Equipped with ramp	No bathroom
	No A/C
	No insulation
	No windows
	No lighting

1.5.1.4 Concept 4: shipping container.

A shipping container has similar advantages and disadvantages to the enclosed trailer. It is a bare option that requires modification to meet most of the design targets. The simplicity of the option does mean that the shipping container is at a lower price point, between $3,000 and $5,000 depending on the selected size, than the camper hauler and motor home.

There are 2 options to achieve the desired interior temperature between 68 and 77°F. One option is to install an A/C unit on the simple model. The cost of the A/C unit, wiring, and installation would add at least $3,000 to the design cost. That number would vary depending on the complexity of the A/C unit. The other option for cooling the interior is to purchase a refrigerated unit. These units have temperature settings between -20 and 70°F, so the upper limit would satisfy the target value. Again, the upgraded feature of having a refrigerated unit would increase the price of the shipping container by roughly $2,000, again depending on the size. The shipping container option does not include a restroom, but the restroom package from Diamond Cargo company is installable in this option.

Shipping containers come in three standard lengths, 10’, 20’, and 40’. Each length has the same height and width dimensions of 7’9-⅝” and 7’8-⅛”, respectively. The dimensions allow both height clearance for operators and racks up to 6’ and the variation in lengths provides options of test space for up to 3 users.

As discussed above, the pricing of this option varies greatly depending on the feature selected at the time of purchase. HVAC, electrical wiring, and restroom installation would all occur after the fact and add to the nonrecurring costs. The distance between Kirtland Air Force Base, the location of the AGT program, and where the program plans to use the mobile lab, is roughly 500 miles round-trip. Using that as the mileage for a cost estimate, having the shipping container transported on a flatbed would cost roughly $2,000 per deployment.

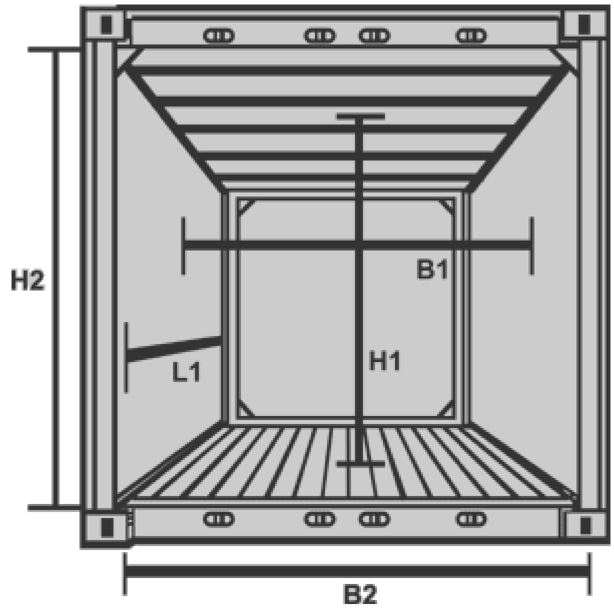


Figure 5. A shipping container (left) and an interior view of a shipping container (right).

Table 6
A Pro and Con Comparison for the Shipping Container

Pros	Cons
Can easily ship by air, land, or sea	No plumbing or electrical
Can purchase refrigerated containers	Need flatbed to transport
Already empty	Expensive tow vehicle
Can buy pre-insulated	No A/C
Can get with lights/power setup	

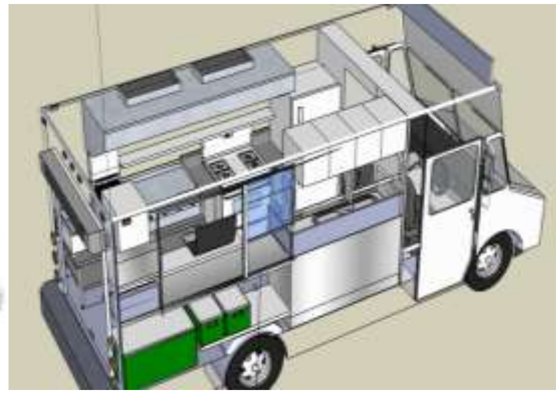
The ISO shipping container is a standard size, and therefore can adapt to many different situations. It is possible to ship, truck, or fly these containers. They also have the capability to be a roll-on, roll-off system for flight testing in a C130 or 747F.

1.5.1.5 Concept 5: step van.

A step van requires moderate modification for transformation into a suitable mobile lab space. It is also self-powered and compact, which can potentially benefit convenience and ease of use.

If outfitted with a proper heating and cooling system, a step van provides a suitable working environment for workers. Temperature control is common practice in the food truck industry, in which workers spend extended time in the van's cargo area, so the necessary modifications would be replicable in a mobile lab unit. Restrooms are not a standard feature of step vans, so technicians would need to rely on bathrooms near the testing site. Step vans vary in size, so a larger model could accommodate the needs of the lab. A large model, around 20 feet, provides the cargo space both in front and behind the wheel wells for up to three workstations and accompanying server racks. The mobile lab requires storage of 6-foot server racks, and step vans meet this requirement, depending on the selected model.

Step vans also meet the initial investment and operational cost requirements. New vans require an investment of $50,000-$70,000, depending on size and features, well within the specified sponsor limit. Further, the cost of deployment is based on transportation and power generation. Since gasoline is the only significant recurring expense, the cost of deployment satisfies sponsor requirements, as well.



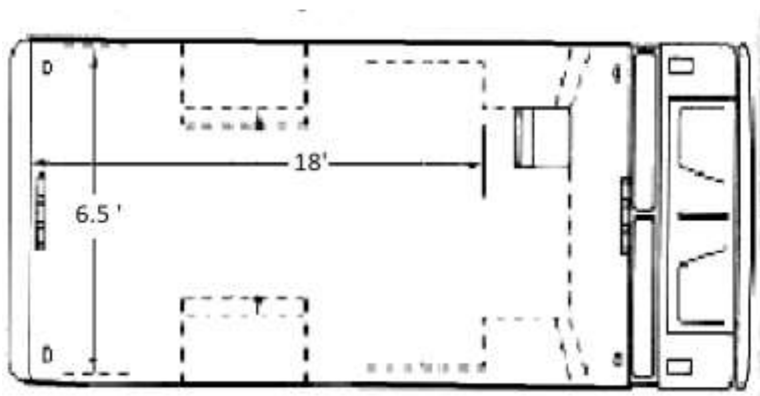


Figure 6. A step van (top left), sample interior layout (top right), and top-down view (bottom).

Table 7
A Pro and Con Comparison for the Step Van

Pros	**Cons**
Easy transportation	Smaller interior
Low initial investment	Moderate modification needed
Low operational cost	
Adaptable interior	
Often modified - plans likely available	

Due to the size of the food truck industry, many resources are available to provide guidance on step van modification. The vans are also available in many sizes, with cargo zones ranging from 10ft. - 20ft. in length.

1.5.2 Interior concepts.

The interior layout of the mobile lab is dependent on the selected vehicle. Without having a single vehicle's dimensions to work with, concept generation for the interior layout does not contain exact dimensions. The concepts generated are broad and more heavily based on the proximity of the operators to the equipment that is critical to their testing.

A maximum of three operators will be testing in the mobile lab at any given time, so lab space for three was allocated. Each operator is a different color with their seated position shown by an X. A solid circle represents each operator's reach radius. Entry points are undetermined and only included for scale and reference.

Input from the AGT test team influenced the interior concepts. Two operators, those shown in green and yellow, will primarily be using the equipment in rack 1, with limited use of some equipment in rack 2. The third user, shown in blue, will only be using the equipment in tack 2. All operators will need access to the storage.

1.5.2.1 Interior concept 1.

Equipment in the racks must connect to the vehicle's power supply and to the computers used by each of the operators. To avoid have cables running across the aisle of the lab, all of the operators and their equipment racks are located on one side of the vehicle in concept 1. The yellow and green operators are located on either side of rack 1, close enough that their reach radius allows access to the equipment in that rack. Rack 2 is located between the blue operator, who uses only the equipment in that rack, and the yellow operator who occasionally needs access to that equipment. On the occasions where the green operator needs to access the equipment in rack 2, that operator would need to leave their seated location. If the desks and racks are close enough for the operators to access the equipment while seated, there will be very little space for the green operator to access rack 2. Additionally, having the storage directly behind the yellow operator might limit the aisle space for walking.

The arrangement of the racks and the operators could vary from that shown below. If the racks switch positions, then the green operator could switch with the blue operator and the arrangement would still meet the requirements.

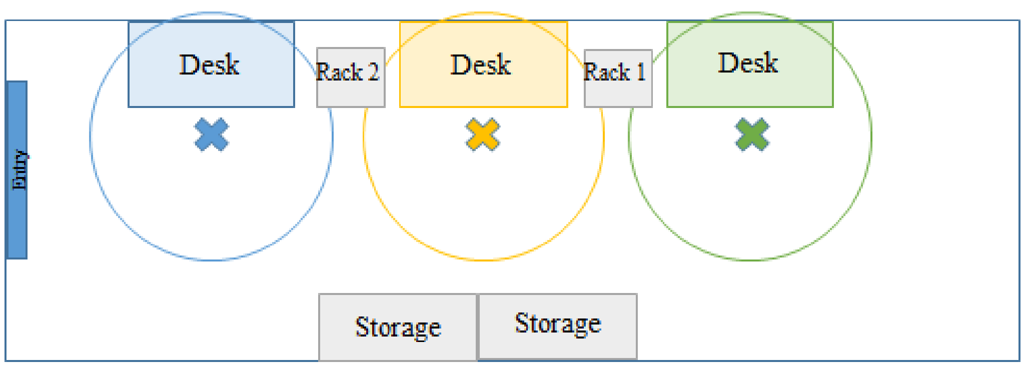


Figure 7. Possible arrangement for interior concept 1.

1.5.2.2 Interior concept 2.

This concept uses a single work surface, instead of three separate desks. This arrangement is advantageous because it allows for easier collaboration between the operators. Without equipment racks between them, they have better access to the test stations of the other operators. This is especially true for the yellow operator. As with concept 1, the blue operator still has constant access to rack 2, and the green operator has access to rack 1. The disadvantage to this arrangement is that the yellow operator doesn't have access to either rack. This means that the yellow operator might need to move about the lab frequently to access the racks. The green operator will also have to leave the seated location for access to rack 2. Having two operators move about the lab might frequently might be a problem given the limited width.

Similarly to concept 1, the arrangement of the racks and the operators could be changed and allow the operators the same access to their required equipment.

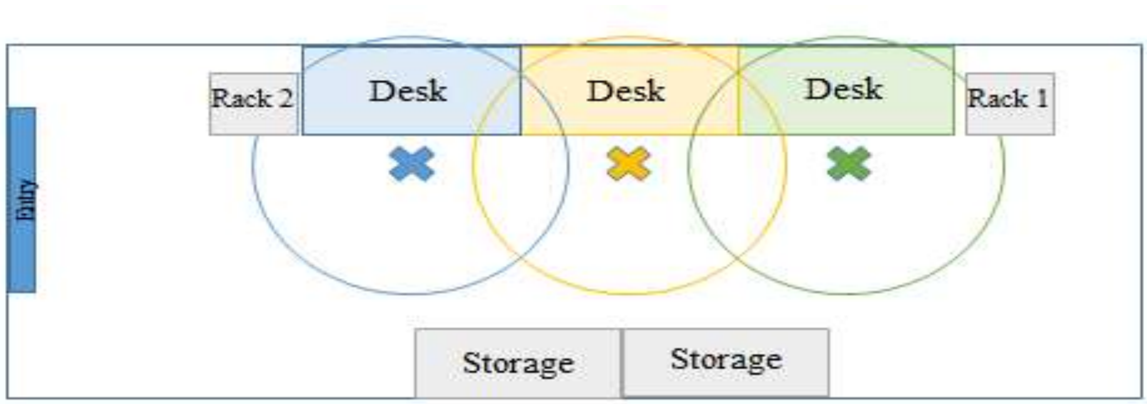


Figure 8. Possible arrangement of interior concept 2.

1.5.2.3 Interior concept 3.

As discussed above, having cables running across the aisles is not optimal. It puts the operators at risk of injury and the equipment at risk of damage if the operators are moving around. Concept 3 avoids having cables run across the width of the vehicle, but gives a little more space to the operators. The operator access to equipment is the same as that in concept 1, the green and yellow operators still have constant access to rack 1 and the blue operator has constant access to rack 2. The green operator will need to leave the seated position to access rack 2. This layout would allow the use of a vehicle that is smaller in length than the other interior concept.

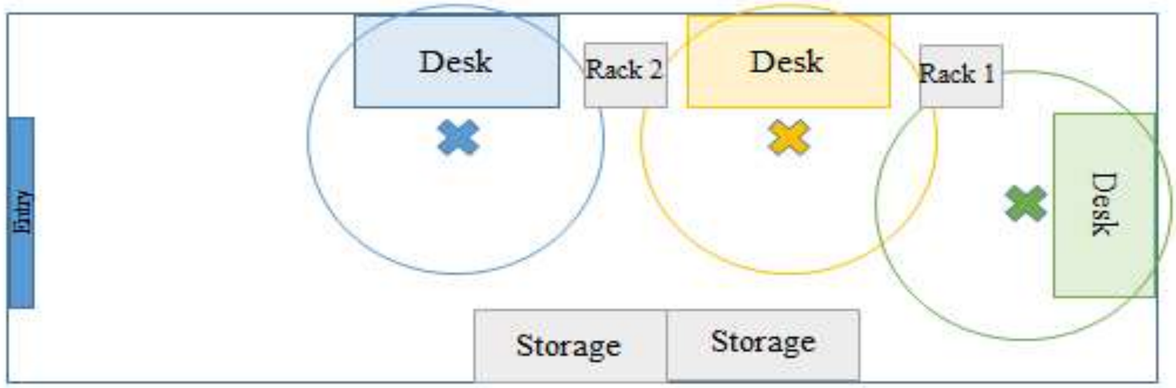


Figure 9. Possible arrangement for interior concept 3.

1.6 Concept Selection

Several selection tools helped to eliminate concepts and establish the best concept for selection. An analytical hierarchy matrix produced weighted selection criteria to narrow down two potential concepts. These criteria are based on the customer needs, and the analytical hierarchy process determined the weight of each criterion. Finally, the analytical hierarchy process allowed selection of a single vehicle concept.

With a single vehicle selected, a morphological chart outlined the subsystems and sub functions that are integral to further design development. Additional Pugh charts helped to make selections for each of the sub functions.

Even with a selected vehicle, there are options for the size. The necessary interior space influences the size of the vehicle, and the size of the vehicle influences the limits of the interior space. In order to account for this interdependency, a network analysis of workers and equipment, and an ergonomic analysis influenced the selection of the size of the vehicle and the most suitable interior layout.

1.6.1 Vehicle selection.

The first decision to make is the vehicle to use for the design. The options for vehicles include; motor home, camper trailer, enclosed trailer, shipping container, and step van.

1.6.1.1 Criteria comparison matrix.

The analytical hierarchy process determined the selection criteria weights. Outlined below are the steps taken with this method. Table 8 compares the importance of each characteristic. For reference, a 1 corresponds to equal importance. A value greater than one means that the characteristic in question (row) is more important than the one compared to it (column).

Table 8
Analytical Hierarchy Matrix to Determine Relative Importance of Selection Criteria

	Technician Space	**Versatility**	**Equipment Protection**	**Cost Effective-ness**	**Unpaved Road Capability**	**Ease of Loading**
Technician Working Space	1	3	1	0.20	5	5
Versatility	0.33	1	0.33	0.20	0.33	0.20
Equipment Protection	1	3	1	0.33	1	0.33
Cost Effective-ness	5	5	3	1	1	5
Unpaved Road Capability	0.20	3	1	1	1	3
Ease of Loading	0.20	5	3	0.20	3	1
Totals	7.73	20	9.33	2.93	11.33	14.53

The comparison values were then normalized using the totals at the bottom of each column. The resulting number in each row were then averaged to determine the weight of each criterion. The averaged values, or weights, are at the far right in Table 9, below.

Table 9
Analytical Hierarchy Table with Normalized Values and Average Ratings

	Technician Space	**Versatility**	**Equipment Protection**	**Cost Effective-ness**	**Unpaved Road Capability**	**Ease of Loading**	**Average Ratings**
Technician Working Space	1	3	1	0.20	5	5	**0.21**
Versatility	0.33	1	0.33	0.20	0.33	0.20	**0.04**
Equipment Protection	1	3	1	0.33	1	0.33	**0.10**

Cost Effective-ness	5	5	3	1	1	5	**0.33**
Unpaved Road Capability	0.20	3	1	1	1	3	**0.15**
Ease of Loading	0.20	5	3	0.20	3	1	**0.17**
Totals	7.73	20	9.33	2.93	11.33	14.53	**1**

1.6.1.2 Vehicle selection matrix.

The weighted selection criteria were used in a decision matrix to determine the two most viable vehicle concepts. Each concept was rated on a scale from 1-5 on ability to satisfy each of the selection criteria. These ratings were then multiplied by the corresponding weighting factor and the sum of the weighted ratings for each column was calculated. The concepts with the highest totals were determined to be the most viable options. Based on this procedure, the enclosed trailer and the shipping container were chosen as the most practical lab spaces, as shown below in Table 10.

Table 10
A Vehicle Selection Matrix Based on the Selection Criteria Determined Above

Vehicle Selection Criteria	Weight	Motor Home	Camper Trailer	Enclosed Trailer	Shipping Container	Step Van
Technician Working Space	0.21	5	5	4	5	2
Versatility	0.04	2	3	4	4	5
Equipment Protection Capability	0.10	4	4	4	5	4
Cost Effectiveness	0.33	1	2	4	4	3
Unpaved Road Capability	0.15	2	1	2	2	3
Ease of Loading	0.17	2	3	5	3	1
Totals		**2.49**	**2.88**	**3.86**	**3.84**	**2.64**

1.6.1.3 Analytical Hierarchy Process: design alternatives.

In order to compute the best vehicle, the team evaluated both possibilities against technician working space, versatility, equipment protection, cost effectiveness, unpaved road capability and ease of loading. The way the team weighted the ranking was by using 1's and 2's. The better choice received at two when compared to the other item. Once the ranking was made for the first column, the inverse was completed for the second column. When being ranked against itself, the item received a 1.

1.6.1.3.1 Working space comparison.

Below in table 11 is the AHP for the working space comparison. The enclosed trailer ranked higher for space because it has a wider base than that of the shipping container even though the shipping container has more volume.

Table 11
AHP for Technician Work Space Comparison

Working Space Comparison [C]		
	Enclosed Trailer	Shipping Container
Enclosed Trailer	1	2
Shipping Container	0.5	1
Sum	1.5	3

Normalized Working Space Comparison [NormC]			
	Enclosed Trailer	Shipping Container	Design Alternative Priorities {Pi}
Enclosed Trailer	0.66	0.66	0.66
Shipping Container	0.33	0.33	0.33
Sum	1	1	1

1.6.1.3.2 Versatility comparison.

The enclosed trailer also received a higher ranking for versatility because it would be able to be pulled out to the site with a standard pickup truck. Along with that, the same additions can be made to the enclosed trailer and the shipping container; so neither gain an edge there. This is shown in table 12 below.

Table 12
AHP for Versatility Comparison

Versatility Comparison [C]		
	Enclosed Trailer	Shipping Container
Enclosed Trailer	1	2
Shipping Container	0.5	1
Sum	1.5	3

Normalized Versatility Comparison [NormC]			
	Enclosed Trailer	Shipping Container	Design Alternative Priorities {Pi}
Enclosed Trailer	0.66	0.66	0.66
Shipping Container	0.33	0.33	0.33
Sum	1	1	1

1.6.1.3.3 Equipment protection comparison.

The two vehicles received the same rating for equipment protection because both are weatherproof and can house the necessary equipment protection. Since both had the same rating the comparison matrix is a matrix of ones, as shown below in table 13.

Table 13
AHP for Equipment Protection Comparison

Equipment Protection Comparison [C]	Normalized Equipment Protection Comparison [NormC]

	Enclosed Trailer	Shipping Container
Enclosed Trailer	1	1
Shipping Container	1	1
Sum	2	2

	Enclosed Trailer	Shipping Container	Design Alternative Priorities {Pi}
Enclosed Trailer	0.5	0.5	0.5
Shipping Container	0.5	0.5	0.5
Sum	1	1	1

1.6.1.3.4 Cost effectiveness comparison.

Below in table 14 is the AHP for cost effective comparison. The shipping container received the higher ranking for cost because the customizability and maintenance would be cheaper for that. It is important to note that this is only cheaper in the long run as long as an 18-wheeler is readily available for use.

Table 14
AHP for Cost Effectiveness Comparison

Cost Effectiveness Comparison [C]		
	Enclosed Trailer	Shipping Container
Enclosed Trailer	1	0.5
Shipping Container	2	1
Sum	3	1.5

Normalized Cost Effectiveness Comparison [NormC]			
	Enclosed Trailer	Shipping Container	Design Alternative Priorities {Pi}
Enclosed Trailer	0.33	0.33	0.33
Shipping Container	0.66	0.66	0.66
Sum	1	1	1

1.6.1.3.5 Unpaved road capability comparison.

Table 15 shows that the shipping container received a higher ranking for handling unpaved roads because it doesn't have to rely on its on suspension. It is under the assumption that the 18-wheeler's trailer would be able to handle the unpaved roads better than the suspension of the enclosed trailer.

Table 15
AHP for Unpaved Road Capability Comparison

Unpaved Road Capability Comparison [C]			Normalized Unpaved Road Capability Comparison [NormC]			
	Enclosed Trailer	Shipping Container		Enclosed Trailer	Shipping Container	Design Alternative Priorities {Pi}
Enclosed Trailer	1	0.5	Enclosed Trailer	0.33	0.33	0.33
Shipping Container	2	1	Shipping Container	0.66	0.66	0.66
Sum	3	1.5	Sum	1	1	1

1.6.1.3.6 Ease of equipment loading comparison.

The shipping container also received a higher ranking than the enclosed trailer for ease of loading, seen below in table 16. The reasoning behind this was that the shipping container is very low to the ground compared to the enclosed trailer. This means that the heavy equipment won't have to be lifted as high when being loaded into the shipping container.

Table 16
AHP for Ease of Equipment Loading Comparison

Ease of Equipment Loading Comparison [C]	Normalized Ease of Equipment Loading Comparison [NormC]

	Enclosed Trailer	Shipping Container
Enclosed Trailer	1	0.5
Shipping Container	2	1
Sum	3	1.5

	Enclosed Trailer	Shipping Container	Design Alternative Priorities {Pi}
Enclosed Trailer	0.33	0.33	0.33
Shipping Container	0.66	0.66	0.66
Sum	1	1	1

1.6.1.3.7 Final rating matrix and alternative value.

To determine the best vehicle concept, table 17 takes all of the Design Alternative Priorities and places them into one table for ease of reading.

Table 17
Final Rating Matrix for Enclosed Trailer and Shipping Container

Selection Criteria	Enclosed Trailer	Shipping Container
Technician Working Space	0.66	0.33
Versatility	0.66	0.33
Equipment Protection Capability	0.5	0.5
Cost Effectiveness	0.33	0.66
Unpaved Road Capability	0.33	0.66
Ease of Loading	0.33	0.66

Using these Pi's from above, the alternative value was calculated. This calculation was done by taking the average of all of the above Pi's, and the values are presented in table 18. Since the shipping container had the higher alternative value it is the better choice; however, the alternative value was not much higher than the enclosed trailer, which means that either one could be used if necessary.

Table 18
Table of the Calculated Alternative Values

Concept	Alternative Value
Enclosed Trailer	0.4683
Shipping Container	0.5317

1.6.2 Subsystem selection.

With the vehicle selected, the team developed a morphological chart that covers several of the major systems or functions that must be selected before moving forward with the design process. These include: power generation, HVAC, equipment cooling, vehicle insulation, and vehicle flooring. These systems are analyzed using Pugh charts if necessary. The morphological chart outlining the various subsystems and possible solutions in shown below in table 19.

Table 19
Morphological Chart of Subsystems and Solutions

←Subsystems/ sub functions \ Solutions →				
Power Generation	Solar	diesel generator	Gasoline generator	Propane Generator
HVAC	Packaged HVAC	Split system		
Equipment Cooling	Standalone fan	Rack mount fan	Thermoelectric cooler	Chiller
Insulation	Insulated FRP	Blanket Insulation	Rigid Foam	Reflective Surface
Flooring	Stock Flooring	Soft Foam Panels	Laminate Flooring	False floor

1.6.2.1 Power generation.

Power generation is an important consideration because a requirement is that the lab must be self-sufficient in various locations. Access to power will not always be possible, and so the vehicle must have sufficient power generation for testing. Several sources of power are possible, mainly generators with various fuel sources. Solar power can also be a consideration.

Gasoline powered generators are the most common and least expensive. The disadvantages are that they are loud and have relatively short run times. In addition, gasoline has a shelf life of less than a year, less than that of all other fuel options. Diesel generators are heavier than gas engines but can run longer under extended heavy loads. They are more expensive than gasoline generators. Propane generators are also more expensive than gasoline generators, but they have twice the runtime on a 20-lb. propane tank than a gas generator does on one tank.

Another option is a dual fuel generator. Usually, the chosen fuel types are propane or gasoline and these generators can run on either type of fuel. Solar panels are also a possibility and when added to the roof they can reduce the power required from the generator. As a result, there is a possibility for reduction in fuel consumption and the runtime on one tank would increase. The drawback of using solar panels is that they are not useful at night so solar panels would not be something a standalone source of power, they would have to be in addition to a generator.

After considering the power generating possibilities it was determined that a dual fuel generator, possibly in conjunction with solar panels is the best option. Having two fuel options gives the user more freedom on running the system and solar panels are a good way to increase efficiency.

1.6.2.2 HVAC.

HVAC is a necessary system for the mobile lab. Due to the weather conditions anticipated during testing, the mobile lab will need heating and cooling. There are two main options for HVAC, split and packaged systems. Split systems have two separate parts, the outside and inside systems. These systems are better for cooling larger areas and for applications with duct work. The disadvantage of using a split system is the space used for both parts of the system.

Packaged units provide heating and cooling from one single unit. They are better for heating and cooling smaller areas where there is no duct work. The packaged units do not take up any interior space. The unit would mount on the side or on the ceiling in the center of the trailer. For the mobile lab, a ductless packaged system is the most beneficial option because it saves space and reduces overall weight.

1.6.2.3 Equipment cooling.

The options for equipment cooling are suggestions from the AGT lab technicians. For equipment in the lab that dissipate a significant amount of heat, rising to temperatures above 300°C, AGT uses large chillers. These chillers can cool to temperatures below 0ºC. For less rigorous cooling, using standalone and rackmount fans is an option. The rackmount fan is essentially the standalone fan built for installation in a rack. Both types of fans can only cool to room temperature at the lowest. Thermoelectric coolers adhere to the Peltier effect which creates a temperature gradient through the transfer of heat between electrical junctions. Coupled with a heat sink, the thermoelectric cooler can chill below 0°C. Possible models have ratings up to 200°C, which is above the temperature that the equipment will be running at. A Pugh chart selected the best method of equipment cooling. The selection criteria are, maximum operating temperature, because the cooling mechanism must be rated to at 150°C, to accommodate the equipment, size and weight because space inside the vehicle is limited, cost in order to provide the most cost effective design, and the temperature to which the equipment can be cooled, which is important for equipment that needs to be kept colder than room temperature.

The Pugh matrix is below in table 20. After comparing the equipment cooling options with only the use of and HVAC system, another Pugh chart was necessary to decide on one system to move forward with. The standalone fan was eliminated because of the space it would take up either on the floor or on a desk. The chiller was eliminated because of its large size and weight, as well as its increased costs.

Table 20
Pugh Chart for Equipment Cooling Selection

		Concepts			
Selection Criteria	**HVAC only**	**Standalone fan**	**Rack mount fan**	**Thermoelectric cooler**	**Chiller**
Max operating temp.		+	+	-	+
Weight		-	S	S	-
Size		-	S	S	-
Cost		-	-	-	-
Cool to temp.		+	+	+	+
# of pluses		2	2	1	2
# of minuses		3	1	2	3

		Concepts	
Selection Criteria	**Standalone fan**	**Rack mount fan**	**Thermoelectric cooler**

Max operating temp.		S	-
Weight		S	+
Size		+	+
Cost		-	-
Cool to temp.		S	+
# of pluses		1	3

The thermoelectric cooler is the best equipment cooling option. It is the most compact and lightweight option, it can cool to lower temperatures than the fans, and it has a rating of temperatures well above the necessary maximum temperature.

1.6.2.4 Insulation.

Insulation is a necessary addition to the mobile lab to reduce the amount of energy the HVAC will have to draw from the generator to keep the unit at an acceptable temperature.

Blanket insulation is the most common and widely available type of insulation. It has uses in houses because it comes in standard widths to fit between the studs of the structure. Since the mobile lab structure differs from that of a house, the insulation would not fit in the mobile lab the way the designs specify. This blanket insulation has an R-value range of R-2.9 - R-4.3 per inch.

Rigid foam board insulation usually has the highest R-value per inch thickness of insulation. Some foam boards can have an R-value of R-4 per inch of thickness. Foam boards do a good job of reducing heat transfer through structural elements like the studs in the walls. Fiberglass reinforced panels (FRP) are a much sturdier option. They can be pressure washed for cleaning. They would make a much better interior wall for the inside of the lab. Some models come with an interlocking feature where each piece would lock together. This reduces heat loss between the boards. They have high R-values at R-4.2 per in thickness. FRP is the lowest cost option per R-value

To increase the effectiveness of the insulation, some manufactures include a reflective shield on their insulation. This reduces the heat transfer through radiation. Reflective surfaces can also be purchased separately and applied to each board of insulation.

Fiberglass reinforced panels are the most cost effective and efficient insulation option for the mobile lab. They provide toughness while keeping overall initial costs and recurring costs low. They will also require the HVAC system to do less work.

1.6.2.5 Flooring.

Flooring is an important consideration because the operators must be able to easily roll the equipment racks on and off of the vehicle. Flooring also plays a role in the comfort and safety of the operators. The Stock floor that the shipping container comes with is rough and would not allow the racks to roll in the unit. As a result, the floor will need an overlay of flooring with an option such as laminate, soft foam paneling, or false floor.

Laminate flooring provides an aesthetically pleasing, tough, low maintenance, and easy rolling surface. There are several different color options and thicknesses. Reasonably priced options range from $0.50 to $3.00. Soft foam panel flooring would be a simple, easy to install, and cheap flooring option. It would insulate the floor from heat transfer and sound. It would also reduce the vibration for the equipment while in transit. The disadvantage to this option is difficulty rolling the equipment around with small wheels. This option would cost around $0.36 per square foot. A false floor would allow the wires running between the equipment and generator to run under the floor. This could allow a more direct route for the wires and reduce the required length. Reducing the length of the wire will also lessen the resistance in the circuit and increase the efficiency of the system.

Ease of use and versatility are important, and having to run the wires under the floor each time loading and unloading the equipment means the false floor is not the best choice. The soft foam panel floor has many desirable qualities but causes difficulty with moving the equipment. Those eliminations mean that the laminate flooring is the best option.

1.6.3 Interior layout selection.

Even with a shipping container as the selected vehicle, there are still options for the size of the container. The sponsor expressed interest in the most cost effective design in as small a space as possible. A network analysis aids in determining the most efficient use of space inside of the vehicle and to inform a decision on the vehicle size, the team performed an ergonomic analysis.

1.6.3.1 Network analysis.

A few principles from graph theory were applied in order to grasp a deeper understanding of the dynamics of the operation within the mobile lab. This is a simple process that yields valuable results in the selection process. First, the network is defined as a weighted bipartite network comprising of 5 or 6 nodes: 3 operators, and 2 or 3 server racks respectively. Every operator is connected to every server rack and a weight is assigned to each edge depending on how much an operator uses the server rack. A graph of the 5 node network is shown below in Figure 10.

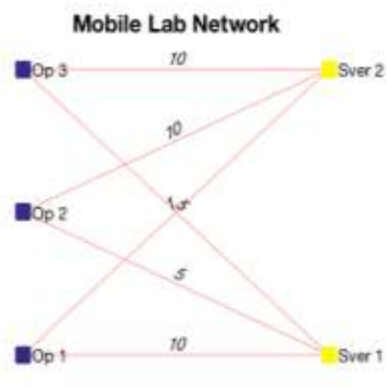


Figure 10. Weighted graph for positions of operators and server racks.

In order to form the graph above an incidence matrix must be made that contains the information of the network. By allowing the server racks to be the columns and the operators to be the rows, a matrix can be formed by applying a Likert-type weight from 1 to 10 for the operator-server rack combination. The incidence matrices formed for the 5 and 6 node systems are shown in Table 21.

Table 21
Incidence Matrices for the 2- and 3-Server Setup with Weighted Degree Centrality

	Server 1	Server 2				Server 1	Server 2	Server 3		
Operator 1	10	1	11	3.7	Operator 1	10	1	1	12	3.3
Operator 2	5	10	15	5	Operator 2	5	10	3	18	5
Operator 3	5	10	15	5	Operator 3	5	3	10	18	5
	20	21				20	14	14		
	4.8	5				5	3.5	3.5		

Table 12 offers a nice comparison between the 2 and 3-server rack networks. In order to decide which of the setups is best for the mobile lab, weighted degree centrality measures were taken for the two incidence matrices by simply finding the summations of the columns and rows.

Once these summations are taken, they were normalized based on the largest degree in the class. For example, Server 1's weight is 20 in the 2-Server rack system while Server 2 is 21; therefore, Server 1 is used 95% as much as Server 2. These proportions are then scaled 1-5 for easy comparison.

Looking at the centrality measures for the 2-Server setup it can be seen that the 2 server racks get much more even use due to the 4.8 rating for Server 1 verse 5.0 for Server 2; while the 3-Server has one rack with the most use, and the other 2 are used 70% as much. In addition, analyzing the centrality of the operators offers insight to the amount of movement the operators will do during the testing process. The only operator affected by the different setups is Operator 1, whose centrality dropped from 3.7 to 3.3 from the 2 to 3-rack setup. This shows that with the addition of a third rack, Operator 1 will move about 8% less while the other two operators will move about the same if not more due to the slightly higher magnitude of the weighted degree centrality.

As a result of the network analysis it can be deduced that it is only necessary to provide 2 Server Racks in order to meet the customer's needs without sacrificing precious space within the mobile lab. This decision is a result of realizing which operators are affected by the different setups, and the only operator affected is Operator 1. Additionally, the analysis also shows that the 2-server setup will put almost equal importance on both of the server racks while in the 3-server setup two of the racks are not being used quite as much. This decision saves precious money and space in the mobile lab.

1.6.3.2 Ergonomic analysis.

Human factors and ergonomics is the study of how people interact with their environment to decrease fatigue and discomfort and increase usability. Extensive ergonomic analysis will serve a tool throughout the design process. For the concept selection, an important factor is the vehicle size. The size of the vehicle depends on the interior layout and vice versa. To inform a decision on the vehicle size, ergonomic analysis helped determine the necessary workspace dimensions.

Ergonomic designs typically accommodate a range of users from the 5th percentile female to the 95th percentile male. This will encompass 95% of all users. The necessary seated dimensions of these groups is provided in table 22 below.

Table 22
Seated Dimensions of Male and Female Users

Measurement	Letter	Female 5th – 95th%	Male 5th – 95th%	Overall Range 5th – 95th%
Sitting Height	A	31.3″ – 35.8″	33.6″ – 38.3″	31.3″ – 38.3″
Sitting Eye Height	B	42.6″ – 48.8″	46.3″ – 52.6″	42.6″ – 52.6″
Waist Depth	C	7.3″ – 10.7″	7.8″ – 11.4″	7.3″ – 11.4″
Thigh Clearance	D	21.0″ – 24.5″	23.0″ – 26.8″	21.0″ – 26.8″
Buttock-to-Knee	E	21.3″ – 25.2″	22.4″ – 26.3″	21.3 – 26.3″
Knee Height	F	19.8″ – 23.2″	21.4″ – 25.0″	19.8″ – 28.0″
Seat Length/Depth	G	16.9″ – 20.4″	17.7″ – 21.1″	16.9″ – 21.1″
Popliteal Height	H	15.0″ – 18.1″	16.7″ – 19.9″	15.0″ – 19.9″
Seat Width	Not Shown	14.5″ – 18.0″	13.9″ – 17.2″	13.9″ – 18.0″

A visual representation of these measurements is below in figure 11. The value corresponding to each measurement has a letter assigned to it, located in Letter column of table 22.

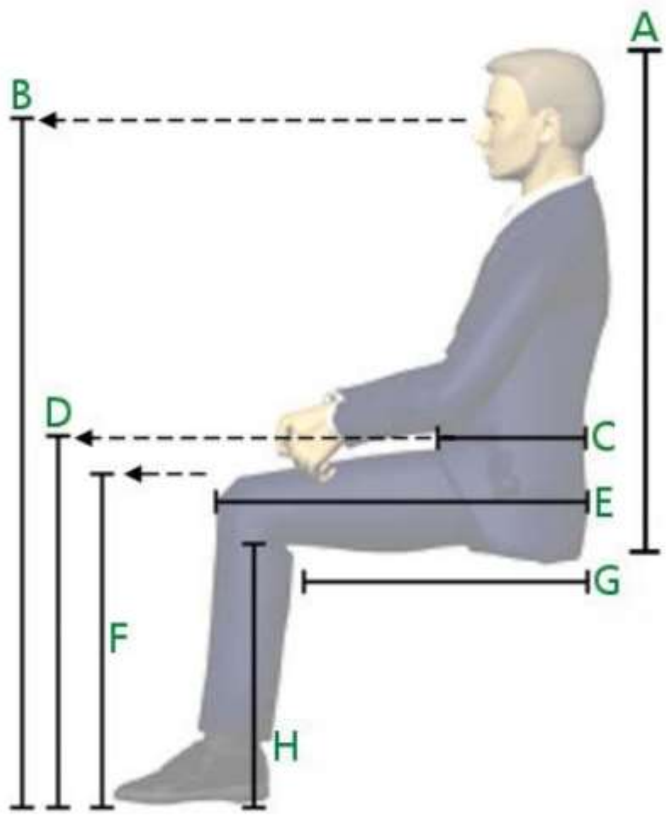


Figure 11. Visualization of seated dimensions.

With a vehicle width of less than 8' as a limiting factor, it is important to determine the depth of the work surfaces. BIFMA, the trade association for business and institutional furniture manufacturers, has a set of standards for seated work stations that accommodates 90% of the population. Figure 12 below is a diagram of the BIFMA work surface guidelines.

Figure 12. BIFMA work surface guidelines.

Below in table 23 are the values represented by the letters A-H. These values are useful in determining the necessary depth from the back of the chair to the wall.

Table 23

BIFMA Work Station Guidelines

			Specifications	
		Letter	Measurement	BIFMA Guideline
Seated Work	Height for Thighs	A	Thigh clearance + Shoe allowance + Popliteal height	At least 26.8"
Seated Work	Depth for Knees	B	Buttock-knee length – Abdominal extension depth	No less than 17"
Seated Work	Width for Thighs	Not Shown	Hip breadth, sitting + Movement allowance + Clothing allowance	No less than 19.8"
Seated Work	Height at Foot Level	C	Lateral malleolus height + Shoe allowance	4.2"
Seated Work	Depth at Foot Level	D	Buttock-popliteal length + Foot length – Abdominal extension depth	No less than 23.5"
Standing Work	Height at Foot Level	C	Lateral malleolus height + Shoe allowance	4.2"
Standing Work	Depth at Foot Level	Not Shown	None	6.5"
Standing Work	Width at Foot Level	Not Shown	Hip breadth, sitting + Movement allowance	19.8"
Support Surfaces for Computer Desks	Sitting Height for Input Devices (Desk)	F	Popliteal height + Elbow rest height, sitting + Shoe allowance – Input device thickness	22.2" – 28.5" (adjustable) 28.5" (non-adjustable)
Support Surfaces for Computer Desks	Sitting Height for VDTs (Eye Height)	G	Eye height, sitting + Popliteal height + Shoe allowance	Complex interdependencies; allow top of screen at eye level; approximate height: 42.6" – 52.6"
Support Surfaces for Computer Desks	Standing Height for Input Devices (Desk)	Not Shown	Elbow rest height, standing + Shoe allowance – Input device thickness	36.7" – 45.6"
Support Surfaces for Computer Desks	Standing Height for VDTs (Eye Height)	Not Shown	Eye height, standing + Shoe allowance	Complex interdependencies; allow top of screen at eye level; approximate height: 56.9" – 69.8"
Support Surfaces for Computer Desks	Viewing Depth	H	None	No less than 15.7" from VDTs to eyes

The relevant measurements to depth are, D = 23.5" from figure 11, and C = 11.4" from figure 12. Assuming the use of laptops or flat screen monitors, the space behind the screen can be mostly eliminated. Therefore, based on the dimensions the depth while seated is at least 34.9”. To provide enough space for the operator to enter and exit their seat, and to give room for another operator to walk behind the chair, an additional 24” will be added to the depth requirements. If utilizing two operators and workstations back to back, as shown in figure 13, the necessary width would be 93.8”.

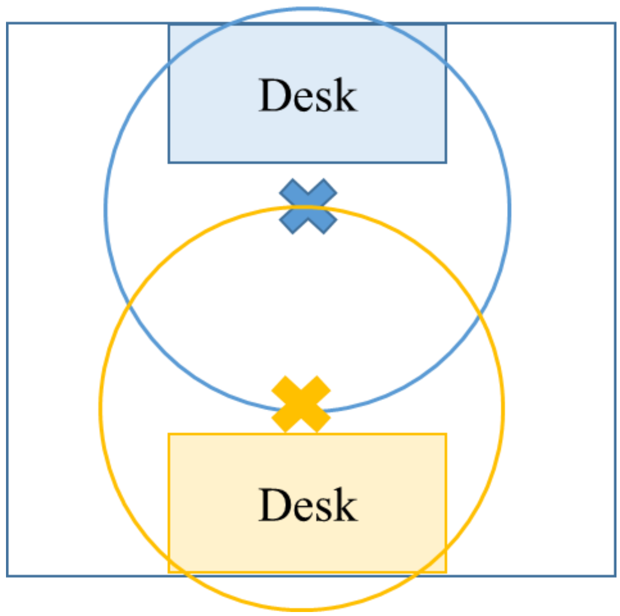


Figure 13. Possible interior layout with back to back operator stations.

This distance is wider than the width of the shipping container, which has an interior width of 92”. Two workstations cannot be placed back to back. Similarly, the equipment racks have depths from 24” to 36”, which would also be unsuitable for placing across from the work stations.

In total, one work station, one seated operator, and walkway will require a vehicle width of 70.9”. The next option for shipping container size is the length. There a are 10’, 20’, 30’ and

40’ containers. Since operators and racks cannot sit back to back, other layouts are necessary. One such layout option is below in figure 14.

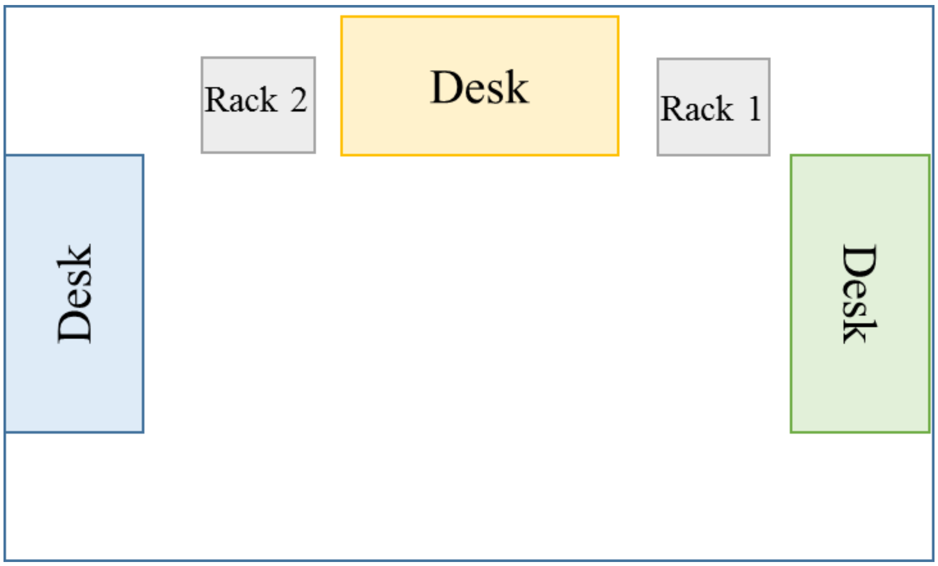


Figure 14. Possible interior layout, optimizing vehicle length.

If considering the 2, 22” wide equipment racks, and 3 workstations at 3’, the necessary length would be 173.8”, greater than the 10’. This eliminates the 10’ option immediately, and leaves the 20’ option as the smallest unit that can fit the necessary equipment. Another possible layout shown below in figure 15 would require a length of 196” which would also be satisfied with a 20’ trailer.

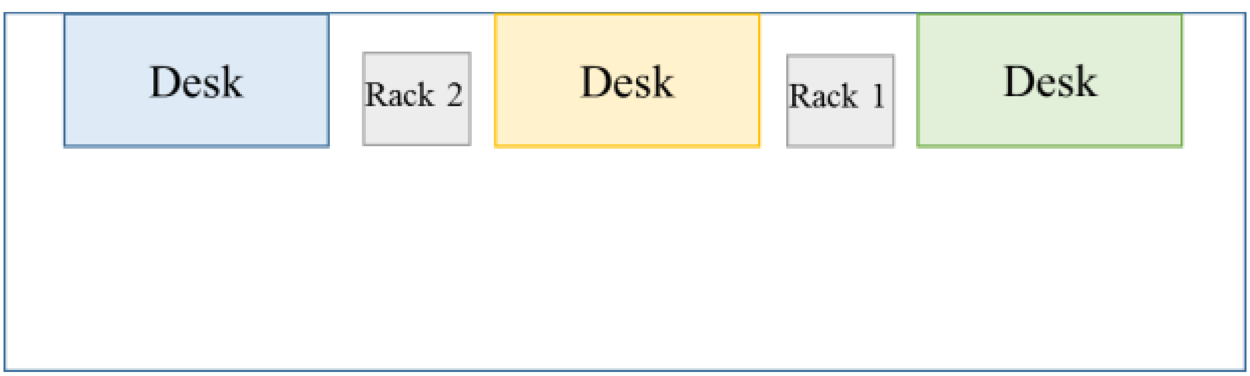


Figure 15. Possible vehicle interior layout for increased comfort.

This layout provides the operators with more workspace than the option provided in figure 14. While it utilizes more of the interior length than the other option, it will offer greater comfort to the operator.

1.7 Spring Project Plan

Looking forward, it is important to identify key dates coming in the near future - some of these dates include the completion of design drawings, completion of a scaled model, and submission of a proposal to AGT. Table 24, shown below, offers a list of the most important due dates coming in Spring 2018.

Table 24
Spring Project Due Dates

Task	Due Date
Complete design selections	10-Feb
Complete analyses	10-Feb
Complete individual part drawings	1-Mar
Complete assembly drawings	15-Mar
Complete scaled model	1-Apr
Engineering Design Day	17-Apr
Submission of all documentation to AGT	20-Apr
Graduation	5-May

The goal for February is to have the design selected and the systems analyzed. Completing these steps will give the sponsor time to review and critique all of the work completed for the design. This will allow for adequate time to make any necessary revisions to the design. After receiving approval for the designs, the goal is to complete detailed drawings of components and subsystems in early March. Completing these designs will lay the groundwork for compiling assembly drawings by mid-March. Finishing all of the drawings by March should allow fabrication of a scaled model. Ideally, completion of all major tasks will occur by April. This will allow extra time in case problems occur while building the model. Along with that, this will give ample time to prepare for Engineering Design Day, and to complete all of the documentation required for AGT before graduation.

During the Fall semester, the team used the Project Management (PM) Sheet to plan due dates and keep track of progress on assignments and tasks. Its use will continue into the Spring semester. Below in table 25 is the key used to show when tasks, are due, in progress and completed.

Table 25
Key for Project Management Sheet

In Progress	Deadline	Complete
○	◉	●

The first section of the PM Sheet is the design task list. This includes tasks such as selecting the vehicle, lab benches, and HVAC. Many of these tasks are in progress or completed, however the finalized and approved designs have completion dates in the Spring. Table 26, shown below, is the design task list.

Table 26
Project Management Sheet for Design Tasks

	Vehicle Abilities	Interior Design	Minimum Cost	Design for Manufacturability	#	Major Tasks	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Travis	Michael	Taylor	Ricky	Raine
Design		X			1	List of equipment inside of lab	○	●												X
	X		X		2	Select lab vehicles (concept generation)	○	●										X		
		X	X		3	Calculate and determine power usage		○	●											X
		X	X	X	4	Setup Power			○			o							X	
		X		X	5	"Furnish" inside (tables, cabinets, etc.)		○	○			o								X
		X	X	X	6	Locking/storage mechanisms for lab equipment						o					X			
			X	X	7	Select/Design HVAC system			○			o							X	
			X	X	8	Complete concept generation (vehicle)		○	o											X
			X	X	9	Design Selection (vehicle)			●	o								X		
	X	X	X	X	10	Finalize Design								o				X		
	X	X	X	X	11	Final design approved by Sponsor								o						X

Project Completed By: May 01, 2018

Below in table 27 is the PM Sheet for the analysis tasks. These tasks are important for ensuring that the design meets safety and operational requirements, and include thermal, stress, and electric load analysis. Completion of the analysis will include the use of tools such as Matlab. The team will begin all analysis tasks in the Spring.

Table 27
Project Management Sheet for Analysis Tasks

	Vehicle Abilities	Interior Design	Minimum Cost	Design for Manufacturability	#	Major Tasks	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Travis	Michael	Taylor	Ricky	Raine
Analysis	X			X	12	Vehicle terrain abilities/Vibration Analysis					o					X				
				X	13	Thermal Analysis					o								X	
				X	14	Stress Analysis						o				X				
				X	15	Electrical Load Analysis						o							X	
			X	X	16	Cost Analysis							o			X				
		X		X	17	Individual Part Drawings							o				X			
		X		X	18	Assembly Drawings							o				X			
				X	19	Scaled model								o			X			
				X	20	Simulation								o		X				
					21	Documentation		●	●	o		o	o	o	o			X		

Project Completed By: May 01, 2018

All of the class requirements are not yet available for the Spring, but the main milestones, graduation and Engineering Design Day are. Before graduation on May 5, 2018, the project must be complete and meet the standards of the professor and sponsor. Engineering Design Day is set for April 11, 2017, which means that date marks the completion of all major parts of the project.

Any work taking place after that will be regarding documentation and final edits. The estimated VDR and class requirements task list is below in table 28.

Table 28
Project Management Sheet for Known Class Requirements

Class Reqs.	Vehicle Abilities	Interior Design	Minimum Cost	Design for Manufacturability		Major Tasks	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Travis	Michael	Taylor	Ricky	Raine
	X	X			A	VDR 1	○	●												X
			X		B	VDR 2		○	●									X		
	X	X		X	C	VDR 3			○	◎						X				
					D	VDR 4						◎					X			
					E	VDR 5							◎						X	
					F	VDR 6 (Engineering Design Day)								◎		X				
					G	VDR 7									◎			X		

Objectives: Vehicle Abilities, Interior Design, Minimum Cost, Design for Manufacturability; Major Tasks; Target Dates; Project Completed By: May 01, 2018; Owner / Priority

The project management sheet serves as a visual display of the deadlines and milestones. Assigning group members with final responsibility over each task ensures proper distribution of work. Overall, the main goals of the Spring semester are to have analysis, results, and future work outlined before graduation in May.

Chapter Two: EML 4552C

2.1 Spring Plan

The spring plan outlines class due dates, major milestones such as graduation, and completion dates set by the team. The plan will hold the team members accountable for their assigned tasks and the required due dates.

2.1.1 Project Plan.

With the start of the new semester, we looked to revise our Spring project plan created last semester. Our original design experienced changes due to feedback from AFRL which ultimately resulted in design modification from a 20’ shipping container to a 40’ shipping container. This change is due to the additional workspace requested by AFRL and more desk-space for each operator. Table 29, shown below, shows a list of the major target dates this semester.

Table 29
Spring Project Dates

Task	Due Date	Owner
Component Selection	10-Feb	ALL
Complete Design Selection	12-Feb	Michael
VDR 4	12-Feb	Raine, Taylor, Ricky, Travis
Website 1	16-Feb	Travis
Complete drawings	9-Mar	Michael
Website 2	16-Mar	Travis
VDR 5	20-Mar	Michael, Travis, Ricky

Complete scaled model	5-Apr	Taylor
Website 3	6-Apr	Travis
Engineering Design Day	12-Apr	ALL
Submission of all documentation to AGT	20-Apr	Raine
Final Report	20-Apr	Taylor
Prototype Demo	27-Apr	Ricky
Graduation	5-May	ALL

The timeline of project dates has three phases – component selection, drawings, and fabrication – separated by bold lines in the table. The first phase, scheduled for completion in February, is to have all components for the design selected. This includes HVAC, generators, lighting, etc. Once all component selections receive approval from AGT, the team will generate CAD files and drawings for each part as well as for the assembly. This second phase will be completed before Spring Break to allow for adequate time to get approval from AGT and to make any necessary revisions to the design if requested. Following approval of the model and drawings is the third phase, fabrication. The CAD files will go to 3D printing services in late March. Submitting the print request shortly after Spring Break should allow for plenty of time to fabricate the scaled model in early April, before Engineering Design Day. Finishing the drawings and models according to the proposed timeline allows time to: handle any unforeseen obstacles; prepare for Engineering Design Day; and complete all of the documentation required for AGT and Senior Design before graduation.

It is important to note that Team 17 has to account for potential bottlenecks that may occur. Some places in the timeline where bottlenecks could occur are at the design selection phase and the production of a completed model. The design selection phase is a potential bottleneck because the design has already changed several times due to sponsor feedback and requests. If the design keeps changing, the team will not be able to move forward with creating a prototype until the design has approval from AGT. Similarly, there is a potential bottleneck with completing the scale model because the design relies on 3D printed parts. This could create a problem if prints begin to fail and the prototype experiences delays.

The budget given to this project is $2,000. Since a full-scale model is not a requirement, this budget will go towards producing a scaled model of the Mobile Lab. The costs predicted for the model are materials for 3D printing, and possibly the cost of having the model printed by a third-party company. The team plans to use the 3D printer available to Senior Design teams at the College of Engineering (CoE), but acknowledges the printer's high demand. In addition to that printer, the 3D printers at Dirac Science Library and FSU's new Innovation Hub are possible options. The only cost associated with 3D printing is for materials if using the CoE printer. Printing materials have various prices ranging from $20/kg to $175/kg.

In the case that none of these printing options suffice for the project, a third-party 3D printing company will print the model. To ensure enough funds are available, the team will set aside $1,000. The other $1,000 can go towards printing material costs for the CoE printer. In addition to the model printed in Tallahassee, the team will print a second model for AGT in New Mexico at AFRL's Maker Hub.

Class Reqs.	Vehicle Abilities	Interior Design	Minimum Cost	Design for Manufacturability		Major Tasks	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Travis	Michael	Taylor	Ricky	Raine
	Objectives					**Major Tasks**	**Project Completed By: May 01, 2018**									**Owner / Priority**				
	X	X			A	VDR 1	○	●												X
			X		B	VDR 2		○	●									X		
	X	X		X	C	VDR 3			○	o						X				
					D	VDR 4						o					X			
					E	VDR 5							o						X	
					F	VDR 6 (Engineering Design Day)								o		X				
					G	VDR 7									o			X		

Objectives / Major Tasks / Target Dates

2.1.2 Build Plan.

A full-scale model of the design will not be feasible; therefore, the team will deliver a scaled prototype. In order to deliver a proper prototype, the specifications of the model must be similar to those of the intended model.

The delivered model will include a scaled model of the intended design depicting all of the interior equipment as well as the overall size of the design. The majority of the items will be 3D printed once the design has been completed in CAD. The CAD drawings will be completed by March 18 to leave ample time for the printing process to be completed.

Appendices

Appendix A: Code of Conduct

Mission Statement

To have fun and work productively on designing a cost effective, simplistic, and multi-use mobile GPS lab for the Advanced GPS Technologies Program of the Air Force Research Lab.

Team Roles

The team members will each have an explicit title and role in the design process. The roles are outlined below, however team members are encouraged to ask for assistance when needed, and all members will support each other with their specified tasks.

Sponsor liaison.

The sponsor liaison will be the main point of contact with the sponsor and will arrange all telephone, Skype and in-person meetings with the sponsor. Additionally, they will manage a schedule or calendar for the project and deliverables as well as keep minutes of all team, instructor, advisor and sponsor meetings. Emails from team 17 to the instructor will be sent by the sponsor liaison.

Administrative lead.

The administrative lead will work with all written material for the project. Specifically, these responsibilities include editing, ensuring a cohesive voice, and submitting the documents in the required formats.

ME lead.

The ME Lead will be responsible for overseeing all CAD models, making sure that the team is consistent and uniform in their designs. They will also insure the quality of the drawings and will be responsible for final oversight of any modeling presented to the sponsor.

Webmaster/financial lead.

The Webmaster/Financial Lead will oversee the creation and management of the team website and will maintain an accurate financial analysis of the designs. They will manage the budget report and have final input on the budget before it is presented to the sponsor. Additionally, they will oversee Matlab computations and ensure uniformity among all Matlab codes.

ECE lead.

The ECE Lead is responsible for learning about and providing the team with necessary electrical and computer engineering concepts relevant to this project. They will have final review of all ECE decisions, and will ensure that the payload is properly supported which will include decisions on power, cooling, and electrostatic discharge safety.

All members of the team will be responsible for attending meetings and presentations, completing their tasks on time, listening to others' opinions, making good choices that reflect well on the team, and having more fun than everyone else.

Organizational Chart

The organizational chart shows the relationship between the team members and specifies each member's role. There is no hierarchy to the organizational chart, each member will report to the entire team. The team member assigned to each role and their duties are shown below in Figure 16.

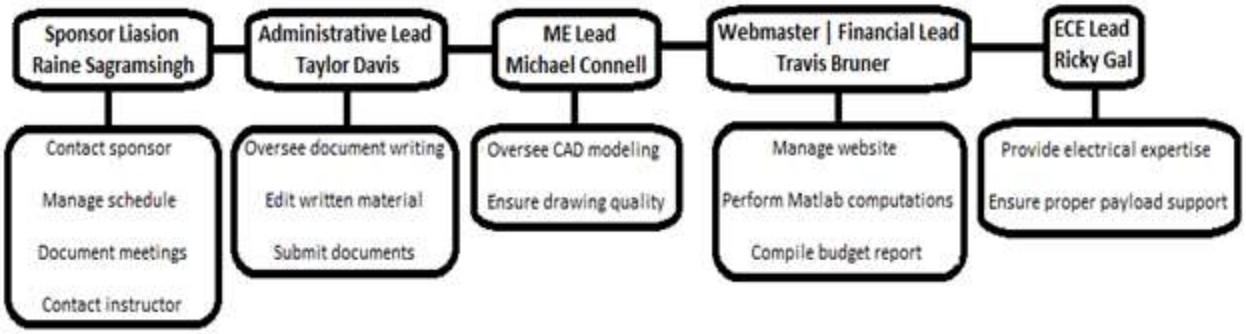


Figure 16. Organizational chart for team 17, outlining member roles and duties.

Communication

Email will be used to correspond with advisors, instructors, and sponsors. Regular in-person meetings will occur with all members of the team. Meeting times and dates will be discussed and determined using GroupMe (group messaging). Skype and phone calls will be used to include the team's remote student in all lectures, meetings, and presentations. Google Docs will be used for collaboration on assignments and presentations, and email will be used for the exchange of documents.

Dress Code

For any meetings with the team, the advisor, the professor, or for phone meetings with the sponsor, casual attire is acceptable. Business attire is expected for all face to face meetings with the sponsor and all presentations. Business attire is defined as a button up shirt and a tie for men, and comparable clothing for women.

Attendance Policy

All team members are expected to be present for meetings, and the remote student must call or Skype. If a member of the team is unable to attend a scheduled meeting, they must give reasonable notice through GroupMe. All members are expected to be present for the presentations, aside from the remote student who will be present through Skype for the presentations they are not a part of.

Work Schedule

Team members are expected to be available during at least part of the designated class time, Tuesdays and Thursdays from 2:00-6:15 pm (EST). The team will meet after class ends on Tuesdays, when lectures are held, for a brief review. A full team meeting will take place at least once a week unless deemed unnecessary by the team. The day and time of the weekly meeting will be determined by the team members the week prior.

Decision Process

Decisions will be made based on the severity and implications of the decision. Separate processes will be used for formal and informal decisions. Team members may formally object to the decision process at any time.

Formal decisions.

All formal decisions will be made after a full discussion by the team. The following process will be used:

1. The problem or topic will be presented to all members.
2. Any questions will be answered.
3. A vote will be taken on the decision.

4. The majority, 3 out of 5 members, rules.

Informal decisions.

For delegation of certain tasks and assignment of responsibilities, Nohs-Geaux will be used. The rules of Nohs-Geaux are as follows,

1. The task or responsibility will be stated out loud.
2. Each member will put their forefinger to their nose as quickly as possible.
3. The last person to put their forefinger to their nose is delegated the task.

*If the outcome of Nohs-Geaux is obviously unfair, the team will reconsider the outcome.

Morals and Ethics

The team will refer to and follow the rules of practice and professional obligations of the NSPE Code of Ethics when participating in any activity that may impact the team, the University, or the sponsor. Team members will hold themselves and their teammates to these rules and regulations.

Process to Amend Code of Conduct

Shall the need arise to amend this document; a team member must schedule a meeting and present the amendment to the team. The team will then discuss the amendment, and a decision (see Decision Process) can be made whether the document will be amended. Four out of five members must be in attendance for a change to be made to the Code of Conduct.

Statement of Understanding

I acknowledge full understanding of the procedures and regulations outlined in this Code of Conduct and by signing below, I agree to comply with all guidelines.

Name	Signature	Date
Travis Bruner		09/26/17
Michael Connell		09/26/17
Taylor D. Davis		09/26/17
Ricky Gal		09/26/17
Raine Sagramsingh		09/26/17

Appendix B: Functional Decomposition

Overall Design

- Operates in most weather conditions

Equipment

- Protects fragile equipment during testing
- Enables operation and storage of outside equipment
- Restrains equipment for safe transit
- Permits loading and unloading of equipment
- Resists overheating electronics
- Adapts to fit different sized equipment
- Sustains running equipment for duration of test
- Provides storage for equipment in cases

Vehicle

- Commutes to test site, potentially in rough terrain
- Generates its own power
- Secures vehicle against intrusion
- Satisfies Federal Motor Vehicle Safety Standards
- Absorbs the shock from the road in transit

Operator

- Accommodates multiple lab workers with pre-prepared work stations
- Allows workers to use a restroom

- Provides ergonomically friendly layout
- Maintains acceptable temperature for workers
- Stores food and drinks at desired temperatures

Appendix C: Target Catalog

Table 30
Complete Target Catalog Including Categories, Functions, and Targets

Category	Function/Need	Target
Operator	The mobile lab is technician friendly.	Storage of food at 70°F or 40°F
		Heat food and drink to 90°C
		Interior temp of 68-77 °F
	The interior provides ergonomic conditions for operators.[1]	Lifting index below 1
		REBA postural MSD risk of 1
		RULA MSD risk level less than or equal to 2
		SNOOK table task assessment meeting 75% of the total population
	Operators have access to a restroom on site.	Restroom within 5 min. drive of testing
		Restroom access 24/7

[1] Ergonomic targets established based on information from ergo-plus.com.

	The vehicle interior allows users ample test space.	2 ft. clearance on any side of operator while testing
		overhead clearance for operators up to 6’2”
		3 ft. center aisle walkway
		test space at least 2 ft. from doorways
	The lab has workstations for multiple operators.	can accommodate 1-3 test operators
		seating for at least 4 people
		at least 8 ft^2 of desk space per test area
Lab Equipment	The vehicle allows for easy loading and unloading of lab equipment.	ramp with incline < 10% grade -or- lift with load capacity of at least 150 lbs.
	Lab equipment functions inside of the vehicle.	equipment continuously runs between 32°F and 104 °F
	The unit accommodates varying sizes of equipment.	storage for racks of varying heights up to 6’
	The equipment is not damaged in transit.	restraints resist 100 lb. force shock
	There is proper control of electrostatic discharge.	ESD below class 1B

Vehicle Capabilities	The unit is capable of driving on unpaved roads.[2]	total wheel torque < max tractive torque
	Vehicle satisfies Federal Motor Vehicle Safety Standards.	See Part 575.103 for truck-camper loading
	The unit transports all the desired equipment.	See Table 1
	The unit is self-sufficient.	provides at least 6kW of power
		Runs for 55 hrs. without recharge/replace
	The vehicle can withstand various climates/environments.	withstands outside temperatures between 20 °F and 105 °F
		can withstand up to 3” of rain

[2] Information for driving on unpaved roads taken from the University of Florida’s Design and Manufacturing Lab.

		can withstand up to 3" of snow
		can withstand up to 75 mph winds
Overall Design	The design provides the sponsor with a reasonably priced option.	Interior cost: ~$30,000
		Non-recurring costs: ~$150,000
	The design minimizes operational costs.	Each deployment: < $2,500

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