CUSD SYSEN 5900 Mobility

Spring 2020 - Project Report

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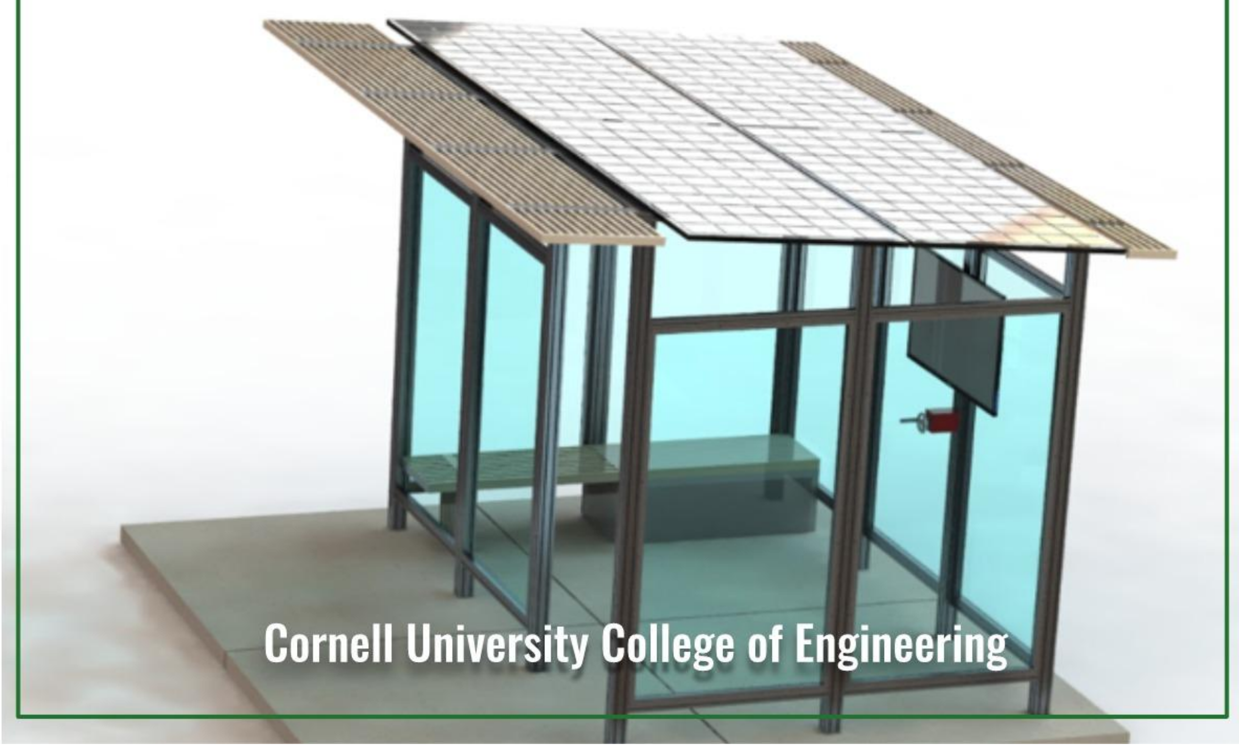

SYSEN 5900-CUSD Sustainable Mobility-Shelter

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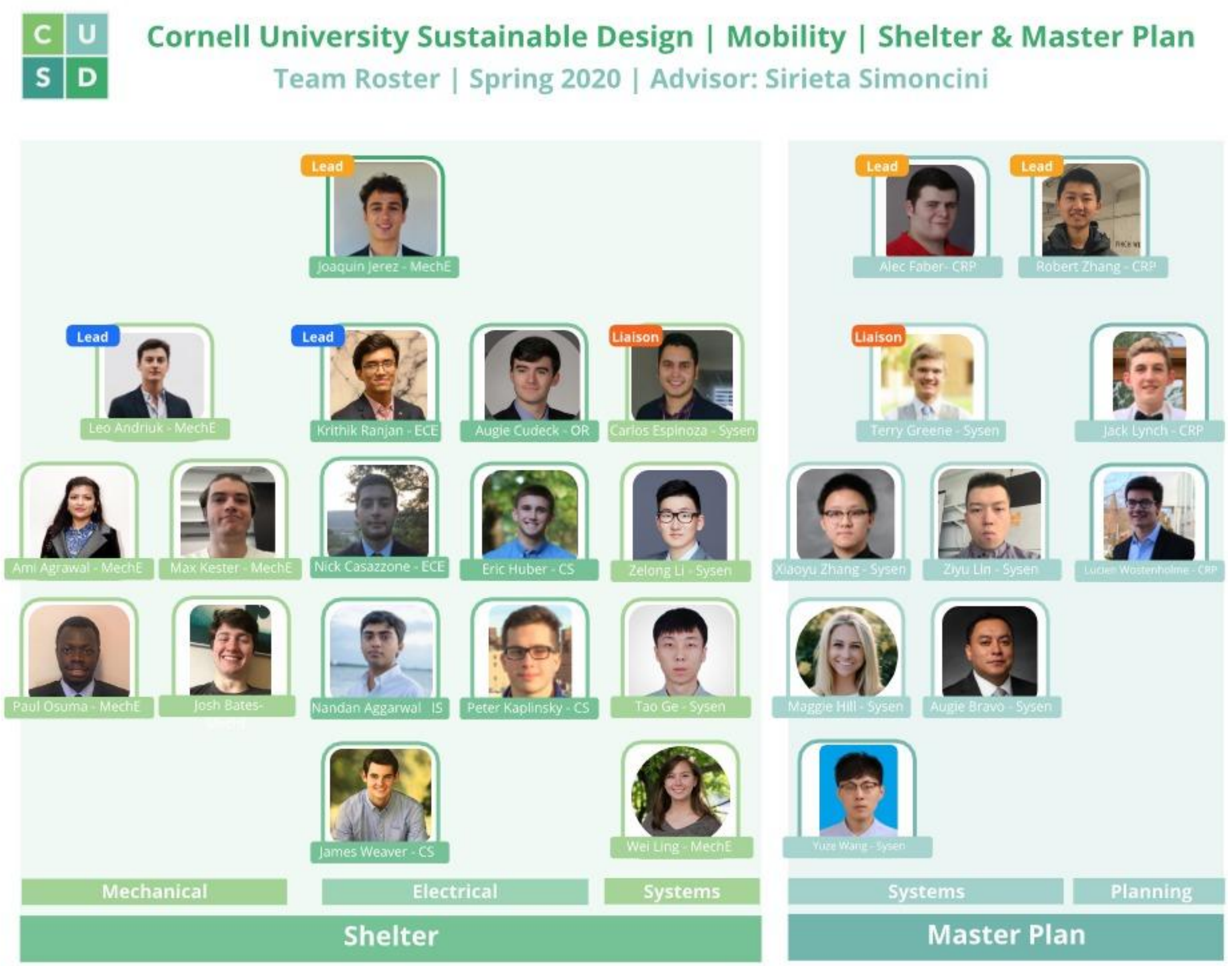
Best Regards, *CUSD – Sustainable Education Mobility Team – Shelter*

Table of Content

Preface

Within the larger Cornell University Sustainable Design (CUSD), the Shelter Design Team enacts the mission of designing, constructing, and implementing a solar powered bus shelter for use by residents of the Ithaca, and the Cornell community. This team, in conjunction with the overall Sustainable Mobility cohort are dedicated to improving public transportation in Tompkins County. The team itself is made up of undergraduate and graduate students at Cornell University pursuing a variety of degrees ranging from architecture to electrical engineering to systems engineering and beyond. These teams are advised by Sirietta Simoncini, with whom they communicated continuously to create a comprehensive design and implementation plan.

The Team



The Shelter

A modular, sustainable, informative, and safe bus shelter that allows users to comfortably wait for their buses to arrive, promotes the use of public transportation, and has a low environmental footprint. Several subsystems make up the overall Shelter system design. Notably, the structure, notification, power, and subsystems, are outlined below.

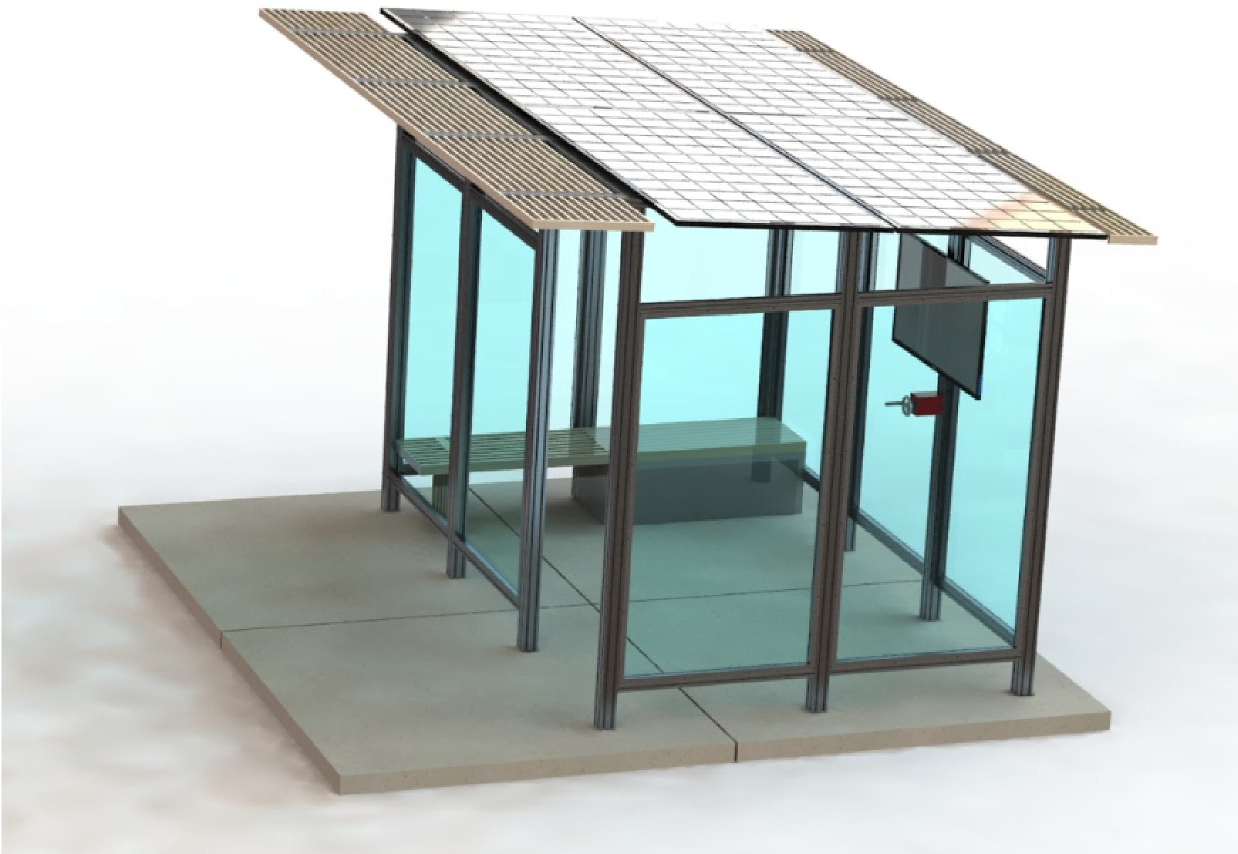


Figure 1: The Shelter

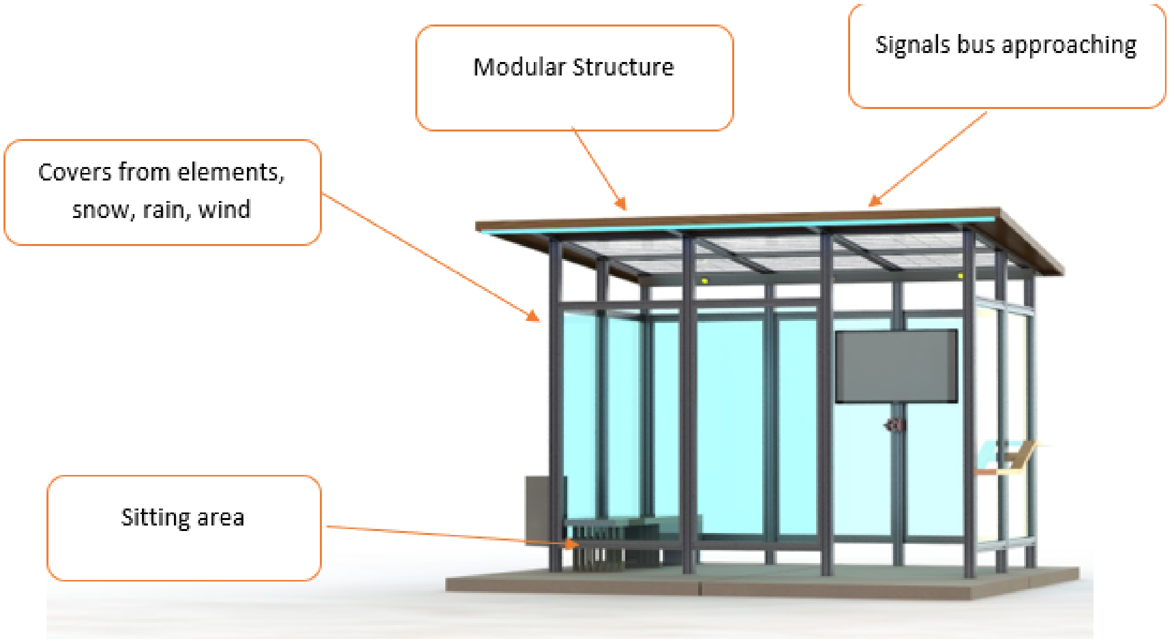


Figure 2:Shelter Structure

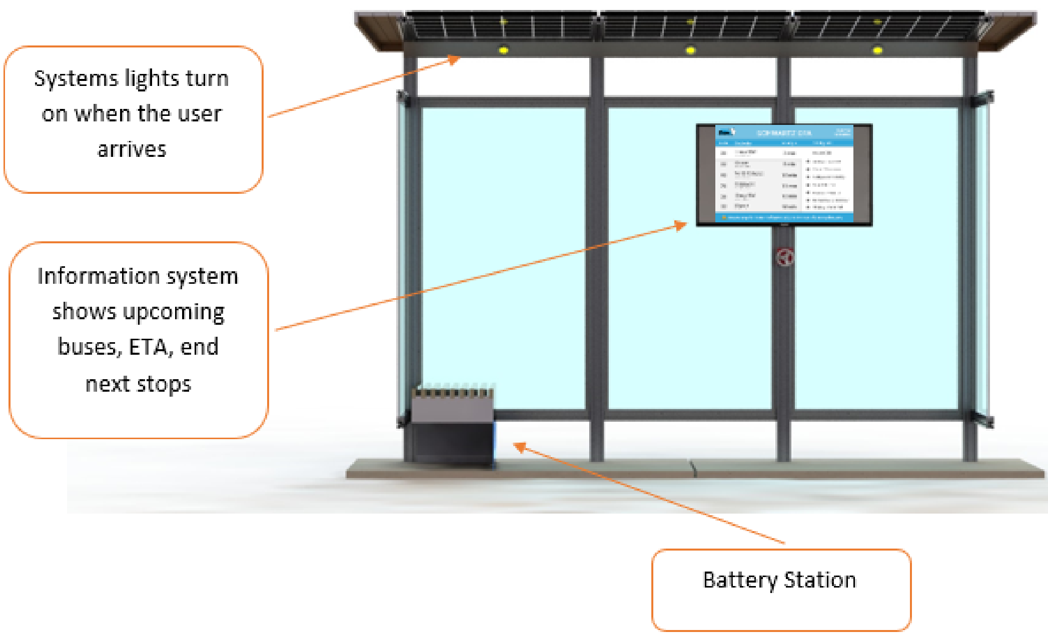


Figure 3: Shelter Electrical

Structure Subsystem

The structural subsystem comprises the main body of the Shelter system. This subsystem is formed by an aluminum set of rods that hold in place a glass screen that acts as a barrier to shelter passengers against the elements - while they wait for the bus to arrive. These glass panels are assembled into 20'x 40' modules and capped with a solar panel that acts as a roof. The interior of the structure contains a bench that serves as a storage unit for a battery and logic board which are used to power and control the system. The structural design for this Shelter is capable of resisting the loads imparted on the structure by rain and snow collect on the roof. Ease of maintenance and installation were prioritized in designing the shelter, so the use of bolts and other detachable elements is a driving requirement.

Notification Subsystem

The Notification subsystem provides the user (passenger) complete and updated information about buses' routes, operational schedule, their Estimated Time of Arrival (ETA), and whether or not a bus route is currently active. The main component of the notification subsystem functions through a diagram which displays the upcoming bus stops and an estimation of the time the next bus will arrive at each. The Notification subsystem also displays the hour, and has the ability to notify the passenger of system alerts, updates, or other information TCAT has a desire to convey to its users. Within this notification subsystem, embedded python programs run on PI. The light strip (LED bar) within the subsystem will begin to blink when the nearest bus arrival ETA is less than 3 minutes from the stop (timing can be re-configured within the program). This main notification display interface is depicted in Figure 4 below.

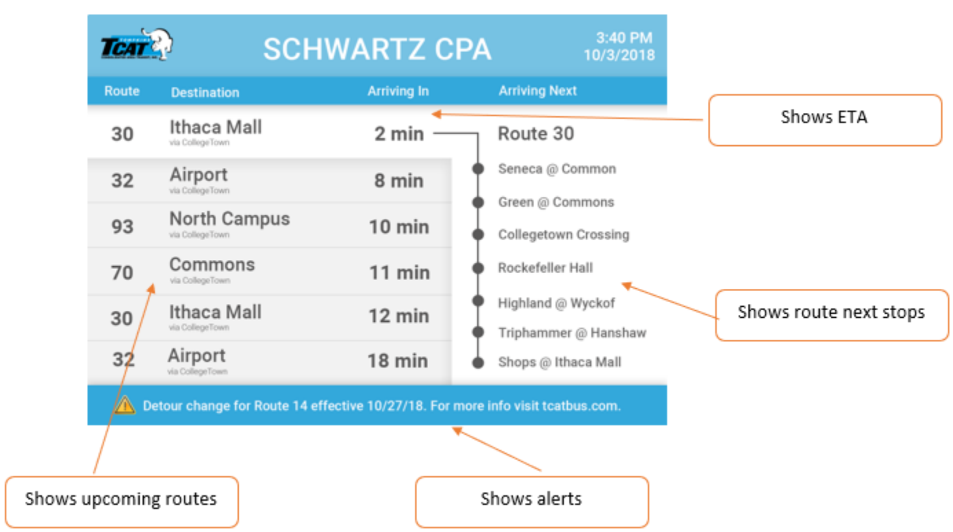


Figure 4: User Notification Interface

Power Subsystem

The Power subsystem is responsible for the consumption, charging, storage, and distribution of energy throughout the Shelter system. This subsystem can consume energy from the electrical grid, or from the sun via the installed solar panels. The Power subsystem then charges and stores this collected energy in a lithium battery. Power storage within a lithium battery is needed because of the intermittent nature of solar energy. The main challenge in this subsystem is the thermal isolation of the battery. This isolation must be maintained at a certain level of warmth during the coldest times in the winter, but also below a maximum temperature during the summer to ensure proper and safe operation. The Power subsystem includes safety relays, sensors, wiring, and connectors. It is standardized in order to facilitate the repair of individual components prone to failure.

Information Subsystem

The Information subsystem serves as the interface with TCAT. It provides up-to-date, accurate data to the Notification subsystem that the Notification subsystem will then display. The Information subsystem's main function is to store and operate the inputs for the Shelter. It utilizes a modem to communicate via APIs with both the Google Transit Application and the TCAT proprietary database. This subsystem operates through a series of functions that send requests of specific strings, store the responses, and then post and commit changes to an internal memory.

System Tools

The details of the shelter, including its potential locations, construction, and implementation, have been under development for four years, under the advisement of Sirietta Simoncini. Sirietta and her team have established and maintained direct communication with the Tompkins Consolidated Area Transit (TCAT) stakeholder. The team uses this relationship to build and refine the tools that govern shelter design and implementation.

In developing the Shelter Master Plan, many systems engineering tools were considered, analyzed, constructed, and used. These tools were developed in conjunction with system life cycle processes such as the Concept Process, Requirements Development, Design Definition and will hopefully one day include Operations. Each tool presented an opportunity to explore a new part of the overall system. The criticality of each tool to the success of system development and production was made evident throughout their use. Using the tools discussed below, the team was able to build upon its knowledge of system design and development to continue building and refining the master plan.

While refining the design of the shelter, analyzing the needs of associated stakeholders was critical to narrowing down design decisions and prioritizing tasks. A Stakeholder Management Tool provided an opportunity to layout these objectives, examine them granularly, and then draw upon this list throughout all decision making. This tool is shown in Table 1.

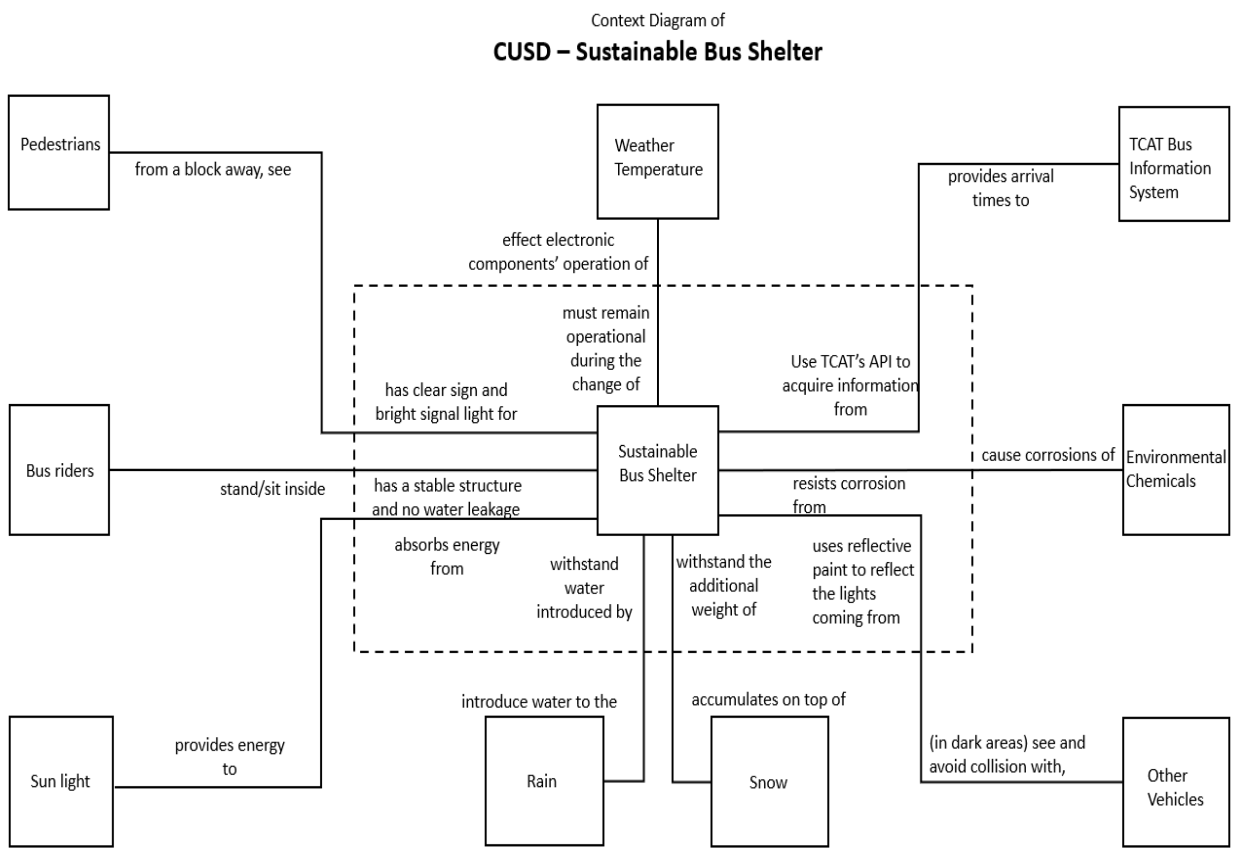
Table 1. Stakeholder Management Tool

User or Stakeholder	Priority	Position	Role on Project	Stakeholder Objectives	Communication style	Action Steps to Maintain and Nurture this relationship
Students	H	N	user	To have a shelter that is easy to use and makes taking bus more convenient and efficient	Prefer informal communications	Schedule on-campus events and discussion sessions
Police	M	N	Emergency solver	To have better connection with campus safety	Prefer written emails	Submit documentations and reports of the project
TCAT Company	H	+	Investor and operator	To have a more stabilized shelter that requires less maintenance and can help increase the utilization rate of the public transportation	Prefer formal meetings	Holding conferences at each milestone
Project Advisor	H	+	Advisor, approver, and monitor	To build a prototype that will be accepted by TCAT	Prefer weekly zoom meetings	Scheduling recurring weekly zoom meetings
Visitors	M	N	user	To visit the famous sightseeing as much	Prefer random	Organizing Campus tour events by bus

				as possible	conversatio ns	

Context Diagram

The team used the stakeholders laid out in Table 1to aid in the creation and critical analysis of the Shelter Design Context Diagram. This diagram, shown below in Figure 2, is a visual representation of the interactions that exist between the shelter system and all internal and external stakeholders. These interactions provide the operational context of the shelter to the planning team, allowing prioritization of design factors and stakeholder needs.



This analysis of the Design Context Diagram allowed the team to re-emphasize and evaluate who the shelter system's stakeholders are and what interactions are necessary to meet those stakeholder's needs. Stakeholders are not only customers, those who ride the bus or use the TCAT Bus Information System, but also environment –factors such as rain, snow, and sunlight. The needs of all stakeholders must be met to create a successful system. However, design factors will be tailored to meet these needs in different ways. For example, environment stakeholders will require the shelter design to withstand their presence or absence and continue to meet performance requirements prior to, during, and after exposure. The human stakeholders, pedestrians and bus riders, are critical to successful operation of the shelter because without riders, the shelter does not serve its purpose. Without clear indicators of the shelter's location, features, and purpose pedestrians will not be drawn to using the shelter. Taking all of these factors and stakeholders into account, the shelter design moved forward accordingly.

After analyzing the shelter design's context diagram, use cases were developed to tie together stakeholder actions, shelter design, and shelter operation. Use Cases are a tool used to define the interactions between an actor or stakeholder and the system to achieve a project goal. This development considers all stakeholder actions, needs, and capabilities to determine what events will take place in the use, build, testing of the shelter. Use case development in the creation of this shelter informed the identification of originating requirements for the shelter. Thesis will be discussed later in this report. The development of use cases is tool that is used to ensure stakeholder needs are met and that the operation of the shelter will be consistent with these needs. The development process for these use cases included creating a list of potential use cases and then ranking them by priority. Organizing these events by priority focused development of the highest priority events into the design of the system. Unintended actions are also identified through use case analysis and brainstorming activities. A list of use cases and associated rankings for each use case of the Shelter are shown in Table 2.

Table 2. Use Case Rankings

Number	Use Case	Priority
1	Seek transit information	H
2	Check electronic screen	M
3	Seek shelter	H
4	Cover from rain	H
5	Cover from darkness	H
6	Provide structural cover	H
7	Maintain the shelter	M
8	Send emergency alert	H
9	Get feedback	L
10	Connect with police	M

Use Case Behavioral Diagram

Use case behavioral diagrams are used to identify behavioral interactions between the operator or stakeholder involved in the use case event and the system itself. These diagrams are constructed based on the events described in the use case analysis of Table 2. Passenger use cases were a focal point of Shelter design analysis. An example of this is shown in Figure 6 below. Passengers utilize the Shelter for a variety of reasons including waiting for the bus, seeking transit info, or seeking shelter from the elements outside. To further analyze Figure 6, if a passenger uses the shelter as a resource to seek shelter from the elements, additional use cases are levied on the system. This leads to the use cases included in the figure such as shelter from rain and illumination in darkness. This informs the requirements for developing a structural design.

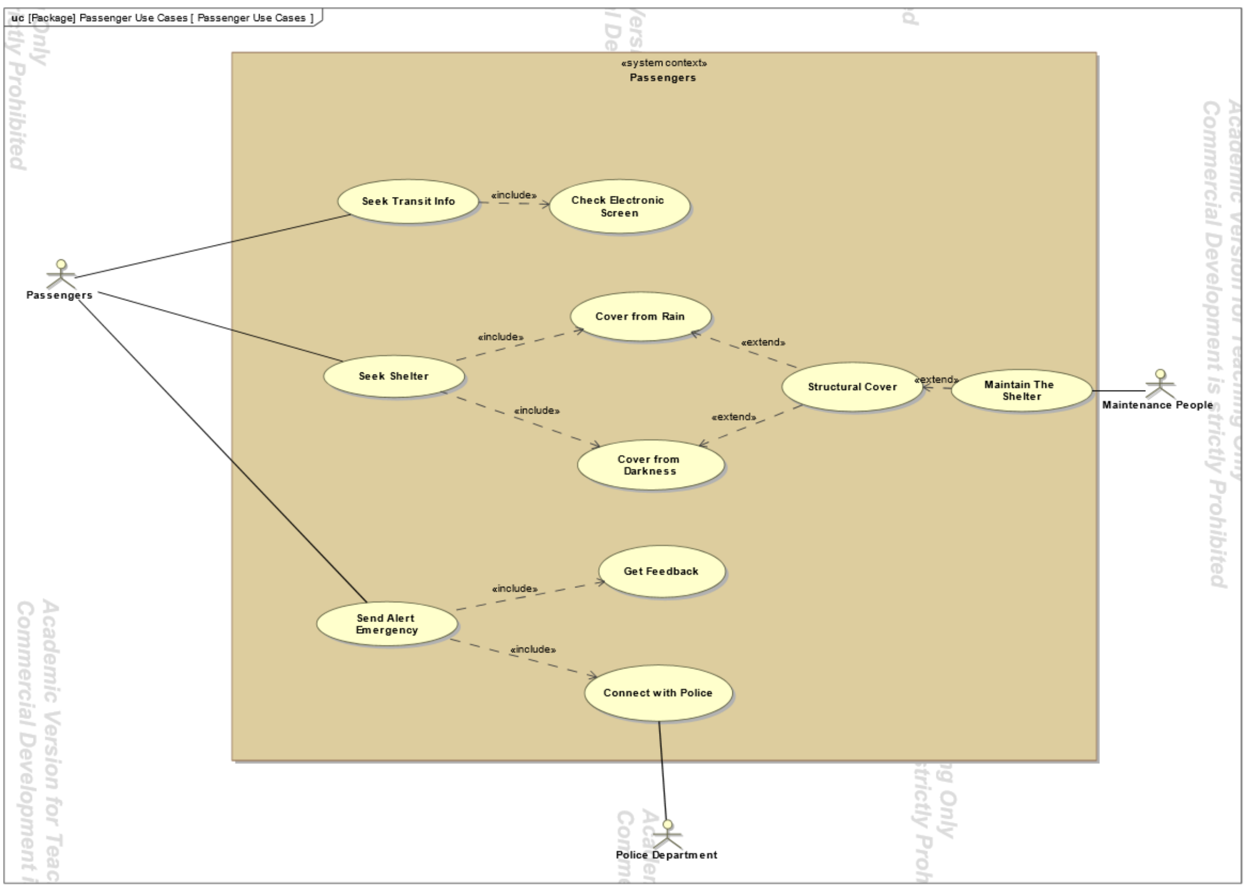


Figure 6: Passenger Use Case Diagram

Block Definition Diagram

In “drilling down” into the shelter, the team was able to better appreciate its composition with a Block Definition Diagram (BDD). BDD’s are often used to showcase elements of a system as well as any constraints levied against the system that will ultimately impact its design. Figure 5 is an example of a BDD used in Shelter development. Here it is shown how the shelter can have a 0 or 1 structure subsystem. This ensures the shelter does not require a modular structure. The Notification subsystem, therefore, would also be optional. In deciding to include this subsystem, however, a need for the Information and Power subsystems emerges for proper operation.

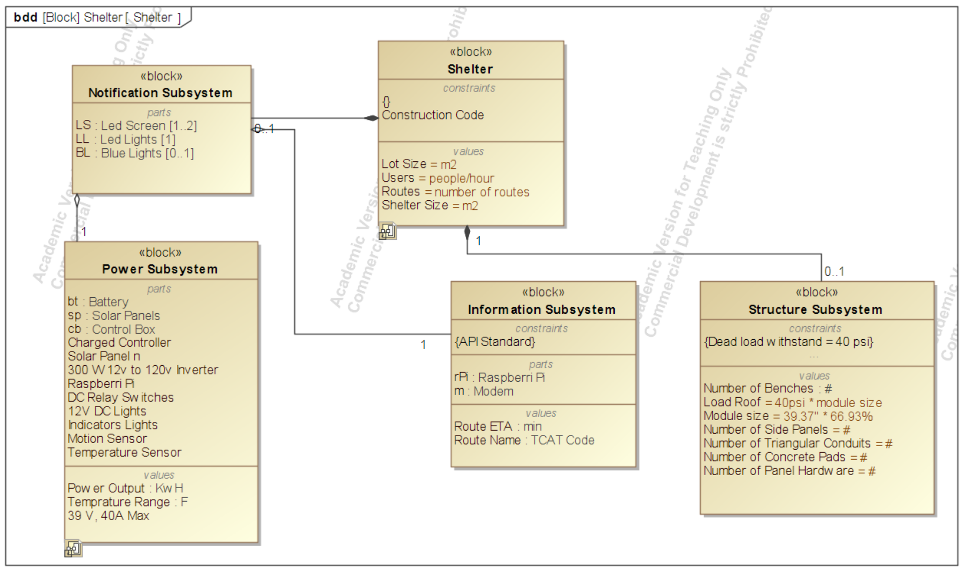


Figure 7: Shelter BDD

This model perspective allows the team to continue drilling into the internal structure of the defined blocks. In this case, analyzing the inside of the structure of the Power subsystem can provide a better understanding into how it works. As shown in Figure 6, a solar panel is connected to a charged controller that only accepts 39C at a 40 A max current within this Power subsystem. This power is stored in a battery. A 300W DC to AC inverter is used to transform that energy into usable input for the raspberry pi controller, the lights, the sensor(s), and the screen(s). A relay system is also placed in place to prevent possible electrical failure.

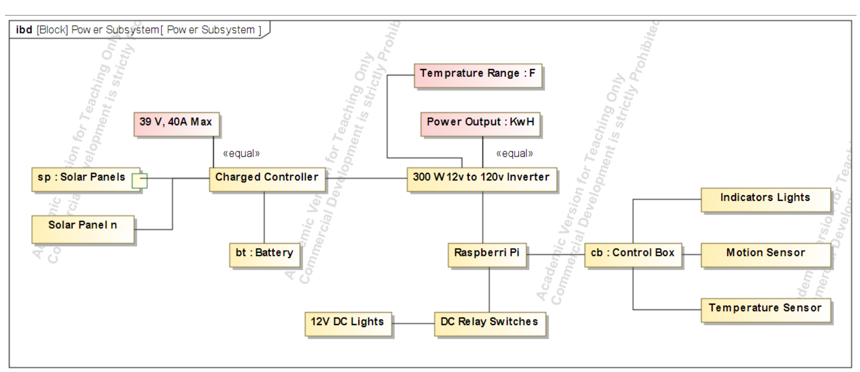


Figure 8: Power Subsystem IBD

Lastly a State Machine Diagram shows how the Power subsystem switches between states. This system moves from initializing, into sensing, temperature control or charging mode. It then switches back and forth to maintain equilibrium. This state machine is demonstrated in Figure 9.

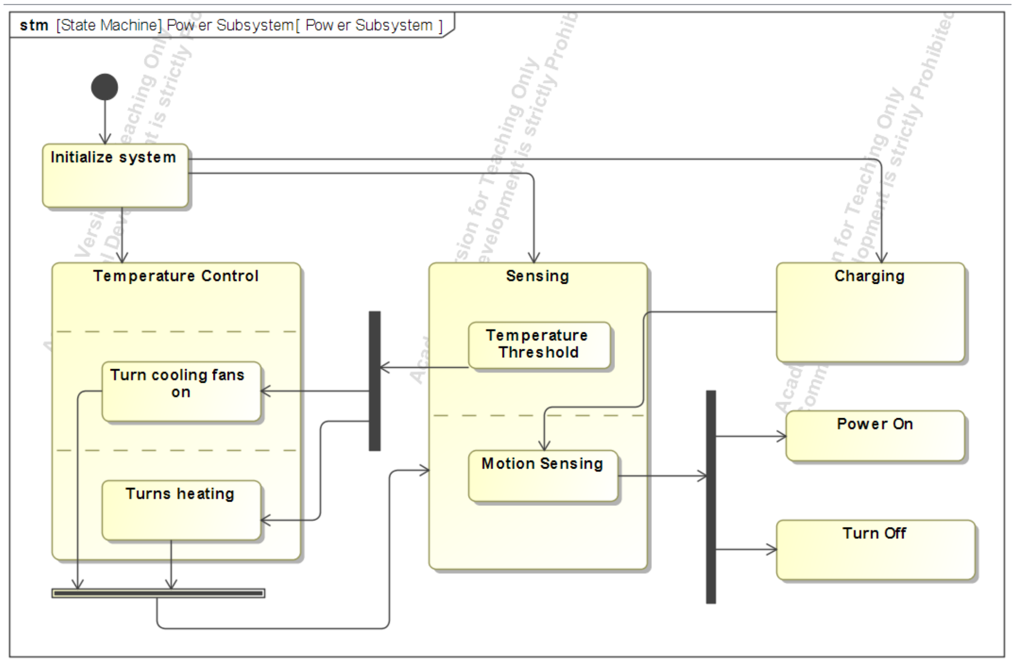


Figure 9: State Machine Diagram

Behavioral and Activity Diagrams

Behavioral diagrams denote the sequence of activities the system will go through. Temperature control is one of the key safety features. The Raspberry Pi logical control will monitor the bench temperature via a set of sensors, it can detect when the threshold values are being crossed. When that happens, the Raspberry Pi activates either the cooling or heating mechanism. Activity diagrams are created using events from Use Case Behavioral Diagrams. The diagram starts with the initial node or starting condition of the system and ends with the end state or condition of the system. A control flow is visible to walk a user through the events that make up an activity. These behaviors are shown in Figure 10 on the next page.

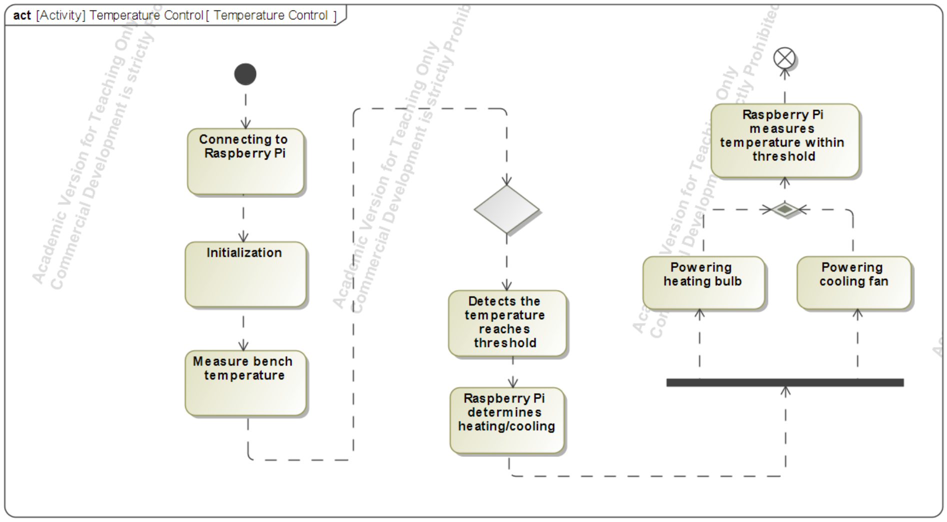


Figure 10: State Machine Diagram

In the same fashion, the power subsystem needs to accept the solar power energy, charge its battery, and control the led indicators for the battery levels. This is demonstrated in the Activity Diagram below, Figure 11.

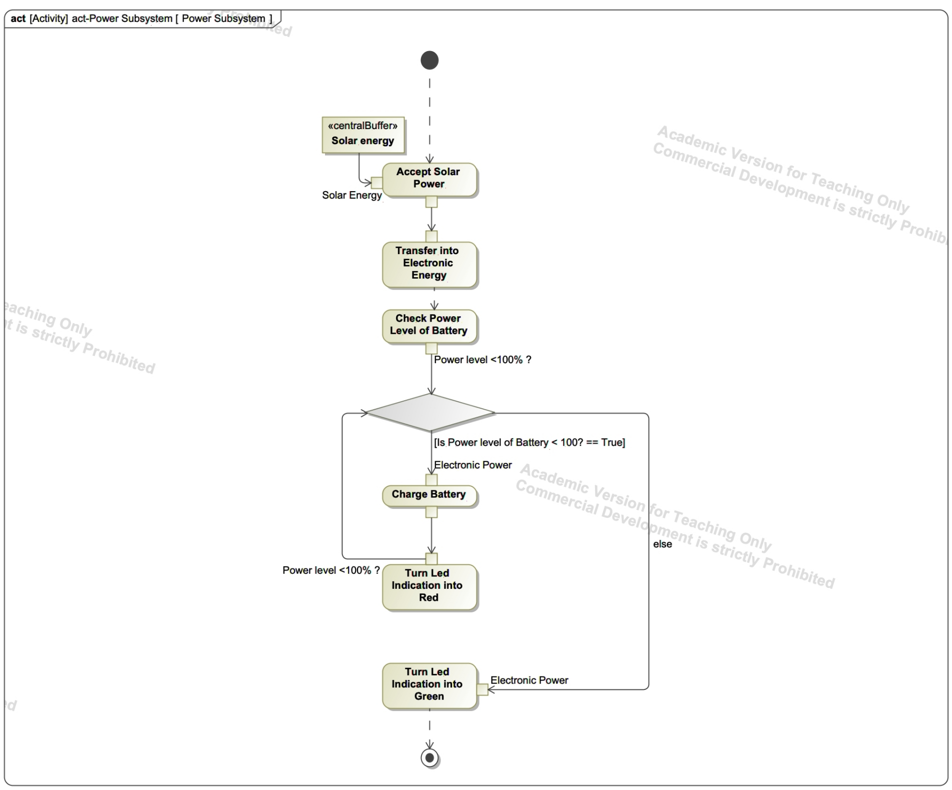


Figure 11: Power Subsystem Activity Diagram

A final example of the activity diagrams developed for the shelter design can be seen in figure 12. It depicts the Notification subsystem of the shelter.

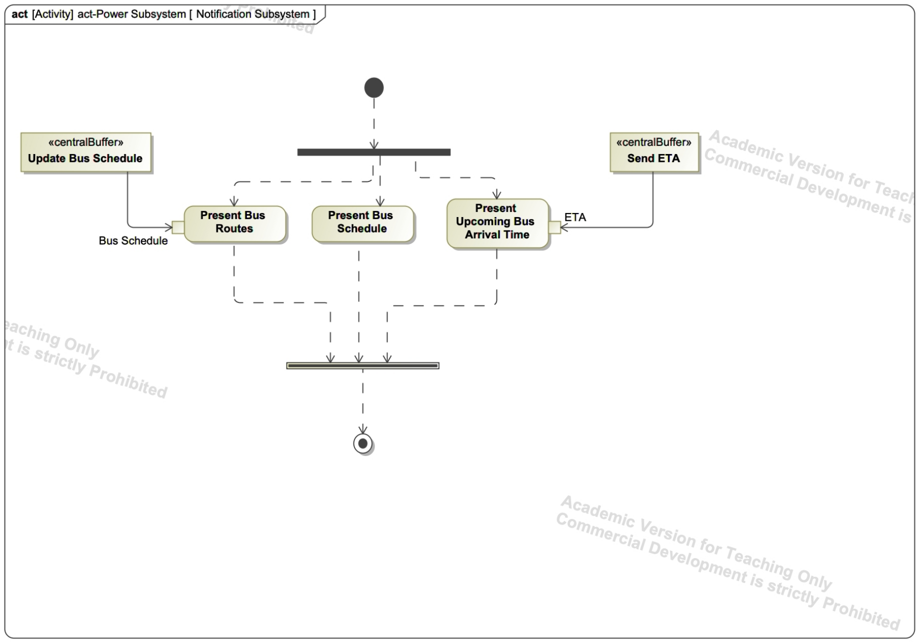


Figure 12: Notification Subsystem Activity Diagram

Behavioral Diagram

In continuing development of the shelter, analyzing behaviors between stakeholders was critical to defining the overall system functionality. Behavioral diagrams were used to capture design behaviors. An example of this is the flashing light bar feature, described in Figure 13 below. This behavioral diagram analyzes how a passenger would react and what they would witness in approaching the shelter. Taking time to analyze passenger behaviors informs use case development and the overall system design to encourage passenger use of the Shelter.

Passenger walk towards shelter		
Initial Conditions		
1. Numbered starting conditions		
Passenger	***Shelter***	***Light Indicator***
	The shelter shall be able to communicate with remote data server	
	The shelter shall receive the	

	information that next bus is coming with in 3mins	
		Light Indicator start to change light
		Light Indicator flashes blue light
Passenger see the flash light		
Passenger walk towards shelter		
Ending conditions *Passenger get into shelter*		
Notes		

Figure 13: Passenger Approaching Shelter Behavioral Diagram

Sequence Diagrams

A sequence diagram was also utilized to analyze the sensor's read and display functionality. Figure 14 on the next page illustrates the logic flow between the different system components of the shelter. The controller unit- PI will periodically request the sensor for hardware information and help to make decisions or perform maintenance.

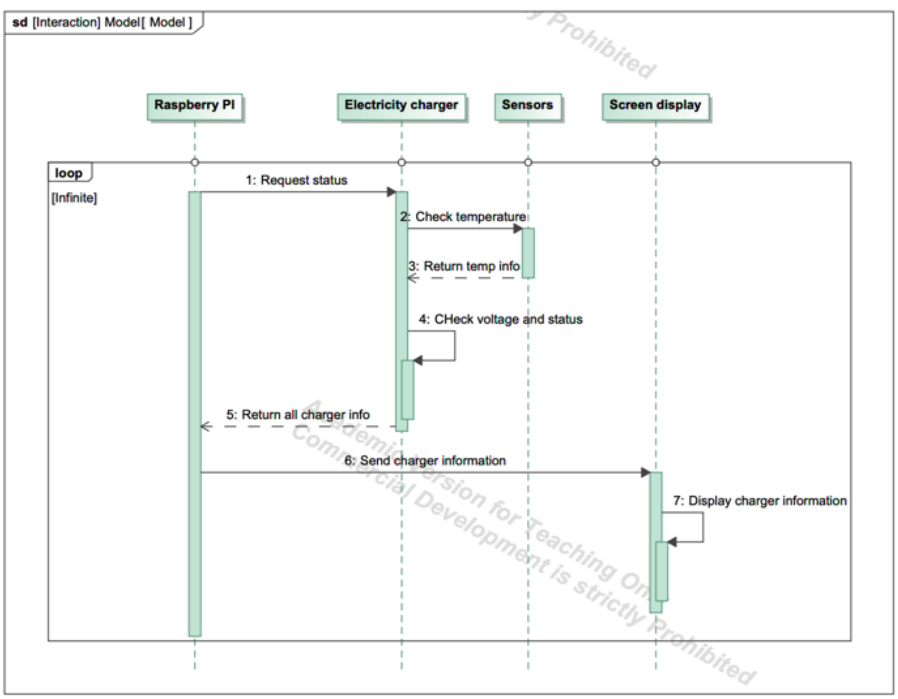


Figure 14: Sequence Diagram

Functional Block Diagram (FFBD)

FFBD's were used to analyze the light bar's functionality. This diagram modeled the workflow and logic of the light bar. It has to take into account the bus shelter's ability to either sense the bus signal within a specific distance or receive the information from TCAT API. This is shown in Figure 15, below. Another example for controlling bench temperature is shown in Figure 16.

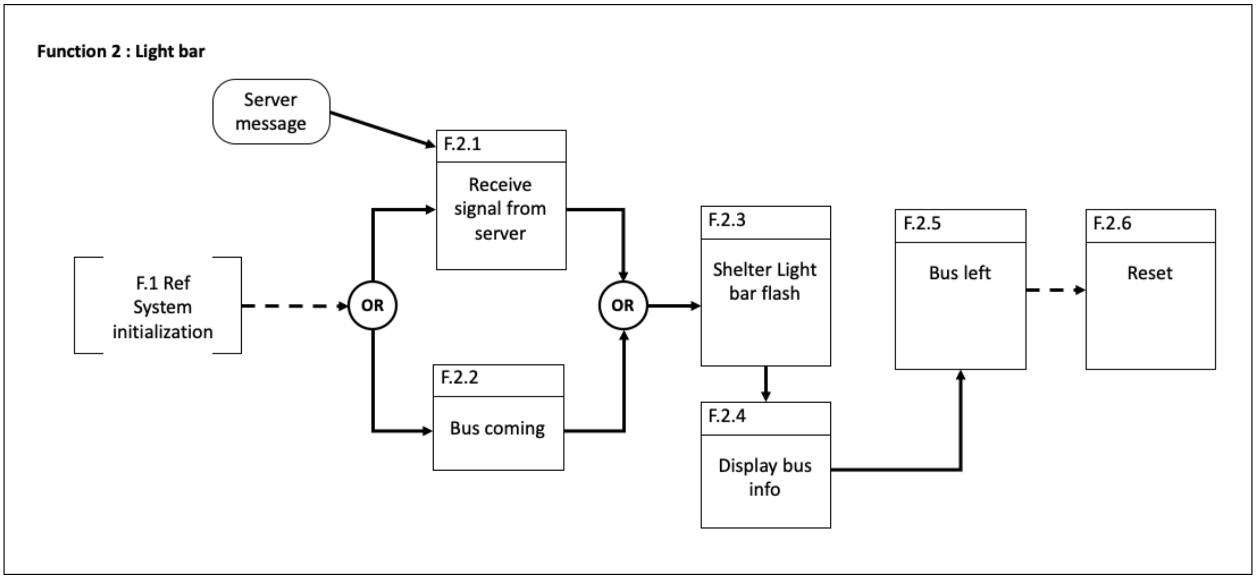


Figure 15: Light Bar FFBD

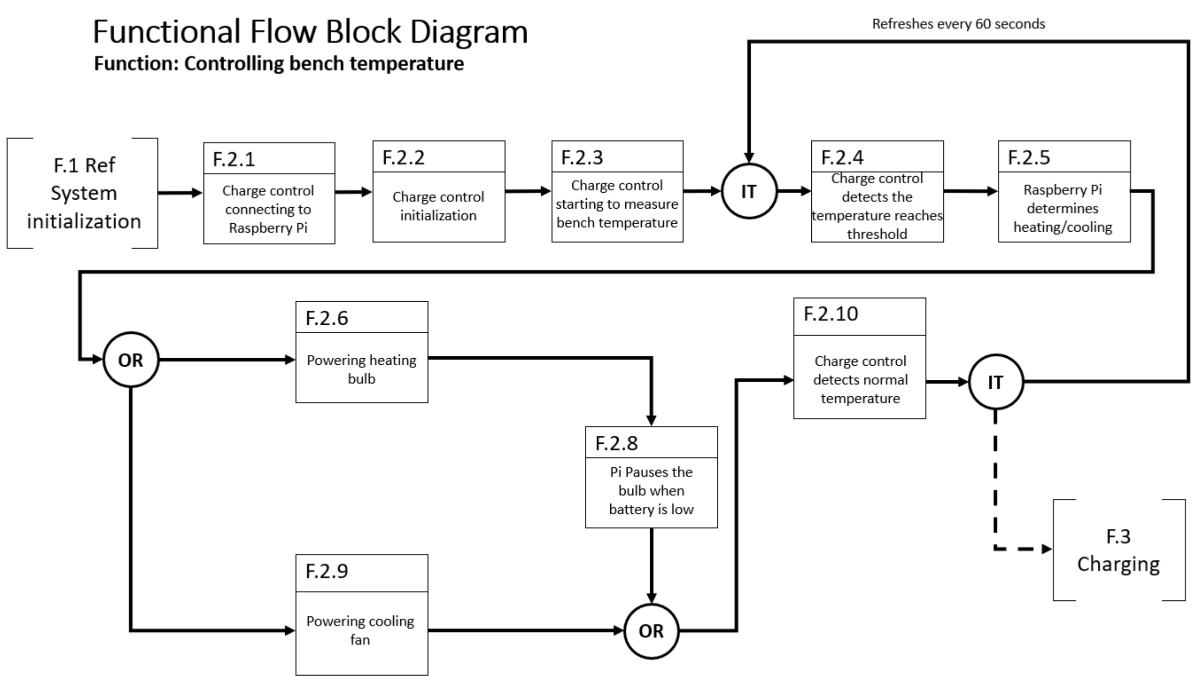


Figure 16: Controlling Bench Temperature

Decision Matrix

A decision matrix establishes criteria for making system design decisions. Using these criteria, different design factors are prioritized and incorporated accordingly. In decision matrices, user dependencies are considered and scored accordingly and goals are compared and assigned an objective value for proper analysis. The decision matrices shown in Figure 17 and 18 demonstrates the criterion analyzed for Shelter's design. In order to provide the most convenient service to different stops, the team developed multiple sizes for the shelter. To determine the most proper size, a decision matrix was used for each stop, as shown below. The stops are different in their daily ridership and available space. In addition to those dominating factors, the team focuses on the total cost and the compatibility as well. A high score for the criteria of compatibility means that the size of the shelter fits well with its location and surrounding environment. For example, a small shelter at the A-lot and a large shelter at Lake-St. IHS would give a relatively low score.

	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*	
Display system initialization	60	20	15			0.00	0.67	0.75	0.05	0.00	0.03	0.04	Opinion A: Original Design.
Readability and obviousness of Display	4	4	3	3		0.80	0.80	0.60	0.14	0.11	0.11	0.08	Opinion B: Remove sound and lights from the Original Design.
Calculating estimated arrivals	5	4	2	3		1.00	0.80	0.40	0.17	0.17	0.14	0.07	Opinion C: Using a LED display to save energy and cost.
Cost	11400	11000	8900		11400	0.00	0.04	0.22	0.17	0.00	0.01	0.04	
Display notifying riders	5	3	2	2		1.00	0.60	0.40	0.19	0.19	0.11	0.08	
Energy Cost	150	120	60		447	0.00	0.20	0.60	0.11	0.00	0.02	0.07	
Weeks needed to build the computer module	3	2	1		3	1.00	0.33	0.67	0.17	0.17	0.06	0.11	
Score Totals						**3.80**	**3.44**	**3.64**	**1.00**	0.64	0.48	0.48	

Scale Measure for Readability and obviousness of Display	
Score	**Scale Condition**
5	The display can be easily found and understandable to all users
4	The display can be easily found and understandable to most adults
3	The display can be easily found and understandable through some calculation (subtraction of time)
2	The display can be found with some instruction and can only be understood by staffs
1	The display is hard to understand by all users

Scale Measure for Calculating Estimated Arrivals	
Score	**Scale Condition**
5	The system will estimate arrivals with an accuracy of ± 30 sec
4	The system will estimate arrivals with an accuracy of ± 1 min
3	The system will estimate arrivals with an accuracy of ± 2 min
2	The system will estimate arrivals with an accuracy of ± 10 min
1	The system can only display a fixed schedule from TCAT

Scale Measure for Display Notifying Riders	
Score	**Scale Condition**
5	The display will notify riders with sound, light and changed graphics on the display
4	The display will notify riders with light and changed graphics on the display
3	The display will notify riders with only changed graphics on the display
2	The display will notify riders by listing the closest bus on top of the list (no graphical changes)
1	The display will rely on the listed time realized by riders to notify bus arrivals (passive)

Figure 17: Display System Decision Matrix

Sage Hall		Design Sizes							
		Small		Medium		Large		Customized	
Requirement	Weight	Normalized	Final	Normalized	Final	Normalized	Final	Normalized	Final
Compatibility	*1*	5	5	8	8	10	10	5	5
Daily Ridership	*5*	1	5	3	15	8	40	10	50
Available Space	*2*	10	20	8	16	8	16	4	8
Total Cost	*2*	10	20	7	14	5	10	2	4
Final Score			***50***		***53***		***76***		***67***

A-Lot		Design Sizes							
		Small		Medium		Large		Customized	
Requirement	Weight	Normalized	Final	Normalized	Final	Normalized	Final	Normalized	Final
Compatibility	*1*	1	1	1	1	6	6	10	10
Daily Ridership	*5*	1	5	3	15	10	50	8	40
Available Space	*2*	10	20	10	20	10	20	10	20
Total Cost	*2*	10	20	7	14	5	10	2	4
Final Score			***46***		***50***		***86***		***74***

Lake St. - IHS		Design Sizes							
		Small		Medium		Large		Customized	
Requirement	Weight	Normalized	Final	Normalized	Final	Normalized	Final	Normalized	Final
Compatibility	*1*	10	10	8	8	3	3	1	1
Daily Ridership	*5*	7	35	10	50	2	10	1	5
Available Space	*2*	10	20	8	16	3	6	1	2
Total Cost	*2*	10	20	7	14	5	10	2	4
Final Score			***85***		***88***		***29***		***12***

Figure 18: Shelter Size Decision Matrix

IDEF0

An IDEF0 defines how complex systems interact with each other. Boxes represent actions or events of the system with inputs flowing from the left, outputs flowing out from the right, control constraints defined flowing in from the top, and resources flowing in from the bottom. This tool demonstrates how design elements relate to each other and what information is required by each element to complete its respective function. Functionality of elements is determined or constrained by the components flowing in and out of the events. Key elements of each functional event are defined here with recognized constraints included to demonstrate what would be present during each step of an operation. The bus shelter is designed to provide a convenient and comfortable service to the users of TCAT, and the IDEF0 shown in Figure 19 was used to guide the design of it. The IDEF0 focuses on the event to control the temperature of the shelter. The power supply is mainly from the solar panel and the battery. After the entire system is powered up, information including current temperature, bus location, and route status is gathered and analyzed by the controller. The heating bulb and the cooling fan will then work under the control of the Raspberry Pi.

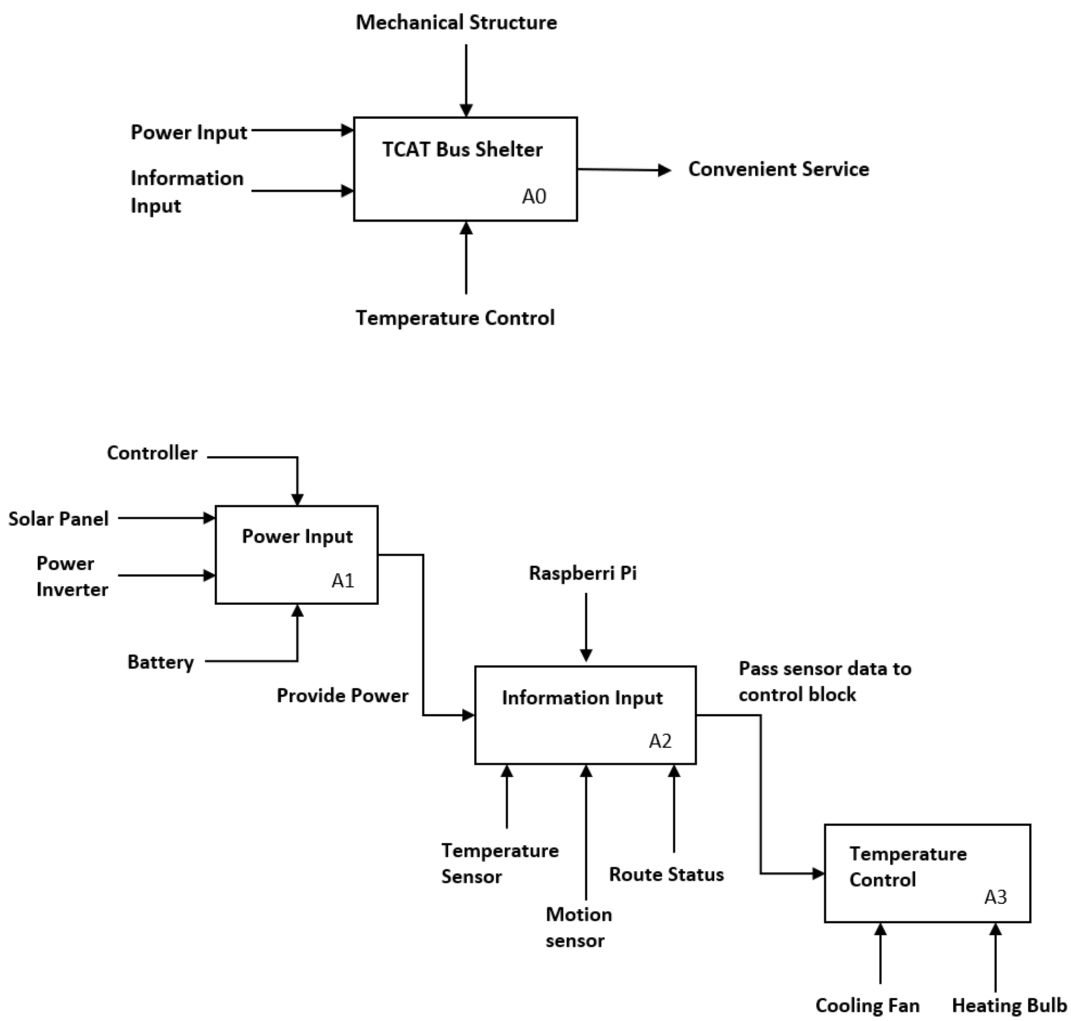


Figure 19: IDEF0

Analytical Hierarchy Process

An Analytical Hierarchy Process is a method of making decisions for a system based on the weights a goal is assigned. Decision elements are ranked and then compared between each potential grouping. This results in factors that are deemed more critical than others. Findings should directly align with project goals which were established through customer surveys and in-depth team discussions. This is demonstrated in Figure 20 below for Shelter functionality.

1	Inform Riders		Good Using Experience		Operational Complexity			Durability	Energy Independence
	0.15		0.15		0.2			0.3	0.2
2					Maintenance	Construction			
3	Make a bus shelter that displays estimate arrivals accurately	Make shelter easy to spot at night.	Make a user-friendly bus shelter.	Make the shelter aesthetically appealing.	Make the computer module easy to maintain and update.	Make a bus shelter that is easy to build.	Make the cost of the shelter as low as possible.	Make a bus shelter that is durable.	Make a bus shelter that does not heavily rely on public energy sources.
4	0.67	0.33							
5			0.67	0.33					
6					0.3				
7						0.3	0.4		
8								0.3	
9									
10	0.1	0.05	0.1	0.05	0.06	0.06	0.08	0.3	0.2

Figure 20: Analytical Hierarchy Process

Goal Question Matrix

A Goal Question Matrix is used to prioritize what goals the customer has set for the system to achieve. A goal is listed in the far-left column of the matrix followed by questions asked of the goal such as "Is the temperature inside the Shelter hotter than outside?" The analysis of the question is then assigned an ideal metric, an approximate metric, and how the collected data is measured. This is shown for Shelter development in Figure 21. This GQM helped the team further analyze the shelter in relation to stakeholder needs by developing proper metrics for project goals. Then decomposing them to ideas of how to collect data and prove that the Shelter meets the goals put in place. For example, if it may be a goal to rate and improve the accuracy of the bus arrival forecasting, but questions are needed to define how to measure "accuracy." Questions such as "What fraction of forecasting is accurate?" and "What is the average deviation?" Data provided by TCAT can be analyzed and used to calculate the average deviation time for each bus stop. If collection of ideal metrics is not possible, approximate metrics can be a backup method to evaluate performance to plan. For example, if first-hand data cannot be acquired, users' satisfaction levels can be surveyed and collected.

	Goals	Questions	Ideal Metrics	Approximate Metrics	Data Collection Methods
1	Keep user warm in winter	Is the temperature inside Shelter higher than outside?	Temp difference between inside and outside	User answer: 100%/90%/80%/70%/60%	Direct Measure on Temp of inside and outside in winter
2	Provide user with accurate bus arrival time	What fraction of bus time displayed by shelter is accurate?	Fraction of buses whose difference between actual arrival-time and displayed time is less than one minute	User answer: Excellent/Good/Fair/Poor	On-site measure on deviation
		How different is the inaccurate time from the actual time?	The average deviation time	(No Approximate)	On-site measure on on-time bus
3	Protect user from direct sunshine	Is the sunshine inside Shelter weaker than outside?	Ultra Violet difference between inside and outside	User answer: Absoutely/Yes/Somehow/No feeling	Direct Measure on UV intensity of inside and outside on sunny day
4	Protect user from wind	Is the wind speed inside slower than outside?	Wind Speed difference between inside and outside	User answer: Absoutely/Yes/Somehow/No feeling	Direct Measure on wind speed of inside and outside
5	Provide user with quiet enviroment	Is the decibel inside lower than outside?	Decibel difference between inside and outside	User answer: Absoutely/Yes/Somehow/No feeling	Direct Measure on Decibel of inside and outside
6	Provide user with illumination	Is the luminance inside higher than outside?	Luminance difference between inside and outside at night	User answer: Absoutely/Yes/Somehow/No	Direct Measure on Luminance of inside and outside
		Is the shelter bright enough for book reading?	Is Luminance higher than 20000 lm	User answer: Absoutely/Yes/Somehow/No	Direct Measure on Luminance of inside
7	Make the battery usable for a long time.	How long does the battery last until it is less 70% of its original capacity?	Days of operation until battery fall below 80% capacity.	(No Approximate)	Data from TCAT maintenance crew
8	Make the screen reliable	How oftern does the screen break down?	Frequency of maintenance in one year.	(No Approximate)	Data from TCAT maintenance crew
9	Make voice of reminder can be heard clearly	Is the voice loud enough?	Decibel of Speaker	User answer: Excellent/Good/Fair/Poor	Direct Measure on Decibel of Speaker
		Is the voice clear enough?	Fraction of people can hear the message clearly	User answer: Excellent/Good/Fair/Poor	Quesionnaire
10	Make sure user see outside clearly	Is the glass transparent enough?	Transmittance of glass	User answer: Excellent/Good/Fair/Poor	Direct Measure on Transmittance of glass

Figure 21. Goal Question Matrix

Shelter FFMEA

Risk reduction is important to the TCAT stakeholders because any failure of the shelter system can have detrimental monetary, legal, safety, and customer satisfaction impacts. A Functional Failure Modes and Effects Analysis (FFMEA) was conducted on the current shelter design to identify and rank possible functional failure modes as well as their associated effects and probable causes. This FFMEA analysis allowed the shelter team to proactively identify potential failures and analyze them to determine what additional functionality should be incorporated into the shelter system. When utilized, the information obtained from this analysis will result in a more failure resistant shelter system. The team's efforts with this tool are shown in Figure 22, 23 and 24.

The first step in the FFMEA analysis is to identify the most basic functions of the system. The entire shelter system is broken down into its primary subsystems — structure, notification, power and information — which was used to facilitate determining these functions. Next, failure modes for each function were identified. For each failure mode, the effects on the user as well as the causes associated with each function were determined. Numerical ratings taken from a tabulated scale are then used to characterize both the severity and likelihood of each failure. The Risk Priority Number is the product of the severity, likelihood, and detection scores. The Risk Priority Number reflects the criticality of the failure and is used to decide which failures need to be mitigated. Failures with a higher Risk Priority Measure are assumed to be the most important to address.

System	Subsystem	Function(s)
Shelter	Structure	Withstand environmental loading scenarios
		Protect user from the elements
		Provide ease of installation
		Provide ease of maintenance
		Support the integration of accessory features
	Notification	Provide user with route information via TV display
		Provide user with route information via LED indicator lights
	Power	Enable Power Consumption
		Provide charging capabilities
		Provide energy storage
		Distribute energy throughout system
	Information	Communicate with Google Transit and TCAT database
		Store inputs from the shelter
		Provide actions to notification system

Figure 22: Shelter System Functions

Failure ID	Subsystem	Failure Mode	Effects Experienced by the User	Possible Causes	Severity	Likelihood	Detection	Risk Priority Number (RPN)	Criticality Rank	Corrective Plans
F1	Structure	Degradation of structural elements	The user feels unsafe	Support member mechanical fatigue	5	1	5	25	7	Enable feedback from user about "shelter condition" that will be relayed to the shelter maintenance steward
			The user is not protected from the elements	Bolted connections loosen	5	2	5	50	2	Implement more robust secondary retention at connections
				Tampering	5	3	3	45	3	Implement more effective tamper proof hardware. Detect tampering with shelter security camera
F2	Notification	Fail to show notification	The user misses the bus	Faulty TV display	4	2	5	40	4	Repair/replace the TV display
			The user takes the wrong bus	Faulty LED indicator lights	2	2	5	20	9	Repair/replace the LED indicator lights
F3	Power	Fail to consume power	The user can not use electrical features on shelter	Power outage	5	4	3	60	1	Shelter relying solely on grid ties can have a small power storage source until the outage is resolved by the utility company
				Tampering	4	3	2	24	8	Implement tamper proof electrica connections to the grid source.
F4	Power	Over charging of battery	The user's safety may be compromised by smoke, fire and explosion	Faulty charge controller	5	1	1	5	12	Repair/replace charge controller
F6	Power	No charge to battery	The user can use limited electrical features on shelter	Insufficient solar energy	2	3	1	6	11	Maximize solar efficiency with high efficiency PV cells, minimize energy consumption of operating electrical components
				Faulty charge controller	3	1	1	3	3	Repair/replace charge controller
				Faulty wiring	3	2	5	30	6	Implement redundancy to failure prone wiring
F6	Power	Energy is not stored	The user can not use electrical features on shelter	Faulty battery	5	1	3	15	10	Repair/replace battery
				Temperature exceeds operating range of battery	4	3	3	36	5	Implement additional active heating and cooling features/insulation, use more robust battery
F7	Information	Failure to connect to database	The user does not receive accurate information on routes	Faulty transmission device	3	2	5	30	6	Repair/replace transmission device, implement redundancy

Figure 23: Functional Failures Matrix

Severity	
Score	**Description**
5	Potential safety implications, Failure takes more than a month to resolve, Shelter functionality is reduced more than 50%
4	No safety implications, Failure takes more than 2 weeks to resolve, Shelter functionality is reduced more than 30%,
3	No safety implications, Failure takes more than 1 week to resolve, Shelter functionality is reduced more than 20%,
2	No safety implications, Failure takes more than 4 days to resolve, Shelter functionality is reduced more than 10%
1	No safety implications, Failure can be resolved within 2 days, No discernable change to shelter functionality

Likelihood	
Score	**Description**
5	Occurs at least once a week
4	Occurs at least once a month
3	Occurs at least once every 6 months
2	Occurs at least once every 3 years
1	Occurs less than once every 10 years

Detection	
Score	**Description**
5	There is currently no implemented design control
4	Low chance the current design control will detect cause/failure
3	Moderate chance the current design control will detect cause/failure
2	High chance the current design control will detect cause/failure
1	Current design control will most certainly detect cause/failure

Figure 24: Numerical Subjective Estimates of Severity, Likelihood and Detection

Shelter Fault Tree Diagram

A fault tree analysis diagram is another tool utilized to visually map the individual causes to failures and then to the overarching shelter system. The causes and failures presented in Figure 22's fault tree diagram come directly from the FFMEA analysis.

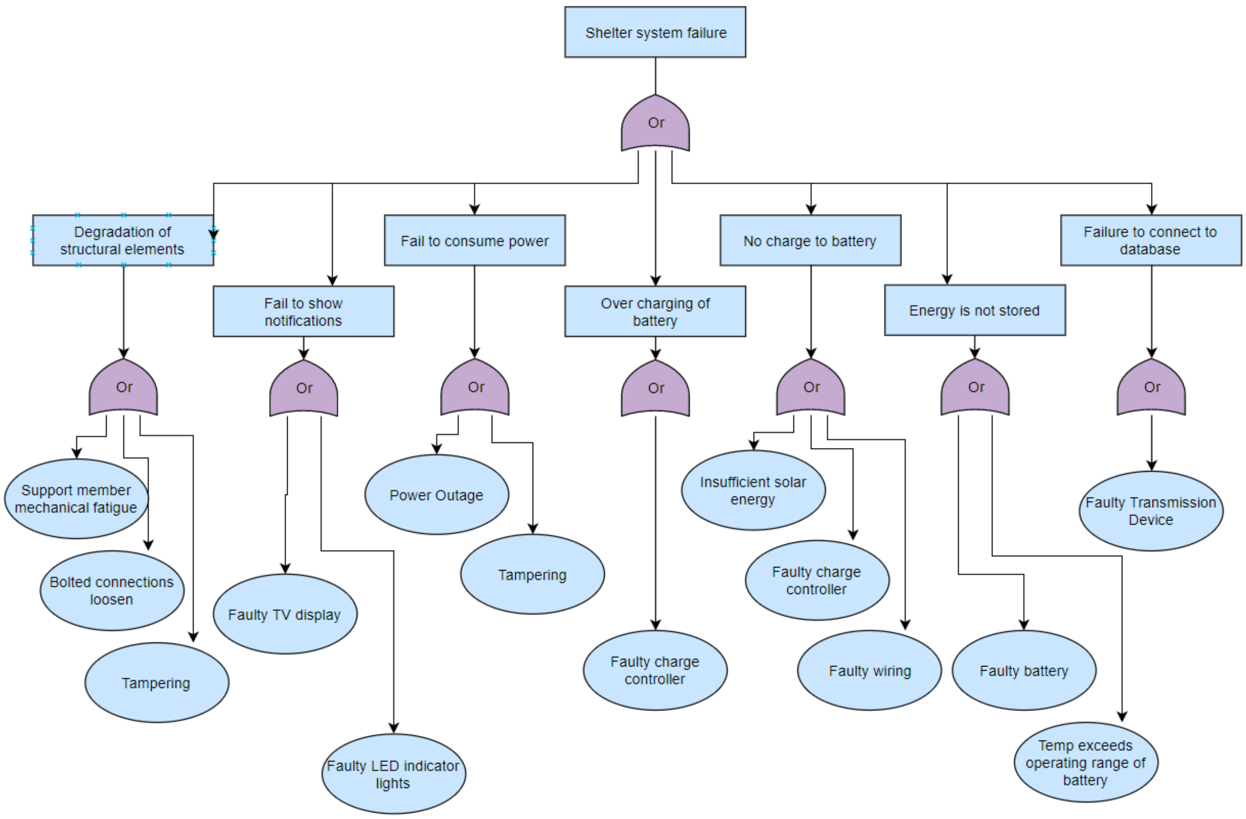


Figure 25: Fault Tree Diagram of Shelter System

Master Plan Efforts

Master Plan students were faced with the broad and daunting task of creating a system or plan to improve the TCAT system. Building on previous semesters' work, and using systems tools to help drive definition, the envisioned future system is beginning to take shape. Based on an analysis of the data available and potential optimization methods, the Master Plan team has begun building two complementary bussing system improvement tools. The aim of the first tool is to enable simple, user-friendly analytics of the current Tompkins County Bus System - the desired output being recommended locations for new bus shelters and places where bus shelters could be combined or eliminated. The second system, which could potentially be integrated with the first, takes the bus shelter design and allows the user to model design decisions based on funding, location, community needs, etc. The decision to develop these two tools in parallel was reached by the systems analysis described herein.

One of the first tools used in previous semesters to define interaction with "The Master Plan" is a context diagram. The context diagram was continually referenced and updated throughout the spring of 2020. As new data stores became apparent or available, the model was refined and as the team began to better understand stakeholders the model was further refined. Figure 26 below shows the context diagram in its current state.

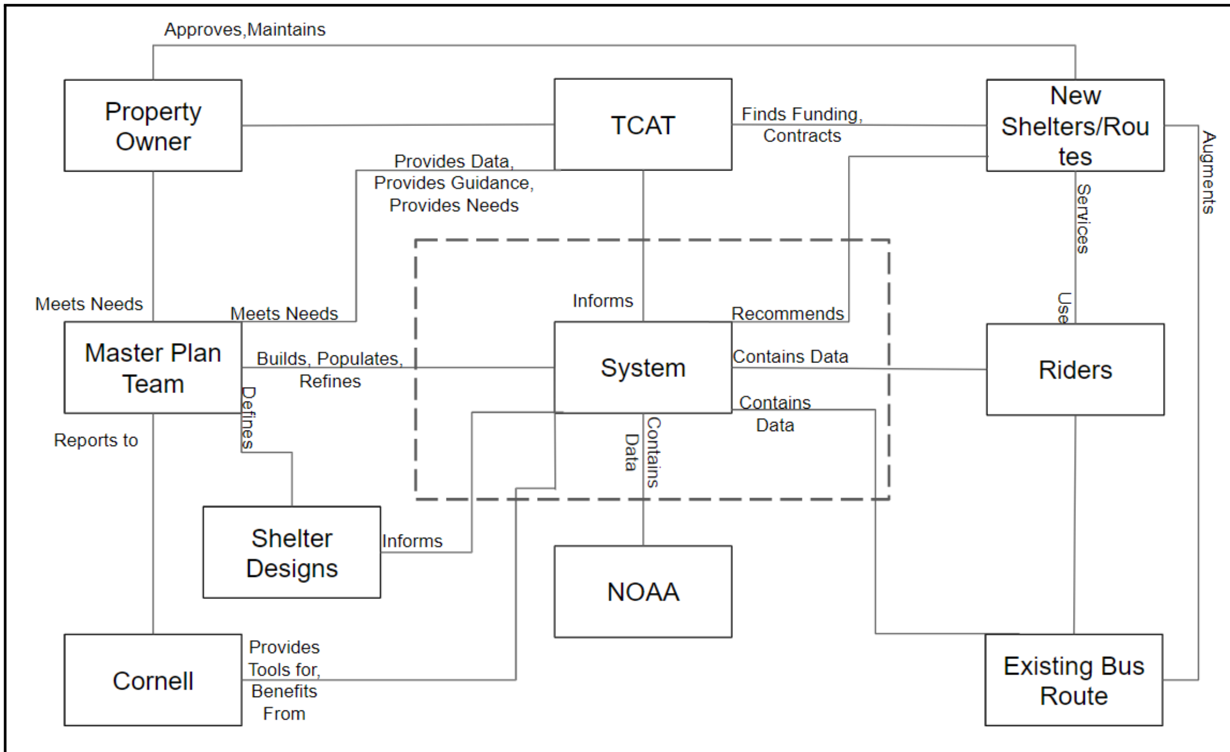


Figure 26: Master Plan Context Diagram

The need for robust data sources is highlighted by the context diagram. Data from ridership, weather, population, and bus efficiency can all feed into the decision of where to place what shelters. This is why a large focus of this semester was obtaining large sets of meaningful data that can drive decisions. Throughout the semester, the team worked to strengthen the relationship with TCAT, and were rewarded with plentiful data. The transit authority made available over 1 million records recorded by buses throughout Tompkins County during 2019. These records recorded at bus stops throughout the county show delays and passenger changes at each stop as related to a bus route and date-time. This data is augmented with bus performance metrics and required maintenance counts.

Team brainstorming quickly fell upon the idea that stormy weather would likely impact ridership, especially in route locations with no shelters. This being the case, they requested 2019 weather data from NOAA (National Oceanic and Atmospheric Administration). This data shows the hour by hour precipitation and temperature of an Ithaca Weather station. Though weather data obviously is not available for each individual bus shelter, this still integrates nicely with the data provided by TCAT.

In order to encourage further brainstorming as to how the data may be used, the team began putting together various use cases for data interpretation tools. These use cases began in a single table, but it soon became clear that two distinct tools were described. For clarity and efficient division of labor, these use cases were broken out into two tables. The first set of use cases describes a tool for interpreting TCAT's ridership data. These use cases can be seen in Table 3.

Table 3 Ridership Data System Use Cases		
Label	**Use Case**	**Priority**
RD 1	User Access Tools from any computer	High
RD 2	User updates data sets	High
RD 3	User inputs new data	High
RD 4	User obscures outliers	High
RD 5	User Removes incorrectly input data	High
RD 6	User Interrogates all data for an individual stop	High
RD 7	User ranks routes by delays	High
RD 8	User ranks stops by delays	High

RD 9	User visually interprets precipitation's effect on ridership across stops	High
RD 10	User visually interprets precipitation’s effect on delays across stops	High
RD 11	User applies modeling to an entirely new dataset	High
RD 12	User filters analysis to a specific route	High
RD 13	User filter analysis to a specific date range	High
RD 14	User visually interprets temperature's effect on ridership across stops	Medium
RD 15	User visually interprets time of year's effect on ridership data across stops	Medium
RD 16	User visually interprets time of day's effect on ridership data across stops	Medium
RD 17	User visually interprets median and 95% max when interpreting ridership	Medium
RD 18	User visually interprets ridership's effect on delays across stops	Medium
RD 19	User visually interprets precipitation’s effect on ridership across stops at varying temperature ranges	Medium
RD 20	User visually interprets distance between stops on the same route	Medium
RD 21	User individually quantifies the ridership gain at adjacent stops	Medium
RD 22	User visually interprets temperature's effect on delays across stops	Low
RD 23	User visually interprets time of day's effect on delays across stops	Low
RD 24	User visually interprets time of day's effect on ridership data across specific seasons	Low
RD 25	User visually interprets precipitation’s effect on ridership across stops at varying times of day ranges	Low
RD 26	User visually interprets time of year's effect on delays across stops	Low

This table is meant to include many of the potential use cases a person might have when interacting with our tools. The focus of use cases in Table 3 is the manipulation and interpretation of ridership data, as identified by the label (RD). It is important to note that the table is not necessarily meant to represent a full list of potential use cases. Rather, this list of use cases was used as a jumping-off point for requirement derivation. The process of brainstorming use cases and assigning priorities began to give the team a picture of a tool – what it must do and what it could do. The use cases were refined throughout the semester and used to drive the requirements shown in Table 4 below.

Originating requirements are largely levied by the end-user and are based on overall system goals for a product, defined by the project team. Derived requirements are generated during the design phase by determining how a product will meet customer needs. These requirements serve as a further step to define exactly what is necessary to ensure successful product roll-out and operation. Originating and derived requirements are defined in Table 4 below to ensure the system is in line with customer (passenger) goals.

Table 4 Ridership Data System Requirements

Index	**Requirements**	**Abstract Function Name**
OR.1	The system shall be accessible or transferable to any Cornell student or faculty member	Cornell Access
OR.2	The system shall be accessible or transferable to any TCAT employee	TCAT Access
OR.3	The system shall be able to ingest data provided in the format provided at https://public.tableau.com/profile/tom.clavel#!/vizhome/StopPerformance/tripreview	TCAT Data
OR.4	The system shall be able to ingest data provided in the format describe in OR.3 with additional fields include	New TCAT Data
OR.5	The system shall be able to ingest standard CSV downloads from NOAA weather data for Ithaca - standard as of April 2020	NOAA Data
OR.6	The system shall be able to relate TCAT data OR.3 NS NOAA data OR.5 by date time	Data Relation
OR.7	The system shall visually display mean and 95% ridership at each stop	Percentiles
OR.8	The system functionality shall all be interpretable by the color blind	Color Friendly
OR.9	The system shall visually relate ridership and precipitation	Rain

OR.10	The system shall visually display average delay at each bus stop	Delay
OR.11	The system shall visually display shall be interpreted as displaying relative metrics by size, color, and/or shape	Visuals
OR.12	The system shall be able to ingest new data into existing data sets	New Data
OR.13	The system shall be able to obfuscate outliers	Hide Outliers
OR.14	The system shall be able to highlight outliers	Highlight Outliers
OR.15	The system shall provide the same functionality on windows or Macintosh computer	Mac PC
OR.16	The system shall be reconfigurable, as to show metrics included in the data but not originally visualized	Reconfigur able
OR.17	The system shall be built with zero additional material or access costs to Cornell e.g. with existing software and licenses	Cornell Cost
OR.18	The system shall be accessible to TCAT employees at no additional cost e.g. leverage software and licenses TCAT already has	TCAT Cost
OR.19	The system shall be able to house at least 10 distinct analysis dashboards	Dashboardi ng
OR.20	The system shall be able to interpret simple equations levied on the data fields (addition, subtraction, division, and multiplication)	Equations
OR.21	The system shall be able to normalize ridership fluctuation against the average for a stop	Stop Norm
OR.22	The system shall be able to normalize ridership fluctuation against the average for a route	Route Norm
OR.23	The system shall be able to normalize ridership fluctuation against the average for a season	Season Norm
OR.24	The system shall be able to normalize ridership fluctuation against the average for a year	Year Norm
DR.1	The system shall be able to ingest data provided in the format describe	New Fields

	in OR.3 with additional fields include	
DR.2	The system shall be able to ingest data provided in the format describe in OR.3 with fields included, as long as stop number and date time are included	New Format

The team understands some of the requirements listed above may be slightly vague as written. Given the early stage of the system development, the requirements table is still a living document. Two derived requirements have already been added as the project scope continues to be refined. There will be a drop dead point, likely next semester, where what is in an out of scope is distinctly defined. For now requirements continue to be refined as system capabilities are realized. What this list of originating requirements has already helped with is the team's selection of Tableau as a medium for the tool Tableau is quickly becoming an industry standard for large data analysis - meaning Cornell and TCAT both already have license access. In Tableau, experienced users can create dashboards showing complex data relationships with relative ease. These dashboards can be easily interpreted by users with little to no program experience. Examples of the team's early Tableau analysis of the ridership data can be seen in the Qualitative Analysis of TCAT Bus Departure Data on Tableau.

TCAT Bus Shelter Placement

This semester, the undergraduate members of the Master Plan sub-team primarily worked on identifying possible locations to place improved bus shelters, primarily through analysis of TCAT-provided data. In doing so, the team was able to get a large-scale view of ridership and delay trends across the Tompkins County Bus System as a whole, which complements the empathy fieldwork that was done in previous semesters. Using TCAT-provided data, we sought to identify factors that could influence how useful a new shelter would be, from a delay and ridership-focused perspective. This included examining average delay at each stop (i.e. difference between actual departure time and scheduled departure time), how variable the delay is at a particular stop, important sources of delays, and the services that carry the most riders
.
Next semester, we can focus our efforts on replacing bus shelters on stops that serve routes with the greatest ridership, most delays, amd most variable delays.

Table 5. Basic Data on TCAT Bus Departure Data on Tableau (By Route)

Note: Summer dataset has been filtered to only include stops also in the school year dataset (i.e. around Cornell Campus). This leaves out stops such as Seneca Street, which was not present in the school year dataset.

Tableau Route Run ID	Actual TCAT Route	School Year Avg	School Year Delay	Summer Avg Delay	Summer Delay St Dev (min)	Avg School Year Daily Boardings	Avg Summer Daily

	Number	Delay (min)	St Dev (min)	(min)		Across Route	Boardings Across Route
-1	**Unclear**	4.77	8.99	-	-	35.02	-
3	**13**	2.72	3.4	2.06	2.26	22.08	22.77
6	**17**	3.03	3.53	1.86	2.72	73.65	13.27
7	**20**	3.47	5.95	2.61	2.93	42.16	21.59
8	**21**	2.83	3.54	1.69	3.18	171.72	96.95
9	**30**	2.7	3.26	1.71	2.2	1687.65	797.55
10	**31**	3.16	3.91	1.61	2.14	317.86	161.5
11	**32**	1.57	2.41	0.94	2.16	523.51	256.68
13	**36**	2.64	3.05	1.58	2.32	125.4	60.77
14	**37**	2.45	4.36	0.99	3.01	80.71	68.14
15	**40**	2.86	4.85	3.19	5.26	32.42	30.59
16	**41**	9.47	21.05	2.18	13.34	58.03	4
17	**43**	3.19	4.91	1.69	2.74	171.67	99.64
18	**51**	2.27	2.97	1.7	3.5	285.92	102.57
19	**52**	2.76	4.51	1.9	3.59	57.71	41.92
20	**53**	3.63	3.31	1.96	1.85	19.66	13.73
21	**65**	2.41	4.08	0.79	1.87	37.91	32.55
22	**67**	2.85	3.01	1.42	2.48	85.81	40.77
23	**70**	2.03	2.55	1.6	2.01	999.35	373.38
24	**72**	2.81	2.56	0.84	1.99	346.82	163.13
26	**75**	3.61	4.47	2.68	3.19	34.18	19.88
28	**81**	1.43	3.18	-0.44	2.22	520.47	157.36
29	**82**	1.42	2.76	0.56	1.87	2612.28	1134.64
31	**90**	2.03	2.87	0.31	1.92	350.25	24.92

32	**92**	2.3	3.04	1.04	1.61	403.7	11.5
33	**93**	2.92	3.67	N/A	N/A	221.69	N/A
36	**83**	1.82	2.19	N/A	N/A	393.73	N/A
39	**10**	2.85	2.75	0.62	1.82	957.95	419.55
43	**11N**	1.04	2.44	N/A	N/A	28.84	N/A
44	**83W**	1.69	2.24	N/A	N/A	46.96	N/A

Table 6. Qualitative Analysis of TCAT Bus Departure Data on Tableau (By Route)

Tableau Route Run ID	**Actual TCAT Route Number**	**School Year Details**	**Summer Details**
-1	**(Unclear)**	- Avg. delay of 7+ minutes at Schwartz Ctr, by far the largest out of all stops - Surprisingly, the largest delays on the route as a whole take place between 11am-3pm	-
3	**13**	- Large average delay at Stewart Park with delays decreasing gradually along rest of the route - Larger delays along Lake Road during the middle of the day	- Consistent average delay of 2 minutes throughout route, could be consistent delay in departing terminals - Delays spike from 10am to 12pm, likely due to workers heading for the Ithaca Mall in time for its 10am opening as well as park-goers headed to Stewart Park
6	**17**	- Delays are relatively uniform through campus, with largest delays over 5min at Dairy Bar across street and Collegetown Crossing stops - 8-9am and 7-8pm represent the timeslots with the greatest delays, likely because the 17 does not consistently serve	- Delays are heavier during the summer - Same trends as during the semester, but the heaviest delays are around 7am and 10am heading up to A-Lot and down from the Dairy Bar, respectively - The 7am buses headed up to Cornell pass through the commons before, possibly explaining the consistent

		the Cornell Campus, only coming up after passing through the Commons or down from campus after the morning rush is over	delays - The 10am buses (average delay of 14 minutes at Boyce Thompson Institute) appear to be coming down from campus after previously serving other routes, possibly explaining the large delays
7	**20**	- Mild delays along Tower Road, higher average delays along Stewart Avenue - Highest delays occur at the Sage Hall stop - Delays at Sage Hall could be a result of the elimination of the dedicated right turn lane during a recent reconstruction of East Avenue	- Does not operate in the Summer
8	**21**	- Average delays of 4-5 minutes along Tower Road, 2-3 minutes on other parts of the route - Tower Road is one of the most congested thoroughfares in the area, clogged with student, employee, freight, and transit traffic	- Delays peak at 11am and are generally high from 8-6pm - Delays are relatively high across the board, owing to the route's extensive, nearly 20mi reach into Trumansburg via Downtown Ithaca
9	**30**	**-** In an almost linear fashion, the delay swells on the 30 at every additional northbound stop, indicating that the expected departure times probably need to be modified because there are consistent delays of over 5 minutes - Delays are largest in the waning hours of the 30's service at 10pm, and these delays cannot be attributed to	- Summer delays peak around 8am to over 3 minutes and 5pm to over 2.3 minutes, indicative of increased rush hour usage across a wide range of areas including Ithaca, Lansing, and Cornell University - **Daily delay hotspots** occur at: 1. Ithaca Commons-Green Street (8.179 min average) 2. Northway at Triphammer

		traffic so therefore there must be a more systemic problem - Southbound delays are hardly ever a problem, with the largest average at any stop (Sage Hall) just under 2 minutes	(3.401 min average) 3. Thurston at Balch Hall (2.778 min average) 4. Statler Hall (2.765 min average) 5. The Parkway @ Northway (2.410 average) - **Intersections and downtown routing could be responsible for delays**, as most delay hotspots are near a major intersection 1. IC-GS → last downtown stop, follows traffic light intersections at Green St. and Cayuga, Seneca and Cayuga, etc. 2. NT → immediately following the Hanshaw-Triphammer-Upland 2-way stop 3. TBH → follows Forest Home Dr. and East Ave. traffic light intersection 4. SH → follows Campus Rd. and East Ave. traffic light intersection TPN → could be a systemic problem, as it is near no major intersections and does not immediately follow a problem stop
10	**31**	- Delays westbound through campus are constant at all stops between 4 and 5 minutes, whereas they are much smaller going east, at under 2 minutes even at major points like Statler Hall and Corson Mudd Hall - The 9am and 4pm windows experience the largest delays,	- Delays peak at 8-9am and 4-5pm, and are unevenly distributed throughout the day with local maxima at 12pm and 2pm - Delays are relatively evenly distributed, but peak at Sage Hall and State/MLK at Stewart, two high-volume locations with traffic light intersections nearby

		when the East Ave artery is most problematic	- The line overall has lower average delays owing to its primarily Cornell-oriented route, as campus has less traffic during the summer
11	**32**	- Delays higher on campus, lower on the parts of route outside of campus - Delays increase on campus during busy periods (8am to 11am and 4am to 6pm) but delays south of campus remain fairly consistent, with smaller increases in delays north of campus from 4pm to 6pm, likely as a result of employees and professional students returning to their homes in Cayuga Heights	- Small average delays of around a minute throughout the route, with peaks at the Sage Hall stop, indicating high ridership there, and during rush periods
13	**36**	- Delays grow constantly as this long and winding route makes its way through campus, and the longest delays of over 5 minutes are experienced in Collegetown along State St - 7am and 7pm share the same delay of 3.5 minutes, the longest of any hour timeslot of the route. This is actually pretty commendable given how long the route is - The 36 is one of the routes most affected by snow because every run travels up the Lake St and University Ave inclines that are impassible with a few inches on the ground. This leads to alternate routes during the winter season	- Delays are relatively mild throughout the day, but peak from 4-7pm - The route's nearly 25mi one-way length makes delays inevitable - Delays are spread evenly across most stops, suggesting that most delays are due to high travel times between stops

14	**37**	- Consistent mild delays throughout the route, 3-4 minutes on average on Tower Road and 2-3 minutes on average elsewhere - From 7am to 10am and 4am to 7pm delays are higher ar Hasbrouck Apartments, likely due to a surge in riders from those units that mostly house professional students and faculty to campus for work	- Summer delays peak at 8am, 2pm, and 4pm - Delays are generally uniformly spread throughout stops, averaging between 1 and 2 minutes at most stops 1. Possible Explanation #1: The 37 is a long route with generally long distances between stops and a vast coverage area from Ithaca to North Lansing via Forest Home and Cornell, meaning that delays are inevitable but equally spread 2. Possible Explanation #2: Delays originate at one particular problem area and reverberate throughout the route The evenly-spread data would refute #2
15	**40**	- Consistent delays throughout the route of approximately 3 minutes, does not fluctuate very much	- Consistent delays of approximately 3-4 minutes, with higher delays during rush periods - Massive spike in delays to nearly 20 minutes per stop at 10am and 7pm, which are both at the end of the route's two daily running periods, indicating a potential data error that skews the overall average delays
16	**41**	- Rt 41 is a demand-and-response route, so the data in Cayuga Heights and Lansing is not uniform as there is not a set route in those areas - 41 suffers delays of between 5-10 minutes on every single stop through the Cornell campus - The worst delay is at Schwartz Center which has an average of 31 minutes, but this seems to be a fluke in the the way the system is logging	- Delays peak at 9am and 5pm, coinciding with rush hour usage - **Schwartz Performing Arts Center** affects the rest of the route, with an average delay of over 27 minutes because it is a terminal stop on the varied route - The route is a demand-and-response route, which means it takes a non-uniform path through Cayuga Heights and Lansing, owing to varied data and an abnormally high standard deviation

		timepoints - maybe the bus arriving Schwartz is getting logged as the previous run as they are staggered by 30 minute intervals - Delays at 10am and 1pm are the worst, with an average of over 12 minutes; this route is clearly one of the worst in terms of constant large delays and needs to be closely reviewed	- The data suggests that 41 operates ahead of schedule on its Collegetown-bound leg by over 3 minutes at most on-campus stops including Bradfield, Sage, Uris across Street, Dairy Bar across Street, and Anabel Taylor Hall, potentially owing to decreased need for demand-and-response at on-campus stops during the summer
17	**43**	- Delays remain consistent throughout the route throughout its runtime, with slightly higher delays along Stewart Avenue	- Consistent delays throughout the route, with slightly higher delays during higher-congestion rush periods (7am-10am and 4pm-7pm) - High delays along Stewart Avenue in the middle of the day, could be shift changes in Collegetown businesses, or possibly construction on the road the year the data was collected
18	**51**	- Delays remain largely the same throughout the route, from 2-3 minutes per stop to 5-6 minutes per stop during more congested periods	- Delays consistent throughout the route, with delays higher across the route from 7am to 10am and 4pm to 7pm -Delays are the highest at the Commons and Sage Hall, common points of congestion
19	**52**	- Consistent delays throughout the route, slightly higher delays at the Commons around 8am and 4pm	- Consistent delays throughout the routes, higher delays at rush periods - Extremely high spikes at the end of each running period indicates a potential data error
20	**53**	- Delays are higher along Stewart Avenue and at the Commons, slightly lower along Tower Road but still in the 3-4 minute range	- Consistent delays across the route, with higher average delays on the Stewart Avenue stretch and during rush periods

21	**65**	- Higher delays at the Commons, along Stewart Avenue, and on the western segment of Tower Road, reduce significantly near the Vet School, although Vet School delays are around equivalent to the rest of the route from 7am to 9am and 4pm to 6pm	- Consistent low delays, owing to the rural character of most of its route and small number of runs
22	**67**	- Delays remain consistent throughout the route, slightly higher on Stewart Avenue and in the Commons	- Consistent low delays throughout route, higher delays from 7am to 9am and 4am to 6am - Higher delays along Stewart Avenue - Large spike in delays at the end of the day indicates a potential data error
23	**70**	- No specific trouble points on the 70, probably because it is a weekend route and therefore is less susceptible to traffic delays - Anabel Taylor Hall SB has the largest average delay of the route at 3.5 minutes - Delays are largest at 7pm, when bus usage might be high to transport students between North and West Campuses, at 3.75 minutes	- Delays are mild and evenly distributed at the mean throughout the day, with a slight increase between 10am-10pm - Most pain points occur at Ithaca Commons and along the Stewart Avenue corridor, with most delays originating in these areas for reasons similar to those outlined above (downtown volume and intersection density) - As a weekend route primarily doubling the 30 line's capacity on Cornell's campus, lower summertime demand reduces delays across both the 70 and the 30
24	**72**	- Delays highest in Central Campus (around 4-5 minutes) and remaining consistently at that level throughout the day, delays decrease outside of Central Campus on the rest of the route outside congested	- Lower delays south and west of campus, higher delays on campus throughout the day

		times	
26	**75**	- Consistent delays of approximately 3 minutes along Tower Road segment throughout the day, delays north of campus increase towards the end of the day, indicating higher usage and congestion in this period	- Higher delays along Tower Road, lower delays on the portion north of campus due to lower congestion - Higher delays along the Lake Road segment, likely due to higher ridership at Ithaca Falls during the Summer
28	**81**	- First bus exclusively (4:40am) serves Collegetown as well	- Very low delays all day because as a Cornell Campus Circulator there is very low demand due to a dearth of students on campus during this period
29	**82**	- There is not a single stop on the 82 (Cornell's Campus Circulator) with an average delay of over 2.5 minutes - this is exceptional - Given the length of this route, the streets it uses, and how heavily it is used, large delays might be expected, but that is generally not the case - Largest delays occur at 8am, 1pm, 4pm equally at just under 2 minutes	- As the Cornell Campus Circulator, delays are low during the summer time due to lower demand and volume. Delays only reach a maximum of under 2 minutes on average at 8am
31	**90**	- Rt. 90 only operates during the night, so the delays are minimal across the entire route - 7:00 has the highest delay of over 3min, but there are no other hour increments where the delays exceed 2min - Delays are much higher coming southbound towards Collegetown, and this is to be expected since the 90 is a "loop" route as opposed to a route with two "termini" - naturally it will lag on the	- As a night-only route, maximum delays on average occur around 9pm - Maximum delays of nearly 8 minutes occur at Ithaca Commons - Green Street, owing to its downtown location and intersection density

		loop	
32	**92**	- Delays are consistently bad along the route headed towards EHP, but especially along Tower Rd (average of about 5 mins) - increased delays start in Collegetown. Delays are significantly lower in the other direction (average of about 1.4 mins). This trend persists all day, from 8am to 9pm.	- As an evening-only route operated in the Summer when campus is least congested, there are very few delays en route - Highest average delays of around 2 minutes on Tower Rd, likely the busiest part of the route because of its proximity to research labs
33	**93**	- Same issue as with Route 92, delays especially bad headed out of Collegetown. - In the out-from-Collegetown direction, worst stops (in terms of avg delays) depend on the hour - Carpenter Hall and Hoy Field are bad in the PM rush, and Collegetown gets very bad late at night	- Does not operate in the Summer
36	**83**	- Delays are heaviest in the square "loop", around 8am-9am. - Delays significantly worsen (~1 min to ~3 mins) between Goldwin Smith and Sage Hall, only return to less than 2 min avg delay on return trip past Helen Newman	- Does not operate in the Summer
39	**10**	- Delays are heaviest at Sage Hall, but average delay there is only a minute higher than the average delay at the previous stop - Delays are quite consistent between the stops - High traffic periods: Morning rush, afternoon rush and 1pm	- Very few delays due to low congestion on campus - Minor delays on University Avenue, up to just over a minute on average - Highest delays on University Ave occur during morning rush period (7am-9am), not repeated in afternoon rush due to the route's looping nature

43	**11N**	- The direction of the Cornell/Collegetown loop was reversed between Fall 2019 and Spring 2020 (counterclockwise through Collegetown and clockwise through Collegetown, respectively). - The Spring 2020 version of the route had significantly less delays at the Collegetown stop than Fall 2019	- Does not operate in the Summer
44	**83W**	- Delays are heaviest at the end of the "square loop", like with Route 83 (average delay increases by ~1.3 mins from Uris to Sage) - Baker Flagpole experiences minimal delay - the bus experiences less and less delay from Sage Hall through West Campus - 9am delays are reduced compared to other hours	- Does not operate in the Summer

Tableau Analysis – Ridership Data

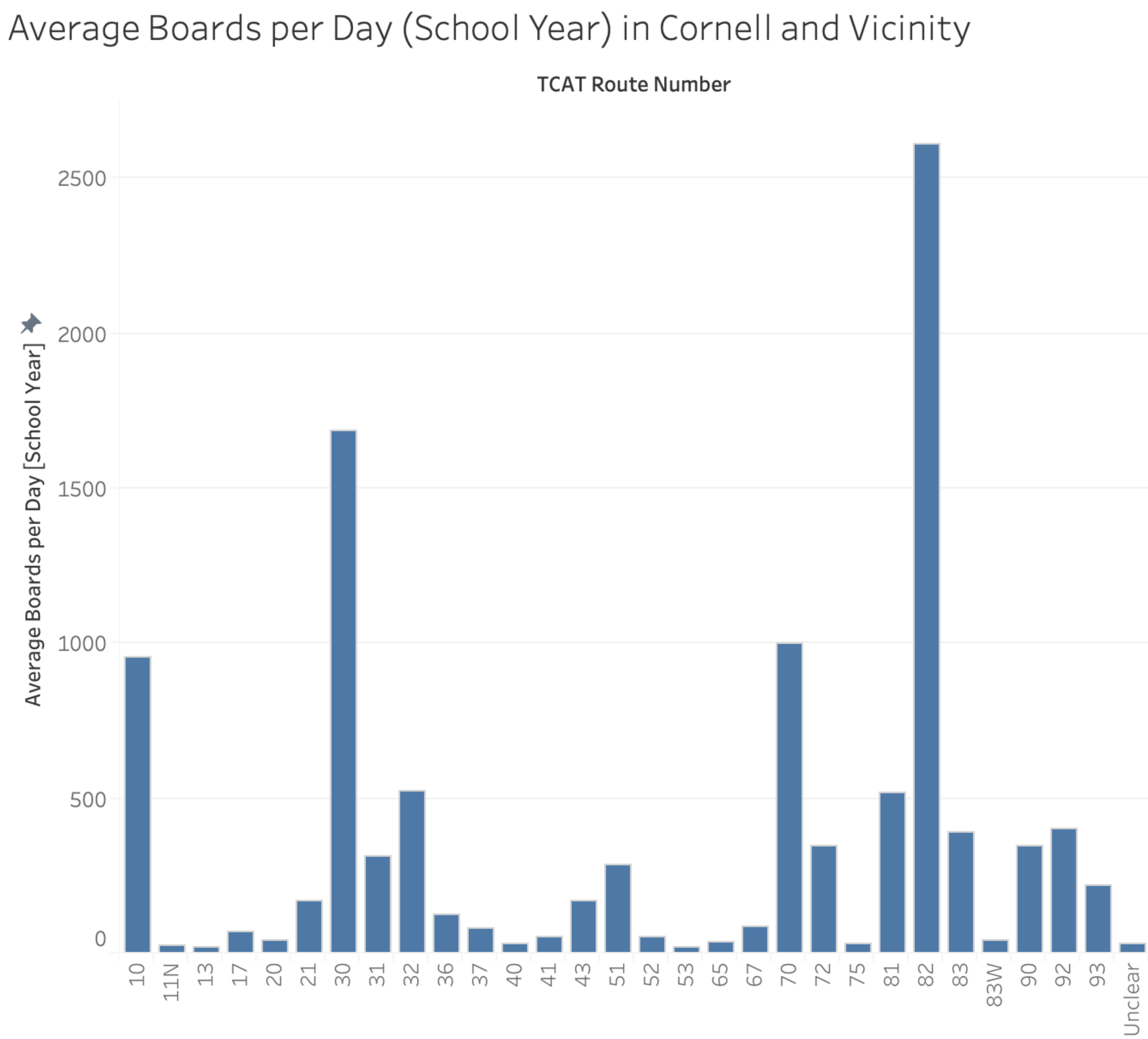


Figure 27: School Year total number of boardings (near Cornell campus) normalized by total number of days in school year dataset.

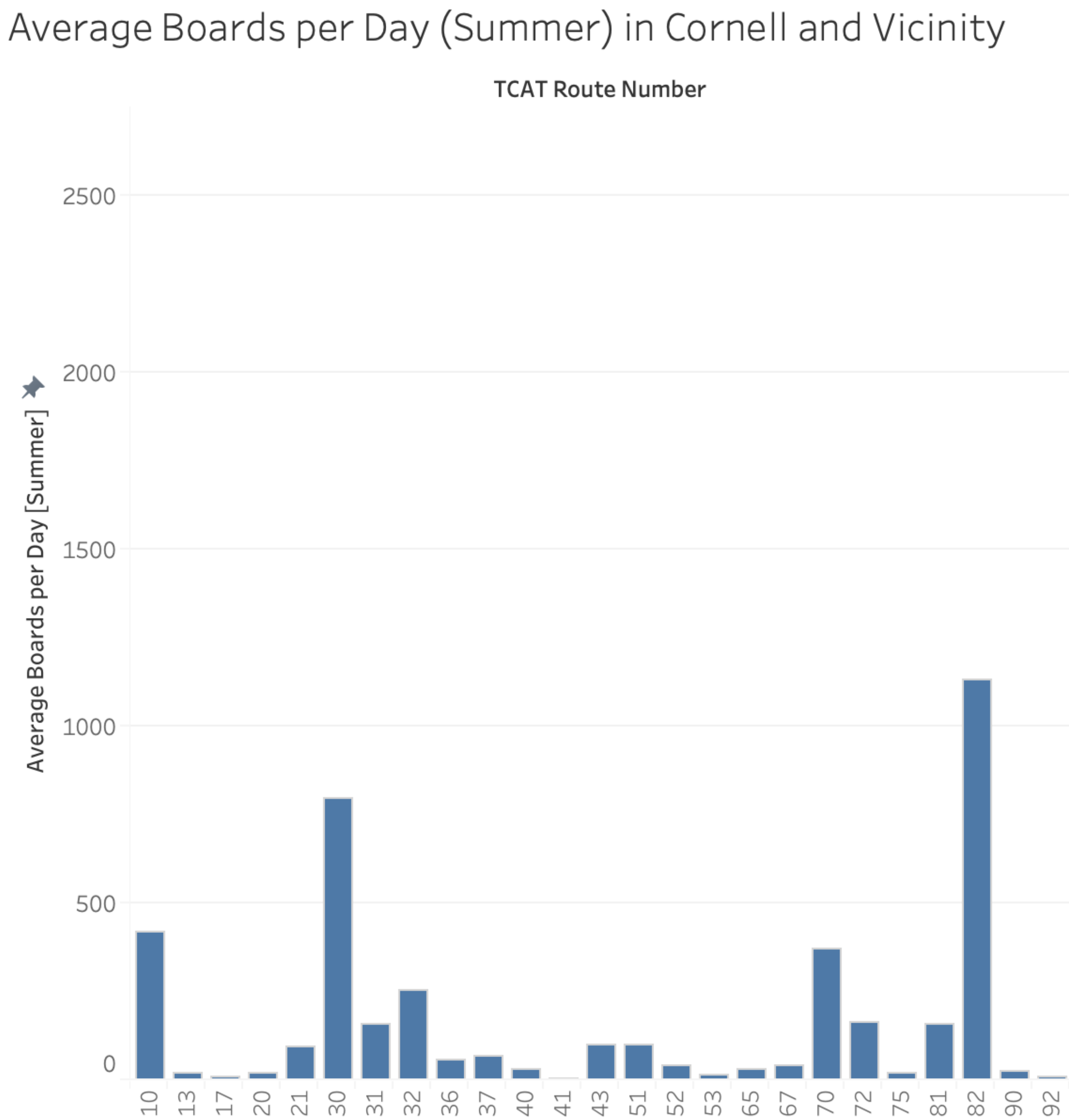


Figure 28: Summer total number of boardings (near Cornell campus) normalized by total number of days in summer dataset.

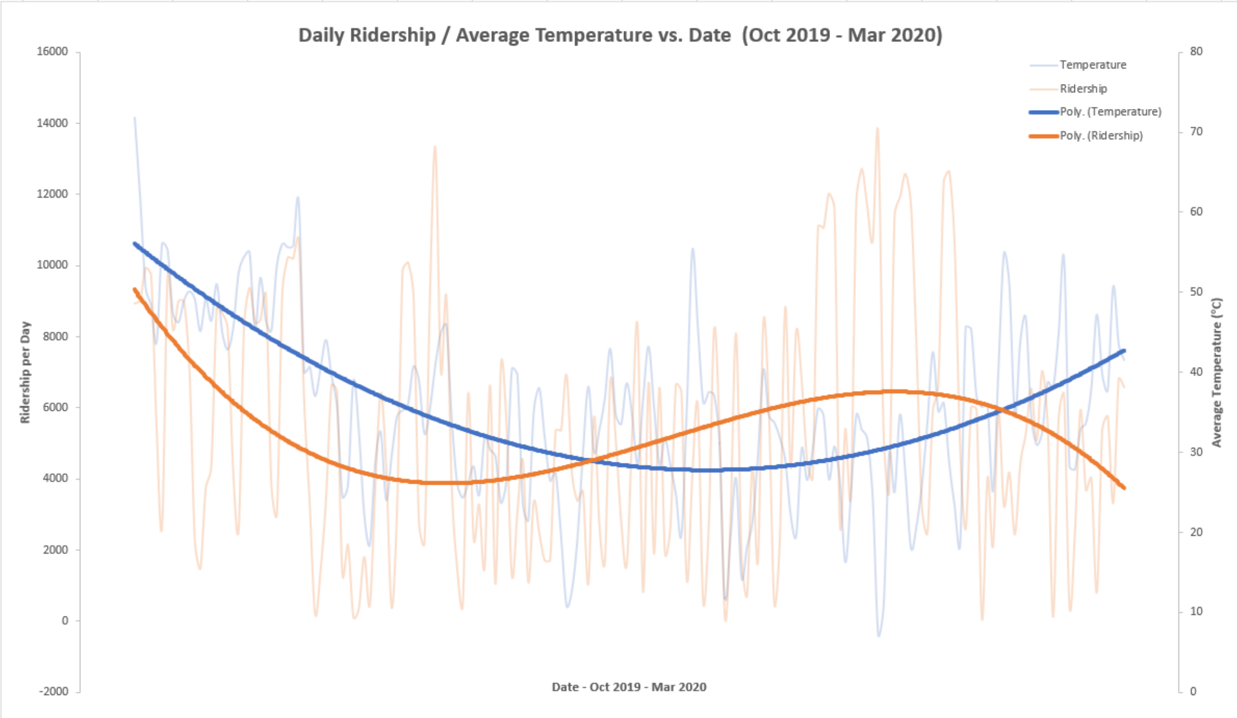
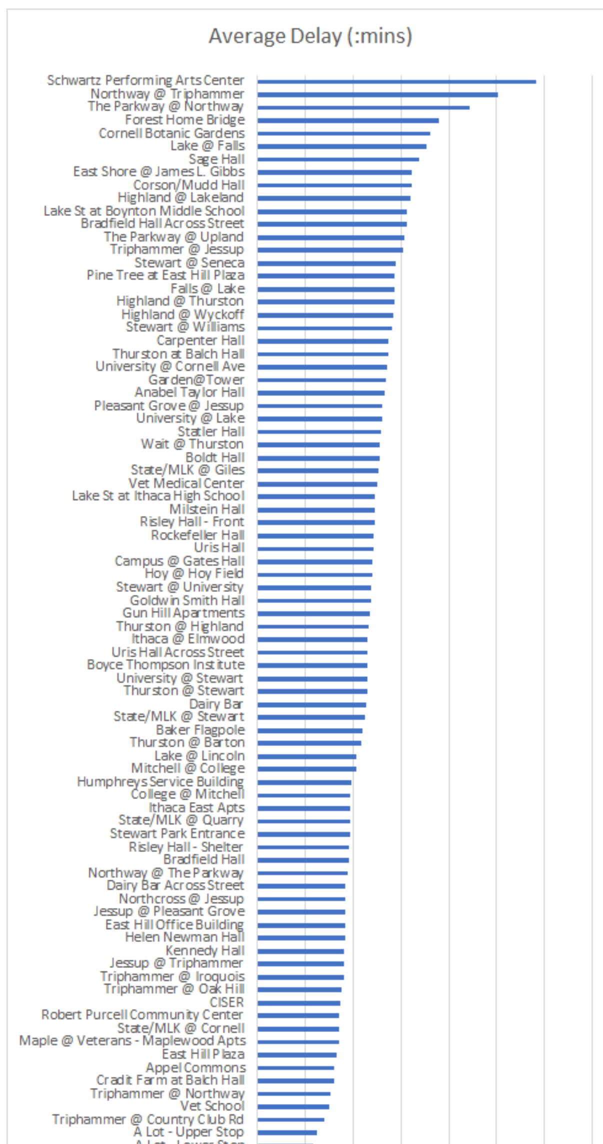


Figure 29: Daily Ridership vs. Date



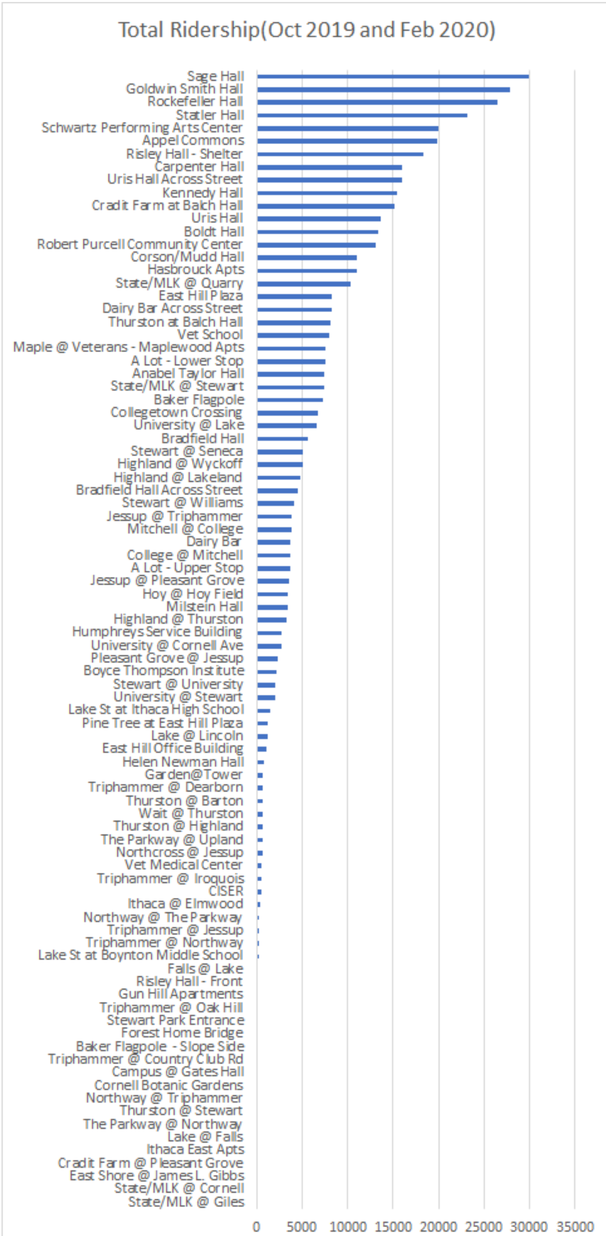


Figure 31 shows of total ridership at each stop in October 2019 and February 2020. Figure 28 shows the average delay time for each bus ride at the stops. It is clear from the data above, the delay issue is more serious for some stops like Schwartz Performing Arts Center and Northway at Triphammer. This is also shown in the visualization of the delay time by Tableau.

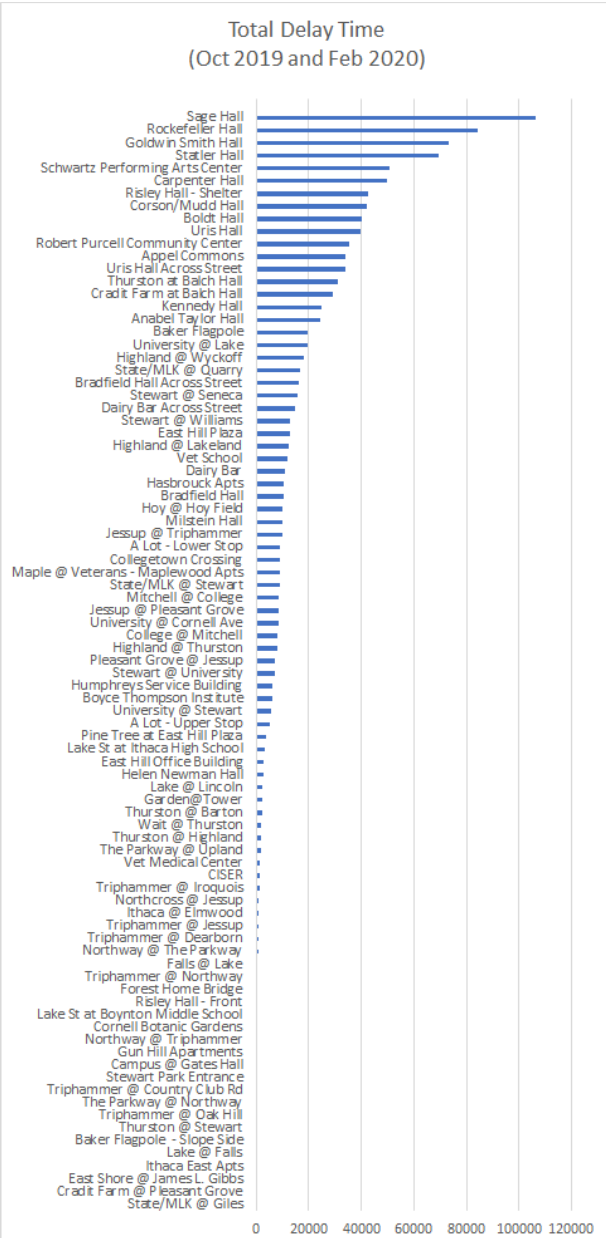


Figure 32

Delay time per bus ride is defined as ridership at one stop * delay time of that bus at the stop. Figure 32 is the sum of delay time per ride. The rank of total delay partly stands for the importance of shelter at that stop. Higher the total delay time, more important the shelter is and more room is required at that stop.

If and when the Tableau tool is used to identify the need for a new bus shelter, the Master Plan team's second tool can be used to determine what that shelter should look like. Working hand in hand with the design team, the Master Plan team has been gathering the potential variations of the shelter that CUSD Sustainable Mobility - Shelter can offer. The design section of this report offers a great deal of detail into the flexible design of CUSD shelters. The Master Plan students' challenge is to build a tool to interpret and display the ramifications of various design choices, namely size and components chosen to enhance a proposed shelter beyond a simple structure.

During early brainstorming, a tool to interpret ridership data and shelter build data was envisioned as the same system. When the team began to break down use cases and requirements for this single system, it soon became clear they made more sense as separate systems. This allows for two systems optimized for dissimilar purposes. As these tools are refined and built, the team may find opportunity to more closely integrate them in the future. Now looking at two tools, the original combine use case set was broken in two. The first can be seen in Table 6, it describes use cases for interpreting the current bus system. The second set of use cases is presented in Table 7 below. Table 7 outlines uses for a tool that helps make design decisions for a new shelter.

Table 7 Shelter Build System Use Cases		
Label	**Use Case**	**Priority**
SD 1	User Access Tools from any computer	High
SD 2	User updates data sets	High
SD 3	User inputs new data	High
SD 4	User Removes incorrectly input data	High
SD 5	User determines Material quantity needed	High
SD 6	User approximates construction cost	High
SD 7	User approximates material cost	High
SD 8	User approximates power requirements	High
SD 9	User chooses shelter dimensions	High
SD 10	User determines shelter optional features/equipment	High

SD 11	User adds equipment/features to available options	High
SD 12	User exports build specifications from tool	High
SD 13	User utilizes tool with internet connectivity	High
SD 14	User utilizes tool without internet connectivity	High
SD 15	User approximates sustainment cost	Medium
SD 16	User visualizes shelter build	Medium
SD 17	User removes equipment/features from available options	Medium
SD 18	User presents build to option to land owner	Medium
SD 19	User presents build to option to TCAT	Medium
SD 20	User adds features to tool	Medium
SD 21	User compares shelter builds side by side	Medium
SD 22	User transfers specifications to another user	Medium
SD 23	User saves build specifications for later review	Medium
SD 24	User deletes saved build specifications	Medium
SD 25	User exports estimated price breakdown	Medium
SD 26	User approximates shelter capacity	Low
SD 27	User sees how shelter will look in chosen location	Low
SD 28	User tracks progress of shelter build	Low

Like the use cases developed for the analysis of existing infrastructure, the use cases in Table 7 are not meant to be exhaustive. Rather the use cases laid out by the team give an idea of the types of analysis and tool interaction that can be offered. Like the bus system optimization tool, the bus shelter optimization tool needs to be deployable on any Cornell or TCAT computer. The advantage of developing this system though is a much smaller dataset is being used, compared to the seven-digit ridership dataset. With a smaller dataset, a full-up system like tableau is not necessary. This affords the team a much greater deal of flexibility in how to interpret and display this data. In order to create something deployable on any computer, the team decided to create a bootstrap dashboard deployable on any machine with a web browser. Such a tool will simply be transferred by zip file, requires no cost to use or maintain, and design options changes and pricing can be easily manipulated in a CSV (comma-separated value) file.

The tool visualized by the team still needs additional requirement gathering and brainstorming to drive a robust tool. However, the team has begun to mock up what the system may look like. This provides insight into tool design tradeoffs and potential functionality. A screenshot of an Alpha design for the Shelter Design Comparison Tool can be seen in Figure 30 below.

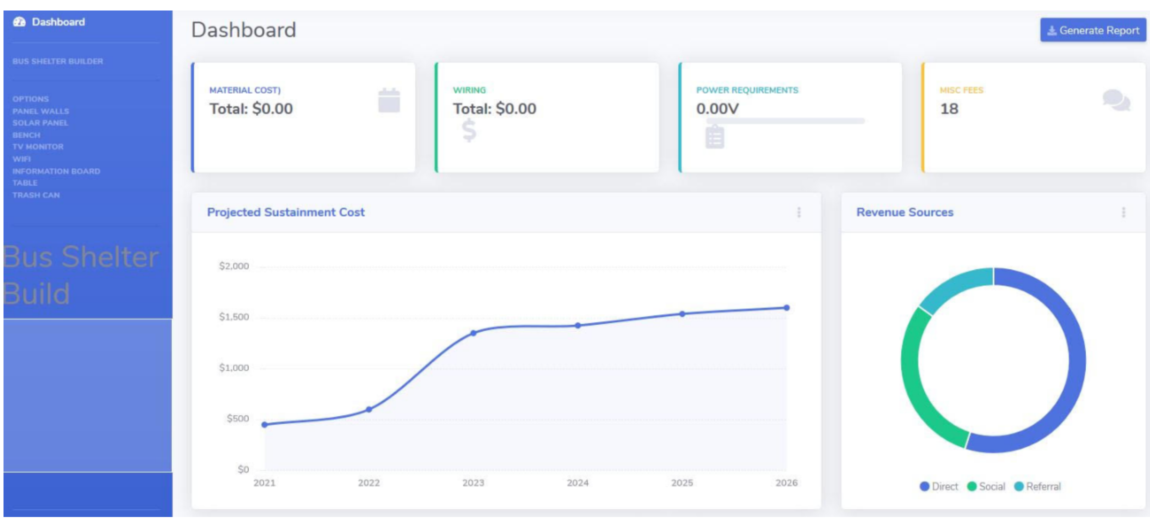


Figure 33: Design Decision Dashboard Example

This first draft of the tool is in work but allows users to model the cost impact of various design decisions. On the left side of the dashboard, the user can drag shelter elements from a list into their preferred design below. This will update build cost, sustainment costs, material cost, and voltage requirements. Figure 31 shows another example of how this tool could be put to use by a user.

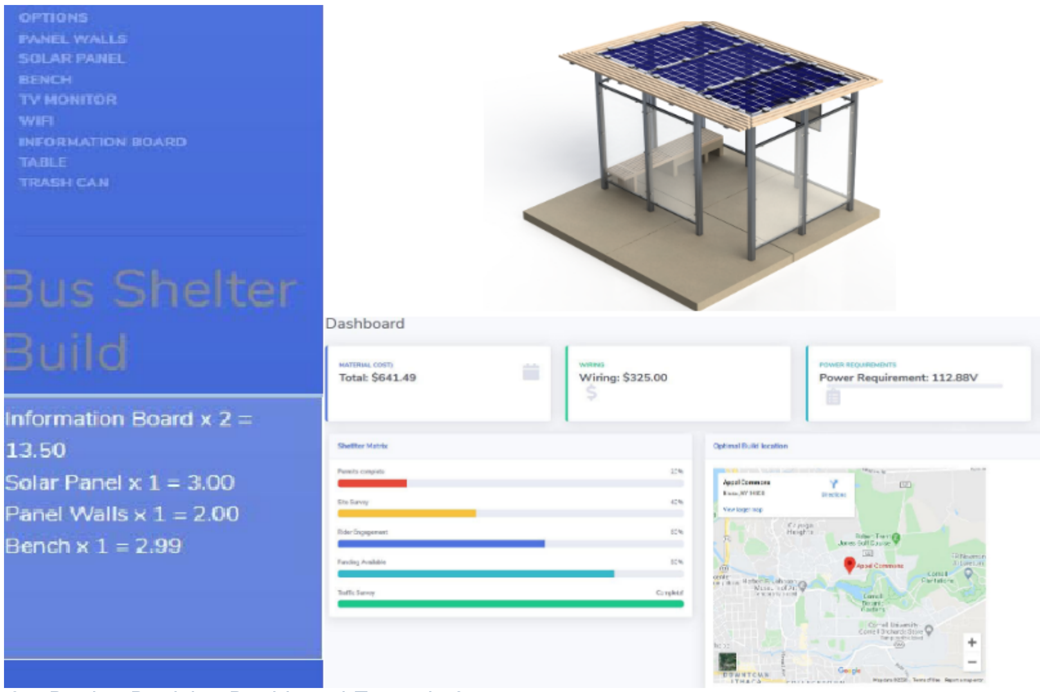


Figure 34: Design Decision Dashboard Example 2

Figure 31 is meant as a summary view of a selected design. This can be used for project tracking and reporting. Allowing the user to include modular elements will give them the capability to report at a high level or provide detailed analysis to stakeholders. This tool is in its infancy and requires more definition and development. Since the team is wholly in control of its framework, there is no limit to the potential it presents. The challenge for the team next semester will be to develop a solid list of requirements. Because this tool is so limitless in potential, it is at risk of substantial scope creep. This can lead to amazing new features, but the first goal, going forward, should be defining a minimum viable product. This is covered in the next section. This guarantees the team's ability to succeed while still allowing for unforeseen growth.

Shelter Mechanical Design

As mentioned in previous reports, a modular design exists allowing for 3 different size shelters, a small, medium and large. All shelters used the same components, making it easy to upgrade or downgrade a shelter depending on the location.

The shelter can be broken down into 40 inch units, or modules. These serve as the basis for any shelter. The dimensions of the base 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.

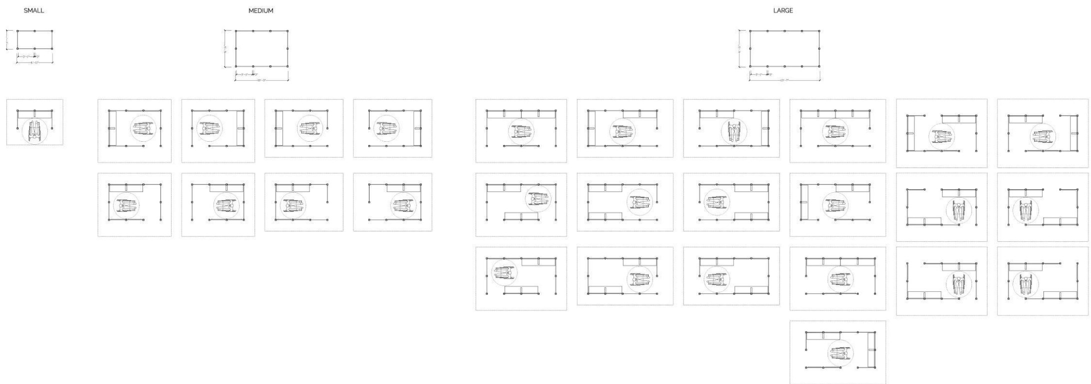


Figure 35: Design Decision Dashboard Example 2

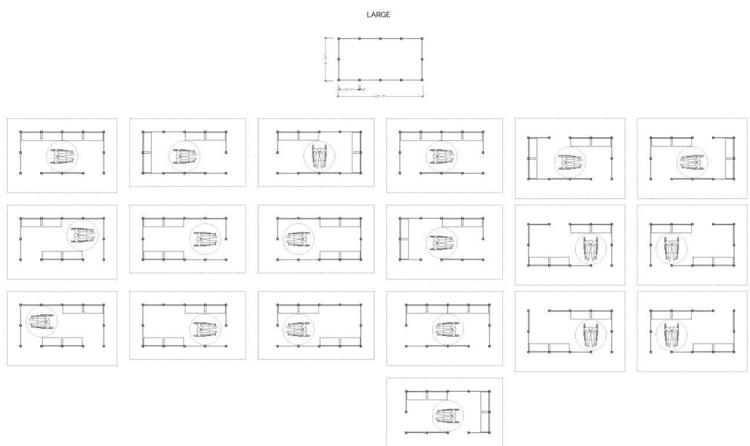


Figure 36: Layout and feature variations of the large shelter

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.

Given the site locations currently under consideration, the first shelter will most likely be a medium shelter. For this reason efforts were focused this semester on the medium shelter. The following manufacturing plans are specific to the medium shelter. After having the plans reviewed by Taitem, the team will procure manufacturing plans for the small and large shelters.
View of Shelter:

Figure 37: Shelter Design

On Campus Shelter Site Plans

A contending location for the first prototype shelter is in the A Lot on North Campus. Currently this location is service by two relatively dated shelters located on opposite ends of the Parking lot. The two shelters on the site lead to ambiguity on both the commuter and driver. Even regular commuters express confusion and dissatisfaction as to which shelter the driver will stop at. Commuters who initially choose the incorrect shelter must walk across the A Lot to the opposite shelter to board the bus on time. This team is proposing to locate a medium shelter on the central parking lot divider within the A Lot. With this new location, the hope is to eliminate the current confusion associated with two separate shelters. Additionally, the A Lot poses a great opportunity to showcase the efforts of this organization to prospective students, visiting parents, and alumni during high traffic campus events such as Cornell Days.

This semester, a preliminary site analysis of the proposed location of the shelter was performed. The dimensions, slope, and nearby features of the site were recorded and plotted to evaluate feasibility of shelter construction. The site analysis of the central parking barrier resulted in the following conclusions:

1. The A Lot central divider appears to be large enough to place a medium or large shelter. The slope at the projected location close to the sidewalk appears to be gradual enough to place the concrete base of the shelter without costly landscaping operations.

2. There appears to be grid power at the site because there is a light post and ground enclosure for electric lines behind the projected location for the shelter. The possibility of

access to the grid allows for flexibility in the addition of more power intensive features to the shelter without the limitations imposed by producing power only from the solar panels.

Future work on shelter site analysis must be conducted to finalize the appropriate size of the shelter and ensure conformance to municipality construction laws relevant to shelter placement. An analysis of the maximum number of occupants that use the shelters in the A Lot on a given day would aid in determining the necessary size of the shelter, as the current two shelters on the site are fairly large in size. The design team will be collaborating closely with the master plan team to get these numbers.

It will be critical to thoroughly research municipal laws regarding shelter construction and placement, as well as the feasibility of TCAT coordinating their bus stop locations to reflect the change in location of the shelter. The relationship the master plan team has been building with TCAT should help facilitate these discusions.

In the next sections, a breakdown of the shelter in the three main systems: bench, structural, and power system is addressed.

Shelter Design

Bench

The bench system is the housing for the shelter's primary electronic components, excluding the UI features such as the LED lights and the TV. According to the design, the bench enclosure houses:

- Solar charge controller
- DC-AC inverter
- Raspberry pi
- 2x Battery
- Overcurrent protection module
- Distribution panel
- Temperature sensor
- Heating element (black bulb)
- Cooling element (2x CPU fan)

Bench Thermal Analysis

Once specifications and models for all components were finalized, the operating temperature ranges for each was compiled and compared to local temperature data.

Component	Min. Operating Temp (°C)	Max. Operating Temp (°C)
Battery	-10	60
Charge Controller	-20	45
Raspberry Pi	0	50
Inverter	-20	40

Figure 39: Operating Temperature Ranges of Major Components

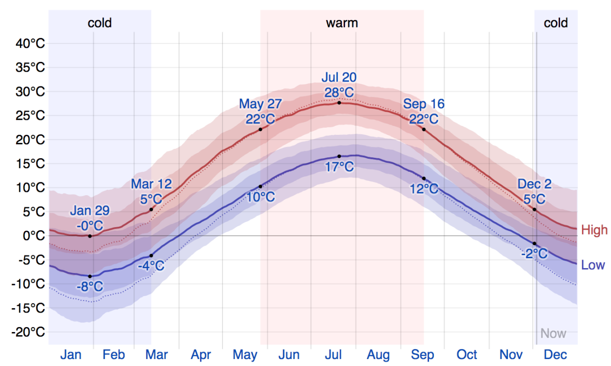


Figure 40: Average High and Low Temperature in Ithaca, NY; 2018-2019

This analysis showed that the Raspberry Pi falling below zero was the most likely temperature driven failure scenario. Figure 40 shows the Pi would generally be inoperable for at least four months of the year, and revealed transient cold temperatures may lead to battery failure. Batteries in general are very susceptible to temperature, with the charge rate and storage capacity decreasing exponentially when temperatures are below optimal. Another number stood out; the inverter fails at 40°C / 104°F. With summer temperatures capable of peaking at 35°C / 95°F, the team investigated whether additional heat generated by surrounding electronics could damage the inverter. Using specifications from datasheets, assumptions regarding charging loss, and bench dimensions, the heat capacity of the enclosure was determined. These calculations are shown in Figure 41.

Battery: 12W*100Ah = 1200Wh
Cycle use: 14.9v*30A = 447W

Efficiency: 85% (assumed for sulfuric acid batteries) at storing
Standby Use: 13.8V*30A = 414W
Charging Loss: 447W*15% = 67.05W (J/s)
Maximum Charging Loss: 447W*40% = 178..8W (J/s)

Internal Resistance: 5m
Maximum Heat Generated due to resistance: 30A^2*5m = 45W

Enclosure size: 500*400*200 = 4*10^7 mm^3 = 0.04 m^3
Battery size: 12.17in * 6.61in * 8.30in = 667.68 in^3 = 0.01m^3

Cv for Air = 0.718 (at 300k) kJ/kg*k Air density = 1.225 kg/m^3
Air weight= 1.225 kg/m^3 * (0.04-0.01)m^3 = 0.0367 kg

Air Heat Capacity: 0.718*0.03675*300 = 7.916kJ = 791.6 J

Figure 41: Calculation of Heat Capacity of Air inside Enclosure

The order of magnitude of the result shows that the heat produced by the battery will most likely not contribute to a large increase in ambient temperature. However, the Charge Controller and Inverter are estimated to produce substantial heat. Though empirical data is be required to make a definitive conclusion, this led the team to determine the bench must be heated during the winter, and potentially needs cooling during the summer.

The solution for winter includes passive and active heating. As a passive heating element, the bench should be insulated. This would trap any heat generated by our electronics and reduce heat transfer to the outside. Given that cold temperatures pose a substantial threat to the operation, efficiency, and life expectancy of the system, the team wanted an active heat source as well. This led to researching a 60 Watt ceramic bulb that emits heat to raise and maintain the enclosure's ambient temperature. Using the Raspberry Pi and a temperature sensor, provided logic can communicate with the outlet relay and provide power to the bulb when the temperature falls below a set threshold.

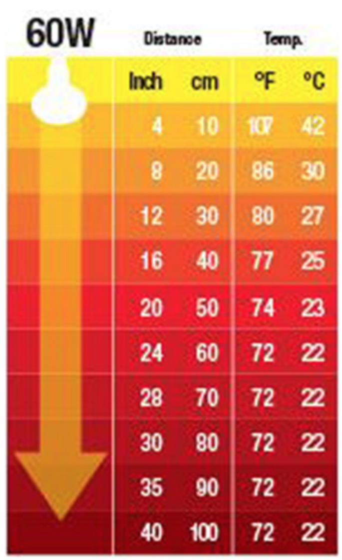


Figure 42: Temperature vs Distance at Maximum Power

An important consideration for design layout is that the bulb could potentially overheat electronics, if placed too close. Figure 42 indicates a minimum distance of 8 inches between the heat source and the most heat sensitive component (the Inverter), and ideally a close proximity to the most cold sensitive component (the Raspberry Pi). The threshold temperature which activates the bulb would be determined by the rate at which the bulb is able to heat up; the longer it takes, the higher the team would want the threshold to be. Ideally imperial data will be gathered to set the threshold.

A fan system has been added to the bench design to create air flow through the bench. This is to account for the potential failure states caused by high temperatures and continued operation. Considering the cost associated with incorporating a large heat sink into the design, the current plan is to only include the fan system and test the bench once the team gains lab access.

Bench Design

The bench design consists of two systems - the electronics enclosure, and the structural outer shell that will house it. The electronics enclosure will be a custom manufactured box sized to fit the electrical components. The box shall be waterproofed and insulated, and shall include a removable front panel for maintenance access. The outer layer of the bench will be a concrete mold, laid on the foundation of the shelter floor, topped with a wood layer for sitting. It too will have an access panel to allow for the electronics enclosure to be removed. The enclosure then can be place of the bench to provide comfortable table-height maintenance.

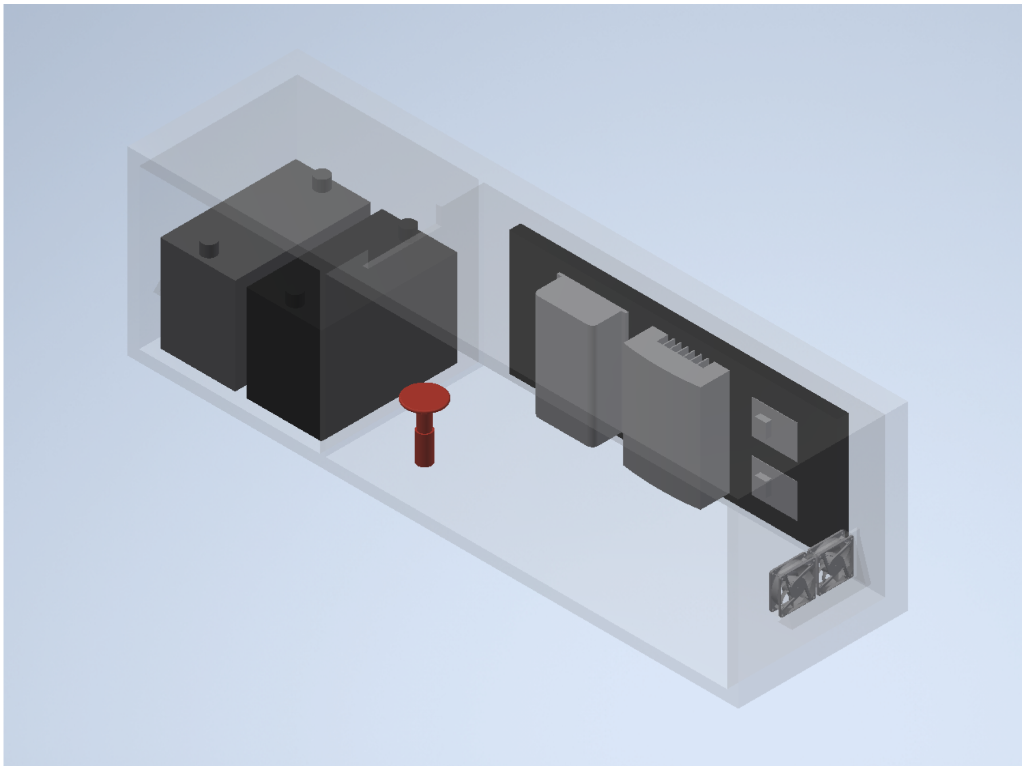


Figure 43: CAD of Electronics Enclosure

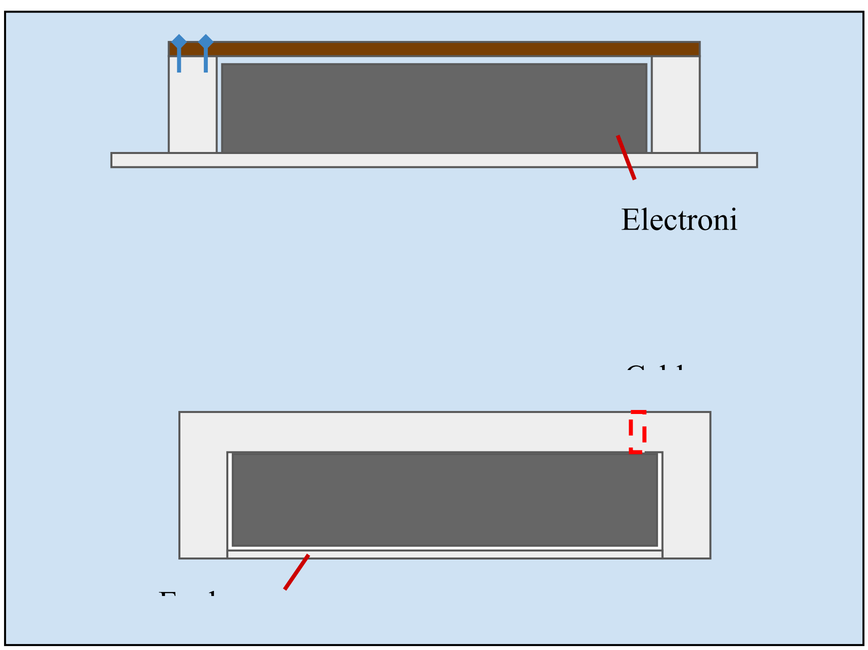


Figure 44: Layout of Concrete mold

According to suggestions from the Taitem team, several changes were made to the design in order to conform with the National Electric Code (NEC).

- The front face of the enclosure is now removable, therefore a hinge needs to be designed for the front of the bench. Currently the team acquired a plastic box for testing/prototyping purposes. However, since the final design is going to be molded with concrete, the front panel should be designed with some durable/corrosion-resistant material for durability and easy access.
- The electronics enclosure will be fully waterproofed. This requires rubber gaskets on the seals to the access panel and cable exits to prevent water pooling.
- The overall size of the enclosure was increased and reoriented all the electric components vertically with a stand. This is to ensure 36 inches of working space in front of these components.
- The batteries have been separated into their own non-corrosive compartment, with an interface where the battery disconnect panel and overcurrent protection shall be. This is done for fire safety.
- A second fan and air vents were added to increase potential airflow and heat dissipation capabilities.
- The enclosure will have a single cable exit point.
- The enclosure will have all necessary warning labels on the exterior detailing its contents.

Bench Future Work

A further and more rigorous analysis needs to be done of the NEC (NFPA 70) regulations, and apply any required changes to the design.

- Long-term winter and summer empirical tests are required to optimize various parameters:
  - The threshold temperatures for turning on/off the heating element
  - The threshold temperatures for turning on/off the cooling element,
  - The threshold temperatures are relative to the heating/cooling speed of the elements. The idea is to turn on the elements as late as possible before the system could fail to preserve energy.
  - The algorism (on/off time of the heating/cooling elements) of the temperature control system. This can be done via solving for the heat capacity of the enclosure or find out through testing. Thermal analysis is helpful if any team member can generate Ansys results. (The charge controller has a temperature sensor which could be read by the Pi)
  - Designing necessary waterproofing features is critical to satisfy the NEC

    regulations, including the front lid of the bench, henges, gaskets, and grooves (considering cold temperature will cause gaskets to fail). Currently, the bench is molded from concrete with openings, and the vent covers are designed to be pressed from sheet metal and screwed on. This will add water-resistance to the bench.
  - The battery should have its own anti-corrosion container, which is generally stock battery boxes. However since the battery needs to be connected outside of the container, and the bench is not humidity-proof, short-circuiting might be a future reliability problem.
- Notice the wood top for the bench and the wood for the overhang (the top part of the shelter) should be consistent, in case the team decided to change the material for the overhang, the bench top is suggested to change to that material to reduce cost.

Bench Testing

After a working prototype is made, the system is ready for testing. In order to determine optimal threshold temperatures for temperature elements, empirical data will need to be gathered to verify the successful environment control of our system. The main goal is to determine how much heat the electronics generate with different loads in different ambient temperatures, and therefore how to best control the internal temperature of the electronics enclosure.
A suggested testing procedure is as follows:

1. Place the bench outside on a really cold / really hot day, and record the ambient and internal enclosure temperature
2. Run charged batteries, charge controller, inverter, raspberry Pi, heating/cooling element, and an electrical load of:
   a. 0 magnitude
   b. 100 Watts
   c. 200 W
   d. Max expected load
3. Leave for X hours or until detrimental to electronics, then record:
   a. Internal enclosure temperature
   b. Ambient outside temperature
   c. Time to reach failure temp (if applicable)
4. Then turn on relevant thermal element, leave for X hours or until detrimental to electronics, then record:
   a. Internal enclosure temperature
   b. Ambient outside temperature
   c. Time to reach failure temp (if applicable)

Bench Manufacturing

The manufacturing design is not suggested to begin until the design is finalized and the prototype is tested. A full manufacturing design is required for the electronics enclosure (bench). This shall be outsourced to a company such as Polycase or Protocase. However, some manufacturing guidelines should be provided by the team. Since the bench has air vents and interior features, a two-times molding process is suggested. However, this will increase the cost of manufacturing greatly. Considering that the current system is already expensive, some optimization of the manufacturing design is encouraged. Overall, a full manufacturing design is required for the concrete mold, wood layer, panel, and fasteners.

Frame

The frame of the shelter serves as the skeleton on which all other components are added. It will consist of 15-series Aluminum T-slot extrusion bars placed vertically and horizontally. The vertical posts, referred to as the mainframe posts, are 3” x 3” hollow aluminum, which allows wires to pass inside when necessary. The horizontal posts, referred to as the subframe bars, are 1.5” x 1.5”. The T-slot features allow easy connections between these posts to be made through the use of 15-series Double Anchor Assemblies, which are assembled using an impact drill with a U-joint attachment on 5/16” bolts. In order for the connection to be seamless, a minor machining edit is needed on the subframe bars - a counterbore hole must be added to accept the fasteners, which is shown on the corresponding drawing.

Roof

Cornell Sustainable Mobility’s shelter design uniquely incorporates an integrated solar panel roof design — meaning that the solar panels themselves act as the roof elements to shelter occupants from weather elements. These solar roof elements follow in the same vein as the modular design as the rest of the shelter, with one solar panel outfitted to each two modules. Meaning for a small size shelter (2 x 2 modules) two roof solar panels are incorporated; for a medium shelter (2 x 3 modules) three roof solar panels; and for a large shelter (2 x 4 modules) four roof solar panels are incorporated.

Frame to Roof Attachment

The attachment component to join the shelter mainframe to the roof bars was finalized this semester. The function of the component is to securely join the vertical shelter main frame bars to the roof at roughly a 4 degree angle for proper drainage. One goal of the component design was to stick to relatively simple manufacturing processes and utilize readily available materials and hardware. This system should be prototyped in future semesters when the university reopens.

Roof with Solar Paneling

Lumos' GSX BiFi Module solar panels were selected for the integration into the shelter design. The GSX system uses bifacial solar cells to garner energy from both sides of the cell. The array arrangement of these cells and their integration into one large glass panel allows for adequate shade for the shelter occupant in sunny conditions, while still allowing light to pass between the cells and provide natural light to the shelter occupant in overcast conditions. The GSX panels overall packaging incorporates integrated weatherproofing and the overall sleek design is consistent to the clean aesthetic of the shelter

Solar Panel Mounting

The solar panel mounting components affix the solar panels to the roof bars. A design constraint of the mounts is that they must interface with the solar panels without damaging the glass edges of the panels. This soft handling functionality is achieved by using polyurethane bumpers to interface with the glass, because the polyurethane is non marring and has some give, but also has weatherproof characteristics and is stiff enough (80A durometer) to provide a rigid connection. The mounts must also integrate with the extrusion slot profile of the roof bars. This integration is achieved by using t-slot nut hardware. The design of the solar panel mounts was redesigned this year to a clamping style setup to provide a more robust connection and support compatibility with shelters of all sizes.

Roof without Solar Paneling

If the shelter is configured without solar panel functionality, an alternate Non-Solar Roof design can be implemented. The non-solar roof will consist of thicker polycarbonate sheets of the same sheet size as the GSX solar panels to maintain the same mounting hardware and module compatibility.

Triangular Conduit and Lighting

The triangular conduit serves the function of housing wiring harness components so they can be routed along the length of the shelter to power components like the internal lights, solar panels, and motion sensor. The triangular conduit uses water resistant panel-mount connectors to eliminate the need to splice and snake the wiring harness components within the conduit. A major design constraint of the conduit is that it must be weatherproof and sealed so the wires are not damaged. This semester, the conduit was changed to a one-module design rather than spanning the width of the shelter. The one module design allows for a decrease in the number of unique parts because the same conduit can be used across all three shelter sizes in increasing quantities.

Side Panels

This semester the team moved away from machining a separate sub frame designed to house the side panels and offer a way to affix them to the main shelter frame. The machining proved costly in terms of time and labor, thus was not a feasible pursuit. The team therefore opted to go with off-the-shelf aluminium side panel mounting blocks as the mechanism of attaching the side panels to the main shelter frame. The blocks are slid and tightened into the main shelter frame before the side panels are bolted onto them. There are three blocks along the length and two along the width. The side panel material is 40% carbon filled polycarbonate. The team chose polycarbonate because it allows for visibility, doesn't shatter, and has relatively a long life span. The finite element analysis the team ran on the side panels against a wind load of 118 mph showed they have an assuring factor of safety under such an extreme condition. The panels are purchased off the shelf too. The versatility of their attachment mechanism to the shelter allows for customized advertisement panels to be mounted in their place and as such can be used for economic purposes.

LED Light Mounting

The LED Lights on the bus shelter is a novel idea to alert people far away from the bus shelter of the TCAT buses' imminent arrival. This was inspired by the observation that most people avoid waiting for buses inside the shelter during extreme weather conditions for example when it is snowing heavily and it is extremely cold. People often take refuge in nearby buildings and only frantically dash to the shelter when they see the bus. Having the LED lights flash to alert people of the buses' arrival is an attempt to solve this hasty running to catch the bus. The LED lights are controlled by a microcontroller that receives data from the buses's GPS information source and commands the lights to flash accordingly. The LED lights are waterproof but are still housed inside an aluminium channel that is fixed to the wooden overhang of the shelter. The channel has a light diffuser as its covering which gives a uniform display of the light emitted by the linearly scattered led bulbs. The aluminium extrusion is purchased and it comes with mounting clips that are screwed into the wooden overhang and hold down the channel to the shelter via snap fitting. The channels are cut to about 40'' of length so that they can be affixed to each module of the shelter thus allowing modularity for different shelter sizes.

Electrical System

The electrical system consists of all the electrical components in various parts of the shelter: solar panels, batteries, solar charge controller, inverter, LCD, heating lamp and the digital components. These are connected together as shown in the one-line diagram. The various segments of the digital system with a Raspberry Pi as the main computer are as follows:

- Collection of data from the Renogy Rover solar charge controller about solar power, battery consumption, etc.
- Display real-time information about incoming buses on an LCD screen
- Control the lights inside the shelter through a motion sensor

- Run the indicator LEDs outside the shelter depending on time before the next bus

These subsystems had been tested together last semester as a complete prototype set-up. This semester, the team worked on a more comprehensive integration of the system, for which the team re-arranged and changed several of the components keeping in mind scalability and ease-of-installation. The team also documented the system and created a few schematics of the various parts of the electrical circuit.

Schedule Analysis Recommendations

From the data collected this semester, the team was able to create some preliminary recommendations for how to address the bus schedule prediction problems. It may be possible to alter timetables to match typical traffic conditions in order to predict more accurate arrival and departure times for riders.

Further, it appears that the majority of delays begin and compound at stops throughout Collegetown and the Cornell campus. In particular, the Schwartz Performing Arts Center station at the northern end of Collegetown is a stop that appears to cause frequent delays. Based on the personal testimony of team members, this can occurs College Avenue and East Ave quickly overflow with private vehicles, vans, trucks, and TCAT buses. Additionally, frequent pedestrian jaywalking can implead the flow of traffic. Measures to reduce congestion such as banning private vehicles and implementing methods of pedestrian flow across College and East Avenues are being examined by other CUSD teams.

Any measure taken to change timetables or alleviate traffic congestion will impact shelter design and placement. Thankfully all CUSD Sustainable Mobility initiatives share a common adviser in Sirietta Simoncini. Through her, teams can more deeply collaborate in the coming semesters, allowing each to produce a better product. Proper planning and cooperation as sustainable mobility plans are implemented will allow teams to build on each other's success and create a cohesively functioning system of systems.