C U S D
CORNELL UNIVERSITY
SUSTAINABLE DESIGN

Cornell University
Systems Engineering

GRADUATE PROJECT REPORT

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Introduction

Overview

The Sustainable Mobility team is a part of Cornell University Sustainable Design (CUSD) and is dedicated to re-designing public transportation in Tompkins County, New York. This interdisciplinary team, comprised of both undergraduate and graduate students from Cornell University, is advised by both Sirietta Simoncini and Wenqi Yi.

To best identify and meet the needs of both stakeholders as well as users, the team utilizes the design thinking process because of its human-centered approach. After, the team goes through an iterative process by working alongside key stakeholders such as Tompkins Consolidated Area Transit (TCAT) to get feedback and critique on their current designs. This semester the team worked on multiple different projects as indicated by the five subteams: Logistics, Shelter, Routing, Electrification, and Master Plan.

Project History

Last semester the team had two main subteams: Routing and Shelter. The Routing team worked on analyzing Lansing bus routes to address low ridership problems in certain geographical areas. Using fact-finding and empathy fieldwork, Routing examined TCAT routes 36, 37, and 77. Several aspects of their proposal were recently implemented; additional details can be found in the Routing section. The Shelter team works on designing an innovative bus shelter system that is both modular and solar-powered. Last semester, the team added a few new features to their shelter including an indicator light to tell passengers when a bus is approaching.

Most projects that are a part of Sustainable Mobility were originally from the class SYSEN 5740: Design Thinking for Complex Systems. Taught by Sirietta Simoncini in the Spring, it encompasses ideas such as empathy fieldwork and prototyping. After the conclusion of the class, projects are transferred to Sustainable Mobility for further development. The most recent addition from 5740 is the Collegetown project, which includes the Collegetown business improvement district and a satellite parking lot.

Team Structure

Although last semester the team was composed of two subteams, this semester started with three subteams - Shelter, Routing, and Logistics. The Shelter team is still focusing on creating an innovative bus shelter system and identifying a viable spot for the first ‘showcase’ shelter. In addition to Lansing, the Routing team has been focusing on a portion of the Collegetown Project, creating a satellite parking lot to address the issue of parking in Collegetown. The Logistics team focuses on general team logistics as well as another part of the Collegetown project, establishing a Collegetown business improvement district.

During the semester we added an additional two subteams, Electrification and Master Plan. With TCAT receiving a grant for up to three electric buses, the Electrification team was formed to help identify potential routes and charging station options. Additionally, the Master Plan team was tasked with identifying optimal locations for potential new bus shelters by creating a profile that accesses different aspects like land ownership and feasibility.

Logistics

Introduction

The purpose of the Logistics team is twofold. First, the team handles general logistics with regards to CUSD and Sustainable Mobility specifically. This includes matters such as the Town Gown Award and CUSD's Freshmen Pilot Program. Second, a portion of the team is dedicated to the idea of establishing a business improvement district or BID within Collegetown.

General Logistics

Town Gown Award (TOGO)

This semester, Sustainable Mobility was awarded the Town Gown Award (TOGO) on Saturday, December 8th. This award is in recognition of the connection between Cornell University and local communities. In the case of Sustainable Mobility, the award recognized the team's partnership with TCAT. In particular, the award highlighted the successful implementation of the bus signs we helped design. The Logistics team helped track attendance for the event and provide a list of the 25 students who would represent the entire Sustainable Mobility team to Matt Yarrow, the team's point of contact at TCAT, for his speech.

Figure 1: TOGO award group picture

CUSD's Freshmen Pilot Program

A new addition to CUSD overall is the introduction of the Freshmen Pilot Program. As part of CUSD's commitment to inclusion, this program is designed to address the gap that some underclassmen may experience during regular recruitment. For example, many previous underclassmen have noted that they have less previous experience working on technical teams than their upperclassmen peers. Thus, the purpose of this credit-free program is to provide exposure to CUSD's projects so that freshmen, as well as sophomore transfers, are fully prepared to become a regular CUSD member the following semester. The interview process consisted of both group and individual interviews that were focused on behavior rather than technical skills. Fifteen students were selected for the program and of those, three were assigned to shadow Sustainable Mobility. However, due to several unavoidable conflicts, the students were only able to attend two meetings. During these meetings, they attended an overview presentation of each subteam and also shadowed the Shelter and Routing team.

Collegetown Business Improvement District (BID)

Introduction

This semester, the Logistics team has been working towards determining if it is possible to implement a Business Improvement District, or a "BID" in Collegetown. A BID is a defined area within which businesses are required to pay an additional tax/levy in order to fund projects within the district's boundaries. Our team has been interested in the possibility of proposing a BID in an effort to promote local business. This proposal would imply offering desirable services for the Collegetown area such as marketing, planning, events, and economic development.

While the BID project has been a main focus of the Logistics team, we have also been working closely with the Routing team, particularly those who are working on the satellite parking lot project. The satellite parking lot project can be used as an incentive to develop a BID as it helps aid the problem of parking scarcity in Collegetown.

This Semester

This semester consisted of researching the purpose of BIDs in upstate New York which involved contacting local community members. Over the course of the semester, we talked with Collegetown Small Business Alliance founder Marty Johnson, Deputy Director for Economic Development Tom Knipe, and Downtown Ithaca Alliance Executive Director Gary Ferguson. Additionally, we also worked with Benjamin Richer, the previous lead for the Collegetown Project and, at the time, a Systems Engineering student. From their combined insight, we learned about the various challenges associated with BID formation. In Collegetown, gauging interest in a BID will need to be assessed in depth prior to drawing boundaries. Furthermore, property owners will need to agree on an appropriate levy for the area, which is already burdened with unusually high real estate prices and labor issues. Lastly, different needs must be accommodated to ensure that both large and small businesses, as well as commercial and residential property owners, are benefitting equally from the BID.

Moving Forward

After speaking with different community members, our team has decided that the next step is to research the benefits and drawbacks of a BID in Collegetown. Our goal for next semester is to understand what businesses in Collegetown would want from a potential BID. Thus, we plan to assess local business priorities in order to formulate explanations for why businesses might be willing to pay more money for the amenities that a BID can offer. Once we have a more complete understanding of how we can effectively enhance Collegetown for local businesses, we plan on reaching out to Marty Johnson to decide the best way to connecting other local businesses.

Shelter

Introduction

Goals for the semester

In our most hands-on and impactful semester yet, we started off with several important goals to be completed by semester's end. First and foremost, it was imperative for the team to finalize all design components for the shelter structure, as well as for the implementation of the shelter. Specifically, all design choices, ranging from materials for certain parts of the shelter, to the type of concrete pad being poured, needed to be completely finalized. These design choices were derived through diligent research, and through the use of systems engineering tools such as decision matrices and top-down design.

Once all the design choices were finalized, it was important for the team to determine the funding situation to begin prototyping. In this way, this semester provided its own challenges, as we needed to understand the differences between funding for the prototype and funding for the actual finalized structure. Thankfully, CUSD was able to provide a substantial aid for the prototype funding. The prototype, although delayed due to shipping time and other unforeseen circumstances, was intended to provide a rough overview of the electronics of the shelter as well as a real-life look at implementation of the structural connections. Essentially, we were unable to produce a full shelter for the prototyping phase, as only the essential parts were ordered. This way we could we could start prototyping in order to see for how the full shelter might turn out.

Aside from prototyping, it became evident that the the team needed to determine how the actual shelter will be funded. The team learned this semester that our first shelter will tentatively be in Lansing, NY at an intersection near Village Solar, a newly developed apartment complex. The costs will most likely be split between Village Solar and TCAT. TCAT will most likely pay a minority share of the material costs as well as installation and maintenance costs. Village Solar will probably pay the rest of the materials costs as well as pouring the concrete.

A further goal for the team this semester was to finalize the manufacturers list for components that are not made in-house. In order to optimize efficiency and minimize costs, the team set out to find the best suppliers for each component of the shelter, such as the polycarbonate panels, the aluminum T-Slot extrusions, and the transparent solar panels, among other components. By finalizing these manufacturers, it gave the team a more refined estimate of how much the total shelter would cost in the end.

Aside from the technical specifications and design choices that needed to be finalized this semester, it was crucial for the team to create a network of communication with Cornell, TCAT, the Town of Ithaca, and the Town of Lansing. By having a more open line of communication with these stakeholders, it allowed the team to acquire more transparency with town codes as well as how we will be implementing our shelters. Additionally, the team formed the early workings of a new partnership with Taitem Engineering, a firm located in Ithaca that specializes in construction and engineering. Due to the fact that the students on the team cannot fully participate in the design and construction of our shelters due to liability reasons, it was important to create this partnership with Taitem, and eventually make this a “Taitem project” to escape liability. In fact CUSD (and the CUSD Mobility team) is not a professional engineering firm and all the deliverables that we produce have to be intended as recommendations or guidelines, which can be used by external organizations (like TCAT) at their discretion. Furthermore, before any of the materials provided by CUSD can be implemented, they must achieve the needed verifications and authorizations (such as PE stamp) of external licensed professionals (like TAITEM). Apart from this liability assurance, Taitem helped provide valuable knowledge on how to further continue this process and be able to construct our first shelter with compliance with town regulations.

Design V.0/V.1

Picking up from where the team left off last semester, the team has created several iterations of the shelter throughout this semester. Each new iteration aimed to solve certain issues relating to structural member placement, component layout, ease of electrical implementation, and application of brand new design components. Also, it was important to the team that each new design iteration became increasingly aesthetically pleasing, as this is a very important factor for everyone involved with the project. The evolution of our shelter design can be seen in the following figures.

Figure 1: Design iteration renderings for the beginning of the semester, middle of the semester, end of the semester

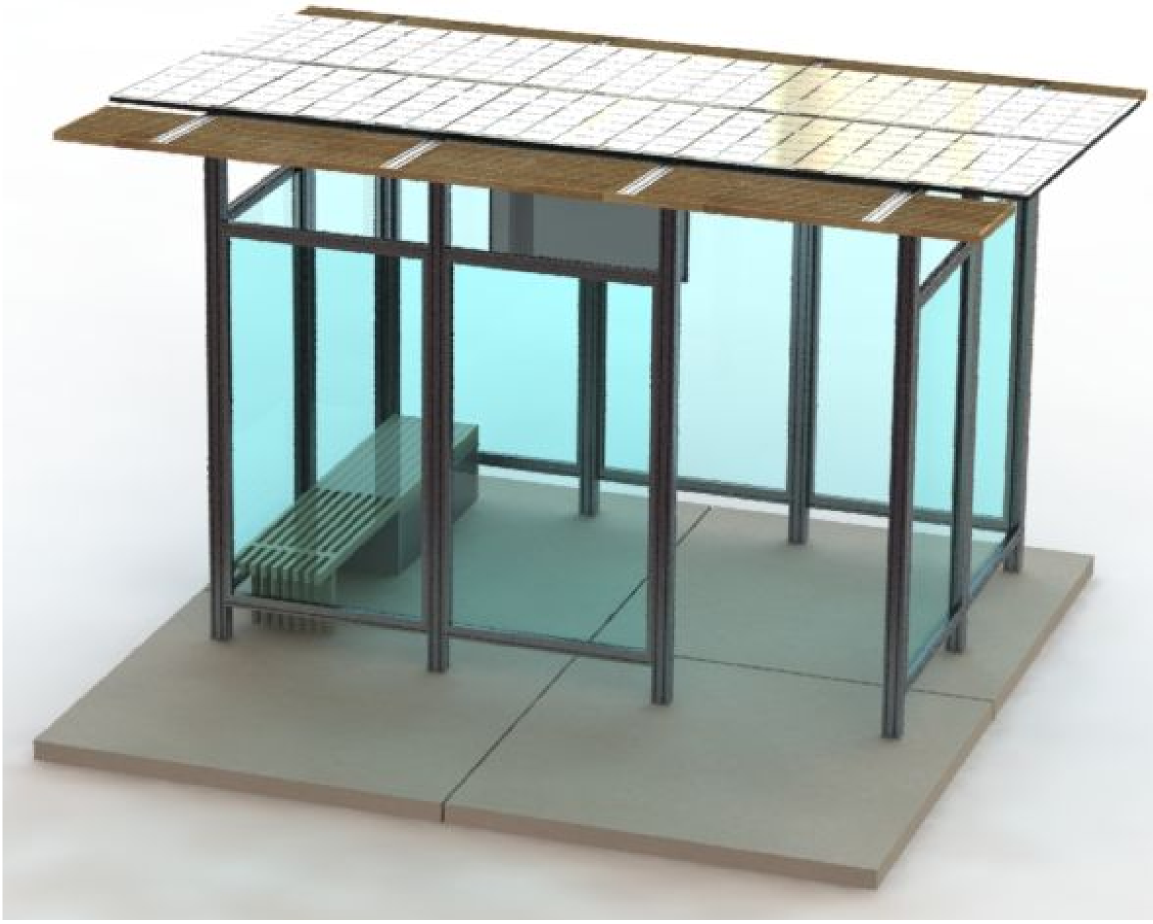


Figure 2: Final revision rendering (Diametric View)

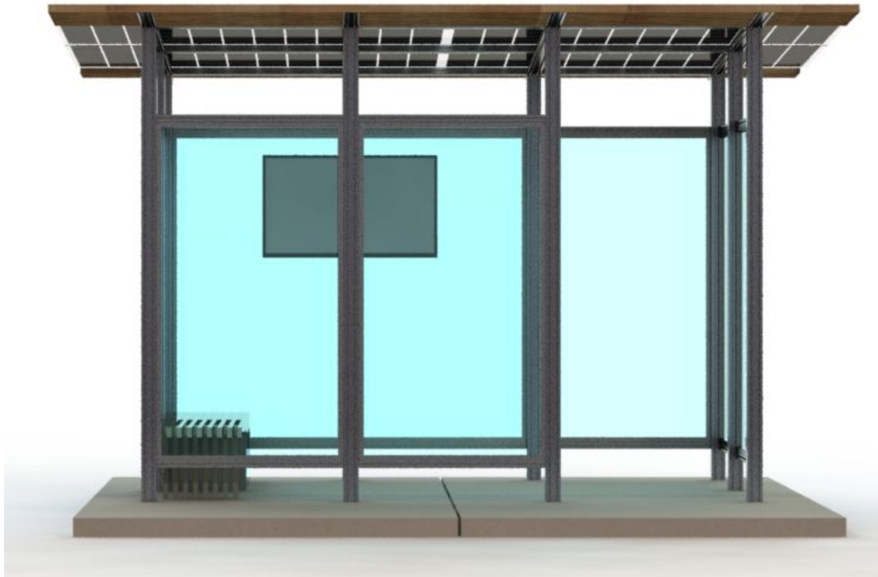


Figure 3: Front view of final design

Figure 4: Side view of final design

The final design iteration is a testament to all the hard work and effort that was put in this semester. The team iterated through several design reviews with the help of stakeholders including Yossi from Taitem Engineering, Matt Yarrow from TCAT, Michael Long from the Town of Lansing, and Larry Fabbroni, the head civil engineer at Village Solar. Everyone's constructive criticism and guidance helped us achieve our final design, which we were able to solidify by the end of the semester.

The mechanical design includes aluminum T-Slot extrusions as the mainframe and subframe bars, polycarbonate side panels, transparent solar panels, a custom roof racking system for the solar panels, a roof overhang, a bench made of wood and concrete, and more. The specifics of each component will be explained in detail later in the report.

Main Design Changes

With each new iteration came more and more design changes. We made certain small changes to existing components and connections, and we also made brand new additions. The main design changes that came out of this semester's work are as follows:

- The concrete pad dimensions and cuts were finalized
- The shelter mounting scheme and mounting braces were selected
- The solar panel quantity, orientation, and mounting scheme were decided upon
- The new roof overhang was designed and implemented
- The bench was completely redesigned in order to provide more space to store all electrical components, and is made of entirely new materials

These new design additions will be discussed at length later in the report.

Structural Frame

Modularity

The shelter was designed with modularity in mind in order to streamline all the shelters while allowing for flexibility and customization based on the specific needs of each site. For example, the placement of features such as the entryway, the television display, and the bench can be varied while retaining the same design aesthetic as the other shelters. This modularity contributes to the overall ecomodernism of the design.

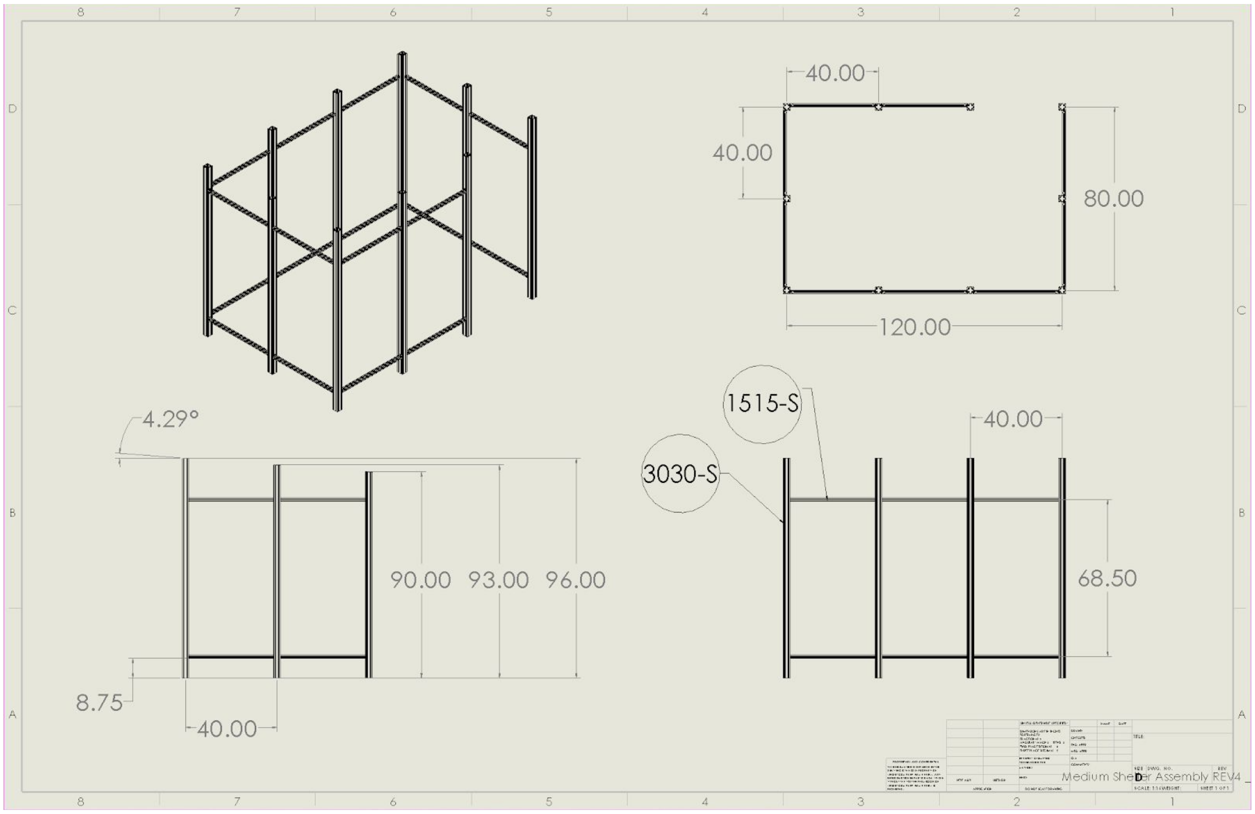


Figure 5: Shelter frame schematic

The shelter can be broken down into 40 inch units, or modules, which serve as the basis for any shelter. The dimensions of each module was determined in order to comply with ADA regulations. To scale from a small shelter to a medium shelter and a medium shelter to a large shelter, additional modules are added.

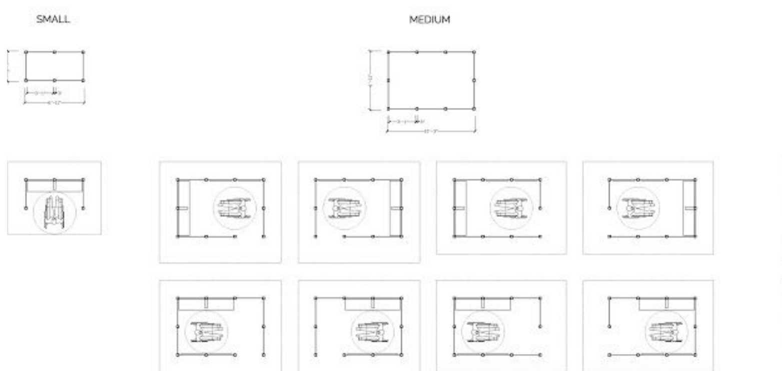


Figure 6: Layout and feature variations of the small and medium shelter.

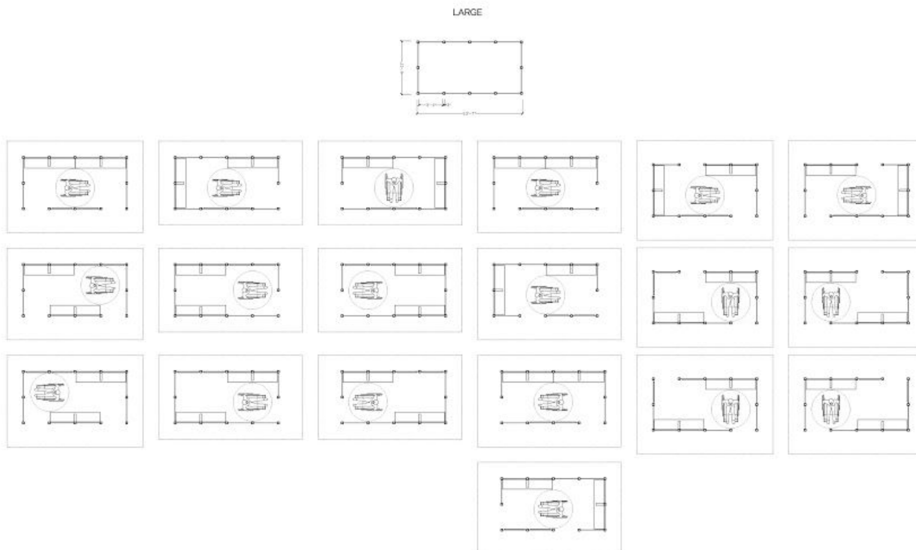


Figure 7: Layout and feature variations of the large shelter.

The modularity of the shelter also serves a practical role for assembly and part procurement, as it allows the process to be streamlined, leading to shelters that can be built more quickly while costing less.

Frame Profiles

For the shelter frame, 80/20 15 series solid profiles were used. The frame can be divided into three categories, each with different T-slot profiles: the mainframe, the subframe, and the roof. The specific dimensions of each of these profiles can be seen in the figure below.

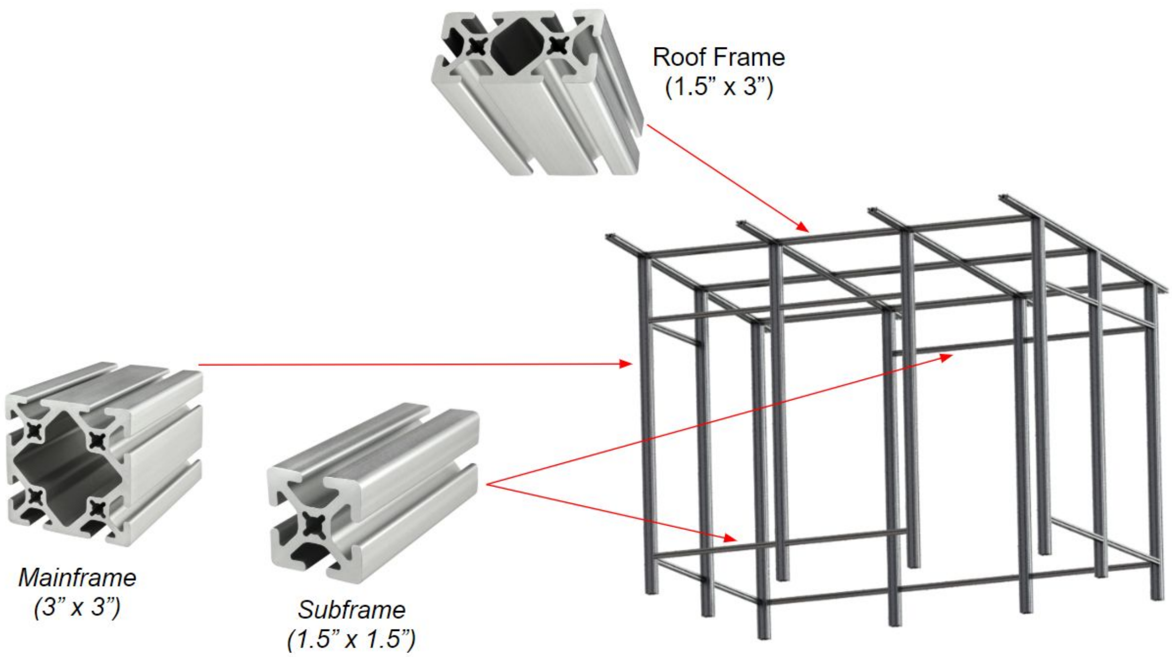


Figure 8: Shelter frame schematic showing the three variations of 80/20 T-slots required.

The mainframe members are to be machined with a 4° cut on the top in addition to access holes for the electrical conduits. The members comprising the subframe need counter bores on either end for butt fasteners (to be discussed in detail in Frame Joint Connections and Mechanisms section). Finally, the roof members require access holes for the electrical conduits.

Frame Joint Connections and Mechanisms

The joint connections for the frame were finalized in the Spring of 2018. The T-slot profile of the frame members allows for seamless connections that add to the shelter’s aesthetic appeal. In order for the shelter to be structurally stable, we used the strongest, most durable profiles available for the 15-Series T-Slot members.

The joint connections we are using are called butt-fasteners. These are ideal because they are incredibly strong and are hidden within the T-slots. If the frame was held together using these connectors, there would be no visible hardware, further adding to the ecomodern concept that defines our shelter.

Figure 9: Butt fastener being used in a T-slot.

Additionally, we chose to utilize triangle fasteners for the roof because these connections are discrete, very strong, and require no additional machining.

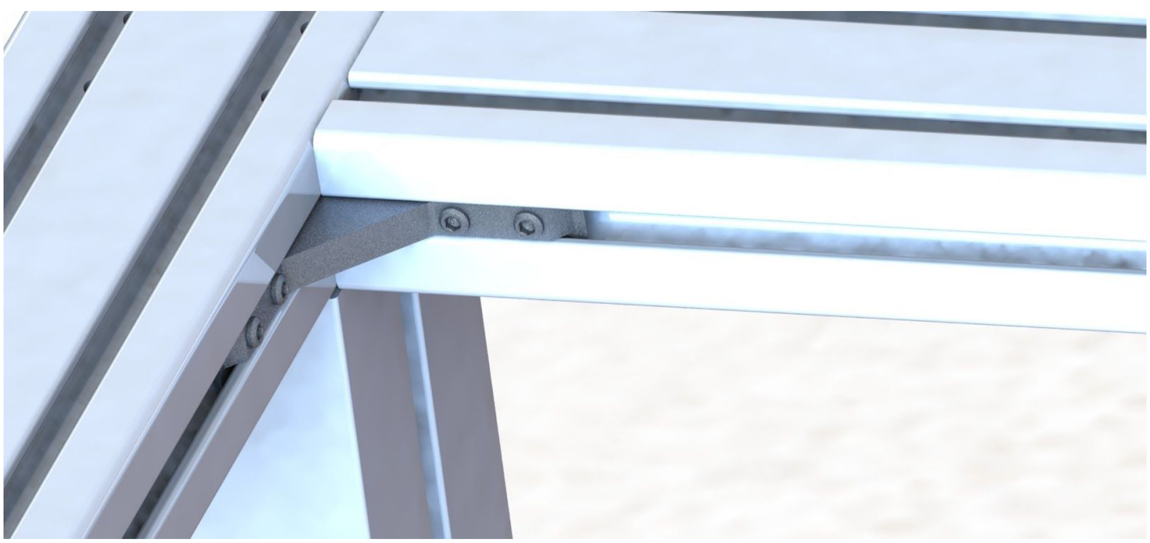


Figure 10: Triangle fastener being used in a T-slot.

Material Properties

We analyzed the material properties of our selected materials in order to justify the choice and ensure that the material met our needs. After much research, we decided on the 6105-T5 Aluminum Alloy because it delivers the same strength as steel, but is a lighter and more machinable alternative.

	Tensile Strength - ksi*	
Aluminum Profile Alloys: Number and Characteristics	**Ultimate minimum**	**Yield minimum**
6105-T5 (80/20's Alloy)	38.00	35.00
6063-T6	30.00	25.00

*Figures based on material thickness of 0.125" to 1.00"
From The Aluminum Extrusion Manual, published by The Aluminum Association and the Aluminum Extruders Council.

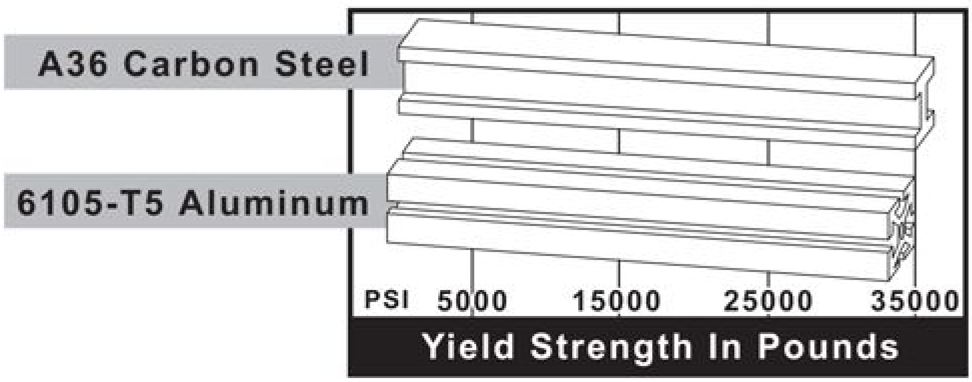


Figure 11: Material properties of 6105-T5 Aluminum from the resources provided by the 80/20 website.

	1515-S	3030-S	1530-S
Material	Aluminum	Aluminum	Aluminum
Grade	6105-T5	6105-T5	6105-T5
Finish	Anodize	Anodize	Anodize
Color	Clear	Clear	Clear
Drop Lock	2°	2°	2°
Moment of Inertia - IX	0.2631"^4	3.3496"^4	1.8127"^4
Moment of Inertia - IY	0.2631"^4	3.3496"^4	0.4957"^4
Surface Area	1.138 Sq. In.	3.109 Sq. in.	2.036 Sq. In.
Yield Strength	35,000 psi.	35,000 psi.	35,000 psi.
Modulus of Elasticity	10,200,000 Lbs / Sq. In.	10,200,000 Lbs / Sq. In.	10,200,000 Lbs / Sq. In.
Weight lbs	0.1109 per inch	0.3032 per inch	0.1985 per inch

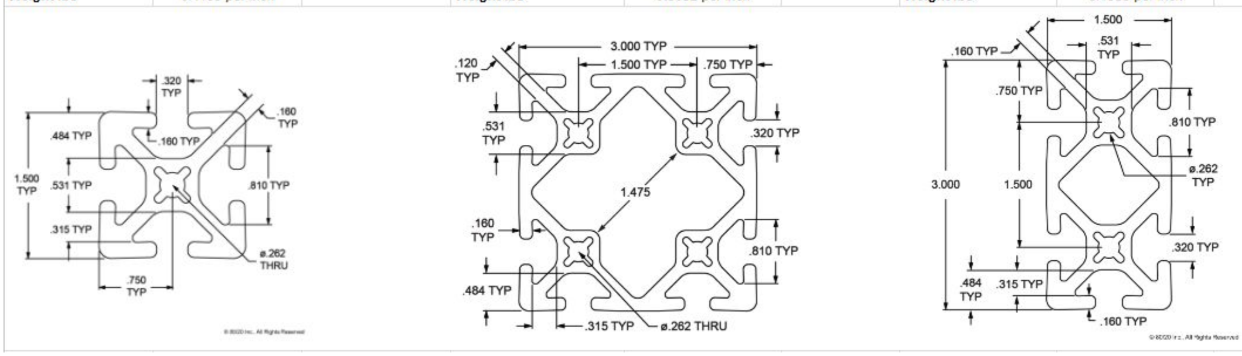


Figure 12: T-slot profiles and properties

The wood and concrete on the roof and bench, respectively, break up the metal appearance of the T-slots and help to seamlessly integrate the shelter with the environment surrounding it.

Full Frame ANSYS

The following analysis sections come from the Spring 2018 Report and few changes have been done:

The goal for the engineers was to evaluate the structural integrity of all the components. The frame was the first process since we needed to ensure that the frame could handle all kinds of loading cases simultaneously. Observing our design initially also raised concerns about lateral loadings since all connections were orthogonal. The purpose of the frame analysis was to ensure that the structure was stable in all axes under the highest loading conditions and that the chosen T-slots would not fail under the loading experienced.

Initial attempts at developing the model of the structure for analysis were to apply a mesh normally to our full structure frame assembly (imported from Solidworks). This excluded all the joint details since we were making the assumption that the joints were not the limiting factor in order to observe the forces and moments at the joints for more detailed analysis. Due to the amount of detail of the T-slots and the large size of the shelter, this method took over 2 hours to only generate the mesh and solve. This indicated some methodology errors and was also unusable for generating the amount of information we needed, since we need to apply various loading cases.

Upon closer observation of the shelter frame and discussion with others experienced in ANSYS analysis, we discovered that using a form of beam analysis, tube analysis, would model our shelter frame reasonably well.

Tube Structure ANSYS

Since the frame consists of various T-slot profiles, a 3D sketch in SpaceClaim can easily apply different post profiles to the sketch lines. This method resulted in an easy-to-solve ANSYS and treated all of the connections as welds. Another benefit of using SpaceClaim is that iterations of one's design can be easily analyzed by updating the beams within SpaceClaim and not having to update the CAD model. Using the beam tool analysis in ANSYS, we generated shear-moment diagrams, stress, and deformation at all points in the shelter. This information was useful for analyzing the integrity and feasibility of the structure itself and for more detailed analysis of the joints as discussed later.

The basic steps for tube structure analysis using ANSYS and SpaceClaim are as follows:

1. Import the Solidworks part into Spaceclaim.
2. Use the Prepare → Extract tool and select everything, yielding a set of lines.
3. Use the Connect and Extend tools (also under the Prepare tab) to fix any tiny gaps and over-extended tubes.
4. Under the Workbench tab, use the Share feature on everything- this is essential.
5. Return to the ANSYS Project tab interface, right-click on Geometry and select the saved beam geometry.
6. Mesh: Once the Beam geometry is created and loaded into ANSYS, create the mesh. Ensure that none of the bodies have "pre-integrated" selected under options and instead have "mesh" selected.
7. Apply loads to the structure as per typical ANSYS procedure. Note: ANSYS' Beam analysis will give the best results when loads are applied to the joints where beams meet.
8. Solution: Under Solution, make sure to right-click and select "Beam Tool" for analysis. All of the normal options when Solution is selected will be greyed out and unselectable.

The same analysis methodology from the Fall 2017 report was used to analyze various loading scenarios of the shelter. The structure must be designed taking into account both use cases and misuse cases. Using a use cases list, which lists all possible interactions with the structural frame system, we can ensure that all potential loadings to the system are accounted for and analyzed. A use cases list includes both normal uses, misuses, unintended uses, and environmental interactions.

Use Cases and Loads					
Use Case	**Design Priority**	**Load Priority**	**Load Type**	**Support Location**	**Load (approx.)**
User	1	3	Distributed Load	Concrete Pad/ Bench	200 lb
Shelter	1	1	Distributed Load	Concrete Pad	3300 lb
Bench	1	1	Distributed Load	Concrete Pad	550lb
Users Sit on Bench	1	2	Distributed Load	Concrete Pad/ Bench	1150 lb
User Lies on Bench	1	2	Distributed Load	Concrete Pad/ Bench	750 lb
Users Stand in Shelter	1	3	Point Loads	Concrete Pad	2000 lb
Users Lean on Handrail	1	2	Point Load	Concrete Pad/ Frame Mounts	200lb
User Puts Bag on Bench	1	2	Point Load	Concrete Pad/Bench	800 lb
Users Bring Large Luggage Inside	2	2	Point Load	Concrete Pad	750 lb
User in Wheelchair Uses Shelter	1	2	Point Load	Concrete Pad	300 lb
Snow Falls on Shelter	1	1	Distributed Load	Concrete Pad/Roof/Frame	6800 lb
Rain Falls on Shelter	2	1	Distributed Load	Concrete Pad/Roof/Frame	3570 lb
User Takes Shelter from Sun	3	3	Point Load	Concrete Pad	3500 lb
Users Chat Inside Shelter	3	3	Point Loads	Concrete Pad	3700 lb
User Eats Inside Shelter	3	3	Point Loads	Concrete Pad/Bench	3510 lb
Wind Blows on Shelter	1	1	Distributed Load	Concrete Pad/Frame/Panels	6800 lb

User Leans on Panel	2	2	Point Load	Concrete Pad/Frame/Panels	3500 lb
User Hangs off Roof Overhang	3	2	Point Load	Concrete Pad/Roof/Frame	3500 lb
User Kicks Shelter Panels	3	3	Point Load	Concrete Pad/Frame/Panels	600 lb
Rock Hits Shelter Panels	3	2	Point Load	Concrete Pad/Frame/Panels	200 lb
Tree Limb Falls on Shelter	2	2	Point Load	Concrete Pad/Roof/Frame	400 lb
User Hits Display Panel	3	3	Point Load	Display Panel/Frame	180 lb
User Throws Trash in Can	3	3	Point Load	Shelter Frame	0.25 lb
User Leans Bicycle on Shelter	2	2	Point Load	Frame/Panels	18 lb

Figure 13: Shelter Loading Use Case Table

Such a list also includes the importance of each use case. In our use cases list we added additional loading priorities to analyze which use cases would apply a significant load that could affect our structural design. We also added the approximate loading type, load application location, and location most likely to experience greatest stress, shear, or deformation. Finally, we gave overestimates of the load that would be applied in each use case scenario in order to ensure that the structure would be able to survive these loadings (a factor of safety of 2). The snow loading, one of the most significant design factors, was decided as 40 psf based on ASCE 7-10. These load cases were then iterated into our ANSYS to understand the structural behavior under normal usage and worst case scenarios.

In this example, simple snow loading (assumed as a low impact scenario) is compared to a heavily loaded scenario.

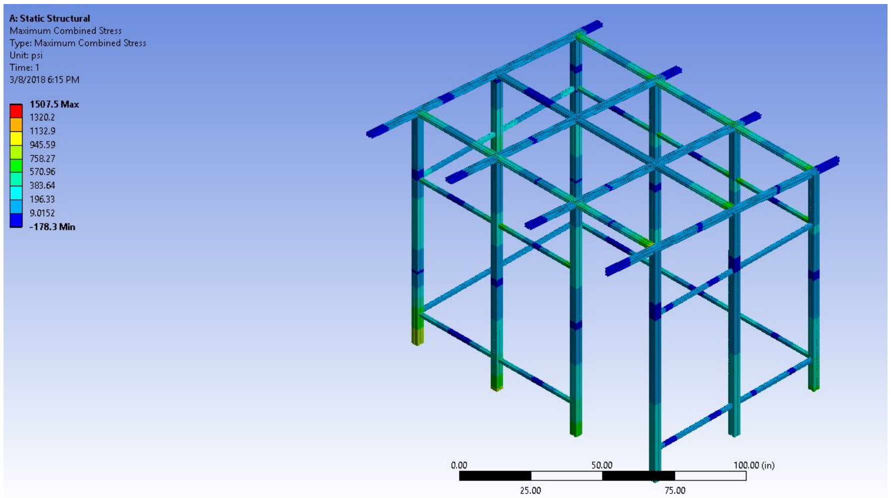


Figure 14: Shelter structure maximum combined stress results under snow loading conditions

Figure 14, shows that the maximum stress experienced by the shelter structure is 1507.5 psi. Compared to the 28 ksi lower bound maximum tensile stress of Al-6105 there is a significant factor of safety and the structure is not under any compromise. Figure 15 below, shows the maximum stress under all sorts of loading (leaning, pushing, pulling, and hanging) and the resulting maximum stress is 1662.2 psi which like above is also of no concern. The scale is exaggerated for clearer visuals of the deformation of the structure, but the highest stressed areas of the structure are near the joints between subframe and mainframe and at the shelter foundation mounts.

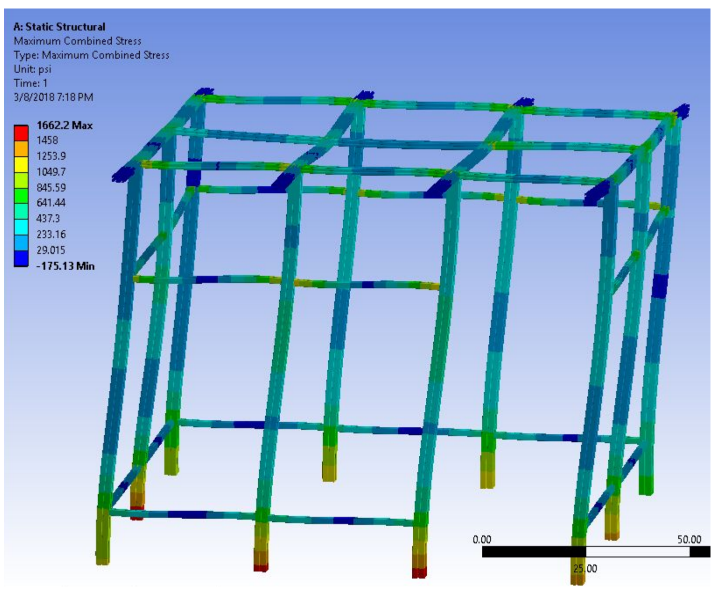


Figure 15: Shelter structure maximum combined stress results under various loads including snow loads

The results of the structural analysis hint that transverse support is unnecessary. However, further analysis of components such as joints and roof are required to ensure proper behavior of the design.

Joint ANSYS

After the final decisions of the butt fasteners being the joint of choice for the subframe members, the design was implemented into the CAD files. The goal for the analysis was to ensure that the joints would not move/shift under the loading cases described in the previous section.

The methodology for generating results for this analysis was to create test joint assemblies that represented the subframe to mainframe connections, apply the loading and moment definitions to the assembly based on results from the beam tool, and then use bolt pretensioning and contact tool to determine the contact behavior of the joints and the posts. The reason bolt pretension can be used here is due to the idea that the joints are held together using friction which originates from the bolts in the butt fasteners being tightened down. The contact tool will generate solutions that show if the post members are “sticking” or “sliding” to each other.

To ensure the different joint scenarios were evaluated and the results were recorded in an organized manner, we generated an analysis databook to control the inputs and outputs of the analysis. The databook creates an informational slot for each of the joint locations which is split up based on levels. Figure 16 shows the nomenclature for the databook and how all the joints analysis will be covered.

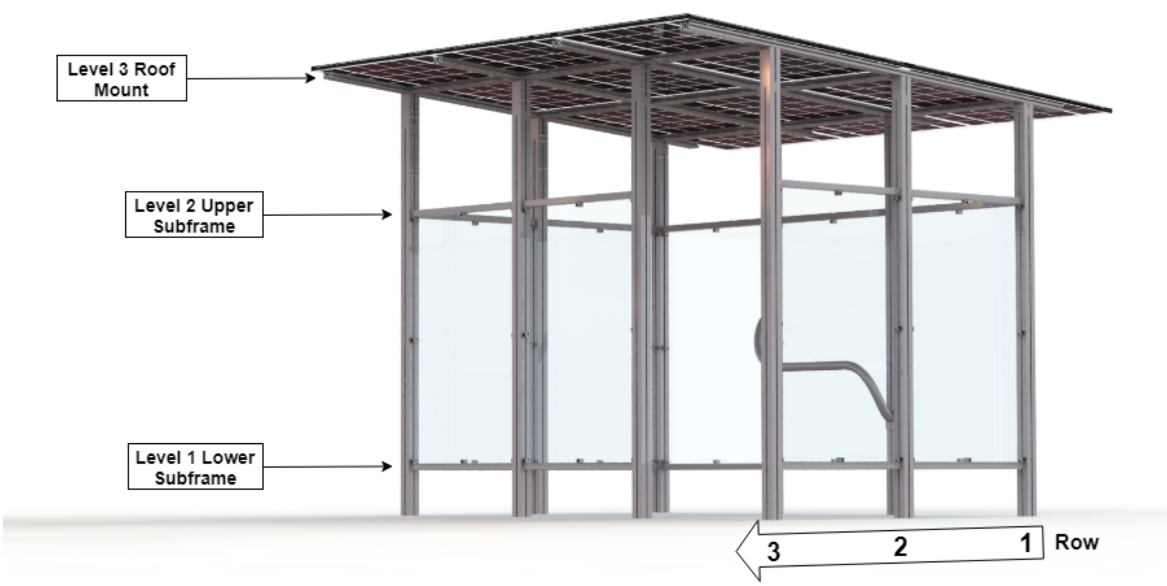


Figure 16: Nomenclature description for the ANSYS Databook with rows describing the joint location and the levels indication the sheet in the Excel file

The inputs from the beam tool discussed in the previous section that will be applied to the joint test assembly are the bending moment, shear force (2-axis), and axial force. Due to the vast amount of joints and loading cases, only a few examples that were assumed to be the critical loadings were evaluated.

The excel data book resembles the 2D top view floor plan of the shelter as shown in Figure 17. This better helps identify the location of joint results to improve user simplicity. Figure 18 shows a completed example of the databook at subframe member (2,5,4) which is the upper level subframe member located in the front, next to the left of the entrance.

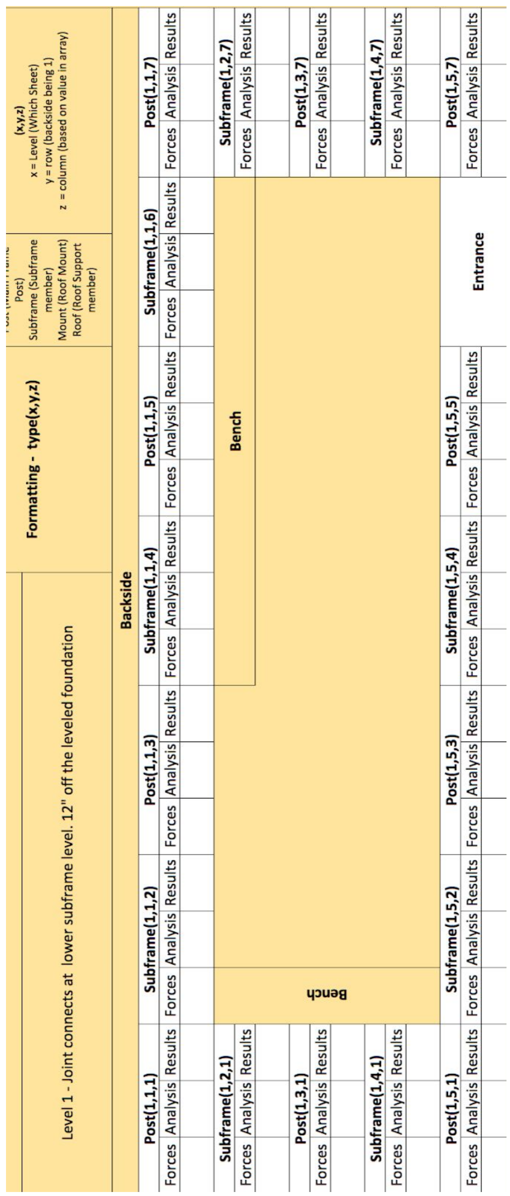


Figure 17: Empty example of the ANSYS Databook for Level 1 (Lower Subframe)

Subframe(2,5,4)			Post(2,5,5)	
Forces	Analysis	Results	Forces	Analysis
Snow Only Moment = -12.07 lbf*in Shear = -1.6805 lb **Snow and More** Moment = -879.08 Shear = -111.78 lb	Bolts pretensioned with displacement of .0075 in	**Snow Only** Bar sticks -No material failures **Snow and More** Obvious bending but t-nut sticks but only bottom of subframe is sticking	**Snow Only** Axial = -3.029 lbf **Snow and More** Axial = -44.573 lbf	Bolts pretensioned with displacement of .0075 in
Frontside				

Figure 18: Filled out example between subframe member (2,5,4) and the main post (2,5,5)

Using these inputs, the information is input into the test joint which is full defined, but with shorter posts since only the behavior at the joint is being investigated. Like previously, the snow loading is used as a baseline design requirement and is compared to a heavily loaded scenario.

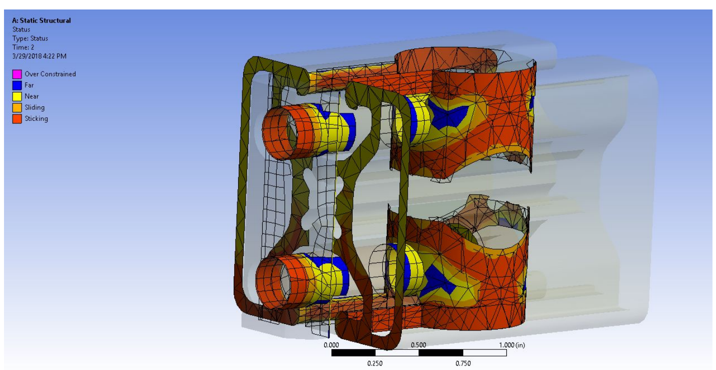


Figure 19: Contact results on the subframe member under significant loading of structure in all directions

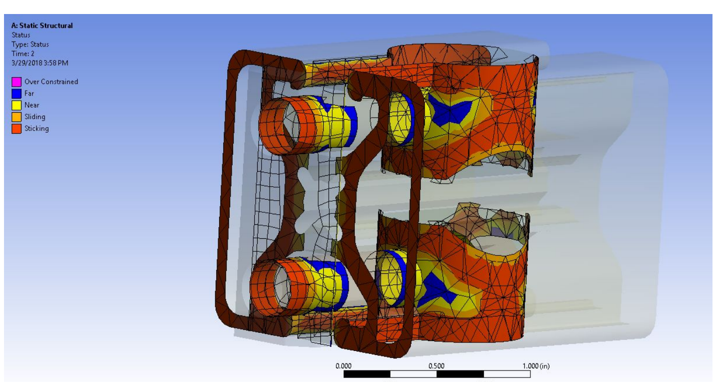


Figure 20: Contact results on the subframe member under snow loading only of structure

The contact tool in ANSYS generates both quantitative and qualitative results that both can lead to interesting conclusions. Conducting the analysis with a frictional coefficient of 0.15 between aluminum and steel and 0.2 between two aluminum surfaces yields the results seen in Figure 19 and 20. These frictional coefficients seem lower than usual to account for any sort of potential lubricant and design safety. Figure 19 and figure 20 show the comparison in the “sticking” of the subframe to the main post. The contact tool defines sticking as a solid bond comparable to a proper weld. Sliding indicates that the surfaces are in contact, but does not offer structural support. In the specific scenario shown in the two figures, the subframe member would remain in place under both loading cases. Figure 19 indicates that loading forces in the member may create some bending in the subframe member but remains partially bonded with not visuals of disconnection from the main post.

Other surface connections can be seen as well such as the T-nut contact, but based on multiple iterations, that contact seemed to always be “sticking.”

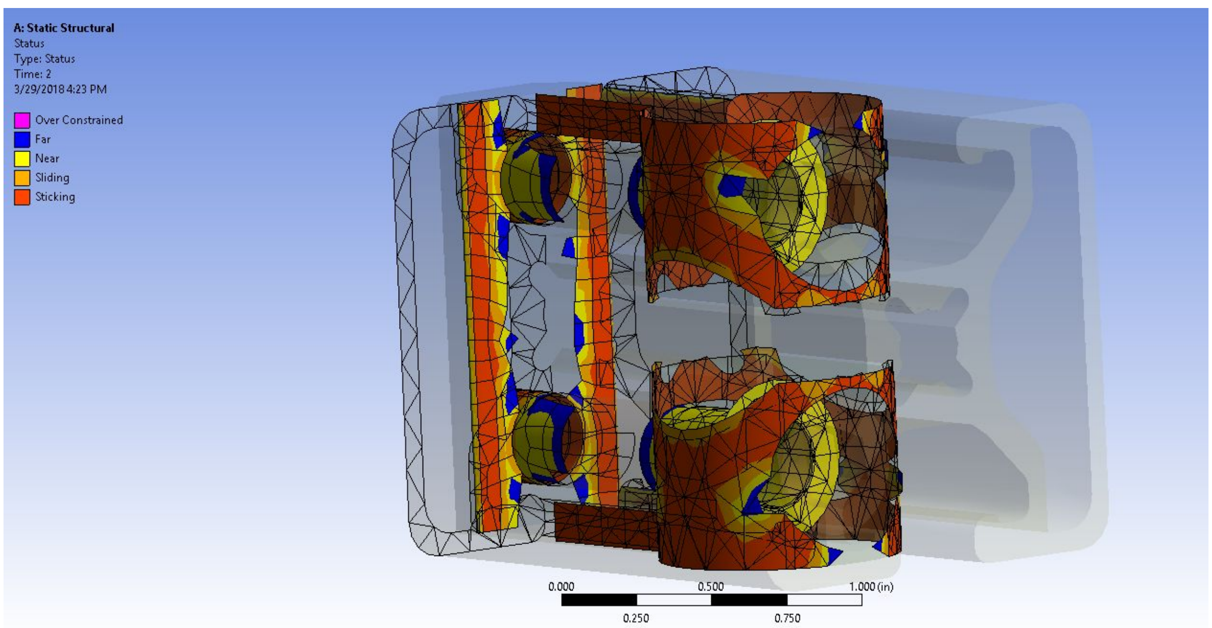


Figure 21: Contact results on the subframe member

Stress and deformation of the joint area were also considered to ensure that the bolt pretension was not too tight/harmful to the joint components themselves. The maximum stress using the pretension for ¼” - 20 allen head cap screws was observed to be 22 ksi which is under the the maximum yield stress for structural steel. For future semesters, even more iterations of the analysis need to be completed to ensure full coverage of the structure.

Results and Conclusions

The goal for the ANSYS models was to ensure that the overall structure was feasible and safe under our current design. The primary design constraints were snow loading and high impact use case loadings. The results indicated that the structure itself stands at a factor of safety of about 25 and poses no legitimate concern. Based on data from these analyses, the joints would also operate safely with a factor of safety of about 3 considering the low frictional coefficients. One of the greater risks would be loosening joint nuts which can be mitigated using proper components. Although further ANSYS simulations can be run, current results indicate that the bus shelter frame will be stable and is ready for the prototyping stage to confirm these results.

Side Panels

Material Selection and Analysis

Based on Fall 2017 research we narrowed down the side panel material to either polycarbonate or tempered glass. We constructed a decision matrix that featured lifespan, scratch resistance, appearance/transparency, shatter resistance, weight/density, cost, weather resistance/UV stability and sustainability in order to make an informed decision. For a conclusion on shatter resistance/strength performance for the two materials, we ran finite element analysis for a model 37” x 67” panel in ANSYS. We created split lines in Solidworks to simulate the frame that would hold the panel in place and considered an extreme case of 111.8 mph wind hitting the panel. We conducted this test on different iterations of the panel design, from the thickness to the number of holes we would want the screws to go through. We got the following results:

Summary of material options and corresponding material properties							
Thickness	Holes	(Laminated) Tempered Glass			Polycarbonate		
		Max stress (psi)	Yield stress (psi)	Factor of safety	Max stress (psi)	Yield stress (psi)	Factor of safety
.25 in	3 by 3	9542.9	5148.84	0.54	10093	9021.34	0.89
	4 by 3	6457.2		0.79	6657		1.36
	5 by 3	6199.6		0.83	6381.1		1.41
.375 in	3 by 3	4168.9	5148.84	1.26	4464.9	9021.34	2.02

	4 by 3	2867.6		1.8	2992.8		3.01
	5 by 3	2659.3		1.94	2775.2		3.25

Figure 22: Summary of material options and corresponding material properties

From the results, based on the factor of safety, it became clear that not only would polycarbonate be our better choice for shatter resistance/strength but also a 0.375” thick panel would be better than a 0.25” panel even though the latter means saving money. Other observations we made was that the more holes along the length of the panel, the better the factor of safety for both thicknesses- so we consequently put that into consideration even for our intended frame design.

On weight and density, polycarbonate scored higher because being lighter at 1200 kg/m^3 compared to 2400 kg/m^3 for tempered glass. It would be easier handling a panel made out of polycarbonate, for instance, during installation and maintenance.

Side Panel Material Decision Matrix					
Design Method		Polycarbonate sheet		Tempered Glass	
Metric	Weight	Normalized	Final	Normalized	Final
Lifespan	4	10	40	7	28
Scratch Resistance	5	4	20	8	40
Shatter Resistance	5	9	45	8	40
Appearance/Transparency	3	5	15	10	30
Weight/Density	2	10	20	5	10
Cost	5	10	50	2.34	11.7
Weather Resistance / UV Stability	4	10	40	7	28
Sustainability / Green Impact	4	4	16	10	40
Total		62	**246**	57.34	**227.7**

Figure 23:: Side Panel Material Decision Matrix

Panel Mounting Plan

This new mounting plan is to allow for easier replacement of a damaged panel. This semester we worked on finding a mechanism to attach the frame to the Aluminium T-Slot extrusions and modifying the panel frame design into one that can be easily machined for the prototype shelter.

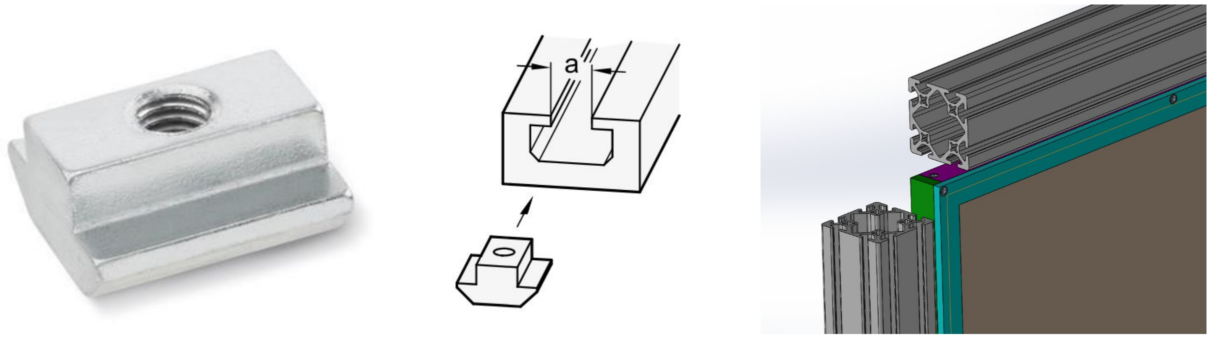


Figure 24: Panel frame to T-Slot connections

We will use nut bolts to attach the frame to the T-slots. Once the T-slot nut has been slid into the T-slot extrusion, allen screws are driven through the holes aligned on the panel's back frames (as depicted above) and into the nuts. This way, both the horizontal and vertical inner frames of the side panel are bolted onto the aluminum T-slot extrusions.

On reduction of machining cost:

I. The 0.25in long and 0.375in wide counter bore holes were reduced to just 0.25in holes that dips all the way into the frames. This would make the hole drilling of the aluminum bars a one stage process instead of a two stage one.

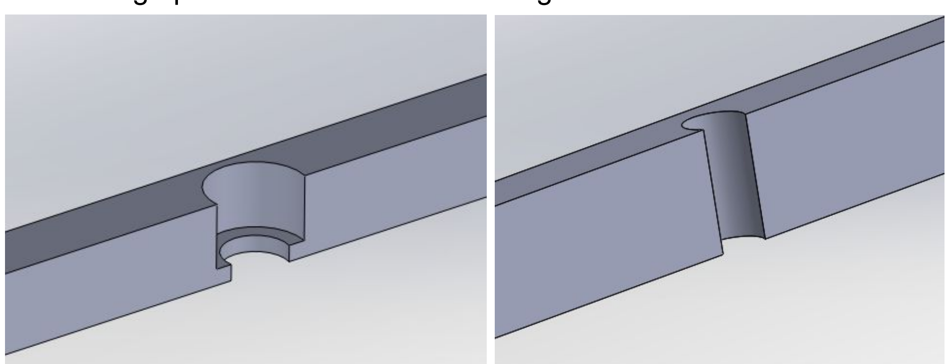


Figure 25: Screw hole with counterbore (before) and without (after)

II. The indentation on the back frame where the polycarbonate side panel rests was redesigned to be more deep and in turn the indentation on the front pieces was omitted. This again would prevent machining both the front and back pieces of the panel's frame while only the back piece can be machined to get the same result.

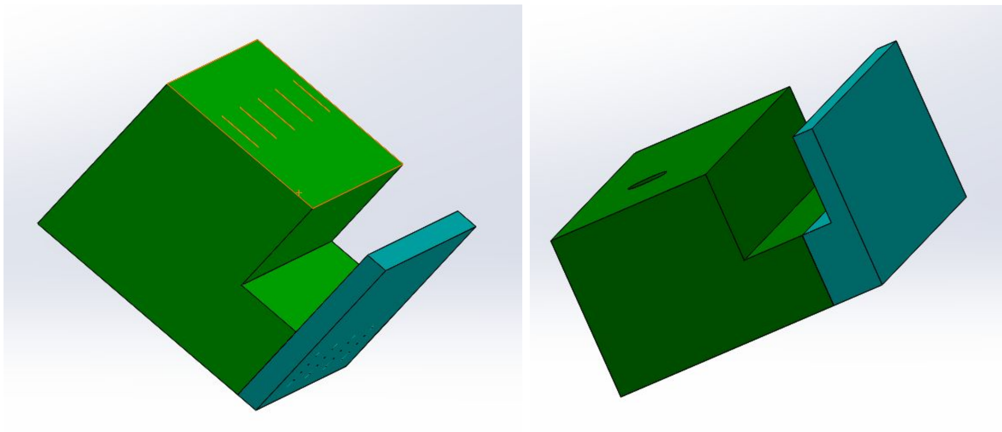


Figure 26: Indentation moved to only the back frame

III. The meshing of the inner frame pieces was omitted in the design. As it is right now, every piece (length and width) of the panel's frame is independently assembled.

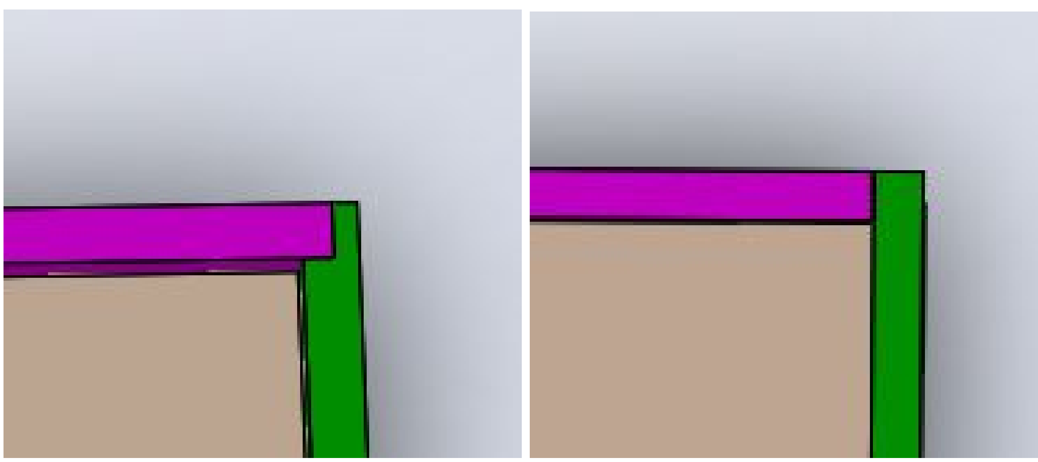


Figure 27: Laying of the frames into one another omitted

With the design ready and the machining cost cut down, next semester we hope to purchase the materials and machine them accordingly in Emerson manufacturing lab to prototype and test our design.

Roof

Appearance and Dimensioning

The roof acts as an integral system of the shelter by providing cover, supporting weight, and integrating solar panel functionality, all while contributing to the overall aesthetics of the shelter. Last semester, significant work was invested in optimizing roof angle dimensions, while this year much of the dimensional changes to the roof occured to accomodate for ease of manufacturing, efficient material use, and part availability as the shelter moved from design to reality.

With regards to roof angle, a steeper angle generally allows for maximized solar gain, at the expense of a larger gap above the side panels; however, upon a completion of a solar simulation specific to the conditions in Ithaca, the roof angle was found to have negligible effect on solar gain. Ultimately, the angle of the roof was decreased from 15 degrees to 4.29 degrees to decrease the gap between the side panels while still preventing natural debris from building up on the roof of the shelter. Additionally, this decreased angle allows for a smaller overhang to be implemented, while still effectively covering shelter users from the elements.

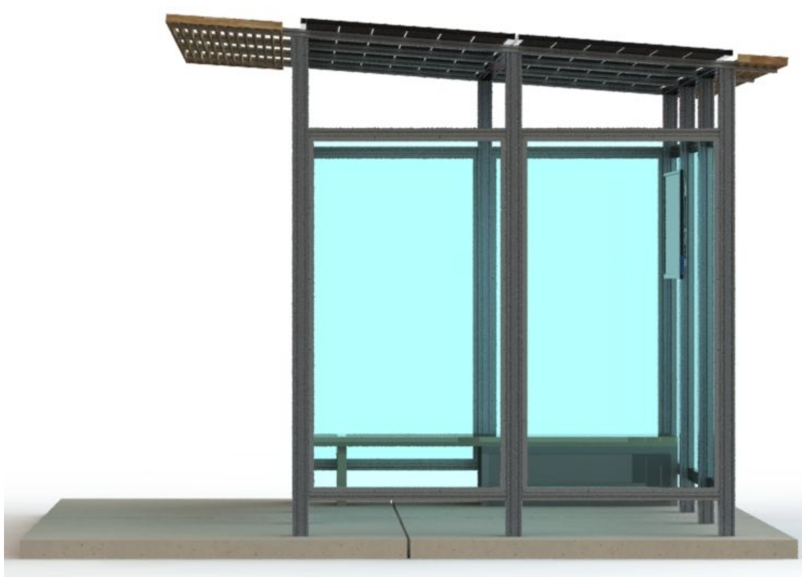


Figure 28: Shelter with 4.26° Roof Incline

As mentioned previously, much of the dimensional change to the roof structure occurred as a result of part availability. Specifically, the desired solar panels—Lumos GSX 60 series—were unavailable, so design alterations were taken to accomodate for a similar, larger panel, the Lumos GSX 72 series. Although roof designs are now available for both sizes of GSX panels, sourcing and availability of panels from Lumos should be heavily considered as procurement of materials for the shelter moves forward.

Originally, the roof arrangement consisted of a 2 X 3 arrangement of Lumos GSX 60 series (39.370in X 62.929in) panels. When altering the medium shelter solar panel arrangement to accommodate the Lumos GSX 72 series (39.370in X 79.173in), the same orientation of the panels could not be maintained without an unsightly long and exaggerated overhang—not to mention a precarious cantilevered mounting situation for the glass panels. Using a 2 X 2 mounting configuration, the long axis of the panels was turned 90 degrees from the axis of the incline. With this orientation, an auxiliary overhang had to be implemented (to be discussed in detail in the overhang section) because the solar panels alone provided no overhang in the new orientation. Ultimately, the new orientation of solar panels will decrease costs as only 4 panels are necessary for a medium shelter, while still providing ample solar energy to power shelter electronics. Additionally, the panel orientation allows for more structural integrity in the mounting of the panels without compromising aesthetics because the panel edge is no longer the fore and aft edges of the shelter roof.

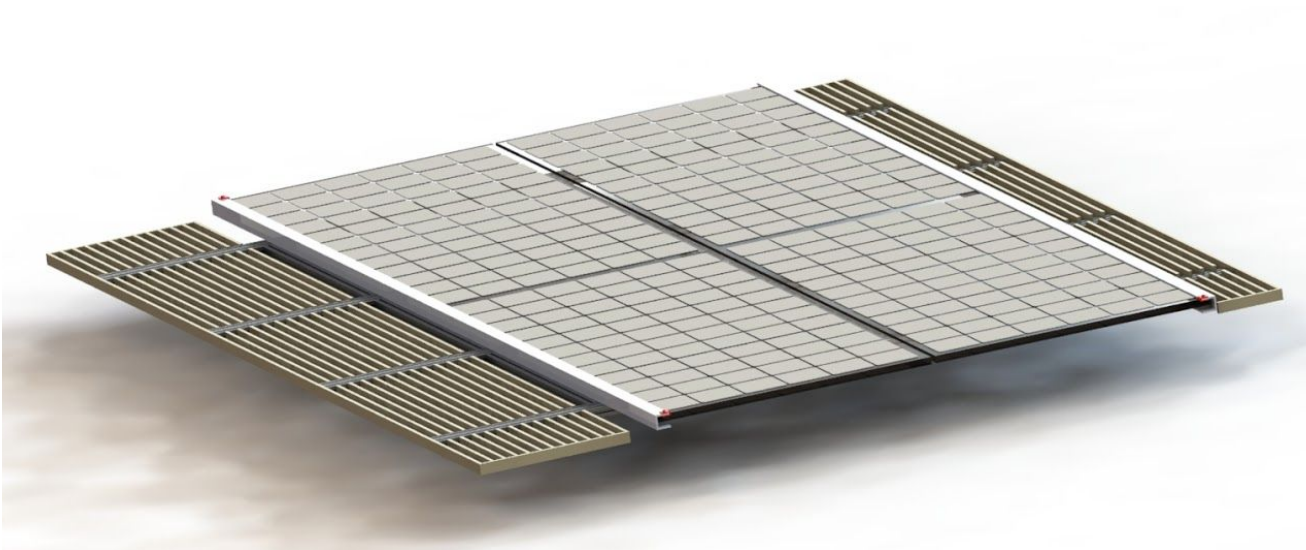


Figure 29: Roof Assembly With New Panel Arrangement and Overhang

Roof Panel Material Selection and Analysis

Last semester, considerable efforts went towards careful material selection for shelters without solar capability. When comparing materials using a decision matrix that considered weather resistance, cost, weight, yield strength, sustainability, and other factors, polycarbonate performed the best and was chosen over closely scoring metals such as steel and aluminum because its structural properties proved sufficient for shelter roof loads.

Utilizing polycarbonate roofing allows for ample flexibility with regards to transparency and color. The intensity of light entering the shelter can be tuned by selecting a target opacity level for the polycarbonate. Additionally, color can be customized at each shelter location to add a broader sense of style. Lastly, the shared use of polycarbonate in the side panels and roof allows for a reduction in types of materials used to construct the shelter and simplifies procurement of materials.

An in-depth explanation of roof material analysis can be found in the Spring 2018 report, but the ultimate conclusions from the analysis proved that 0.5 in polycarbonate would be structurally sufficient in all locations of the roof except for at the edges of the overhang in the previous design. The analysis found the deformation at the overhang to be unacceptable at 0.3 in, and thus additional supports would be necessary at the edges of the roof panels. However, since the roof panel arrangement has changed such that the roofing panels (or solar panels, in shelters with solar capability) are inboard on the shelter roof and supported at the edges by a custom mounting system, this edge deflection is no longer a concern.

Solar Panel Mounting Scheme

One important development in the design of the shelter this semester was the design of a custom racking system for Lumos GSX solar panels. Although Lumos offers their version of a rather bulky and expensive racking system to be purchased separately for the GSX panels, our implementation of a custom racking system allows for various benefits including reduction of cost, weight, and number of components for the shelter.

The custom solar panel mounting solution utilizes 6063 Architectural Aluminum U-channels with outer dimensions 2” X 2” and a wall thickness of 0.25”. 6063 Aluminum resists corrosion in outdoor applications, is a building material standard for metals used in construction, and is easily machinable. Essentially, the edge of the panel is housed in the U-channel with an internal gasket made of weather-resistant EPDM to create a weatherproof seal so water does not leak through the shelter roof. Next, the panel is constrained from sliding out of the U-channel by threaded hex clips that are attached to drilled holes in the U-channel. Lastly, the entire racking assembly is fixed to the T-slot extrusion roof members by T-slot nuts (also used to mount the side panel frames).

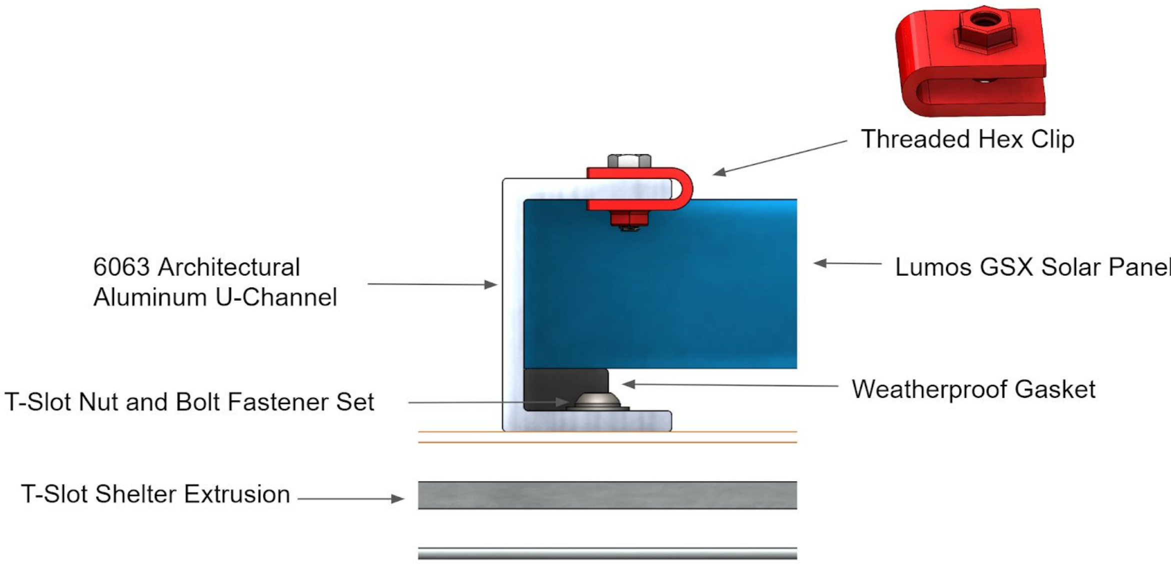


Figure 30: Custom Racking System Component Breakdown

One of the driving reasons behind developing a custom racking solution was the requirement that the system had to integrate with the 1.5” X 3” T-slot extrusion roof support members. In addition to designing a simple solution that integrated easily with the T-slot extrusions, the racking system is also constructed from readily-available stock and hardware that can be flexibly sourced from various suppliers. The system is also designed for manufacturability in that the only machining necessary is to cut the U-channels to length and drill through holes for hex clips and T-slot nut hardware. Lastly, the racking system is easily scalable to all shelter sizes, and allows for accessibility to solar panels for maintenance or replacement.

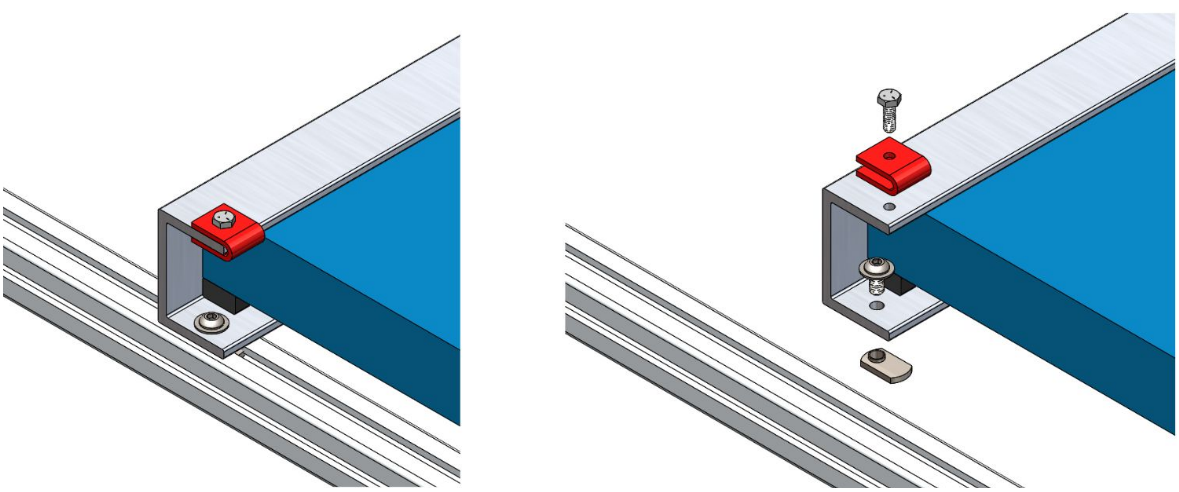


Figure 31: Custom Racking System Assembly Schematic

Moving forward with the custom racking design, one recommendation to explore and finalize is the implementation of tamper proof/anti theft hardware to prevent solar panels from being removed. Although many systems on the shelter could benefit from utilization of tamper proof hardware, the solar panels in particular are very costly and visibly mounted, thus they may be especially vulnerable to theft.

Roof Overhang

A wood overhang system is applied to create solar control / solar shading. This crucial element blocks undesired sun light. As it is fixtured outside of the shelter on to the solar panels (10” on one end and 20” on the other), it is constructed to utilize and manipulate the energy from the sun. During low sunlit times, for instance winter, it could also shield rain and snow.

To keep the design as sustainable and easy access as possible, the wood selection is treated red pine with a nominal size of 2*4 (actual 1 ½*3 ½ inches). All assembly could be done as simple as wood gluing the segments.

Foundation

Concrete Pad Design

Based on a review of the shelter design from previous semesters and the TCAT request for bid documents, it was noted that the proposed shelter mounting, though structurally sound and appropriate for new installations, did not work well with shelter installations as part of existing bus stops with existing concrete pads. A key shelter design goal for the semester was to address this limitation and investigate and analyze shelter mounting options that worked with existing shelter locations, new shelter and pad installations, and met all Ithaca, NY building code requirements for the mounting and the concrete pad. A sub goal for the semester was to establish requirements and propose a design for the concrete pad. Where previous semesters had limited the design to the shelter itself, the team felt that including the concrete pad in the overall design was important as the structural stability of the shelter was closely tied to the concrete it was mounted to.

To formulate the shelter mounting and concrete pad requirements for the system, a review was first performed of the use cases and structural requirements for the shelter from previous semesters, the TCAT Invitations for Bid #701-2017 (bus shelters) and #751-2017 (bus shelter installation services), Ithaca, NY building code, and Americans with Disabilities Act (ADA) requirements for bus shelters and comparable public infrastructure locations. Requirements were broken down into three categories: Technical Requirements (TR): explicit technical requirements for the shelter and concrete pad, Design Requirements (DR): design elements for the shelter and the concrete pad desired by TCAT, and Operational Requirements (OR): requirements detailing the shelter fabrication, delivery, installation, maintenance, insurance or build procedures. 40 Technical Requirements, 33 Design Requirements, and 33 Operational Requirements were established for the shelter and concrete pad for a total of 106 traced requirements as shown in the tables. Some of portions of the requirements contained “will” or “should” statements. The team rewrote these requirements to reflect the appropriate “shall” statement format.

TCAT IFB #701-2017 Requirements	
Req. #	Requirement
DR.1	The seat shall be secured with vandal free and rust proof hardware
DR.2	The shelters required shall be three (3) sided, five feet wide, eight feet long, and ten feet high with four to eight-inch opening at the bottom of each side.
DR.3	All structural members and mullion shall be fastened and secured with minimum of two (2) stainless steel bolts, nuts, flat washers, and ¼" lock washers.
DR.4	All structural fastenings shall be internal. Only tamper-proof rivets (approved or equal) for windows shall be exposed.
DR.5	All independent window units shall be completely framed.
DR.6	Each window unit shall include window, four piece frames with mitered corners, corner keys, and gasket, and shall not form any part of the structural frame.
DR.7	All windows shall be factory installed in the window frame which shall be installed into a separate structural frame.
DR.8	The window frame design shall be constructed so that only authorized personnel may remove window units.
DR.9	All structural members (frames and window frames) shall be constructed of extruded aluminum alloy 6061-T6, 6063-T52 or approved equal; one piece and seamless.
DR.10	Structural members shall measure 2 ½" X .125" thick minimum.
DR.11	All members shall be hollow aluminum tubes.
OR.1	All shelters shall be completely prefabricated, completely glazed, pre-caulked and gasketed.
OR.2	All structural joints shall be neat and clean.
OR.3	All edges shall be free of burrs and bends.
DR.12	Bench seat shall cover the length of the shelter minus spacing for ADA compliant access, approximately twelve-inch (12") deep with eight-inch (8") back rest.
DR.13	The seat shall be constructed of aluminum a minimum of .128" thick. The finish shall be anodized finish; color shall be selected from available options.
DR.14	Partitions shall exist between seated areas, so as not to allow for users to lie across the bench.

DR.15	The design and construction of each shelter shall permit integration of light fixtures, benches, schedule panels, transit map and other integrated street furniture.
DR.16	The roof shall be aluminum due placement in a rural environment
TR.1	All shelters shall have a built-in leveling system for adjusting to varying slopes and special conditions.
DR.17	All external flanges shall be anodized or anti-graffiti finish like the shelter.
TR.2	All aluminum shall conform to the standards of the Aluminum Association, AISC, ASTM, U.L., ASCE, etc.
TR.3	All shelters shall be designed to withstand dead loads of forty (40) psi minimum and wind load over one hundred forty (140) mph, and shall meet NY State structural legal requirements for load and wind.
OR.4	All installation hardware and ground anchors shall be supplied and shipped with the shelters.
OR.5	All materials shall be crated and protected against damage at time of shipment.
DR.18	All seating and openings shall be ADA complaint.
DR.19	All side windows shall be non-tinted.
DR.20	All openings in design shall be greater than 4 inches OR less than three inches. To reduce any potential trap conditions for users, particularly children.
DR.21	Smaller glass panels for less expensive replacement due to vandalism concerns shall be used; polycarbonate is not considered due to its lack of scratch resistances
DR.22	Narrow footprint shall be designed due to limited space availability
DR.23	Customizable facia design shall be included
DR.24	The roof dimensions shall be 5 ft. Roof Width – 10 ft. Roof Length (nominal dimensions +/- 3 inches)
DR.25	Roof Fascia shall have 4 inch – Wording “TOMPKINS TCAT” * wording subject to change
DR.26	The shelter roof shall be aluminum pan
DR.27	An anti- graffiti powder coating shall be part of the design
DR.28	Solar Power LED Roof mounted Lighting – Color 4K (3200-5000 will be considered) –400 lux shall be part of the design
DR.29	Light shall be evenly distributed

DR.30	Rechargeable batteries shall be readily available (non-specialty).
DR.31	Full charge shall be within 8 hours of 60% of daylight.
DR.32	Lights shall operate no less than 24 hours without additional charge from light source.
DR.33	Accessory Requirement: Display case shall be able to house a print no less than 11 wide x 17 inch length document shall be weather tight.
OR.6	Bids and all written inquiries relating to this bid shall be directed to TCAT's Purchasing Manager or designee, who will be the sole point of contact for this procurement. The Contracting Officer for this project is Raymond Lalley, (607) 277-9388 x. 540.
OR.7	Changes to the contract shall be conducted as follows:
OR.8	Proposed changes by the Contractor shall be submitted in writing to the TCAT Contract Administrator for prior approval.
OR.9	The request shall state the reason, any possible change to the project schedule, and any impacts to the cost of the project.
OR.10	TCAT shall respond in writing to the proposed change.
OR.11	All changes approved by TCAT shall be confirmed by written addendum or change order.
OR.12	The Contractor shall be liable for all costs resulting from, and/or for satisfactorily correcting any specification change not properly ordered or approved by written modification to the Contract.
OR.13	Disagreements that cannot be resolved within negotiations shall be resolved in accordance with the contract dispute clause herein.
OR.15	Except as otherwise provided in this contract, any dispute concerning a question of fact arising from contract which is not disposed by agreement shall be decided by the TCAT General Manager, who shall reduce its decision to writing and mail or otherwise furnish a copy thereof to the Contractor.
OR.16	The decision of the TCAT General Manager shall be final and conclusive unless within 30 days from the date of receipt of such copy, the Contractor mails or otherwise furnishes to FTA a written appeal.
TR.4	All equipment shall be in complete compliance with all requirements of the laws of the State of New York, City of Ithaca and Tompkins County, as well as all applicable Federal laws and regulations at date of delivery and/or installation at TCAT.
TR.5	Workmanship throughout shall conform to the highest standard of commercially accepted practice for the class of work, and shall result in a neat and finished appearance.
OR.17	On procurements requiring multiple units or periodic delivery of a product, all units or product shall be identical unless otherwise stated in the technical specifications.

OR.18	No advantage shall be taken by the bidder and/or manufacturer in the omission of any parts or details, which make the equipment complete and ready for service, even though such parts or details are not mentioned in these specifications.
OR.19	All units or parts not herein specified shall be manufacturer's standard units.
TR.6	The successful bidder shall comply with all applicable requirements of the Americans with Disabilities Act of 1990 (ADA), 42 U.S.C. §§ 12101 etseq.; section 504 of the Rehabilitation Act of 1973, as amended, 29 U.S.C. § 794; 49 U.S.C. § 5301(d); and the following Federal regulations including any amendments thereto:
TR.7	A. U.S. DOT regulations, "Transportation Services for Individuals with Disabilities (ADA)," 49 C.F.R. Part 37;
TR.8	B. U.S. DOT regulations, "Nondiscrimination on the Basis of Handicap in Programs and Activities Receiving or Benefiting from Federal Financial Assistance," 49 C.F.R. Part 27;
TR.9	C. U.S. DOT regulations, "Americans with Disabilities (ADA) Accessibility Specifications for Transportation Vehicles," 49 C.F.R. Part 38;
TR.10	D. U.S. DOJ regulations, "Nondiscrimination on the Basis of Disability in State and Local Government Services," 28 C.F.R. Part 35;
TR.11	E. U.S. DOJ regulations, "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities," 28 C.F.R. Part 36;
TR.12	F. U.S. GSA regulations, "Accommodations for the Physically Handicapped," 41 C.F.R. Subpart 101-19;
TR.13	G. U.S. Equal Employment Opportunity Commission, "Regulations to Implement the Equal Employment Provisions of the Americans with Disabilities Act," 29 C.F.R. Part 1630;
TR.14	H. U.S. Federal Communications Commission regulations, "Telecommunications Relay Services and Related Customer Premises Equipment for the Hearing and Speech Disabled," 47 C.F.R. Part 64, Subpart F; and
TR.15	I. FTA Regulations, "Transportation for Elderly and Handicapped Persons," 49 C.F.R. Part 609.
TR.16	J. Any Implementing requirements FTA may issue.
OR.20	It shall be the responsibility of each proposer to call to the attention of TCAT any apparent discrepancy in the specifications or any question of interpretation thereof. Failure to do so constitutes acceptance as written.

Figure 32: TCAT IFB #701-2017 Requirements

TCAT IFB #751-2017 Requirements	
Req. #	Requirement
TR.17	Eight rural bus shelters which are predominately in fair to poor condition shall be removed from current locations, properly disposed of in accordance with Recycling and Materials Management of Tompkins County, and/or recycled for re-used by others
TR.18	The approximate 5-6 ft x 10-12 ft (sizing variation by location) concrete pads at seven locations shall be repaired and have an epoxy coating applied. Minor repairs shall include filling in cracks or pits due to aging conditions
OR.21	During preparation and painting, area shall be marked clearing with “Caution – Wet Paint” tape for minimum time as indicated by epoxy manufacturer for use by light traffic
TR.19	The concrete pad for the shelter in Freeville is too small, the current pad shall be removed and new concrete pad poured 11 ft x 6 ft x 6” depth, minimum strength of 5000 psi once cured
OR.22	Pad shall be allowed to fully cure before installing new shelter
OR.23	Permits if required shall be obtained by the installer
OR.24	Area surrounding the shelters shall remain in a condition similar to state of first arrival.
OR.25	No loose materials shall remain at location overnight, and no adjacent area shall be damaged as a result of shelter removal, painting and installation actions, direct or indirect.
TR.20	Epoxy coating shall be Floor-Tex 40# = equivalent or better in Slate Gray or similar medium gray
OR.26	A warranty of one year shall be provided
TR.21	Concrete surface shall be textured in a manner to reduce slippage, meet ADA state and federal requirements
OR.27	Epoxy shall be installed in accordance with manufacturer’s installation recommended (not minimum) requirements
TR.22	New bus shelters shall be installed in accordance with manufacturing instructions, utilizing provided hardware for assembly
TR.23	Anchoring shelters to concrete shall be the responsibility of the selected contractor, anchoring hardware shall be stainless steel and not have any protruding ends which are not smooth and vandal proof design which is to be provided by contractor.

Figure 33: TCAT IFB #751-2017 Requirements

Ithaca, NY Building Code Requirements	
Req. #	Requirement
TR.24	Sidewalks and driveways shall be built of concrete, meeting the material specifications prescribed by the Board of Public Works
OR.28	No walk shall be constructed except to a line and grade given by a sidewalk survey by the City Engineer.
OR.29	Application for a survey shall be made at the City Engineer's office 24 hours before the builder desires to start work.
OR.30	There shall be no fee charged for a sidewalk survey.
TR.25	All sidewalks shall be of one-course construction and of a minimum width of five feet, except where variances from this width are either specifically permitted or required by the Engineer.
OR.31	Permits for pouring concrete during weather when it is reasonable to expect frost shall not be issued.
OR.32	Permits shall not be issued during the period from October 1 to May 1, except at the discretion of the City Engineer.
OR.33	They (forms) shall be held rigidly in place by stakes or braces with top edges at true line and grade given by the Engineer.
TR.26	Ends of adjoining forms shall be flush.
TR.27	Forms shall be set so as to give the walk a slope towards the curb of 1/4 inch per foot of width.
TR.28	That portion of the ground surface directly beneath the slab shall be called the “subgrade.”All soft and spongy material in the subgrade shall be removed and replaced with suitable material.
TR.29	Fills shall be compacted in layers not exceeding six inches in thickness.
TR.30	Spots previously compacted by traffic shall be loosened to a depth of six inches.
TR.31	The whole subgrade shall be thoroughly and uniformly compacted to a firm surface having as nearly as possible a uniform bearing power.
TR.32	If a subbase is a required, it shall be laid in separate layers not more than six inches thick
TR.33	Where in the opinion of the Engineer, it is considered necessary to save the walk from damage by frost action, drains of three-inch farm tile or such other type of drainage pipe as may be required shall be laid on the lines and grades given by the Engineer.

TR.34	When drains are impracticable and the soil is poorly drained or colloidal clay, a five-inch subbase shall be constructed of cinders, gravel or other porous material approved by the Engineer.
TR.35	The subbase shall be thoroughly tamped until the surface is firm and shall be drained into the street gutter in a manner approved by the Engineer.
TR.36	Concrete shall be mixed in the proportion of one part portland cement, two parts of fine aggregate and 3 1/2 parts of coarse aggregate.
TR.37	The concrete sidewalk shall be of one course at least four inches in thickness; and at points where driveways are to be provided, the concrete shall be six inches in thickness.
TR.38	The walk shall be marked into separate rectangular slabs. No plain concrete slab shall be longer than six feet on any one side.
TR.39	Where division plates have been used, they shall be removed after the concrete has hardened sufficiently to avoid breaking the edges of corners of the slabs.
TR.40	The surface edges of each slab shall be rounded to a radius of about 1/4 inch. Markings shall be exactly at cuts between slabs.

Figure 34: Ithaca, NY Building Code Requirements

A critical driving requirement for the shelter and the concrete pad was the dead load requirement of 40 lbs/in^2 (psi). Load calculations shown below were performed using the roof area of the shelter which showed that to achieve the 40 lbs/in^2 from the specification, 185ft of densely compacted snow would need to accumulate on the shelter. Analysis of this requirement showed it to be unreasonable (even with significant safety margin) leading a formal written request for clarification which was sent to TCAT. TCAT confirmed that the dead load requirement was intended to be the snow loading and that there was an error in the bid documentation and 40 lbs/in^2 (psi) should have been 40 lbs/ft^2 (psf). With clarification, the 40 lbs/ft^2 (psf) requirement was found to be much more reasonable as it corresponded to 1.3 ft of accumulated snow on the shelter which is to be expected given the relatively flat roof with a slight (<5° incline.) 40 lbs/ft^2 is also in line with ground snow loads for Ithaca/Tompkins County as well as American Society of Civil Engineers ASCE/SEI 7-10 *Minimum Design Loads for Buildings and Other Structures* recommendations.

Initial Snow Load Calculation:

$$Area_{Roof} = 39.37in \cdot 79.173in \cdot 4panels = 12,469in^2$$
$$Load_{Roof} = 12,469in^2 \cdot 40\frac{lbs}{in^2} = 498,727\ lbs$$
$$\rho_{Snow} = 300\frac{kg}{m^3} = 0.0180\frac{lb}{in^3}$$
$$0.0180\frac{lb}{in^3} \cdot 12,469in^2 = 224.4\frac{lb}{in}$$
$$\frac{498,727lb}{224.4\frac{lb}{in}} = 2,222.5in = 185\ ft\ of\ snow\ on\ shelter$$

Revised Snow Load Calculation:

$$Load_{Roof} = 12,469in^2 \cdot 40\frac{lbs}{ft^2} = 3,464\ lbs$$
$$\frac{3,464lb}{224.4\frac{lb}{in}} = 15.4in = 1.3ft\ of\ snow\ on\ shelter$$

Snow Densities	
Density (kg/m^3)	Snow Types and Characteristics
50-100	Fresh falling snow
100-200	New top snow. Uncompacted.
200-300	Settled snow on ground. Self-compacted after several days.
300-500	Compacted snow by grooming machines.
500-550	Called “neve”. Snow that has been partially melted, refrozen, and compacted.
550-830	Called “firn”. Naturally compacted and aged over 1 year. A form of ice still containing air channels, observed during glacier formation.
830-917	Ice with bubbles, typically in the top 1000m of old glaciers
917	Solid ice (no bubbles). Typical of glacier ice below 1000m depth

Figure 35: Snow Densities

Using the revised snow loading, the use case list was updated for normal uses, misuses, unintended uses, and environmental interactions of the system. Key updates included separation of the loads into those that were applied directly to the shelter and those that were ultimately loads on the supporting concrete pad. These loads were then prioritized based on their priority with respect to the overall design of the shelter as well as the significance of the loads on the supporting structure. For the design priority ranking, “1” indicated a use case that the design must accommodate; “2” indicated a use case that the design should accommodate; and “3” indicated a use case that the design could accommodate if possible. Load priorities were assigned based on the overall magnitude of the load as well as the loading location (i.e. bench, panel, pad, etc.) Load priority ranking “1” was reserved for those loads that were extremely large and would be key drivers of the overall shelter design; “2” was for loads that had significant structural impacts for design decisions; and “3” was for those loads that needed to be analyzed, but would not necessarily be the driving factor in a design decision.

Use Cases and Loads					
Use Case	**Design Priority**	**Load Priority**	**Load Type**	**Support Location**	**Load (approx.)**
User	1	3	Distributed Load	Concrete Pad/ Bench	200 lb
Shelter	1	1	Distributed Load	Concrete Pad	3300 lb
Bench	1	1	Distributed Load	Concrete Pad	550lb
Users Sit on Bench	1	2	Distributed Load	Concrete Pad/ Bench	1150 lb
User Lies on Bench	1	2	Distributed Load	Concrete Pad/ Bench	750 lb
Users Stand in Shelter	1	3	Point Loads	Concrete Pad	2000 lb
Users Lean on Handrail	1	2	Point Load	Concrete Pad/ Frame Mounts	200lb
User Puts Bag on Bench	1	2	Point Load	Concrete Pad/Bench	800 lb
Users Bring Large Luggage Inside	2	2	Point Load	Concrete Pad	750 lb
User in Wheelchair Uses Shelter	1	2	Point Load	Concrete Pad	300 lb
Snow Falls on Shelter	1	1	Distributed Load	Concrete Pad/Roof/Frame	6800 lb
Rain Falls on Shelter	2	1	Distributed Load	Concrete Pad/Roof/Frame	3570 lb

User Takes Shelter from Sun	3	3	Point Load	Concrete Pad	3500 lb
Users Chat Inside Shelter	3	3	Point Loads	Concrete Pad	3700 lb
User Eats Inside Shelter	3	3	Point Loads	Concrete Pad/Bench	3510 lb
Wind Blows on Shelter	1	1	Distributed Load	Concrete Pad/Frame/Panels	6800 lb
User Leans on Panel	2	2	Point Load	Concrete Pad/Frame/Panels	3500 lb
User Hangs off Roof Overhang	3	2	Point Load	Concrete Pad/Roof/Frame	3500 lb
User Kicks Shelter Panels	3	3	Point Load	Concrete Pad/Frame/Panels	600 lb
Rock Hits Shelter Panels	3	2	Point Load	Concrete Pad/Frame/Panels	200 lb
Tree Limb Falls on Shelter	2	2	Point Load	Concrete Pad/Roof/Frame	400 lb
User Hits Display Panel	3	3	Point Load	Display Panel/Frame	180 lb
User Throws Trash in Can	3	3	Point Load	Shelter Frame	0.25 lb
User Leans Bicycle on Shelter	2	2	Point Load	Frame/Panels	18 lb

Figure 36: Use Cases and Loads

Driving use cases and loads for the shelter and concrete design were the snow loading, the wind loading, and the load from the weight of the shelter with the maximum number of occupants. The structural mounting scheme was designed specifically to withstand these loads.

Previous semesters selected sonotubes for the foundation and mounting of the shelters. Sonotubes are cylindrical molds used to create foundation columns for commercial use by pouring concrete into the molds shown in Figure 37.

Figure 37: Sonotube Mold

The diameter for the sonotubes depends on the loads that it needs to accommodate as well as the pressure that the underlying soil can withstand. Previous semesters were not able to determine the type of soil that the shelter would be placed on and it was assumed that it would rest in sandy gravel. To be effective, sonotubes need to be placed below the frost line in the region. For Tompkins county the frost line is approximately 40-60” deep as shown in Figure 38. Placement of the sonotube below the frostline allows the overall foundation of the shelter to expand and contract independently from the surrounding soil.

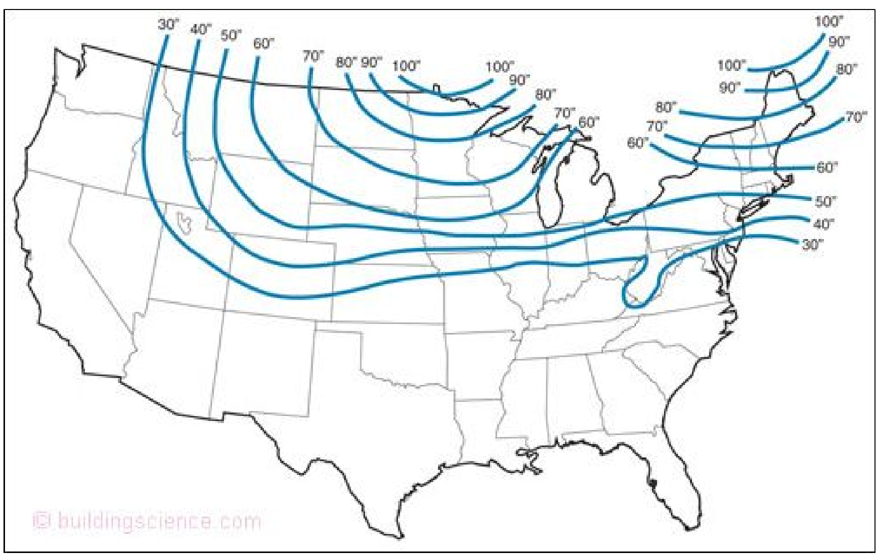


Figure 38: Map of U.S. Extreme Frost Line

Based on the fact that the frost line in Tompkins County is so deep (almost 5’ underground), to auger out holes to support placement of the sonotubes would require a significant amount of heavy machinery and many days of work to dig, place tubes, pour concrete, cure the concrete, and then install the shelter mounting hardware. Figures 39 and 40 below show poured sonotubes and one of multiple possibilities for affixing the shelter structure to the sonotubes in a manner similar to those used for structural deck footings.

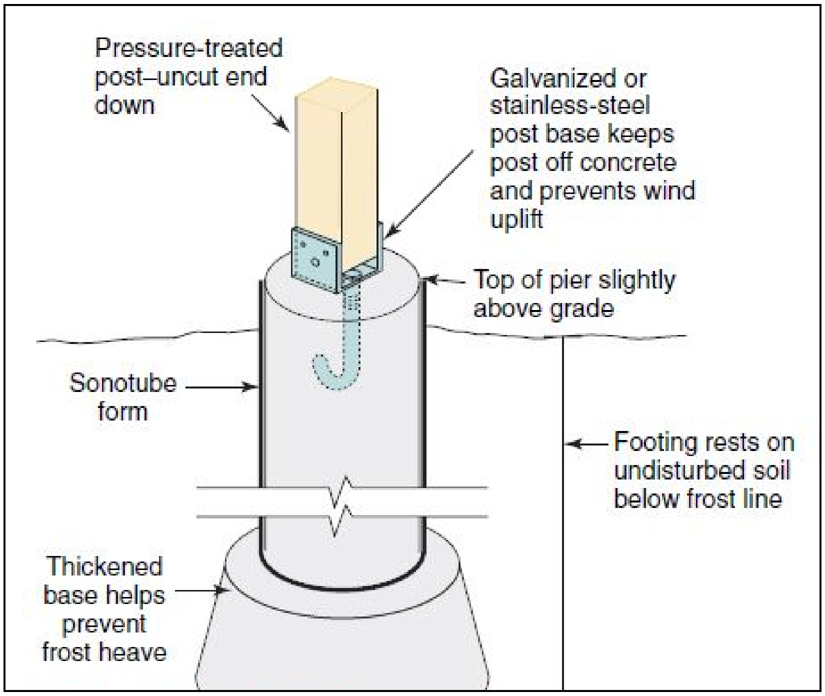


Figure 39: Sonotube Foundation (© - BuildingAdvisor.com)

Figure 40: Sonotube Structural Mounting

The selected site for the initial shelter at the corner of Warren Road and Oakwood Drive in Lansing, NY contains relatively sandy soil with a nearby drainage ditch. Based on TR.28 - TR.35, and suggestions from Larry Fabbroni the chief engineer for the solar village, a 12” layer of gravel will be placed beneath the concrete pad to facilitate drainage of water and to reduce cracking and separation issues with the pad itself. The gravel will be compacted in layers not exceeding 6” in thickness and will be thoroughly and uniformly compacted to a firm surface that has as uniform as possible load bearing power. Since 2 layers are required to achieve the overall 12” depth, it will be laid in 2 layers with 6” of gravel per layer. Per TR.36, the concrete slab will be 1 part portland cement, 2 parts fine aggregate, and 3.5 parts coarse aggregate poured 6” thick. The thickness of the pad was selected to meet TR.37 that calls for a 6” thick pad where driveways or other load bearing slabs are poured. Figure 41 shows the overall design of the concrete foundation for the shelter.

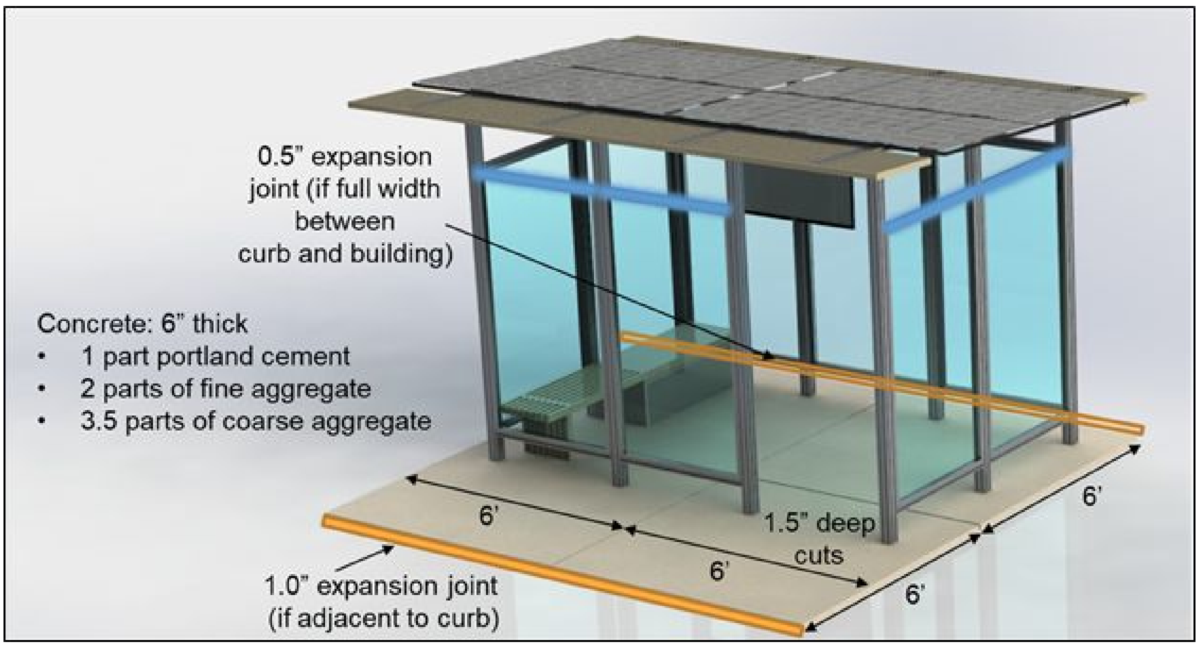


Figure 41: Concrete Pad Design

As indicated in section 324-49 of the Ithaca, NY building code (TR.38-40) the concrete pad will be marked into separate rectangular slabs no more than 6’ on a side by a cut that is 1.5” deep (¼ of the overall depth of the slab per industry best practices). Surface edges of each slab shall be rounded to a radius of ¼”. The forms for the concrete shall be placed so that it slopes towards the road at ¼” per foot of width as described in TR.27. Per OR. 28-33, the City Engineer will provide approval for the line and grade of the pad as proposed and application for the survey will be made at the Engineer’s office 24 hours before the slab is poured. If it is desired to pour the slab between October 1 and May 1, the appropriate permits will also be requested from the City Engineer. Where shelter pads are made adjacent to sidewalk curbs, a 1” expansion joint will be placed between the pad and curb and where they are adjacent to a building a ½” expansion joint will be placed between the pad and the build.

Using the code regulations, a 12’ x 12’ concrete slab with markings at 6’ vertically and horizontally as shown in Figure 42 is proposed for a medium shelter module. This design allows the shelter to be placed towards the back of the concrete pad which provides just over a 4’ deep pad area for bus stop patrons to use in front of the shelter. This area allows comfortable access to the side rail and a large space for standing with bicycles, large luggage, or animals that may be more difficult to have inside the shelter. The width of the concrete pad segments relative to the shelter modules also provides suitable support for the mounting of the shelter.

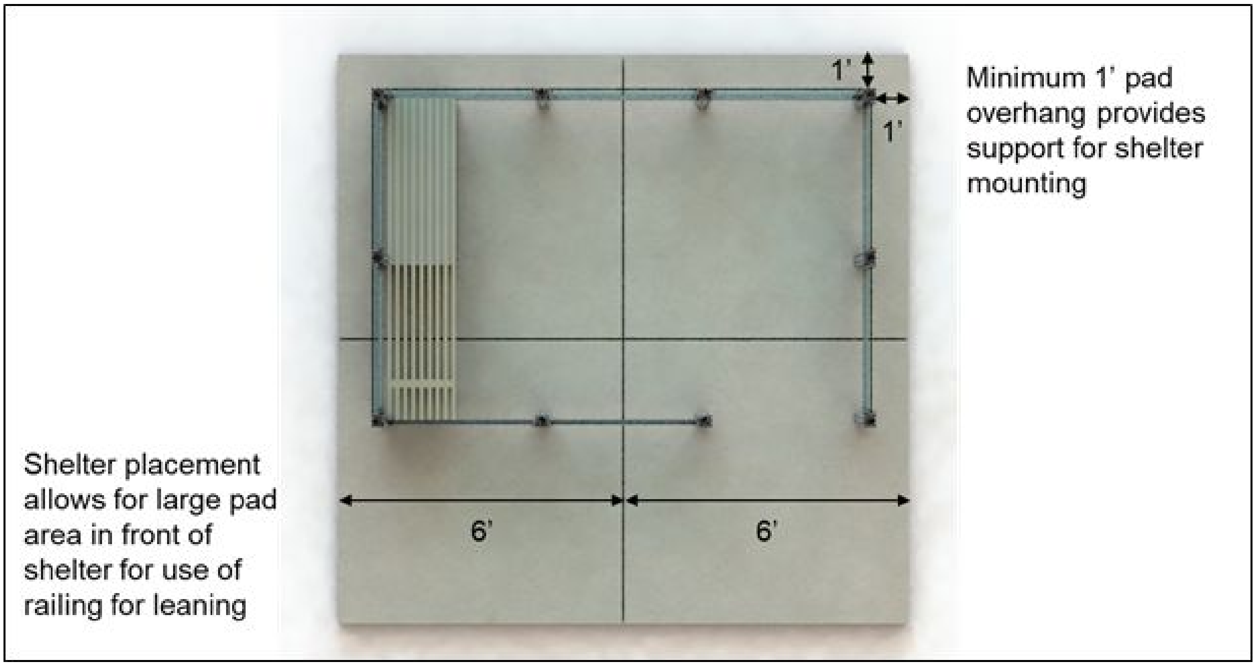


Figure 42: Concrete Pad Expansion and Shelter Placement

Structural Mounting Scheme

After analyzing the use cases and loads in Table R5 and discussing with the Taitem engineers, it was found that sufficient structural support for the shelter could be provided by ¾” stainless steel anchor bolts and using surface mounted brackets to support the vertical uprights for the frame of the shelter. This method is much less invasive than the previously proposed sonotube foundation and allows shelters to be installed on already existing concrete pad locations. Several types of anchor bolts and mechanisms shown in Figure 43 were considered.

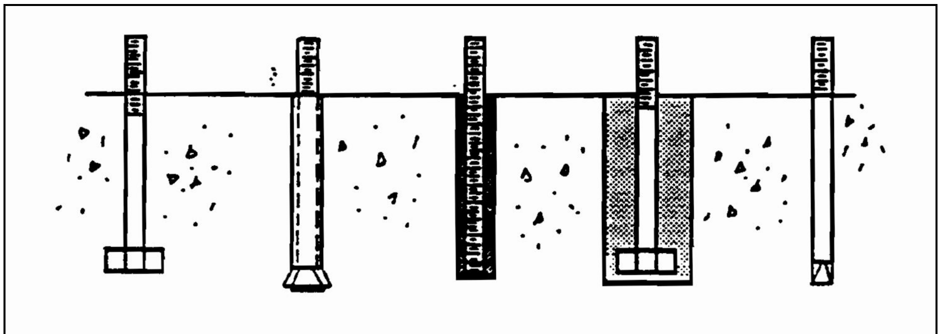
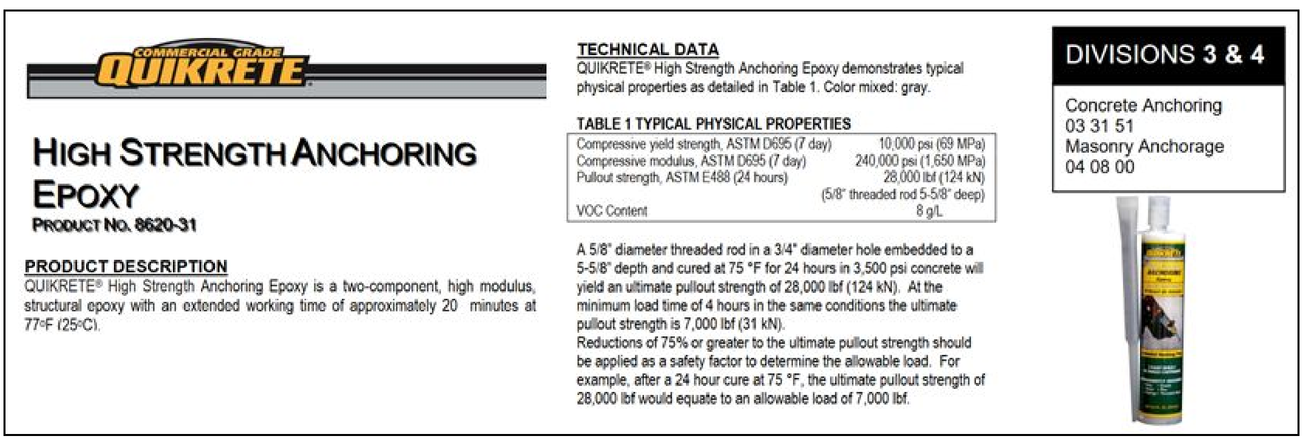


Figure 43: Anchor Bolt/Mechanism Types

Adhesive and expansion anchors were the two primary candidates evaluated as they both provide a relatively simple method for installing anchors on existing concrete pads. While each method has its pros/cons, adhesive anchors were ultimately selected because of the additional environmental resistance they provide in preventing moisture from entering the slab after installation and the additional structural support the epoxy provides for older concrete slabs that may have internal cracks and defects. If shelters are installed as part of new pad installations, cast-in-place anchors would be the preferred method. To ensure sufficient engagement depth of the anchor bolts without compromising the structural integrity of the concrete pad, 4” long anchor bolts were selected for the design. Per best practices from the anchoring epoxy manufacturer, the hole should be drilled ¼” larger than the threaded rod to be anchored to a depth that is at least 4.5 times the diameter of the bolt. Using a ¾” diameter rod, would imply that the hole needs to be 1” in diameter and 3 ⅜” deep.



COMMERCIAL GRADE QUIKRETE

HIGH STRENGTH ANCHORING EPOXY

PRODUCT NO. 8620-31

PRODUCT DESCRIPTION

QUIKRETE® High Strength Anchoring Epoxy is a two-component, high modulus, structural epoxy with an extended working time of approximately 20 minutes at 77°F (25°C).

TECHNICAL DATA

QUIKRETE® High Strength Anchoring Epoxy demonstrates typical physical properties as detailed in Table 1. Color mixed: gray.

TABLE 1 TYPICAL PHYSICAL PROPERTIES

Compressive yield strength, ASTM D695 (7 day)	10,000 psi (69 MPa)
Compressive modulus, ASTM D695 (7 day)	240,000 psi (1,650 MPa)
Pullout strength, ASTM E488 (24 hours)	28,000 lbf (124 kN) (5/8" threaded rod 5-5/8" deep)
VOC Content	8 g/L

A 5/8" diameter threaded rod in a 3/4" diameter hole embedded to a 5-5/8" depth and cured at 75 °F for 24 hours in 3,500 psi concrete will yield an ultimate pullout strength of 28,000 lbf (124 kN). At the minimum load time of 4 hours in the same conditions the ultimate pullout strength is 7,000 lbf (31 kN).

Reductions of 75% or greater to the ultimate pullout strength should be applied as a safety factor to determine the allowable load. For example, after a 24 hour cure at 75 °F, the ultimate pullout strength of 28,000 lbf would equate to an allowable load of 7,000 lbf.

DIVISIONS 3 & 4

Concrete Anchoring
03 31 51
Masonry Anchorage
04 08 00

Figure 44: Quikrete High Strength Anchoring Epoxy

A search of available adhesive products was performed and Quikrete High Strength Anchoring Epoxy with a pullout strength of 28,000 lbf, a 10,000 psi, and a 20 minute working time was selected for use in the design. This selected product provides approximately a three hour cure time which should allow all anchor bolts for the shelter to be installed within the working time.

A number of different surface mounted brackets were evaluated to support the vertical uprights of the shelter. To address TR.1, DR.17, and OR.4-5, several aluminum and stainless steel mounting brackets with slotted mounting holes to allow for horizontal and vertical adjustment were considered. Considered styles of mounting bracket are shown in Figures S3-S5 below.

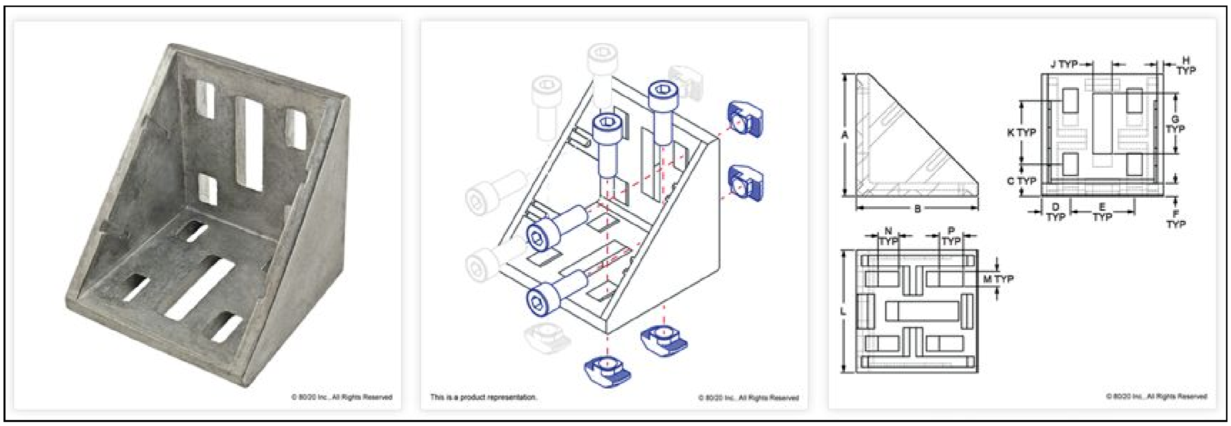


Figure 45: 80/20 Floor Mount Bracket P/N 14095

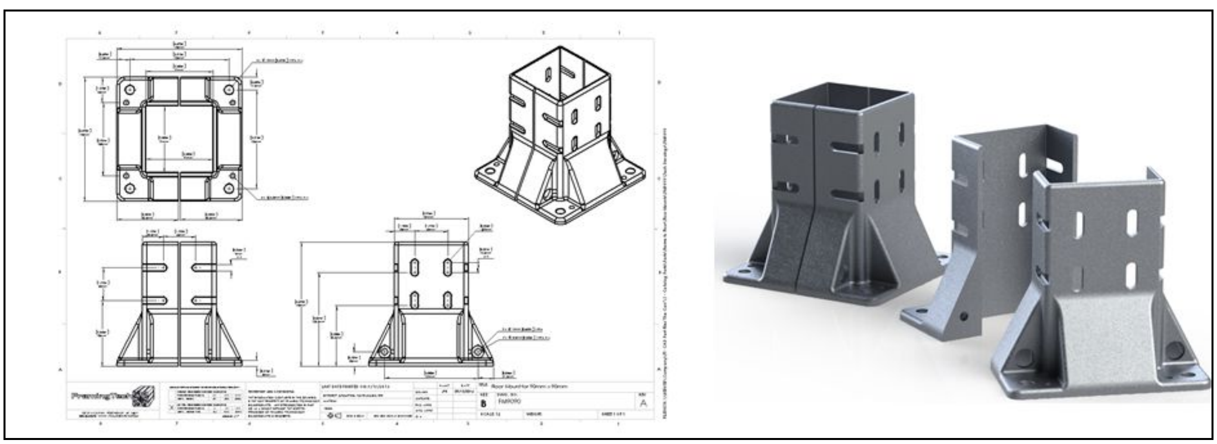


Figure 46: Framing Tech Floor Mount Base P/N FM9090

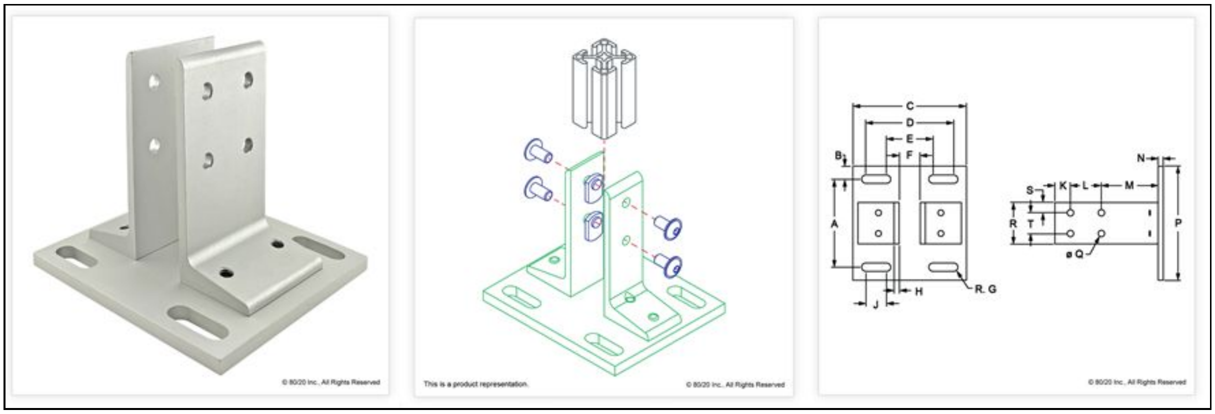


Figure 47: 80/20 15 Series Floor Mount Base P/N 2400

Based on its compatibility with the 80/20 extrusions, its structural support, and its ability to support adjustments in both horizontal and vertical mount points the 15 series floor mount base P/N 2400 from 80/20 was selected for the design. To accommodate the ¾” stainless anchor bolts, a thicker custom base plate will be fabricated with larger slots. To address DR.3 and DR.4, the vertical uprights must be connected to the base plate using a minimum of 2 stainless steel bolts, nuts, flat washers, and ¼” lock washers with tamper-resistant hardware. 80/20 manufactures P/N 3325 (5/16-18 x 0.750” black slide-in flange studs with washer and hex nut) and P/N 3320 (5/16-18x0.687” flanged button head socket cap screw with slide-in t-nut) as shown in Figures S6 and S7 which are compatible with the selected P/N 2400 bracket. 5/16-18 slide-in flange studs, screws, and lock washers are available in stainless steel (to improve environmental resistance) and should be ordered with star or torx bit heads (as shown in Figure S8) to ensure tamper resistance of the shelter mounting. Similarly, 4” long ¾” diameter stainless steel anchor bolts and grooved nuts should be use to ensure tamper and environmental resistance of the mounting of the bracket to the concrete pad.

3325 is comprised of:

Part Number	Description	Qty
3116	5/16-18 x .750" Slide-In Flanged Economy T-Slot Stud	1
3214	5/16-18 Hex Nut	1
3260	.349" ID Washer	1

Figure 48: 80/20 Part Number 3325: 5/16-18 Slide-In Flanged T-Slot Stud, Hex Nut, and Washer

3320 is comprised of:

Part Number	Description	Qty
3330	5/16-18 x .687" Flanged Button Head Socket Cap Screw (FBHSCS)	1
3278	5/16-18 Slide-in Economy T-Nut - Offset Thread	1

Figure 49: 80/20 Part Number 3320: 5/16-18 Flanged Button Head Socket Cap Screw and T-Nut

Figure 50: Stainless Steel Tamper-Resistant Screws and Driver

Figure 51: Stainless Steel Tamper-Resistant Grooved Nuts and Driver

Floor Pattern Considerations

TCAT Invitation for Bid #751-2017 contains TR.18 for repairing seven existing shelter locations that require filling in cracks or pits and applying an epoxy coating. Coating of the concrete pads for existing and new shelter with Floor-Tex 40# in slate or medium gray is proposed to address TR.18 and TR.19. This product is an epoxy based surface coating which helps to seal existing pits in the concrete and prevents water and de-icing salt from penetrating into the slab. For new pad installations, a penetrating concrete sealant (such as Radonseal) could also be applied to further improve the moisture resistance of the concrete. Penetrating sealants must be reapplied over time and should be included as part of the shelter's long term maintenance plan.

From a design standpoint, the concrete pad supporting the shelter is a significant element and its aesthetics should be considered. There are a variety of modern concrete stamping and dying patterns that are available to allow the look of each shelter to be varied based on its location and the desired aesthetics in that area. Figure 51 shows some examples of the range of looks that can be created using stamped and dyed concrete. These patterns must be applied before the concrete slab is fully cured, but colored epoxy could be used to modify the look of existing slabs.

Figure 52: Stamped Concrete Designs

To meet TR.21, any surface pattern and epoxy coating should be textured to reduce slippage and meet Americans with Disabilities Act (ADA) state and federal requirements.

Accessories

Bench

To complement our shelter, we devised a seamlessly integrated bench, made of sustainable, easy to source materials. An upper deck made of laminated 2x4s, sits on top of a sturdy cast concrete foundation. The bench can be constructed rapidly without the need for specialized labor or equipments. Once it's been installed, the bench houses all of the vital systems of the shelter; the heavy concrete structure protects the battery from being damaged. An arm rest at the mid point ensures that the bench is always available for bus riders.

Hand Crank

To go along with our sustainable shelter, we brainstormed ideas for fun and easily implementable ideas for other green energy sources. Our favorite power generating accessory idea is the hand crank. It works by Electromagnetic Induction: where a voltage is induced from a changing (moving) magnetic field. Our idea, shown on Figure 53 is to have one or two hand powered cranks attached to the inside of the shelter, which can provide some power to the shelter solely from inputted human work.

We hypothesized that the most fun and effective method to generate the most power would be to introduce an element of competition. Cost permitting, we would like to install two generators side-by-side, which would display the amount of energy produced using a

Wattmeter. The results would be displayed either on the Wattmeter, or on the TV. By giving the two participants their respective wattage, we would incentivize the participants to put forth more effort than they originally would have.

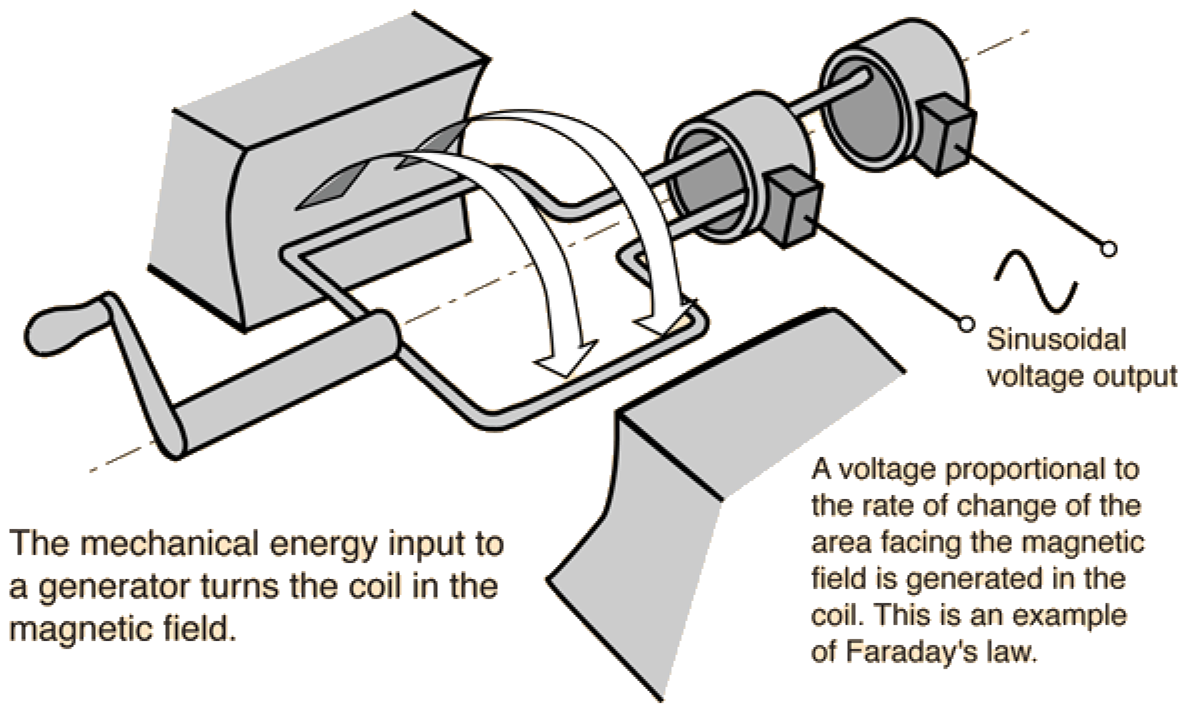


Figure 53: Power generator by Electromagnetic Induction

Railing

To accomodate TCAT users during the hotter months, we wanted to develop a sleek and functional railing where users could sit, lean or hold onto. Our first design, Figure 54, was quite basic, featuring a round aluminum railing near the entrance, facing the way the bus would approach.

The final design, Figure 55, features an offset railing design, which is meant to accommodate sitting, leaning and standing for users of varying heights. The wooden design is more aesthetically fitting to our bench and overhang designs, and will be warmer and more comfortable than an aluminum railing.

Our stakeholders were concerned with bikers using the railing to lock their bikes onto. To address this concern, we will design a railing that is nearly flush with the polycarbonate panels and the T-slots. It will follow the contour of the side of the shelter, and make it impossible for bikers to slip bike locks around.

Figure 54: First aluminum railing concept

Figure 55: Wooden offset railing concept

Indicator Lights

In addition to the real-time information displayed in our LCD screens, we have also added LED indicator lights, Figure 56, to notify TCAT riders (typically standing away from the shelter) that a bus is soon arriving. When a bus is two minutes away from arrival, the indicator lights change its color from white (indicating no bus arriving soon) to blue (indicating a bus is arriving within two minutes). Whether a rider is standing at or a couple of feet away from the bus stop, the riders become aware that it's time to walk/run up to the stop when the indicator lights starts to change colors, preventing missed bus trips.

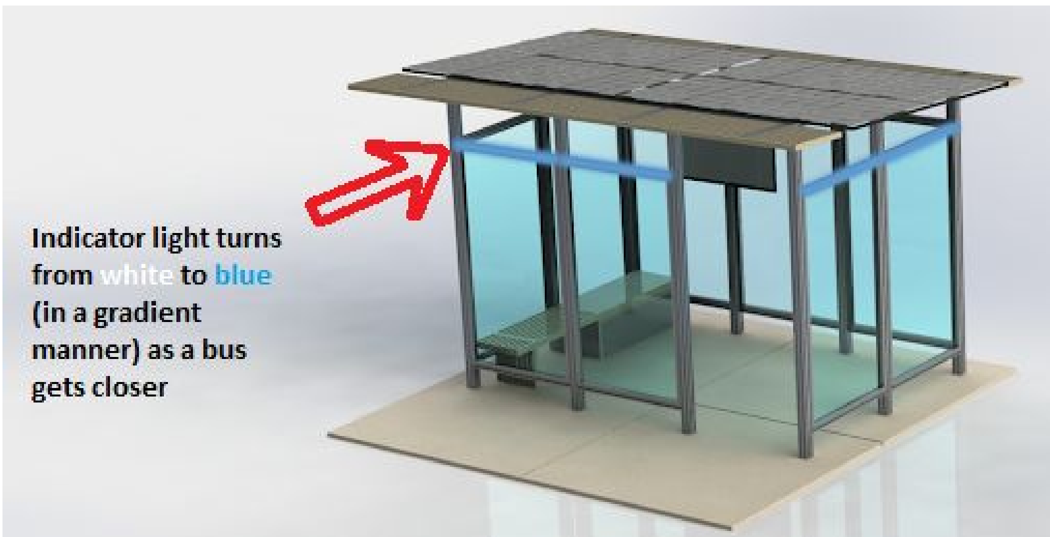


Figure 56: Indicator lights around the bus shelter perimeter

For instance, during cold winters and hot summers, riders waiting for a bus tend to stay inside an enclosed building (e.g. Starbucks coffee shop) for protection against extreme weather. However, there are various problems. Riders cannot see the bus-time information displayed on the LCD screen from a distance. Second, not all riders own a smartphone or the app to be alerted of the bus' arrival time. Although the LCD Screens are fantastic features in informing the riders of the next bus' exact arrival time, it requires the rider to be standing *at* the bus stop in the cold. Fortunately, the indicator lights solves those problems.

Post research, we have decided to order LED lights from *Super Bright LEDs* company (Figure 57), which is a leading online LED light retailer for industrial use.

Figure 57: “Super Bright” LED lights

A great benefit of these lights is its IP66 dust and water resistance, which means it can withstand high dusty winds and strong jets of water with no consequence. Other few perks are, but not limited to, include, longevity of 30,000 hrs constant emittance, can be cut into small strips (this would grant us flexibility in wrapping around the bus shelter perimeter with ease), and it’s dimmable. To take advantage of its dimmability, the lights are slightly dimmer at night to preserve power, while still ensuring light visibility.

The lights will be housed inside an aluminum C-channel (Figure 58), which slides easily into our T-Slot for quick and secure installation. This means, in the event of a light replacement (estimating every five years), the C-channel (with the lights in them) can be easily removed and replaced with new C-channel (LED lights pre-adhered).

Figure 58: LED Indicator lights installed inside the Aluminum C-channel

In terms of safety, this technology also prevents riders from attempting last-second jaywalks (in front of the bus sometimes) occasionally due to noticing a bus approaching from a distance and attempting to run across the road to catch their intended bus, which puts them at risk of injury.

As the indicator lights starts functioning, bus riders can decide the best time for their arrival to minimize their time spent at the bus stops and guarantee a rendezvous. A quick glance at the bus shelter can instantly tell a rider whether to walk or run towards the bus stop, thereby reducing the probability of jay walk accidents, and ultimately increasing the number of TCAT ridership by minimizing missed bus trips.

Solar Introduction

Goal for the semester

The Solar Team worked alongside the Shelter team this year, in an effort to streamline the decision making process for part. The sub team's semester goals included finalizing all electrical parts, ensuring that all parts ordered were compatible with one another, creating structured assembly process instructions for large scale application, and brainstorming unique ways to make use of any excess power generated.

Solar Power System

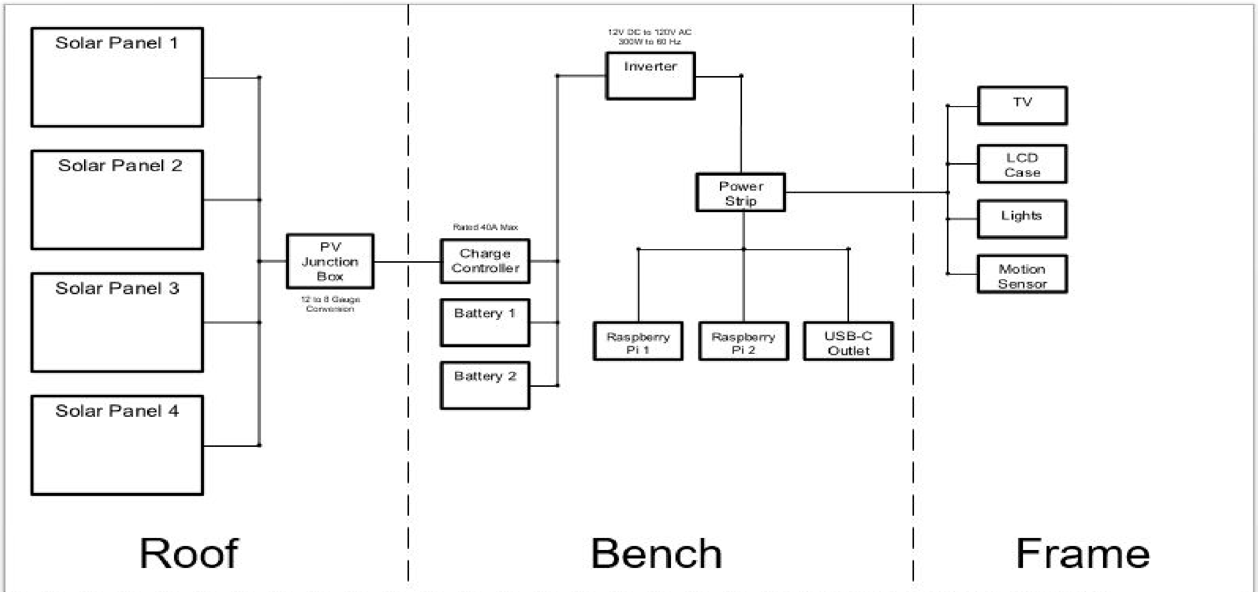
Components

Both the medium and the large shelter are expected to fit four Lumos GSX 72/72 +10% BiFi Boost panels with a rated wattage of 396W. The panels will be 79.17” x 39.4” x .3” and will have a rated efficiency of .197. The panels will output a peak voltage of 38.6V and a maximum current of 9.99A, which when the four panels are wired in parallel the maximum input to the charge controller would be 38.6V and 39.96A where the charge controller chosen is rated for a maximum current of 40A.

The charge controller will be MPPT standard and will regulate the charging for two 12V, 120aH sealed lead-acid batteries that will store excess charge for the solar module. The DC power from the batteries will be converted to 120V AC via a 300W pure-sine wave inverter that will then feed into a power strip for additional appliances such as an LCD monitor, lights, motion sensor, Raspberry Pi, and charging outlet. An additional WiFi router can be powered, but currently we can assume in the locations we will be building bus shelters in the short term will have Wifi access.

One Line Diagram

After meeting with Taitem Engineering Yossi Bronsnick, it was determined that our electrical components should be compiled into formalized documents, which list part specs and connections. Figure 59 is the first draft of the Electrical One Line Diagram, which is meant to act as formal documentation and a generic installation guide.



PV Module & Inverter Specifications	
PV Modules	
Make & Model	Lumos GSX 72/72
Nominal Output	360 W
VMPP (V)	38.6 V
VOC (V)	47.6 V
IMPP(A)	9.32 A
ISC (A)	9.99 A
Inverters	
Make & Model	Samlex 300 Pure Sine Wave
DC Operating Voltage	12 V
AC Operating Voltage	120 V
Wattage Rating	300 W
Surge Rating	500 W

Figure 59 One line diagram

The parts are divided into three subsections: the roof, the bench, and the frame. The Solar Panels will be doubling as the roof of the shelter, so they make up the bulk of the roof section, along with a PV junction box that will be used to make the jump from 12 gauge wire to 8 gauge wire. The bench subsection consists of two separate boxes, one which will house both batteries, and another to fit the charge controller, AC/DC inverter, power strip, Raspberry Pi Computers, and phone charging port. The need for a two container storage system arose over concern that the batteries may overheat and damage other electrical components. Word from Taitem's resident battery storage expert in the coming weeks will shed better light on the situation and provide a solution to this problem. Finally, the diagram shows the frame section, which includes an LCD Monitor equipped with environment controlled casing, indicator lights and ambient lights, and a motion sensing device to help reduce power consumption. As requested by Taitem, a legend was also provided to give better insight into the Solar Module and Inverter specifications. While the one line diagram is merely a first draft, it provides fantastic insight and clarity for those outside of the solar team.

Electrical Loads & Components

All of the electrical loads present were covered in the previous section, however it is important to look at what purpose each will serve as well as the cost to maintain each in the shelter. The charge controller is a crucial element of the electrical system. It uses no power while ensuring that the solar panels do not overcharge the batteries and ruin their lifespans. If the controller senses that the batteries are full, it breaks the connection until the batteries have more storage capacity. The inverter is in place to convert from DC power to AC power, which is necessary for compatibility with all loads. In analysis of each load, both worst case and average case power consumption were computed, and hours of use per day were also factored in. The load calculations are as follows:

	Watts	Time Assumed (hr) WORST CASE	Time Assumed (hr) AVERAGE CASE	Loads in Wh WORST CASE	Loads in Wh AVERAGE CASE
LCD TV	23	12	8	276	184
LCD Enclosure	8	24	24	192	192
Indicator Lights	**9**	**8**	**6**	72	54
Interior Lights (on at night)	**10**	**8**	**6**	80	60
Motion Sensor	7	21	21	147	147
Charging Outlet	20	2	0.5	40	10
1x Rasberry Pi's	10	24	24	240	240
Wifi Router	0	24	24	0	0
Total	87			1047	887
30% Energy Loss				314.1	266.1
Total with loss				**1361.1**	**1153.1**

Figure 60 Load calculations

These calculations show how much power will be consumed by the shelter in a given day, and were then compared with power output calculations to determine the net gains or losses at any given time of the year. The output calculations are currently based on an analysis of A-Lot's solar exposure using Grasshopper, and will be updated in the spring with the help of Taitem Engineering SunEye. The net power calculations report power produced minus total loads and yield positive kWh in all months of the year.

Month	Total Power Produced (kWh)	Net (kWh) - Worst Case
January	2.144997419	0.7838974194
February	3.019672258	1.658572258
March	4.573854194	3.212754194
April	5.73516	4.37406
May	7.245458065	5.884358065
June	7.493286452	6.132186452
July	7.729104516	6.368004516
August	6.785139355	5.424039355
September	4.862101935	3.501001935
October	3.638665806	2.277565806
November	2.063234839	0.7021348387
December	1.724405161	0.3633051613

Figure 61

Digital

Architecture

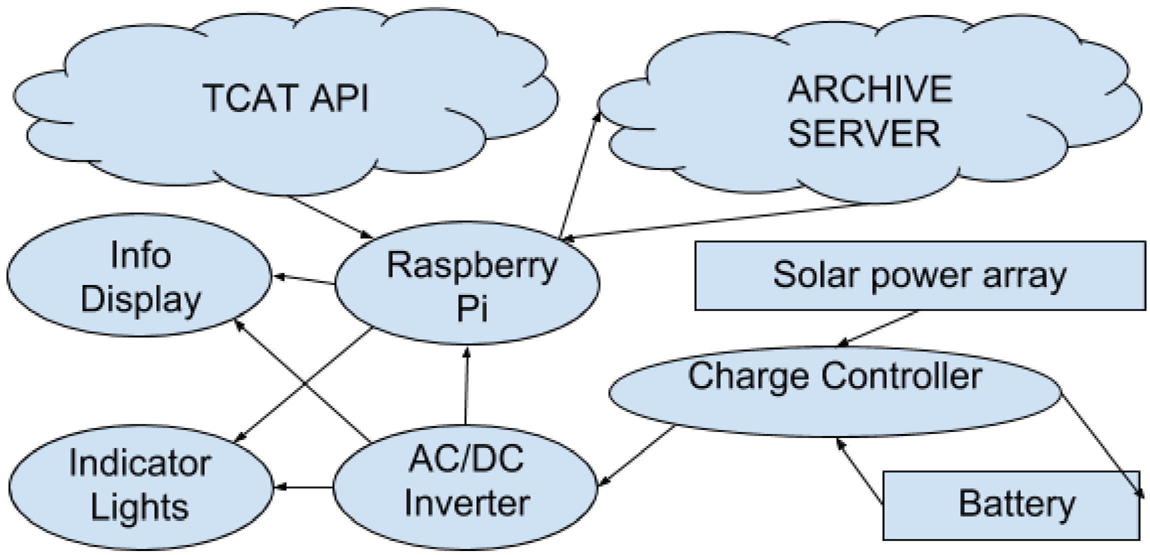


Figure 62: Overall architecture of the digital subsystem as of this semester. Lines indicate flow of voltage or data.

Information Display Redesign

Redesign

After the completion of the first prototype of the display screen, user research was done to determine if the screen fit the needs of the riders. Cornell students age 18-24, as well as Ithaca residents above the age of 25, were interviewed. Participants included those both new to the area and those who had lived in Ithaca for over a year. These interviews were analyzed and an affinity diagram was created to reveal the major themes.

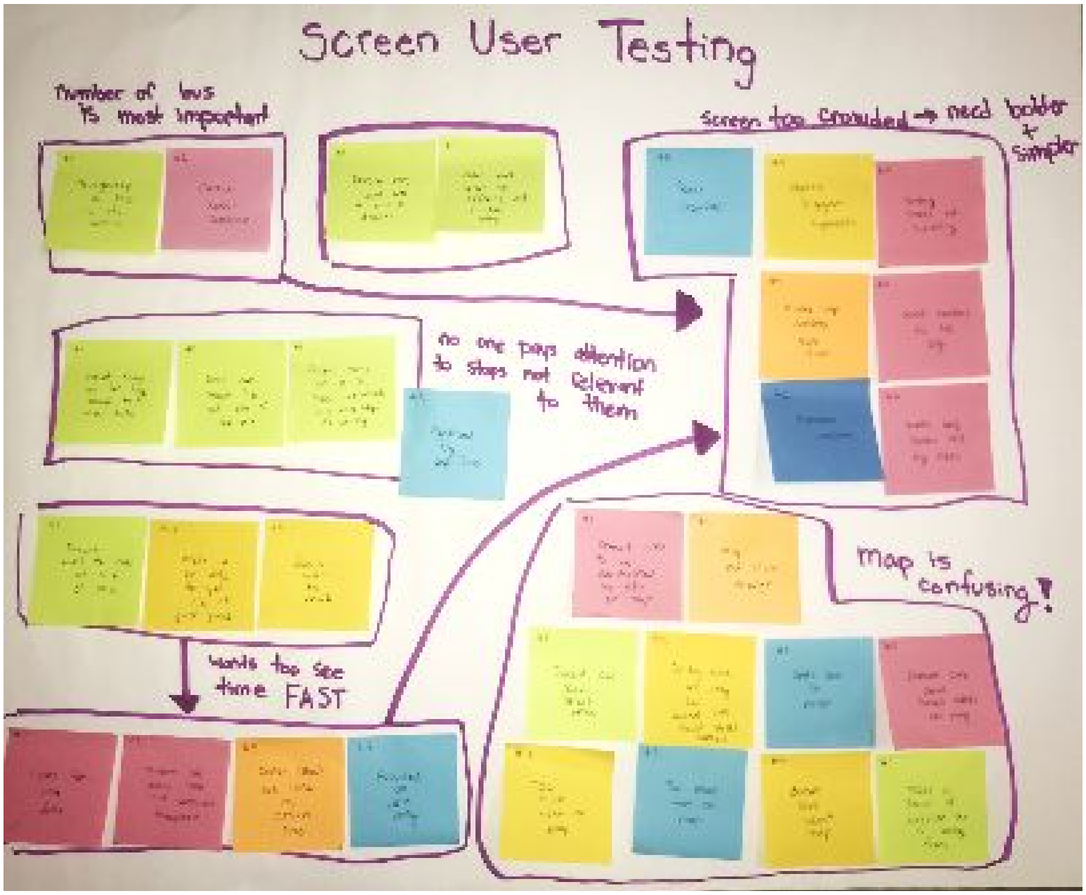


Figure 63: User Testing

The first theme revealed how riders identify their bus. It was found that riders recognize the bus they must take based off of the number of the bus. The second theme was that riders do not care about stops irrelevant to them. Participants revealed that they don't stay on the bus long enough to care about the other stops on their route. It was also revealed that the last stop on the route was irrelevant information to most riders. The third theme found was that riders desired quick and easy information delivery. Participants revealed that they only wanted to have to glance at the screen and that any additional reading effort was extremely undesired.

The last two themes found were both related to the first prototype of the screen. It was found that participants did not understand the map and that they felt the screen was too crowded. Participants felt confused by the map on the prototype and felt overwhelmed while looking at it. Many expressed a lack of sense of direction, making the map completely irrelevant to them. It was felt that in this context the map would not be utilized. Furthermore, many participants felt as if the screen was overcrowded causing it to be difficult to find key information. Many expressed frustration with the fact that nothing stood out to them, causing them to have to read the entire screen to find the information they desired.

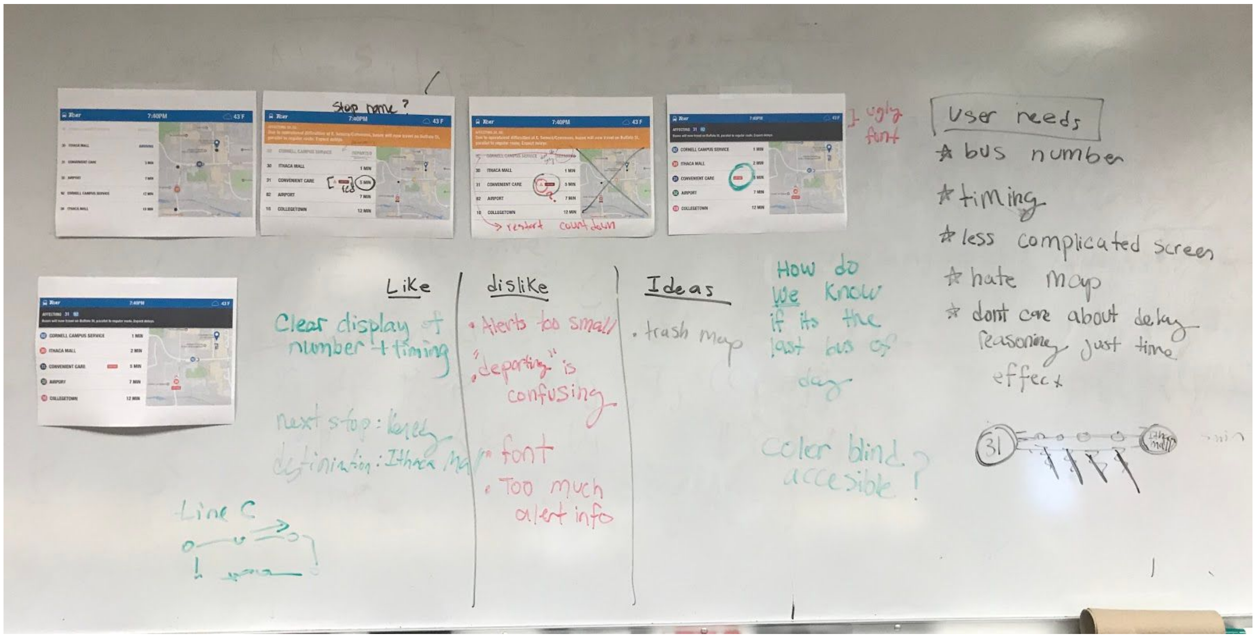


Figure 64: Screen redesign research

After concluding the feedback from user research, we started redesign of the information screen. The biggest change to the original design is the removal of real-time map, since the user research shows that the map causes confusion for the users. Also, we found it essential to give users an insight of the bus route, therefore we replace the part of map with a section showing the next seven stops and the final destination of the latest coming route.
As for the font and color choosing, we decided to make blue the primary color, which is also the logo color of tcat and use clear and clean font. Lastly, we move the alert part to the bottom underneath the bus information, so that it would not cause confusion for the users. Overall, it is a simplistic and elegant redesign.

Implementation

To implement the design changes we made above we took the following measures. First, we created the front end aspect of the information display. This was done using HTML and CSS. The HTML code basically set the text elements of the screen whereas the CSS code was written in a separate file and connected to the HTML using a link tag so that the structure of the text elements could represent the following screen.

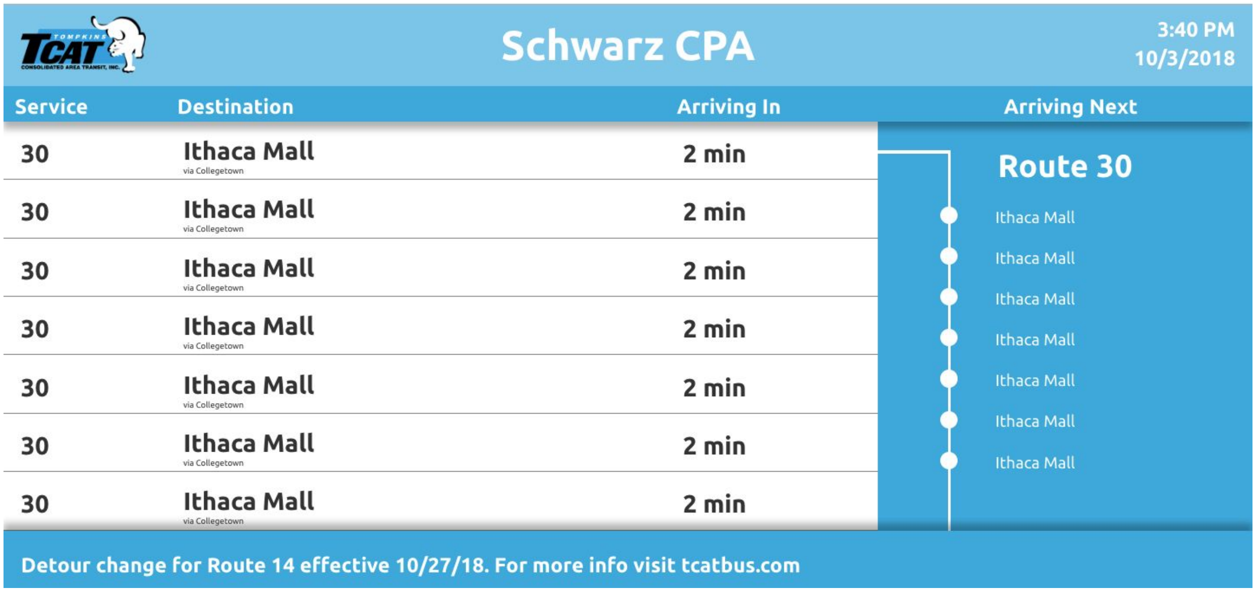


Figure 65: Updated LCD Screen

As seen above, to create this front end design we basically had 4 different sections of HTML code, which were represented in HTML using div tags and then we assigned the class of the tag to each section. Section 1 was for the panel of the image which included the TCAT logo, the title of bus screen, and the time. The next section (i.e section 2) implemented the panel below it which basically included the headers: Service, Destination, Arriving In and Arriving Next. Section 3 involved the Service bus numbers (hard coded as 30 for front end), Destination (hard coded as Ithaca Mall), Arriving In and Arriving Next which too were hard coded as shown in the image above. Finally, section 4 was responsible for the alert panel shown below section 3.

Obviously, such a design could not be used for the actual information display as everything was hardcoded. In reality, the service bus numbers would depend on the stop itself, the arriving times and arriving next would also need to be updated in real time. Similarly, the title of the screen which includes the name of bus stop would have to be location dependent depending on where the bus stop is located. To implement such real life changes, we used javascript, especially the jquery library. What was done is that, for example, for getting the service bus numbers a get request was made in jquery which gave a json that came from the list of buses attending to a bus stop. Then we parsed the string and picked out all the bus numbers from the routeid of the buses in the json and put that into a row format so that the new screen appears as below. Another modification you can see in the screen below is that time also updates in real time. This was simple to implement basically what was done is that 2 functions were created one that checked time and another which ran the clock as appearing in the image below.

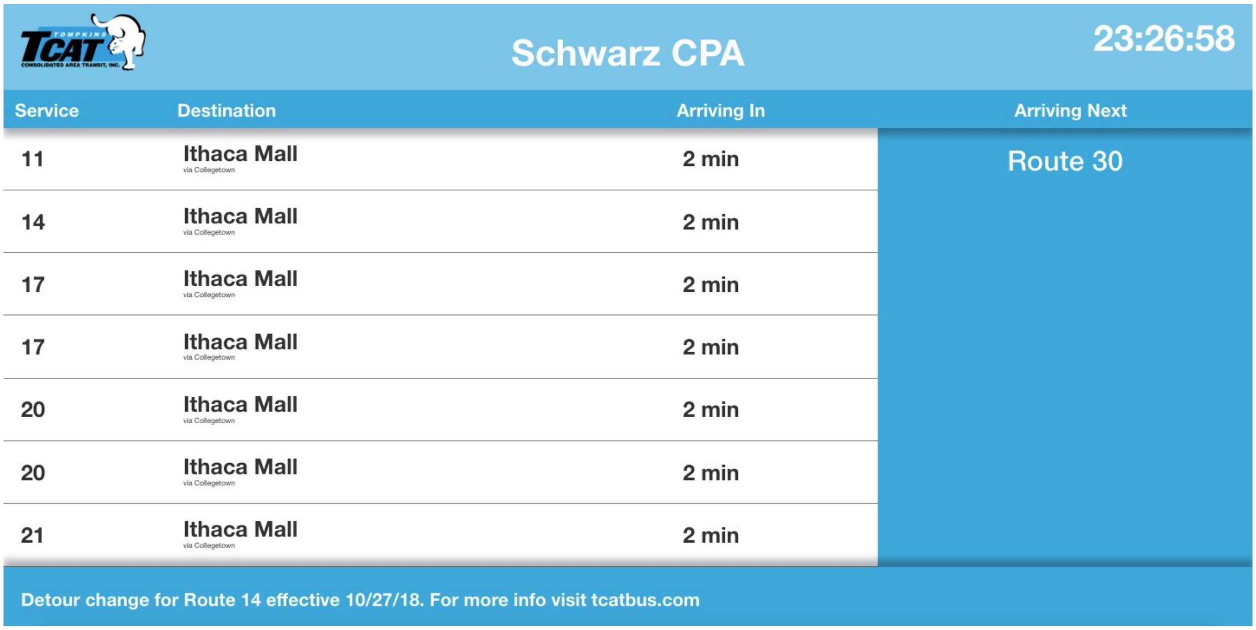


Figure 66: Final Revision of LCD screen

Indicator Lights

Circuit

For the circuit, we are using a breadboard as a base to connect the interface components. The breadboard has a transistor with three pins, each with its own purpose. The first pin connects to the 12V inverter, which converts “direct current” into “alternating current.” The second pin connects to the Raspberry Pi, a credit-card sized inexpensive computer that can lend itself to many light & medium-duty tasks. And the third pin powers and controls the LED lights. The fascinating fact about the third pin is its ability to emit certain types of color. The third pin, which consists of four prongs each, clips to the red, green, blue (RGB) and the ground connections. In order to produce a specific color in our LED lights, different amounts of reds, greens, and blues can be adjusted to produce a distinct color. For example, an X amount of red, Y amount of green, and a Z amount of blue can glow simultaneously to produce our desired color (white) .

Controller

For the indicator algorithm, we are using Python as well as a pigpio library and the TCAT API in order to calculate when a bus is two minutes away from a certain shelter, which is when the indicator lights should turn on and signal that the bus is arriving. Our main function extracts information from the TCAT API about a shelter endpoint and then uses the bus route longitude and latitudes in order to display how far a bus is away from the given shelter. We are using a Google API which takes in two longitudes and latitudes of endpoints and outputs the shortest route time, giving us an estimated arrival time.

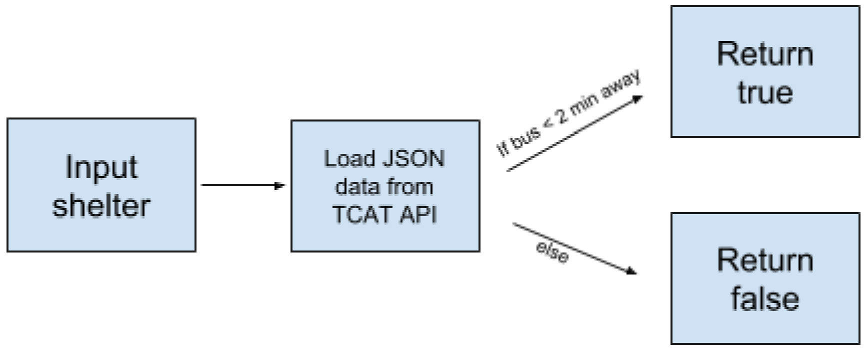


Figure 67: Flow chart of controller functions

Optimization

One of the primary issue we faced when we identified the likely location for our first shelter was the partial tree cover of the site, leading to a decreased ability to product solar power. This in turn required us to think about the best ways to optimize the system and decrease overall power usage. We considered two options to achieve this reduction in power consumption:

Idea	Pros	Cons	Implemented?
Decrease # of microcontrollers from 1 to 2	Relatively simple engineering implementation	Possible performance hit, slower screen reload	Yes
Implement system of tiered shutoff: e.g. non-critical systems power off first when the battery charge is low to save charge for critical systems	Allows the shelter to operate with minimal functionality even in the dead of winter	Complicated engineering task, requiring systems to shut off and restart gracefully and each work independently of lower-tiered systems. Likely that subsystems would sometimes not restart properly, redundancy and failsafe measures would be needed.	Not this semester, maybe next

The outcome of this optimization of the digital system is that the shelter is now self-sufficient through 10-11 months of the year (depending on snow cover and final location of the shelter). See solar section for more details.

Routing

Introduction

Previously, over Summer of 2017, TCAT presented us with the task of defining the Lansing problem. Ridership on the 36, 37 and 77 routes was noticeably lower than other areas of similar population demographics. Their data showed consistently low ridership for several years. The Routing Team was tasked with determining the cause and what could be changed to increase ridership. This task presented itself as a great opportunity to integrate Systems Design Thinking with Quantitative Methods, the integration of which is never done. The integration of complex human centered design and the mathematically rigorous process of quantitative analysis made this project all the more challenging and exciting because something like this had never been tried before.

During Fall 2017, we conducted traditional research (fact finding), finding as much information on Lansing as possible. We divided into two groups, Systems Design Thinking and Quantitative Methods. The Systems Design Thinking group unpacked the empathy episodes and modeled the emotional data, while the Mathematical Modeling team worked to use algorithms and discrete numerical data to model the system and find possible improvements.

Spring 2018 was largely spent on improving our works from Fall 2017. We started the semester by working with our previous empathy fieldwork results to create 16 potential scenarios for the bus routes, and narrowed the 16 potential scenarios down to 3. We presented these scenarios to TCAT and the Lansing stakeholders, and due to our work in Lansing, TCAT held several Lansing community meetings over Summer 2018.

By Fall 2018, our recommendations were partially implemented. While there were multiple timing changes on Routes 36, 37 and 77, the most notable change was the addition of a new park and ride location in the Lansing Town Hall parking lot, a suggestion that we made in order to increase ridership. While the full effect of these changes remains unclear, TCAT has expressed that there is a possibility for additional trips if the ridership does in fact increase.

This semester has largely been focused on laying the foundation for additional work in the next semester. Much of the team graduated, and there was a need to fill the gaps left by them. The goals of the Routing team this semester were twofold. First, we wanted to fully complete the Lansing Project, and determine if there was a suitable site for the shelter in the town**.** Second, we wanted to begin work on aspects of the Collegetown Project, as set forth by SYSEN 5740.

Lansing

For Routing, the Lansing work was mostly completed. However, over the course of our time in Lansing, we developed a relationship with several local stakeholders, most notably Michael Long, the planner for Lansing and Larry Fabbroni, a civil engineer of a new apartment complex, Village Solar, located in Lansing NY. Through this partnership, we developed a working site for a new shelter, and continued to work with Michael Long, the Lansing Planner.

In late October, Shelter and Routing presented to representatives from both TCAT and Lansing. During this presentation, we discussed the pedology and topography of the proposed site. From their comments, we were able to revise the planned site for the new bus shelter.

In the weeks following, a group of Routing and Shelter students, along with our faculty advisor Siri Simoncini, Michael Long, Matt Yarrow, and Larry Fabbroni, visited the site and discussed the likelihood of implementing the new shelter. While we tentatively agreed on the site, and its foundation is slated to be poured in the near future, further work by the Shelter team needs to be done to ensure that this is a feasible location. However, it was only through our continued relationship with Michael Long and Larry Fabbroni that the possibility of this site location was made feasible.

This initial site visit also paved the way for future work to build additional shelters at other locations. This is one of the primary goals of the Masterplan sub-team, which has spent significant time researching other sites that could benefit from our new shelter design. More information can be found in the Masterplan section of the report.

The Collegetown Project

One of the future goals of Sustainable Mobility involves closing down the 300-400 block of College Avenue in Collegetown to car traffic. Ultimately, the main goal of closing off this street is to provide expedited bus travel through Collegetown, expanded sidewalk width, separated bike lanes and improved street décor with trees and other features. To construct a project of such scale, street space in Collegetown needs to be directed away from automobiles and towards alternative modes of transportation. One necessary elimination will be on-street parking. While eliminating street parking is possible, a new problem emerges: where do people, particularly employees in Collegetown, park? Removing street parking along College Ave may force many employees, most working for little more than minimum wage, to either rent expensive parking spaces from landlords or add significant time to their commute by taking public transportation.

In Siri's Spring 2018 5740 class, they recognized this as an emerging problem and sought to address it by constructing a satellite parking lot for Collegetown employees to park in and implementing a new TCAT route that will provide connectivity from this lot to Collegetown. The location for this lot was ultimately selected as East Hill Plaza because of its abundance of underutilized parking spaces. The project was named "The Spoon," due to the appearance of the route on maps.

On the working assumption of keeping East Hill Plaza as the main parking lot, we were fortunate enough to meet with Jeremy Thomas, the Senior Director for Cornell Real Estate. We discussed the future plans for East Hill Plaza, which are still several years away from being implemented. Although the idea of East Hill Plaza as a transportation hub has been discussed before, in order to adequately assess the demand for such a site, Cornell Real Estate would need examine the existing information for on-campus parking and the statistics on who uses it.

While they already possess some of these statistics, they envisioned that a potential site would be used for parking by Cornell employees, not for Collegetown employees. Furthermore, the reality is that the area is tentatively planned for mixed-use development which will require significant parking already. Therefore, the only way to implement a new route to East Hill Plaza would be to build additional parking in the form of a parking garage, at the cost of $30,000 per space. To justify this type of cost, there would need to be multiple bus routes and bus providers using East Hill Plaza as a terminal, similar to that of the former space on State Street.

However, the future of East Hill Plaza is still mostly in the idea phase, and it appears that is still several years away from breaking ground. With this in mind, Sustainable Mobility adopted East Hill Plaza as the likely location for the Spoon. While the location is a significant starting point, we started to think through the viability of the project. One of TCAT's least profitable and most underutilized routes is Route 82, which runs through East Hill Plaza. Since we know it would be difficult to add an additional route to East Hill Plaza given the current state of the site and the unprofitability of Route 82, we began to consider the need to think through possible ways to reroute Route 82.

While the empathy fieldwork completed by Siri's class provided insight into the direction of this project, the findings were not robust enough to quantify the routing problem. To resolve this, we decided it would be important to develop a survey to understand travel behavior in Collegetown, in order to better understand the travel patterns of Collegetown employees. The survey considers primary travel mode to Collegetown, primary parking location, origin location, commute time, employee work hours, level of employment, and likelihood to support travel improvements in Collegetown. With this survey, we hope to better understand where people are coming from and how, the quantity of potential users, the optimal schedule for a new bus route, and how likely people are to support and use this project. We will use this understanding to draw conclusions about whether or not demand is robust enough to justify rerouting Route 82. If demand is high enough, the survey should provide enough information to propose justified routing and schedule changes to Route 82.

Future goals

In the upcoming semester, we hope to finalize the survey and begin distribution. In addition to the work on the survey, we are looking to continue our discussion with Cornell Real Estate and begin a new relationship with Cornell Transportation. By working with Cornell Transportation, we would be able to understand the state of bus shelters on campus and determine if any current shelters would be eligible for replacement with the new shelter design.

Electrification

Abstract

TCAT expects to replace their old and retiring buses with electric buses. With Federal Transition Administration's (FTA) Low to None Emission grant distributed to NY State, TCAT has secured between $2.3 million and $2.7 million for three electric-powered buses and corresponding charging equipment to deploy the initial stage of an E-Bus system within the next nineteen months. The buses will be Proterra's, an American electric automotive and energy storage company based in California.

Electric buses would significantly decrease the pollution and lower the maintenance and fuel costs compared to diesel buses. In recent years, the trend towards zero emissions have made for a better alternative for bus transit agencies in the United States. Due to this trend of implementing electric buses, TCAT is planning to initiate an electric bus deployment project to gain knowledge and experience about the whole electric bus system, and its corresponding implementation, operation, and maintenance.

The tentative plan is for the integration of these three E-Buses into the existing fleet, however, there is a significant likelihood that more E-Buses will be joining TCAT in the near future. Therefore, scalable deployment, charging infrastructure and transit routes need to be taken into consideration.

The Electrification team seeks to address any potential risks for TCAT's entire system, and to find the most economical solution for long-term implementation of the electric buses. In order to satisfy customer needs, our team is using system engineering tools to analyze the electric bus system for TCAT, and help prevent the risks and build cost optimization during the life cycle of the whole system. Ultimately, our team will help TCAT design, create, and document an electrified transit route, including the route selection, operation scheduling, charging schedule and charger locations, all in coordination with intended and selected charger configuration.

Charging Methods

Overall, there are two types of chargers. The first type is the Plug-In Charger.

Figure 68: Universal Standard J1772-CCS Plug-In Charger

It is a standard J1772-CCS Type 1 charger with universal ports. They are offered by Proterra and other suppliers such as Schunk Inc. This type of charger can only be installed and mounted at departure stations or end stations. However, these standardized chargers can be shared between Electrical buses, utility vehicles and cars.

Figure 69: Different Plug-In Charging Infrastructure

More specifically, there are three power output levels for Plug-In Charging Infrastructure: the 60 kW, 125kW, and 500kW. Different output levels serve corresponding E-bus fleets which can all be located up to 492 feet from a dispenser. For scalable and remote purposes, they can be installed side-to-side and back-to-back for high-density charger banks.

Figure 70: Proterra's Power Control System

The second type of charger is Overhead Fast Charger. It is an industry-standard SAE J3105 overhead system with easy depot or on-the–road charging. It enables E-Buses to be charged on the road for longer routes or 24/7 circulator operations. It only has a 500kW level of output and its port is not compatible with consumer vehicles like Tesla. However, it has low maintenance costs and high availability, and it is compatible with roof-mounted pantographs as well as inverted pantograph systems, offered by Schunk and other suppliers. It is a smart choice for large E-Bus fleet which has small parking space and requires continuous operation with little intermittent time.

Figure 71: SAE J3105 Overhead Charging System and Pantograph

Types of E-Bus

There are three major types of Proterra's E-Bus: the FC series, the XR series, and the E2 series. Moreover, there are ProDrive drivetrain and DuoPower drivetrain for each series. As for the body type, there are two different catalysts that are 35-Foot and 40-Foot respectively. Nevertheless, TCAT has basically chosen the latter one with greater seating capacities and larger energy storages. The 40-Foot catalyst has 40 seats, 42'6'' length, and gradeability of 28 degrees. Many other important characteristics and attributes are attached below, which also have significant impacts on the performance of E-Bus operation.

		FC-Series		XR-Series		E2-Series		
	Description	FC	FC+	XR	XR+	E2	E2+	E2 max
CATALYST VEHICLE WITH DUOPOWER™ DRIVETRAIN								
Total Energy	kWh	94	126	220	330	440	550	660
Operating Efficiency*	kWh/mile	1.21-2.02	1.28-2.08	1.15-1.95	1.21-2.02	1.28-2.08	1.29-2.10	1.35-2.16
	MPGe	18.7-31.0	18.1-29.5	19.3-32.7	18.7-31.0	18.1-29.5	18.0-29.1	17.5-27.8
Nominal Range	Miles; Total energy/ projected Altoona efficiency	68	87	164	238	305	367	426
Operating Range*	Miles; Usable energy/ Operating efficiency	37-62	49-79	90-153	131-218	169-276	210-341	245-390
Top Speed (Proterra-governed, per tire rating)	mph	65	65	65	65	65	65	65
Acceleration (at SLW, seconds)	0 to 20 mph	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	20 to 50 mph	15.5	15.5	24.1	15.5	15.5	15.5	15.5
Gradability (top speed at % grade, at SLW, mph)	5%	54	59	41	54	59	57	56
	10%	34	40	24	34	40	37	34
	15%	23	27	16	23	27	26	25
Max Grade (at SLW)		27%	26%	28%	27%	26%	25%	23%
Horsepower	Peak	360	510	240	360	510	510	510
	Intermediate	360	426	240	360	426	426	426
	Continuous	225	257	150	225	257	257	257
Motor	Dual independent 190 kW motors	•	•	•	•	•	•	•
Gearbox	Proterra 2-speed auto-shift EV gearbox	•	•	•	•	•	•	•
Curb Weight	lbs	28,324	29,900	26,750	28,324	29,900	31,574	33,150
Max Gross Vehicle Weight Rating	lbs	43,650	43,650	43,650	43,650	43,650	43,650	43,650

Figure 72: Characteristics and Attributes of 40-foot Catalyst

A Decision Matrix, one of the system tools, is used to determine the E-Bus type for the early stage and deployment. A decision matrix is a list of values in rows and columns that allows an analyst to systematically identify, analyze, and rate the performance of relationships between sets of values and information. And then, pursuing the best result based on certain decision criteria is the optimal goal of decision matrix. Moreover, key attributes are more likely to be weighted based on their relative importance before they are counted into decision criteria. In this case, the three types of Proterra's E-Bus are changing variables, and six important criteria are valued and weighted, in order to filter the optimal option.

Decision Matrix

Instructions:
Use this template to create your own Decision Matrix to assign objective values to your criteria. Your table should include a list of criteria for your different options as well as values, min and max values where appropriate, normalized values, the criteria weight (or importance), and a final score. Be sure to add the necessary scoring guidelines below the matrix for any criteria that cannot be directly measured.

My project is Sustainable Mobility with Prof.Sin, and my focus area is electrification part. Basically Tompkins County received a huge grand from Federal and NY state, and it aims to promote electrical transportation and reduce air pollution by decreasing gasoline/diesel-based transportation emission. TCAT is buying three electrical buses from Poterra for the first stage, and there are few models for the electric bus. I'm choosing three of them as Option A,B and C.

Option A is FC type, Option B is XR type, and Option C is E2 type. The data is extracted from: https://www.proterra.com/products/35-foot-catalyst/

	Values					Normalized Values				Final Scores			Notes	
Criteria	*Option A*	*Option B*	*Option C*	**Min Value**	**Max Value**	*Option A*	*Option B*	*Option C*	**Weight**	*Option A*	*Option B*	*Option C*		**Weight**
Operating Ranges(miles)	79	218	276	60		0.29	0.79	1.00	0.21	0.06	0.16	0.21		10
ENERGY LEVEL (kWh)	126	330	440		500	0.71	0.25	0.00	0.19	0.13	0.05	0.00		9
PLUG-IN CHARGING(Est Time empty to full, hrs)	1	2.5	5		8	0.67	0.17	0.00	0.17	0.11	0.03	0.00		8
CURB WEIGHT (lbs.)	28925	27350	30500		35000	0.05	0.10	0.00	0.10	0.01	0.01	0.00		5
Horsepower	360	240	510	150		0.71	0.47	1.00	0.15	0.10	0.07	0.15		7
Operating Efficiency(MPGe)	25.9	27.3	24.7	20		0.95	1.00	0.90	0.19	0.18	0.19	0.17		9
														48
Score Totals						3.37	2.78	2.90		0.59	0.51	0.52		

Add your scale measure definitions here.

Scale Measure for Operating Ranges	
Score	**Scale Condition**
5	Maximum ranges when bus operates under demanding conditions, including harsh weather, extreme tempera
4	Maximum ranges when bus operates in more mild, temperate weather conditions with low use of HVAC, flatter terrain, and less stops
3	buses' maximum range under standardized Altoona test track conditions.
2	Maximum ranges when bus operates under optimal conditions, including temperate weather conditions, less stops, optimal driver behavior, minimal HVAC usage, express routes, flatter terrain.
1	Maximum ranges when bus operates under ultimate ideal conditions which doesn't exist in real world.

Figure 73: Decision Matrix Table and Specification

As it is shown as above, the FC type has both the the highest normalized and final value, one of the main reasons that TCAT selected it.

Case Study

Since March 2014, a transit company named Foothill has been operating a fleet of Proterra electric buses in the San Gabriel and Pomona Valley region of Los Angeles County, California. These E-Buses are FC type's 35-foot catalyst and are capable of being charged by both Plug-In and Overhead chargers. However, Foothill abandoned Plug-In chargers in favor of utilizing two overhead fast chargers instead. Foothill is using a charging method called "Fast and Short" to operate all of their E-Buses. Essentially, these Battery Electric Buses (BEB) are charged only on route at these two transit centers an average of 12.5 times per day via one of two overhead conductive chargers. With an average charge duration of just 4.99 minutes, the average charging energy delivered equates to 22% of the entire energy storage of an Electric Bus. It is not a huge percentage but this charging behavior is consistent with large fleet operation, where the average battery pack Stage of Charge (SOC) of each E-Bus will never drop below 45%, and at most of the time it is kept between 50% and 75.4% of SOC.

According to research, E-Buses should spend less than 6% of their operation time at 55% or less SOC, to optimize deployment. While achieving that, Foothill's charging and operation behavior also provides each E-Bus an operating range of at least 250 km, with optimal energy consumed and the most efficient time applied. Operationally, the buses could be charged less frequently on route, which would allow drivers to get back on schedule if they are delayed. Systematically, there is a potential opportunity to reduce the size of the energy storage system on the vehicles running this particular route to reduce weight and purchase price.

Overall, this case study emphasizes the importance of understanding how an E-Bus's drive cycle and operating environment influence its overall duty cycle and how that duty cycle impacts the overall performance of Proterra's technologies. While the E-Bus fleet of Foothill Transit demonstrated an energy efficiency of 1.34 kWh/km, road grade and non-tractive energy demands such as HVAC can have a significant effect on overall energy efficiency and must be taken into account when determining the feasibility of deploying "Fast and Short" charging method. However, so far, this kind of charging behavior seems to be the most efficient way to economize energy and optimize time of charging.

Figure 74: Route Map of Foothill Transit E-Bus Operation

Issues to be Addressed

First, we must identify and decide the most efficient, most cost-effective way to electrify our high-priority transit routes, including the route selections and operation schedules. This requires GPS tracking data in order to analyze routes and layover identifications. Factors that can affect an E-buses' battery efficiency include weather, terrain, and speed. The extent to which the battery efficiency is affected by Ithaca's environment has not been fully assessed and understood.

Second, TCAT's aging fleet maintenance and its corresponding effects could also lead to an issue for the E-buses' scheduling. Electric buses will be a drain on the maintenance department's time and budget. According to TCAT's Annual Report of 2017 and Proterra's dataset, diesel buses operated on an average of 258 days, while E-buses operated an average of 224 days. Moreover, the average mileage for E-buses was 24,576, which is significantly less than the average mileage of 30,526 for diesels. However, the E-buses will show improvements in operating efficiency; 5 percent more kWh/mile comparing to same-age diesel buses or approximately 370 gallons of fuel on a bus that travels 25,000 miles annually. Further work is needed to determine a method to coordinate the distribution of E-buses and diesel/hybrid buses in order to achieve routing optimizations and operation efficiency.

Finally, calculations and assumptions are needed to determine the reduction of harmful emissions of diesel buses compared to Electric buses. Additionally, there is the issue of Carbon Emissions since global warming is a worldwide issue with significant consequences. According to the dataset provided by our faculty adviser Wenqi Yi, replacing six older buses results in an estimated elimination of 7,245 gallons of diesel consumption per vehicle per year. This translates to reduced harmful emissions by 337 kilograms of NOx, 119 kilograms of CO, 31 kilograms of HC, and 12 kilograms of PM2.5 per vehicle per year. Moreover, reduced Carbon Emission is approximately 83 metric tons per vehicle per year, based on current diesel consumption. However, E-buses are not totally environmental friendly. Thus, the team is tasked with providing TCAT with a method to measure gas emissions.

Risk Analysis

Risk analysis is important for TCAT because any small mistake in the system could lead to a certain degree of failure of the whole system. The cost of handling the problems could be enormous. If TCAT could notice the potential failures beforehand, they could avoid the failures. TCAT has responsibility to ensure the safety and interest of the public. The standard of measuring failures would be different for different companies. For TCAT, which is a public transportation operator, they should be especially careful about the public safety and service level.

Our team applied FMEA and FTA tools to identify the risks in the electric bus system for TCAT. Before this, our team researched on electric bus systems to analyze the subsystems in an electric bus system. In order to prevent most of the risks in the system, we divided the whole system into several subsystems, such as the power subsystem, bus control subsystem, etc. Figure 74 of the subsystem matrix show the components that belong to each subsystem and also show the main function requirements for each subsystem. Under the subsystem matrix, each component in the electric bus system can be checked if it follows the function requirements for the subsystem. For example, one of the function requirements for bus control system is that the system shall be able to open doors when charging, so the structure of this subsystem, such as electric door actuator shall be able to meet that specific requirement to ensure the service level and safety of the whole electric bus system.

Each subsystem is correlated with other subsystems, and the interactions between each subsystem is also very important because things would go wrong if the interaction between each subsystem is not what it should be. The interactions between each subsystem are called interfaces. For example, in the figure of the interface matrix, the interface matrix shows that the battery power subsystem provides battery SOC (State of Charge) information to the chargers, then the chargers could supply electricity to the electric buses based on the SOC information. However, if the battery power subsystem could not provide the correct SOC information to the chargers, then the chargers could not know how much electricity to charge the electric buses. The rest of the interfaces between different subsystems would be the same, and risks are often occurred at the interfaces.

In addition, before we get to the FMEA and FTA, we should know exactly what the system shall be able to do, otherwise we will not be able to know what are the most important requirements for the electric bus system. In order to know the requirements for the whole system, we have a requirements table to list almost all of the most important requirements for the electric bus system. The figure of the Requirements table shows us the original and derived requirements for the system, and the derived requirements are derived from some original requirements. For example, in the requirements table, the OR.2 (Original requirement 2) is that the system shall be able to remind the drivers to recharge the electric buses, and the DR.2 (Derived requirement 2) is that the system shall be able to alert the drivers when the battery level is at low battery level. The DR.2 is derived from OR.2. The requirement table could allow us to notice the least error-prone place.

After we got familiar with the electric bus system, we created FMEA table for the electric bus system. FMEA (Failure modes and effects analysis) is a tool to define, identify, and eliminate the possible failures in the system. In FMEA, we came up with the failure modes from what we learned from case studies and what we analyzed by using the system tools. For example, the F.3 (third failure mode) is inaccurate estimate of SOC, and we know the importance of the correct SOC from the interface matrix, the wrong SOC could lead to improper charging that could shorten the battery life. We also include the possible causes for the corresponding effects for the specific failure mode, for instance, one possible cause for the wrong SOC is the extreme change in temperature. By using the RPN definition table, we obtain the RPN number for the failure model. The figure of the RPN definitions show the standard severity for the effects and likelihood of the failure modes. For example, the likelihood number is one if it occurs no more than four times per year. After we have the RPN numbers, we list possible correction actions to prevent the failure mode, such as the correction action for failing to show battery level on the screen is to keep an alert system to alert the drivers to recharge the bus. FMEA will help TCAT to prevent some failure modes and save money.

The other tool we used to do the risk analysis is the fault tree analysis, the figure of the fault tree analysis show the causes that could lower the service level of TCAT. The probability for each basic event is just some guessed data, and the fault tree analysis also relates to the FMEA. The causes for each failure mode are the basic events, and the failure modes are in the second level of the diagram. The fault tree analysis could show the probability for the top undesired event clearly if we have the right probability for each basic event.

In conclusion, risk analysis is important for TCAT and the system tools, like FMEA and FTA, could help TCAT define, identify, and prevent risk in the electric bus system. If TCAT could identify the risks beforehand, they could save a large amount of money.

Sensor system	Bus control system	Wireless communication system	Bettery power system	Charger system	Safety control system	Record system	Bus operating system	Bus remind system
The system shall be able to detect the position of the pantograph charge mast.	The system shall be able to contain as many passengers as possible.	The system shall be able to connect chargers.	The system shall be able to show the battery level.	The system shall be able to be charged very often in short time.	The system shall be able to check safety automaically when charging.	The system shall be able to record the amount of passengers.	The system shall be able to move when keep in low-power.	The system shall be able to remind the drivers to recharge the electric bus.
Lidars	Composite frame	Wireless communication system	Display screen	Charger control unit	PE-devices	Inertial measurement unit	Electric power steering	Power sensor
Radar	The system shall be able to open door when charging.	The system shall be able to initiate the charging session by wireless communication.	The system shall be able to have large capacity battery.	The system shall be able to lower the pantograph onto the bus rail.	electric energy sensor	Differential GPS receiver	The system shall save the electricity when running.	Display screen
The system shall be able to detect the position of the primary coils that underground.	Electric door actuator	Wireless communication system	Large battery cells	Pantograph charge mast	The system shall ensure the safety of passengers.	Stereoscopic cameras	Electric air compressor	The system shall be able to remind drivers that the charging session is start.
Lidars	Embedded software computing system		The system shall be able to change high voltage to low voltage.	The system shall be able to raise the pantograph when the charging session is completed.	Optical sensor		The system shall be easy to get maintenance.	Wireless communication system
Radar			DC-DC coverter	Pantograph charge mast	The system shall have safeguard for drivers when drivers use plug-in chargers.		Composite frame	Signal light
				The system shall be able to get power automatically.	Plug-in charger		The system shall be able to get power in extreme weather.	The system shall remind passengers what is the next stop.
				Primary coils	Verification of all requirements shall be conducted in such a way as to preserve the health of human and animal subjects.		Charger shelter	Speaking bus stop reminder
				Second coils	Protective device		The system shall be easy to operate for drivers.	Display screen
					The system shall notify the drivers danger and inherent risk of the system.		Embedded software computing system	The system shall remind drivers when the electric bus is full of power.
					User guide		The system shall be able to be operated under extreme weather.	Wireless communication system
							Electric HVAC	Power sensor

Figure 74: Subsystem Matrix

Electrification

Bus control	Bus remind	Charger	Battery power	Value	Units	Estimate?	Row #	Battery power Subsystem
		Provided to		0-100	%		1	Battery SOC
		Provided to		660	KWh	X	2	Max battery capacity
		Provided to		12	V		3	Voltage of battery
Provided to				200	W/h	X	4	Power for computing system
Provided to					.docx		5	Power connection instructions
Provided to				95	W/h	X	6	Power for electric door actuator
Provided to				8	W/h	X	7	Power for switches
	Provided to			0-100	%	X	8	Battery SOC

Wireless Communication	Bus remind	Safety control	Sensor	Value	Units	Estimate?	Row #	Sensor Subsystem
	Provided to			30-50	cm	X	1	Distance between pantograpg mast and bus
	Provided to				jpg.		2	The image of the object
		Provided to		30-50	cm	X	3	Distance between pantograpg mast and bus
		Provided to		120/240	V		4	Current
Provided to				YES/NO	N/A		5	Connect/Not connect
Provided to				Safe/Unsafe	N/A		6	Safety checking result

Figure 75: Interface Matrix

Index	Originating Requirements & Derived Requirements	Abstract Function Name
OR.1	The system shall be able to show the battery level.	Show
DR.1	The system shall be able to show the battery level on screen.	Show battery level
OR.2	The system shall be able to remind the drivers to recharge the electric bus.	Remind
DR.2	The system shall be able to alert the bus drivers when the battery level is at low battery level.	Alert
OR.3	The system shall be able to have large capacity battery.	Battery capacity
OR.4	The system shall be able to connect chargers.	Connect
DR.5	The system shall be able to connect to chargers by using wireless communication system.	Connect
OR.5	The system shall be able to initiate the charging session by wireless communication.	Initiate
OR.6	The system shall be able to detect the position of the pantograph charge mast.	Detect
DR.3	The system shall be able to recognize the pantograph charge mast accurately.	Recognize
OR.7	The system shall be able to remind drivers that the charging session is start.	Remind
OR.8	The system shall be able to detect the position of the primary coils that underground.	Detect
OR.9	The system shall be able to change high voltage to low voltage.	Change
OR.10	The system shall be able to be charged under different voltage.	Charge
OR.11	The system shall be able to record the amount of passengers.	Record
OR.12	The system shall be able to check safety automaically when charging.	Check
DR.6	The system shall be able to stop the charging process if it is not safe.	Safe
OR.13	The system shall be able to lower the pantograph onto the bus rail.	Charge
DR.7	The system shall be able to stop lowering the pantograph when the bus is moving.	Safe
OR.14	The system shall be easy to implement.	Implement
OR.15	The system shall be able to get power automatically.	Automatic
OR.16	The system shall be able to be charged very often in short time.	Charge often
OR.17	The system shall be able to move when keep in low-power.	Low-power
OR.18	The system shall be able to contain as many passengers as possible.	Space capacity
OR.19	The system shall remind passengers what is the next stop.	Remind
OR.20	The system shall be able to open door when charging.	Running at the same time
OR.21	The system shall save the electricity when running.	Save energy
OR.22	The system shall be easy to get maintenance.	Maintenance
OR.23	The system shall ensure the safety of the passengers.	Safety
OR.24	The system shall remind drivers when the electric bus is full of power.	Remind
OR.25	The system shall have safeguard for drivers when drivers use plug-in chargers.	Safety
OR.26	The system shall be able to get power in extreme weather.	Extreme weather
OR.27	The system shall be easy to operate for drivers.	Operate
OR.28	The system shall be able to be operated under extreme weather.	Operate
OR.29	The system shall notify the drivers danger and inherent risk of the system.	Warn
OR.30	Verification of all requirements shall be conducted in such a way as to preserve the health of human and animal subjects.	Test safely
OR.31	The system shall be able to raise the pantograph when the charging session is completed.	Charge
OR.32	The system shall be able to remind drivers that the bus is in right position.	Remind
DR.4	The system shall be able to alert the bus drivers when the bus is not in right position.	Alert

Figure 76: Requirement Table

Failure Mode #	Subsystem	Failure Mode	Failure Effects	Possible Cause	Failure Effects Severity	Occurrence Likelihood	Risk Priority Number (RPN)	Risk Criticality (Corrective Action Priority)	Corrective Actions
F.1	Bus Control System	Fail to open the door	The customer could not get on or off the bus	The cylinder block	1	1	1	**Low**	Ensure that the door could be open manually
F.2	Power system	Fail to get power from outside	The bus could not be recharged	Aging of battery	2	1	2	**Low**	Change the battery
				Water loss for battery	2	1	2	**Low**	Rehydrate the battery
				Circuit board trouble	3	1	3	**Low**	Repair the circuit board
F.3	Power system	Inaccurate estimate of SOC	Improper charging to shorten the battery life	Extreme changes in temperature	2	2	4	**Medium Low**	Turn on the air condition to regulate the temperature
				Current sensor is broken	2	1	2	**Low**	Change the current sensor
F.4	Bus operating system	Fail to brake properly	The bus could not stop stably	The bus drivers are induffieciently committed to switching to electric	1	5	5	**Medium Low**	More training for drivers
				The brake is broken	4	1	4	**Medium Low**	Change the brake
F.5	Bus operating system	Bus stalled on the hills	The bus require service call and influence the whole traffic significantly	Too steep slope	2	3	6	**Medium Low**	Choose the routes with not too steep slope
F.6	Bus remind system	Fail to show the battery level on the screen	The bus will not be recharged when it is in low battery level	The display screen is broken	2	2	4	**Medium Low**	Keep an alert system to alert the drivers to recharge the bus
F.7	Charger system	Fail to output electricity energy to bus	The bus will not be able to get power	Grid voltage is too high	3	1	3	**Low**	Keep the grid voltage under some level

Figure 77: FMEA

Severity	
5	Causes potential harm to more than one person, Requires more than 1 month to address, Performance is adversely affected by greater than 40%, Cost is more than 30% of the total budget.
4	Causes potential harm to a person, Requires more than 3 weeks to address, Performance is adversely affected by greater than 30%, cost is more tha 20% of the budeget.
3	No harm to a person, Requires more than 2 weeks to address, Performance is adversely affected by greater than 15%, Cost is more than 15% of the budget.
2	No harm to a person,Requires more than 1 week to address, Performance is adversely affected by greater than 10%, Cost is more than 10% of the budget.
1	No harm to a person, Requires less than 5 days to address, Performance is affected by less than 5%, Cost is less than 5% of the budget.

Likelihood	
5	Occurs greater than once a week, Occurs in greater than 15% of the operation.
4	Occurs greater than once a week, Occurs in greater than 10% of the operation.
3	Occurs no more than once a week.
2	Occurs no more than three times per month.
1	Occurs no more than four times per year.

RPN definition table

Likelihood						
5	5	10	15	20	25	
4	4	8	12	16	20	
3	3	6	9	12	15	
2	2	4	6	8	10	
1	1	2	3	4	5	
	1	2	3	4	5	*Severity*

Risk Criticality Ranges

20-25	High Risk
12-16	Medium High Risk
8-10	Medium Risk
4-6	Medium Low Risk
1-3	Low Risk

Spotlight chart

5	1				
4	3				
3	2	1			
2	3				
1	1				
	1	2	3	4	5

Figure 78: RPN Definitions

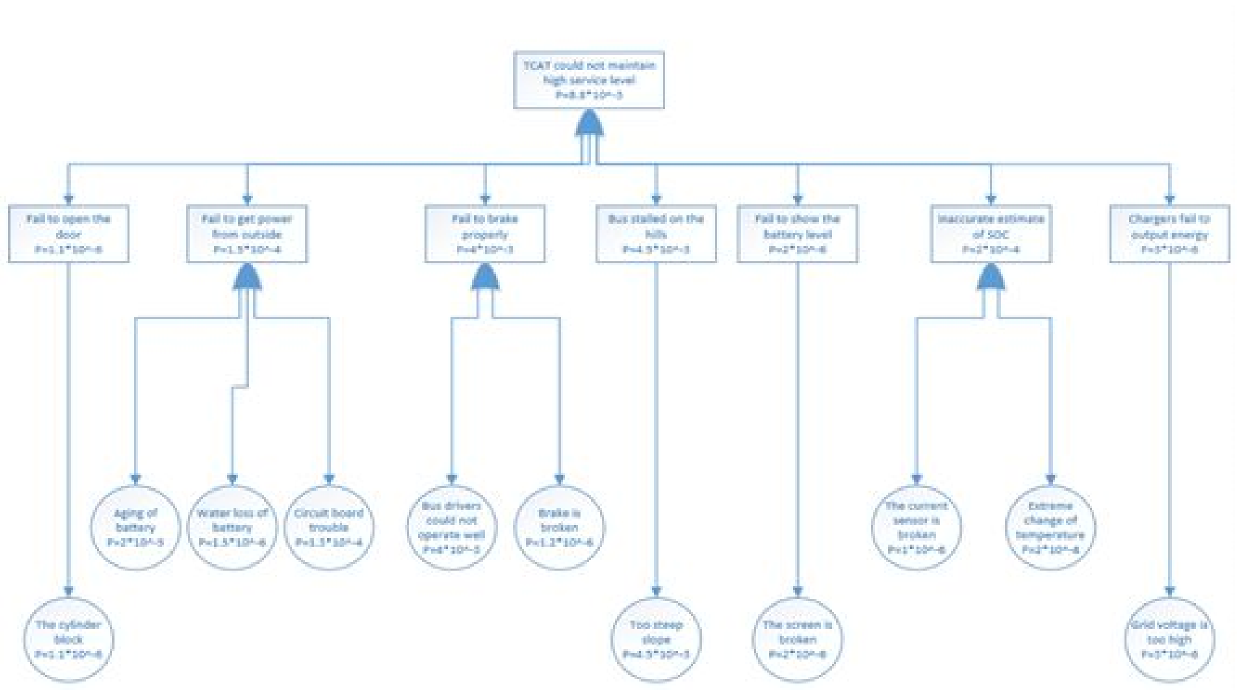


Figure 79: Fault Tree Analysis

Cost Optimization

Our goal is to help TCAT to minimize the total cost for the electric bus system and to provide reference for them to make decisions on whether to buy more electric buses in the future. We are going to construct four versions of cost optimization models to address this challenge. The four versions for the optimization model are base model, version 1, version 2, and version 3. The assumptions for each model are a little bit different, and we will change the goal for each model to reach to our final goal. The difficulty is increasing for the four models, and we will only consider about the fixed electric buses and fixed chargers at the depot for the base model, then we will relax the model to reach our final goal, which is to find how many electric buses is the most economical solution for TCAT. Since TCAT expect to get the long-term plan, we will try to consider the trade-off between diesel buses and electric buses in the long run. For this semester, we will only include the base model and the version 1 model. For next semester, we will do more research to have reasonable assumptions on the parameters to run the base model and the version 1 model. Then we will construct the version 2 and version 3 model based on the first two models. We believe that the cost optimization model will help TCAT to make better decisions on implementing more electric buses in the future.

Base Model

The first step is to build a base model where there is only one charge station and the location of the charge station is fixed. We also assume the number of chargers in the charging station is fixed. There will be three electric buses that will be allocated to three routes respectively. The objective function is to minimize the variable cost per day for all of the electric buses. In order to determine the three suitable routes to allocate the electric buses that could achieve the goal of minimizing total operation cost of electric buses, we set a decision variable x(r) which is binary variable that indicates whether there is an electric bus on a route, r. x(r) = 1 if route r is allocated to an electric bus, and x(r)=0 otherwise. The variable cost per day for three electric buses is consist of the maintenance cost and the electric cost. The average maintenance cost for three electric bus is determined by the variable M(j,r) which is average maintenance cost per mile for electric bus j and for a different route r. T(r) is the numbers of trips per day for the certain route r, and L(r) is the one-round trip distance of the route r. The average electric cost for three electric buses per day is determined by the variable E(r,j), T(r) and L(r). The variable E(r,j) is the average electric cost per mile for electric bus j and for different route r. The E(r,j) is determined by the variable d(r) that is average gradient for different route r, and p(j) that is the parameter of the relationship between gradient and average electric cost per mile for electric bus j.

Assumption 1: Each electric bus will only select one route.
Assumption 2: Fixed chargers (depot charging method).

Equation:

$$min\ V_j$$

subject to :

$$V_j = \sum_r x_r \cdot E_{j,r} \cdot T_r \cdot L_r + \sum_r x_r \cdot T_r \cdot M_{j,r} \cdot L_r$$

$$E_{j,r} = p_j \cdot d_r$$

$$J = 3;$$

$$\sum_r x_r = 3;$$

$$R = 31;$$

Decision Variables:
x(r): Binary variable, indicates whether there is an electric bus on routing r; x(r) = 1 if routing r is allocated an electric bus, 0 otherwise;

Variables:
j: i=1,…,J, where J is the total number of electric buses;
r: r=1,…,R, where R is the total number of routes;
V(j): Variable cost per day for all of the electric buses;
E(r,j): Average electric cost per mile for electric bus j for different route r;
d(r): Average gradient for different route r;
p(j): Parameter of the relationship between gradient and average electric cost per mile for electric bus j;
M(j,r): Average maintenance cost per mile for electric bus j for different route r;
T(r): The numbers of trips per day for the certain route r;
L(r): The one-round trip distance of the route r.

Version 1 Model

Since TCAT plans to have these three electric buses to serve different routes every day, we come up with the Version 1 model. The Version 1 model adds a constraint for the minimal total number of people the three electric buses should serve every day. This new version of the model will help us to find the suitable routes to schedule the three buses during a day. We assume that each electric bus will run 12 hours per day and there are three periods of bus hours for each electric bus per day, each period is four hours. In order to simplify the situation, we also assume that all of the electric buses will start and end from the depot charging station. On the Version 1 model, we change the binary variable x(r) in the base model to x(r,k) that indicates whether there is an electric bus on routing r at the certain period k; x(r,k) = 1 if routing r is allocated an electric bus at the certain period k, 0 otherwise. Accordingly, we change the T(r) in the base model to T(r,k) that is the number of trips at certain period k for the certain route r, and we also add the new variable N(r,k) that is the total number of customers take the bus at certain route r during certain period k. Then we add the constraint that the total number of customers take the three electrical buses at certain route r during certain period k should be bigger than the variable S(k), which is the minimal total number of customers that the total electric buses should serve during certain period k.

Assumption 1: Assume there are three periods of bus hours for each electric bus per day, each period is four hours. Each electric bus will run 12 hours per day.
Assumption 2: Assume all of the electric bus will start and end from the depot charging station.
Assumption 3: Each bus can select multiple routes during 12 hours, each four-hours period for one route.
Assumption 4: Fixed chargers (depot charging station).

Equation:

$$\min V_j$$

$$\text{subject to}:$$

$$V_j = \sum_{r,k} x_{r,k} \cdot E_{j,r} \cdot T_{r,k} \cdot L_r + \sum_{r,k} x_{r,k} \cdot T_{r,k} \cdot M_{j,r} \cdot L_r$$

$$E_{j,r} = p_j \cdot d_r$$

$$J = 3;$$

$$\sum_r x_{r,k} = 3 \;\; \text{for all } k;$$

$$R = 31;$$

$$K = 3;$$

$$\sum_r x_{r,k} \cdot N_{r,k} >= S_k$$

Decision variables:
x(r,k): Binary variable, indicates whether there is an electric bus on routing r at the certain period k; x(r,k) = 1 if routing r is allocated an electric bus at the certain period k, 0 otherwise;

Variables:
j: i=1,…,J, where J is the total number of electric buses;
r: r=1,…,R, where R is the total number of routes;
k: k=1,…,K, where K is the total number of periods of bus hours;
V(j): Variable cost per day for each bus;
E(r,j): Average electric cost per mile for electric bus j for different route r;
d(r): Average gradient for different route r;
p(j): Parameter of the relationship between gradient and average electric cost per mile for electric bus j;

T(r,k): The numbers of trips at certain period k for the certain route r;
M(j,r): Average maintenance cost per mile for electric bus j for different route r;
L(r): The one-round trip distance of the route r;
N(r,k): The total number of customers take the bus at certain route r during certain period k;
S(k): The minimal total number of customers that the total electric buses should serve during certain period k.

Future Work

We plan to build the Version 2 model that will make the number of electric buses be a variable and the other constraints are the same as the Version 1 model. The Version 2 model could help TCAT determine the most suitable number of electric buses they should purchase in the future. Then we will build Version 3 model that will make the location and number of chargers be variable and the other constraints are the same as the Version 2 model. The version 3 model will help TCAT to determine the suitable number of chargers and the locations that will minimize the total cost of the electric buses.

Master Plan and Database

Introduction

The bus shelter master plan team within Sustainable Mobility was established to develop a database that would contain the details of the existing bus shelters as well as propose a plan for the placement of new bus shelters for the next 5 to 10 years. The key reason which gave rise to this team was the lack of a consolidated document of all the existing bus shelters of TCAT within Tompkins County. As mentioned earlier, the shelter team has developed a prototype bus shelter, but in order to place them, a study consisting of a systems engineering approach needs to be evaluated. This study would include analyzing different stakeholders involved along with other factors such as the condition of the existing shelter, the ridership at each of the bus stops, the number of users in the morning and evening peak hours at every bus stop and the preliminary cost of placing the bus shelters.

For this semester, i.e., Fall 2018, the master plan team focused on gathering all the background information related to the existing shelters of TCAT within the city of Ithaca. The geographic restriction was placed owing to time constraints for the team to study the shelters outside of the city of Ithaca. The information that was collected included:

1. Identifying all the stakeholders apart from TCAT who will have a critical role during the placement of bus shelters.

2. Gathering information such as pictures, latitude, longitude and the condition of the existing shelters within the city of Ithaca.
3. Conducting a preliminary analysis of the ridership for the month of September 2018 for all the bus stops within the City of Ithaca.

This information was further studied using the systems engineering approach for developing the database. The sections below list the work that was done by this team specifically for the Fall 2018 semester.

Master Plan Assessment

Identifying Stakeholders of Master Plan

The stakeholders of the bus shelter master plan consists of several groups of people, including the bus users, land owners, private owners, the government (mainly the City of Ithaca and Tompkins County).

While navigating the Tompkins County government website, we found out its database called “Image Mate Online[1]”. It is a online platform that contains the most information about county properties. By entering the street number or street name where each bus stop with shelter is located, we found out the result of its property class. An example is shown below. When we tried to search the property class for the Sage Hall stop at East Ave, we typed “East Ave” into the column and got the information we were looking for. To ensure the accuracy of data, we checked the stop ID in the system. We then repeated this search action for all the bus stops with shelters in the City of Ithaca.

[1] http://tompkinscountyny.gov/assessment/online

Image Mate Online

ssessment Info

Municipality of City of Ithaca			
SWIS:	500700	Tax ID:	31.-1-1.1

Tax Map ID / Property Data			
Status:	Active	Roll Section:	Wholly Exem
Address:	East Ave		
Property Class:	613 - College/univ	Site Property Class:	613 - College/univ
Ownership Code:			
Site:	Com 1	In Ag. District:	No
Zonning Code:	U-1 -	Bldg. Style:	Not Applicable
Neighborhood:	70113 -	School District:	Ithaca
Total Acreage/Size:	2.08	Equalization Rate:	----
Land Assessment:	2018 - $208,000 2017 - $208,000	Total Assessment:	2018 - $75,000,000 2017 - $75,000,000
Full Market Value:	2018 - $75,000,000 2017 - $75,000,000		
Deed Book:	710	Deed Page:	71
Grid East:	847501	Grid North:	891180

Special Districts for 2018

No information available for the 2018 roll year.

Special Districts for 2017

No information available for the 2017 roll year.

Land Types

Type	Size
Primary	2.08 acres

Figure 80: Image mate

The next step was to put the data into the Excel sheet. We sorted out the bus stop with shelters within the City of Ithaca and annotated the property class for each. We took screenshots of the results of data that we input into the Excel as below, and used them in data analysis for later step.

The property classes we identified from *Image Mate Online* thus became the categories in our Excel sheet:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	top_NUMBE	StopName	Region	Latitude	Longitude	Picture	Sun	Mon	Tue	Wen	Thur	Fri	Sat	Total	Private/Public/Business
2	100	Ithaca Commons - Seneca St	City of Ithaca	42.440502	-76.496506		246	470	431	456	477	480	422	2982	Government
3	165	Ithaca Commons - Green St	City of Ithaca	42.438618	-76.497658		753	1723	1238	1206	1283	1301	1300	8804	Business
4	1533	Statler Hall	City of Ithaca	42.44561	-76.482605			84	17	45	30	20	10	206	College/Univ
5	1534	Sage Hall	City of Ithaca	42.445351	-76.482689		51	659	600	626	683	525	55	3199	College/Univ
6	1540	Uris Hall across street	City of Ithaca	42.44759	-76.482399		8	479	489	465	499	457	14	2411	College/Univ
7	1542	Kennedy Hall	City of Ithaca	42.447624	-76.479439		25	579	475	553	499	410	27	2568	College/Univ
8	1543	Corson/Mudd Hall	City of Ithaca	42.44754	-76.479324		12	259	262	286	228	214	11	1272	College/Univ
9	1544	Bradfield Hall	City of Ithaca	42.447594	-76.475822		5	93	86	102	79	73	1	439	College/Univ
10	1545	Bradfield Hall across street	City of Ithaca	42.447533	-76.475578			109	112	93	83	66	2	465	College/Univ
11	1703	State @ Quarry - MLK @ Quarry	City of Ithaca	42.438679	-76.488632		15	39	24	27	30	41	20	196	Private/apartments
12	105	Court @ Linn	City of Ithaca	42.443115	-76.494507			253	249	265	245	202		1214	Privte/family residential
13	1754	Maple at Maplewood Park Apts	City of Ithaca	42.441284	-76.474976			163	144	162	143	122	1	735	
14	1330	Appel Commons	City of Ithaca	42.453255	-76.477318		4	515	451	533	519	492	11	2525	College/Univ

Figure 81: Bus shelter location spreadsheet

From the table above, we could determine that the landowners are:

1) College/University
2) Business
3) Government (including both City of Ithaca and Tompkins County)
4) Private/family residential
5) Private/Apartments
6) No info - No information was available for the land

However, we were not able to find the property information for the following three stops: a) Maple at Maplewood Park Apts (1754), Titus Towers (525), and Triphammer @ Jessup (1357). We left their name in the Excel sheet and named them as “no info” for the later analysis .

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
15	1126	Lake St at Ithaca High School	City of Ithaca	42.455162	-76.496094			25	16	19	18	23	2	103	Private/Apartments
16	1525	Rockefeller Hall	City of Ithaca	42.4496	-76.482788		54	900	781	807	819	759	39	4159	College/Univ
17	1524	Goldwin Smith Hall	City of Ithaca	42.449841	-76.482941		53	819	689	767	740	620	39	3727	College/Univ
18	1326	Risley Hall - Shelter	City of Ithaca	42.452858	-76.481125		475	625	331	386	418	586	767	3588	College/Univ
19	1325	Thurston at Balch Hall	City of Ithaca	42.452957	-76.480995		80	217	90	95	112	243	148	985	College/Univ
20	1328	Cradit Farm at Balch Hall	City of Ithaca	42.452866	-76.47937		2	245	231	251	255	273	8	1265	College/Univ
21	668	Ithaca Bus Station	City of Ithaca	42.439243	-76.511024		10	18	12	22	14	15	11	102	Proffes assc

Figure 82: Bus shelter location spreadsheet cont.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
22	706	Chestnut Hill Apts	City of Ithaca	42.441711	-76.518082		5	8	12	15	12	13	4	69	
23	709	Chestnut @ Elm - LACS	City of Ithaca	42.438648	-76.519127			4	7	6	3	5	1	26	Private/Family Residential
24	713	Elm @ West Village Pl	City of Ithaca	42.436592	-76.5224		24	43	30	38	36	50	29	250	Private/Family Residential
25	1531	Carpenter Hall	City of Ithaca	42.444889	-76.484993		249	507	382	395	366	369	327	2595	College/Univ
26	1143	Stewart Park Entrance	City of Ithaca	42.462711	-76.500809			14		1	1		3	19	College/Univ
27	1507	Stewart @ University	City of Ithaca	42.44912	-76.490311			15	13	13	12	10		63	College/Univ
28	172	Ithaca Commons - Aurora St	City of Ithaca	42.439236	-76.495552		141	94	75	96	105	179	161	851	Vacant comm
29	133	McGraw House	City of Ithaca	42.437733	-76.500595		1			1			2	4	Private/Family Residential
30	512	Clinton @ Corn	City of Ithaca	42.436687	-76.505882			3	1	2	1		1	8	Private/Family Residential
31	541	Wegmans	City of Ithaca	42.434944	-76.509613		53	38	36	39	40	65	136	407	Business
32	549	WalMart	City of Ithaca	42.428844	-76.513329		70	76	66	60	69	122	174	637	Business

33	525	Titus Towers	City of Ithaca	42.431789	-76.504509		6	12	17	20	21	27	17	120	No Info
34	570	Elmira @ Spencer	City of Ithaca	42.419739	-76.520027			4		1				5	Business (Nbh shop ctr)
35	1125	Lake St at Ithaca High School	City of Ithaca	42.455181	-76.496002			9	2	2	3	4	3	23	Private/Apartment
36	1329	Helen Newman Hall	City of Ithaca	42.45322	-76.477264		33	14	3	6	6	11	36	109	College/Univ
37	1357	Triphammer @ Jessup	City of Ithaca	42.456215	-76.481216			2		2		4	1	9	No info

Figure 83: Bus shelter location spreadsheet cont.

Context Diagram

To build up a database for master plan, we have to figure out the stakeholders of the master plan first, and what are the interactions between master plan and each stakeholder. Here, we use the context diagram to help us understand all relationships of the master plan. Further, our team is able to learn about the stakeholders from the diagram. The following picture is the context diagram we currently built.

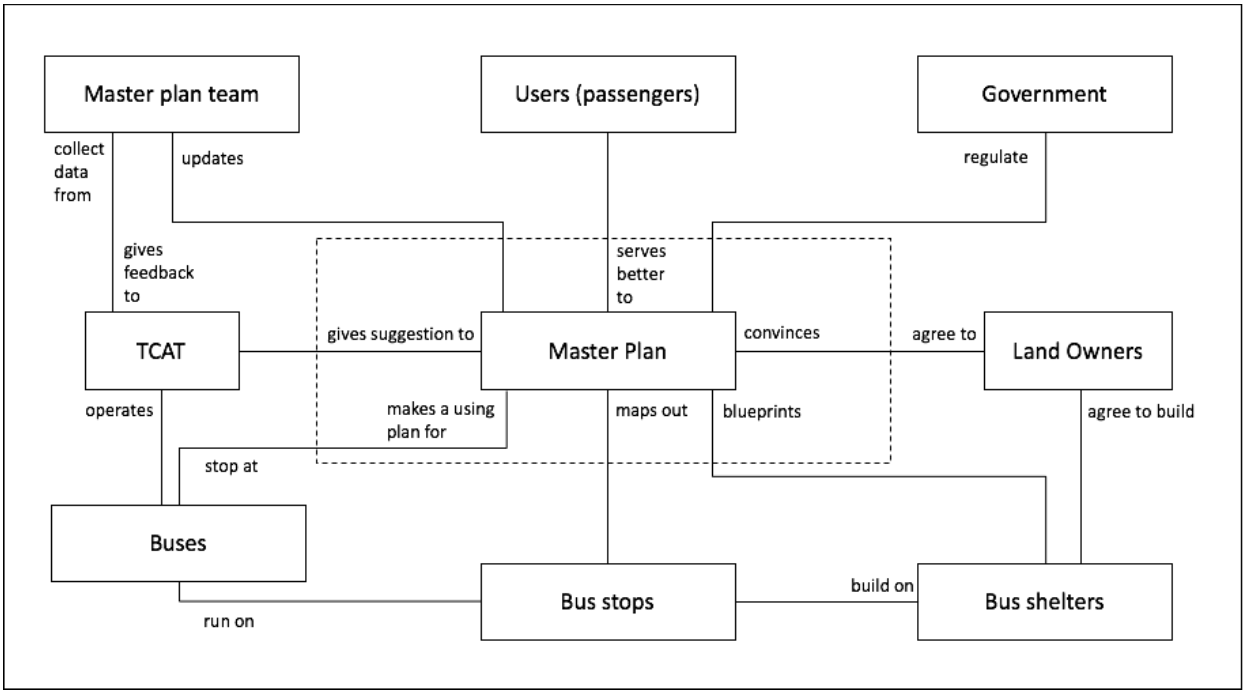


Figure 84: Master Plan Context Diagram

In this context diagram, the master plan is considered as our system which should be well-designed. The system will be placed in the dotted box at center of the diagram. Any other items out of the dotted box will be the environment entities which are not included within our system, but all these items will have interactions with our system. Besides, some of the environment entities may have reactions with each other. In the diagram, we use the solid line to indicate relationships of interactions between two entities or between entities and the system. With the help of the context diagram, we are able to understand deeper in the relationships of master plan and all stakeholders. A clear table can be listed out as following:

Stakeholders	Responsibility to Master Plan	Benefit from Master Plan	Other insights about Master Plan
Master plan team	Master plan team should take the responsibility of designing and updating. master plan	N/A	Master plan team should ask data from TCAT, when the team wants to update the master plan.
TCAT	TCAT has to collect data which master plan acquires.	Master plan can give a suggestion on routing, shelter building and etc.	1. TCAT has to support master plan team on any data requirement. 2. TCAT is the implementer of master plan, and is supposed to negotiate with land owners and other stakeholders.
Users (passengers)	N/A	A better use experience of taking bus will be provided to passengers.	Master plan should be able to help TCAT attract more passengers taking the bus.
Government	Government has the responsibility to provide regulation of building a shelter.	N/A	Master plan should follow any regulation given by government and update it frequently.
Land owners	N/A	Land owners will take a great plan of shelter building, including a low cost, long life span and reliable design.	Master plan has to be designed strong enough to give a persuasive ideas to convince land owners.

Figure 85: Extrapolated Context Diagram

Decision Matrix

Based on the design model, there are three different sizes of the shelter: small size, medium size and large size (See Bus Shelter section for the details).Since each size has different features, the master plan team used the Decision Matrix to make a decision of which size of the shelter is more practical. Moreover, the team can find the advantages and disadvantages for each shelter size.

	Small Size Shelter	Medium Size Shelter	Large Size Shelter
Dimension	3’-7”x 6’-11”	6’-11”x10’-3”	6’-11”x 13’-7”
Capacity	7 people	10 people	13 people
Practicability Level(5 is the best)	3	5	2
Solar Power	220wh	500wh	780wh
Comfort Level (5 is the best)	2	3	5
Cost/unit	$9,899.55	$7,889.89	$5,543.89

Figure 86: Property levels of different shelter sizes

As the above table shows (Figure 86), the team first determined the relative factors of different shelter sizes that were used to help the team make decisions, including the dimensions, the capacities, the practicability level, estimated solar power, comfort level and the cost per unit. Then, the team found the real values of these factors and listed them in the table. For the factors that do not have real values, like the Practicability Level and Comfort Level, the team set a scale from 1 to 5, from which 1 is the worst and 5 is the best. Furthermore, the team rated these factors based on some researches and the life experiences. For example, the team decided the medium size shelter would have the highest practicability level and the large size shelter would have the highest comfort level.

Based on the real values, the team normalized these values. Firstly, the team unified the unit for each factor. Next, for each factor, the team set the largest value of the three sizes as a reference. Then, using each value divided by the largest value to get the normalized values for the three sizes. The results of each factor are shown below.

Dimension	Small Size Shelter	Medium Size Shelter	Large Size Shelter
	3’-7” x 6’-11”	6’-11” x 10’-3”	6’-11” x 13’-7”
Convert Unit	36"*7"*72"*11"	72"*11"*120"*3"	72"*11"*156"*7"
	199584	285120	864864

Normalized Scores	0.23	0.33	1.00

Capacity	Small Size Shelter	Medium Size Shelter	Large Size Shelter
	7 people	10 people	13 people
Normalized Scores	0.54	0.77	1.00

Solar Power	Small Size Shelter	Medium Size Shelter	Large Size Shelter
	220wh	500wh	780wh
Normalized Scores	0.15	0.33	0.52

Cost/unit	Small Size Shelter	Medium Size Shelter	Large Size Shelter
	$9,899.55	$7,889.89	$5,543.89
	1.00	0.80	0.56
Normalized Scores	0.00	0.20	0.44

Figure 87: Normalized property levels of different shelter sizes

The final normalized values of each factor based on different shelter sizes are shown below.

	Small Size Shelter	Medium Size Shelter	Large Size Shelter
Dimension	0.23	0.33	1.00
Capacity	0.54	0.77	1.00
Practicability(5 is the best)	0.60	1.00	0.40
Solar Power	0.15	0.33	0.52
Comfort Level (5 is the best)	0.40	0.60	1.00

Cost/unit	0.00	0.20	0.44
SUM	1.92	3.23	4.36

Figure 88: Finalized normalized property levels of different shelter sizes

The next step the master plan team processed was estimating the weights of the factors. The scale the team set was also form 1 to 5, the specific description for each level are shown in the table below.

Weights	**Descriptions**
1	Not Important
2	A Little Important
3	Medium Important
4	Very Important
5	Extremely Important

Figure 89: Weight table

According to some researches and the life experiences, the team rated the weights for these factors. Then, the team summed all the weights and used each weight divided by the sum to get their normalized weights. Thus, the sum of the normalized weights should be 1. The results are shown below.

	Weight(Scale 1-5)	
Dimension	2	0.09
Capacity	4	0.17
Practicability(5 is the best)	5	0.22
Solar Power	3	0.13
Comfort Level (5 is the best)	4	0.17
Cost/unit	5	0.22
Sum	23	1

Figure 90: Sum of normalized weights

Finally, the team used the normalized values of the different shelter sizes for each factor multiplied by the normalized weights of each factor to get the final results of the Decision Matrix. The final results are shown below.

	Normalized Values				**Final Scores**		
	Small Size Shelter	Medium Size Shelter	Large Size Shelter	Normalized Weight	Small Size Shelter	Medium Size Shelter	Large Size Shelter
Dimension	0.23	0.33	1.00	0.09	0.02	0.03	0.09
Capacity	0.54	0.77	1.00	0.17	0.09	0.07	0.17
Practicability (5 is the best)	0.60	1.00	0.40	0.22	0.13	0.22	0.09
Solar Power	0.15	0.33	0.52	0.13	0.02	0.04	0.07
Comfort Level (5 is the best)	0.40	0.60	1.00	0.17	0.07	0.10	0.17
Cost/unit	0.00	0.20	0.44	0.22	0.00	0.04	0.10
SUM	1.92	3.23	4.36		**0.33**	**0.51**	**0.69**

Figure 91: Factor times normalized weights

As the final results shown, the large size shelter has the highest score, which means the largest size should be more practical and be more cost-effective. Thus, the largest size shelter could meet more customer requirements and it could be the prime option for the future use. Moreover, the Decision Matrix also showed the advantages and disadvantages for each shelter size. Thus, based on different situations, other sizes could also be considered.

Database Analysis

Before starting to develop a database for the master plan, we should first understand what functions it should have. To analyze the problem of what our database should achieve, we implement the system tool of “Use Case”. We have to figure out the scenarios for which the users of the database would utilize the system (database). Thus, we use another systems tool called “Originating Requirement” to list out all requirements of our system with respect to use cases.

Use Case	Priority
User searches the construction information for shelters.	L
User looks at the pictures for shelters.	L
User searches the construction time of shelters.	M
User searches the external environments of shelters.	L
User searches the names of stops.	L
User searches the costs of shelters.	H
User searches the shelter owner information.	H
User searches the land owner information.	H
User looks for the locations of stops.	L
User tracks the data.	M
User updates the data.	H
User searches the ridership information.	M
User searches the bus route numbers.	M
User detects the system.	L

Figure 92: Use cases

The Use Cases Table showed some activities that users can perform in the shelter. Moreover, it offered the team a clear list about what user operations should be realized in the shelter system, and what kinds of services the shelter system can provide to users. Based on customer requirements, the Use Cases converted the customer needs to be specific user activities that should be performed in the system. It further determined what required functions need to be achieved by the team. It was also a guideline for future progress. Since it is only a list of some independent user activities, the team would like to simulate a sequence of user activities by using the Use Case Diagram, Use Case Behavioral Diagram and other tools to get better understanding of realistic methods of application for the shelter system.

Index	Originating Requirements	Abstract Function Name
OR.1	The system shall provide construction information for shelters.	Construction Info
OR.2	The system shall provide pictures for shelters.	Picture
OR.3	The system shall decide whether the old shelters should be replaced.	Replace
OR.4	The system shall decide where to build new shelters.	New
OR.5	The system shall determine the sizes of new shelters.	Size
OR.6	The system shall provide external environments of shelters.	External Environment
OR.7	The system shall provide names of stops.	Name
OR.8	The system shall calculate the cost of replacing old shelters.	Replacing cost
OR.9	The system shall calculate the cost of building new shelters.	Building cost
OR.10	The system shall provide the shelter owner information.	Shelter owner
OR.11	The system shall provide the land owner information.	Land owner
OR.12	The system shall create GIS map for shelters.	GIS map
OR.13	The system shall track the data.	Tracking
OR.14	The system shall update the data.	Updating
OR.15	The system shall have Use_Duration_Limit.	Use_Duration_Limit
OR.16	The system shall have Range_Application_Limit.	Rnage_Application_Limit
OR.17	The system shall provide ridership information for shelters.	Ridership
OR.18	The system shall provide bus route numbers for stops.	Route number

Figure 93: Requirements and function names

Before the master plan team completes the system, the team used the Originating Requirements Table to list all the potential customer requirement that should be realized by the the system. There are some user behavior requirements and parameter requirements in the Originating Requirements Table. The user behavior requirements defined the potential services that the system could provide to users. In addition, the parameter requirements are the parameters that should be defined for the system, which are also some limitations for the project.

The Originating Requirements Table helped the team better understand what functions the system should include and what limitations could be considered in the design processes. This system tool provided a relative more specific range of the project.

Database Prototype

All the bus stops information and current existed bus shelter information should be in the database of master plan. The more information we have in the database, the more questions can be queried by users in the future. Here are all the data name and their definition in the database prototype we currently designed.

Stop Name	The stop name from TCAT routing map
Stop ID	The stop ID in TCAT system
Longitude	The longitude of the corresponding bus stop
Latitude	The latitude of the corresponding bus stop.
Location	The location of the bus stop within the County
Routes	All routes which pass through this bus stop.
Shelter	Whether there is a existed bus shelter on the stop? Yes or No
Ridership	The number of ridership at the stop. (by hour, day, week and even month)
Lights	What is the lighting level at the stop under night?
Condition	The condition information of current existed bus shelters.
Size	The size of existed shelters with respect to our design. (Large, Medium, Small)
Sidewalk	If there is a sidewalk at the stop? Yes or No
Picture	The pictures of current existed bus shelter.

Owner of Shelter	Who own the existed bus shelter?
Owner of Land	Who own the land of the bus stop?
Cost	The estimated cost of building or replacing a new shelter on the stop.

Figure 94: Database Prototype

At this point, we started building up our database prototype in excel to contain all master plan information including bus information and shelters information together. But after we finalizing all data we needed in current master plan, the database can be stored in a better structure such as SQL, so that the database can contain a bigger dataset with quick response and be easier for future update.

Future Work

The next step of this research is to analyze all the bus stops in Tompkins County and complete the existing excel file with the shelter information. The systems engineering tools that have been used will be further refined to achieve better results. For this semester, we assumed the scale based in research and on our experiences but for the next semester, the focus will be to use other multi-criteria decision making tools to develop the weights. This will give a more realistic approach to the value and ranking of the parameters. As mentioned before, the database will be stored in a better structure such as SQL but the team is also going to focus on making a spatial connection so that the data can be easily studied using GIS.

Report Conclusion

With the addition of the Logistics, Electrification, and Master Plan subteams, Sustainable Mobility saw significant changes in team organization this semester. The expansion from two to five subteams allowed the entire team to collectively tackle more projects. This included the addition of the Collegetown projects from SYSEN 5740, as well as creating new projects dedicated to helping TCAT manage new electric buses and creating a plan for identifying future bus shelters. While every team has made progress, all of the projects will continue to be worked on next semester as ideas are revisited and enhanced.