SUSTAINABLE MOBILITY

Cornell University
Systems Engineering

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CORNELL UNIVERSITY
SUSTAINABLE DESIGN

Cornell University
Systems Engineering

GRADUATE PROJECT REPORT

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Spring 2018

TABLE OF SYSTEM TOOLS

1 INTRODUCTION

1.1 Process Overview

The Sustainable Mobility team of Cornell University Sustainable Design, formally Bus Shelter Renovations, is focused on redesigning public transportation in Tompkins County. We comprise of students from all seven colleges of Cornell University and are partnering with the Tompkins Consolidated Area Transit, TCAT, to develop a more systematic approach for urban-to-rural public transportation. As part of this systematic change, we utilize systems design thinking to understand and best serve the needs of our stakeholders.

The systems design thinking process is anchored in three main methods of data collection: inspiration, fact-finding, and empathy fieldwork. The goal of this process is to become immersed in the problem space, so as to develop innovative solutions that best meet the needs of the stakeholders. Throughout this process, there is continuous iteration and testing—ensuring the final recommendations are tailored for the community. We interface all facets of our project with systems engineering practices to develop a complete grasp of the external system context and internal system interfaces. This allows for a thorough and well-documented approach to traditional engineering practices and a greater understanding of our solution space.

Building off design work from prior semesters, this semester the team focused on the following elements:

- Shelter Design
- Map Design
- Bus Pass Design
- Information Display Design
- Solar Integration
- Lansing Routing Design

1.2 Team Structure

The Sustainable Mobility team of Spring 2018 has brought valuable skills from all seven colleges in Cornell University. Led by Byung Hee Chun (bc438@cornell.edu, Economics and Statistical Science), the team has been fortunate to collaborate with our two advisers Sirietta Simoncini and Wenqi Yi. The team has two main divisions: Shelter Design and Lansing Routing.

The Shelter Design team works to build and design the overall bus shelter structure. The team is further divided into teams that specialize in:

- Shelter Structural Design
- Solar Panel Design
- Digital Data Display
- User Experience and Design

The Lansing Routing team is focused on improving the efficiency of TCAT's routes that serve Tompkins County's rural areas in Lansing: #36, #37, and #77. The team has merged extensive in-person fact-finding, empathy fieldwork, and scenario analysis to find the most economical alternative to TCAT's current routes that also serve social needs.

Sustainable Mobility operations are supported by Business Strategy team. They work to determine appropriate sources of funding for building prototypes and provide overall costing structures for design implementations.

1.3 Project History

Prior solutions for the project are provided in the following subsections:

1.3.1 Spring 2015: SYSEN 5740

The project was initiated in Spring 2015 through the Systems Engineering class, Design Thinking for Complex Systems (SYSEN 5740). The class approached the challenge of redesigning the mobility system in Ithaca, so as to set a new standard of sustainability in upstate New York. Following seven weeks of immersive research, teams developed the following solutions, split between improving the TCAT system and envisioning new transportation systems:

Improving the TCAT System:

- **Improved Payment Methods:** Three payment methods were developed to provide more convenient access to primarily the TCAT system as well as to incentivize greener transportation.
  - The first method involved providing additional retail locations for TCAT bus passes and revising the TCAT website specifically to enable an easier card refill process.
  - The second method built upon the current Ithaca Commons parking validation to provide bus ticket validation for Commons visitors. This method incentivizes visitors to shop on the Commons and reduces the demand for downtown parking—a win-win for the city, the people, and local businesses.
  - The third method provided a Tompkins County Transit Card that can be refilled and used to pay for the bus, for local cabs, and for parking garages. This method incentivizes greener transportation by providing a tiered discount system of 10%, 20%, and 30% for parking, cabs, and bus tickets respectively.

- **Integrated Information System:** The concept of a trip-planning mechanism was developed to address the difficulty users were facing with regard to planning their journey. This method involves the development of a user-friendly smartphone application, which would allow users to plan their journey across all transportation modes available in Ithaca, making users aware of all potential options available.

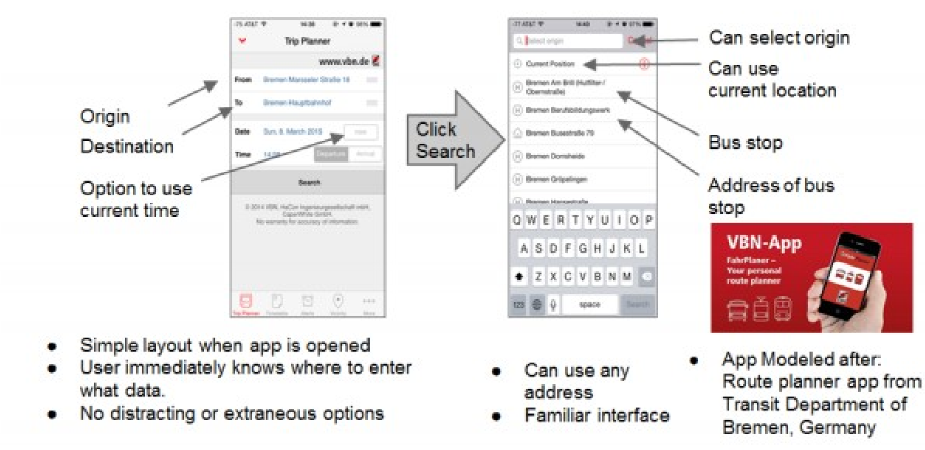


Figure 1: TCAT Mobile App - Design of Trip Planning Screens

Figure 2: TCAT Mobile App - Design of Route Selection Screen

● **Information Design:** Four different information systems were conceptualized to provide easier and more intuitive access to information regarding the TCAT system:

- o The first idea involved developing 'linearized' route maps within the TCAT system.
- o The second idea involved simplifying schedules.
- o The third idea involved developing standardized bus stops and shelters that would communicate accurate and accessible information about journeys on the TCAT.
- o The fourth idea involved developing a clear Next Stop Announcements System inside the TCAT buses giving users greater awareness and accurate information about their current journey.

Figure 3: Integrated Information Systems for Maps and Shelters

● **Smart Bus Shelters:** A comprehensive concept for a "smart" shelter was developed and the following features were suggested to enhance the current bus shelters:

- o Real-time maps can provide information about when and where the next bus is stopping. The information will be personalized for every station and it will also serve as a simplified information interface for first-time bus commuters.

o The shelters can serve as information hubs that will help commuters keep track of all the events around the city. This feature will also keep the commuters entertained during their wait time.
o Local artists can include a piece of art and history in shelters around the city. This will help to connect local artists with people while enhancing the appearance of shelters.
o Advertisements will serve as revenue generators for the implementation of the other measures. However, the intent is to provide a specific type of advertisement called interactive ads. These ads will also contribute to the purpose of enhancing the waiting experience in the shelters by adding diversion and engagement for commuters.

• **Interactive Bus App**: Four major features were included in the Interactive Bus App to incentivize commuters to use public transportation systems:
o Check-in on Bus Application - Commuters can check-in with a specific identification number on each bus using this application (and are rewarded with lower rates for using public transportation more frequently).
o Live Lottery Drawing – Discounts at local sponsoring shops or free bus passes are randomly sent to people who check into the system using the application.
o Traffic Information - A modified local map incorporates route planning, live bus locating and scheduling, and built-in special discount offerings from sponsoring shops along the route.
o Entertainment - Two forms of stimulation that are informative and interactive are featured within the concept. Commuters can choose to read historical stories at points of interest along the bus routes or interact with other commuters who are logged in by playing competitive games or engaging in chatting rooms.

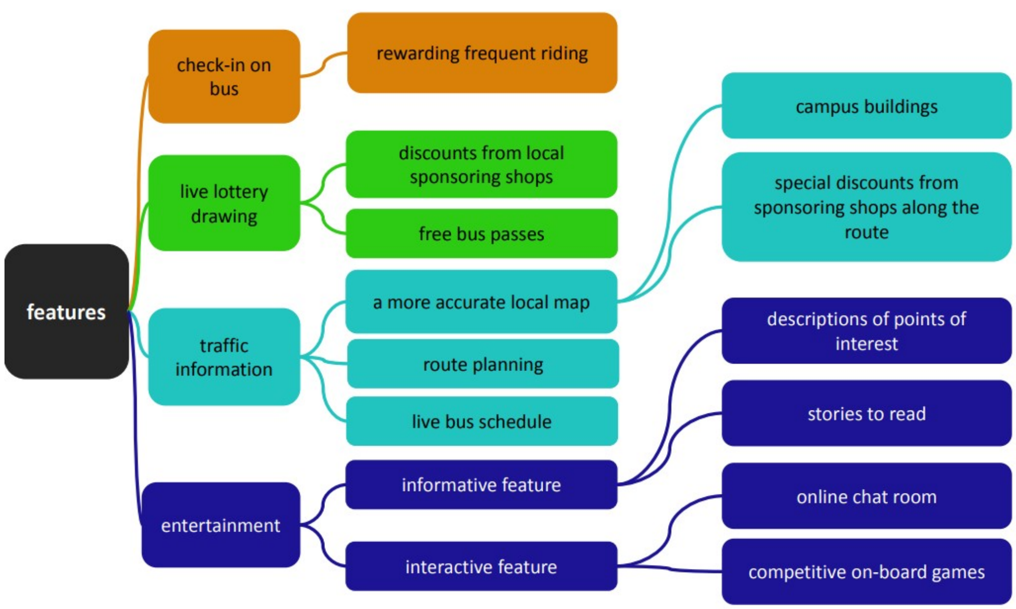
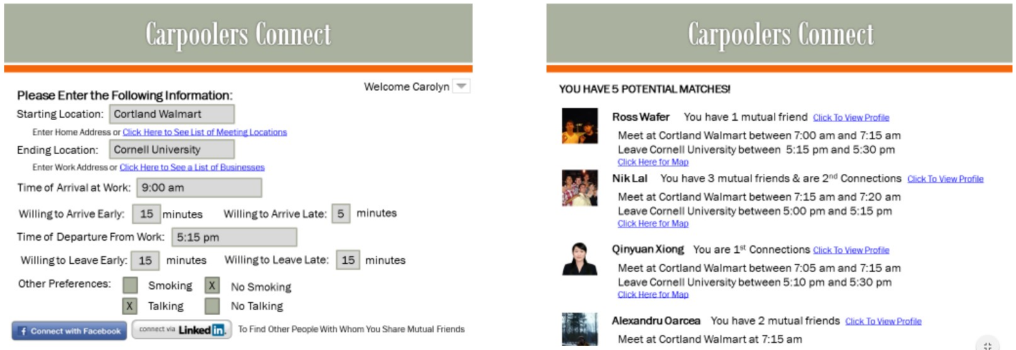


Figure 4: Interactive Bus App Feature Breakdown

Envisioning New Transportation Systems:

• **Carpoolers Connect:** An innovative Carpoolers Connect idea was developed to allow people to meet and be comfortable with other carpoolers. This idea had two parts:

o The first part involved allowing users to connect with social media and other avenues so that they can meet people with mutual friends, allowing for a way to feel comfortable meeting and sharing a long ride to work.
o The second part involves a system that would allow users to be able to get home to their family in case of emergency.



Carpoolers Connect – Webpage Interface

● **Bike Share:** A bike share system concept was developed to provide a more convenient transportation option for places underserved by TCAT and for which a TCAT line would be economically infeasible. The routes focused on the downtown (Ithaca Commons) area and Wegmans from Cornell, Ithaca College and the surrounding areas.

o a decentralized bike share system modeled after Social Bicycles that would allow a user to drop a rented bike off wherever they desired within a high traffic area. The user could either take the bus back to their home location or return the bike for an incentive. We found in our empathy fieldwork that users would enjoy the idea of riding a bike down from Cornell or Ithaca College, but were deterred by having to bring the bike back. We propose a system that redistributes the bikes through an incentive system (coupon or money) to ride a bike back. This incentive would decrease the costs associated with a dedicated bike retrieval truck.

● **Cable Propelled Transit:** A cable-propelled transit system was considered as a unique mode that could effectively address the challenge of rough terrain. There were two possible variations for this mode:

o The first option is the standard Gondola which can tackle the steep and difficult terrain while providing views of the local scenery, bringing in considerable tourism potential.
o The second option utilizes a cable-propelled bike lift which helps overcome the difficult terrain which has proven to be a major barrier to bicycle use.

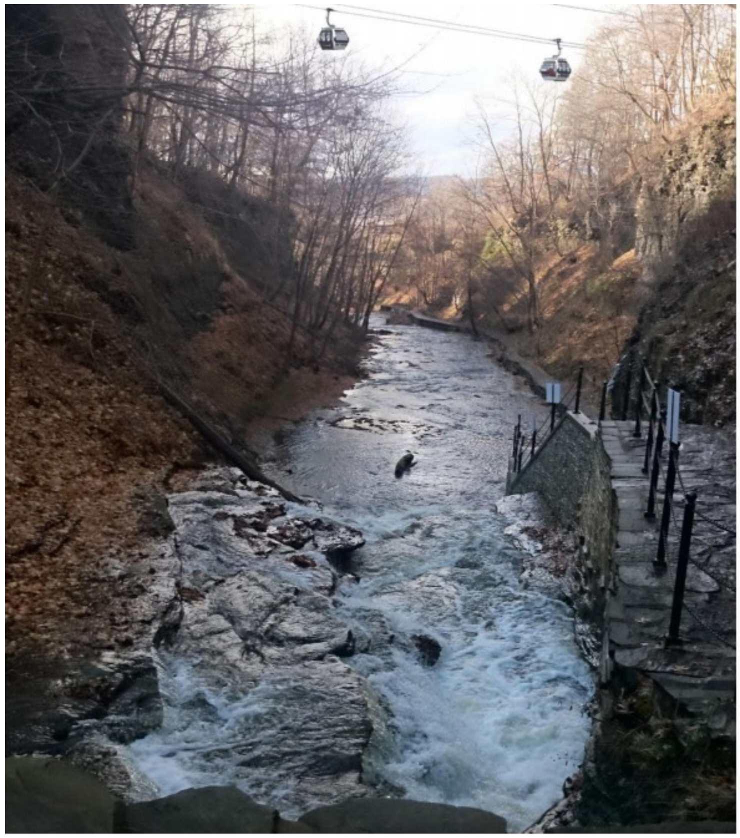


Figure 5: Gondola Lift Vision for Ithaca

● **Ithaca Taxi Fare Bidding Service:** A taxi fare bidding service idea was developed to allow more transparency in cab systems as well as encouraging healthy competition between the taxi services.

- o The idea proposes an app/website where users can enter their requested taxi journey and which allows taxi companies to bid fares for the requested ride and give estimated pickup times. A rating service will also be incorporated allowing users to rate the taxi service for their efficiency and accuracy of the pickup times. This idea could serve as a viable alternative to Uber in smaller towns like Ithaca.
- o This service would also help modernize and centralize the pickup system of various taxi companies in the city who are still using outdated systems such as operator calls and radios.

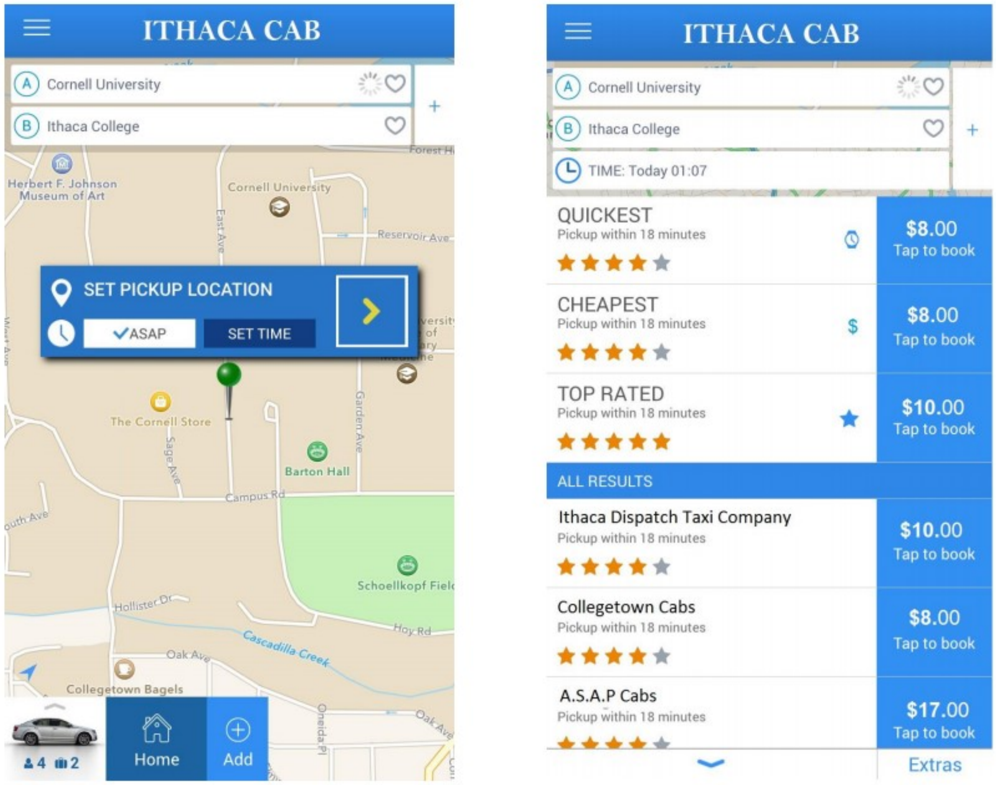


Figure 6: Ithaca Taxi Fare Bidding Service Application

1.3.2 Spring 2016: SYSEN 5740

Spring 2016 was the second iteration of the SYSEN 5740 class looking into redesigning mobility in Ithaca, where students posed the question: “How might we create an intuitive mobility system that is accessible to all, encourages and supports people’s sustainable choices, and fosters a sense of community across zones and age demographics, while providing the efficiency and reliability of a safe system, as well as an enjoyable experience?”

Solutions were the following:

- **TCAT Integrated Mobility Experience (TIME) Booklet:** In light of empathy fieldwork suggesting that current information systems were overwhelming and inaccessible, whether in online or paper format, a small, convenient and personalizable transportation booklet was designed to simplify and thereby encourage TCAT use for those who cannot or prefer not to use online services.
    - o Small booklets, in two distinct sizes (as suggested by fieldwork), would be made available to users on TCAT busses.
    - o Simplified, linear route maps and schedules, optimized to fit the booklets, would be made available at TCAT stops or on TCAT busses.
    - o Users would collect and store in their booklets only those route maps relevant to them, thus avoiding unnecessary information and bulk.
    - o Curated tour maps highlighting points of interest, local businesses, etc. could also be created and made available by TCAT or local organizations.

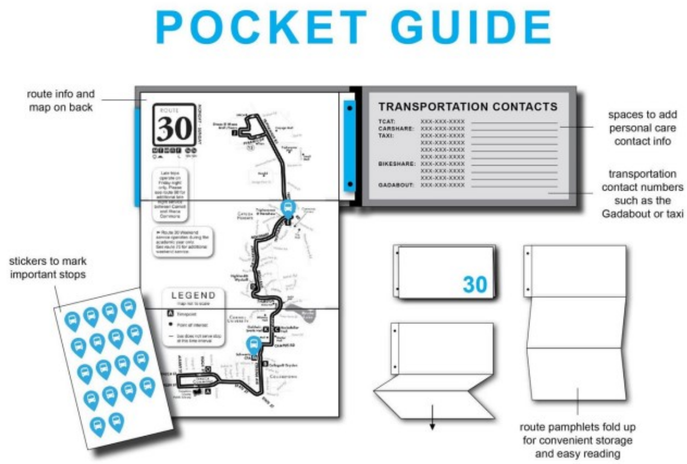


Figure 7: TIME Pocket Guide

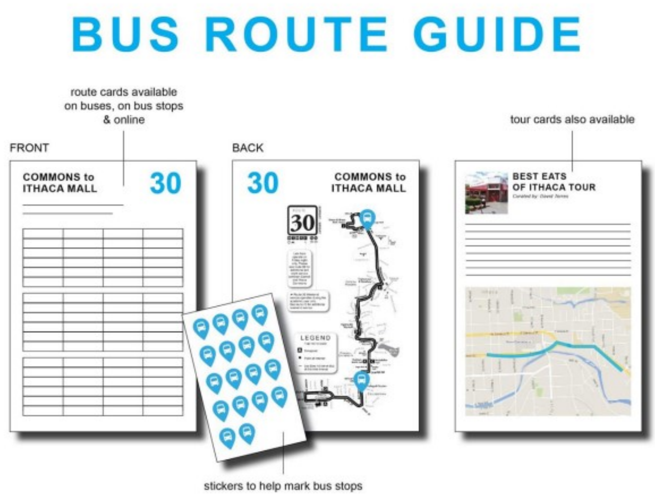


Figure 8: TIME Bus Route Guide

● TCAT Integrated Mobility Experience (TIME) App: In light of empathy fieldwork suggesting that people were interested in a way to personalize their travel options, the TIME app was designed to provide citizens with access to a user-friendly phone application that combines trip planning, exploration, and community engagement into one integrated system.

- o One application combining transportation with community experience.
  - ▪ Trip planner provides customizable routes, departure and arrival times.
  - ▪ The trip planner will also provide multiple transit options with comparisons of time and cost.
- o An interactive transit map that allows users to see real-time TCAT information as well as other transit methods, routes, and information.
- o Route planning will include photos of specific bus stops and information about the routes that use them.
- o Signs will be integrated with the TIME app, allowing users to learn more about the Ithaca area during their travels by scanning the Ithaca walking signs to check-in, get additional site information, and more.
- o The application will allow users to explore the Ithaca area by searching for events and destinations as well as creating and sharing tours.

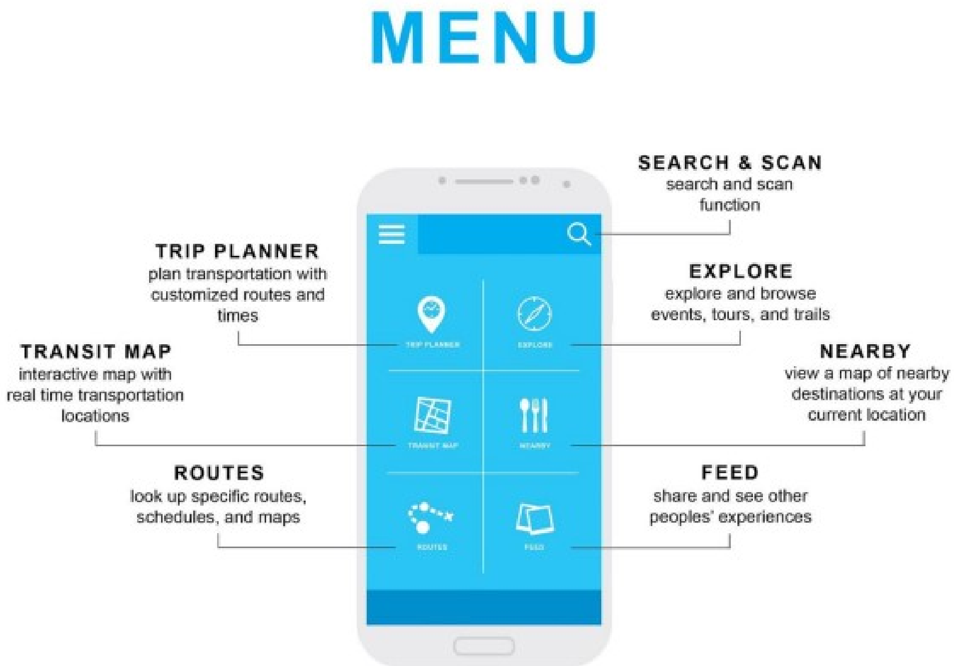


Figure 9: TIME App

- Enhanced Walking and Biking Signage: In light of empathy fieldwork suggesting that smartphone applications cater more towards younger people and are challenging for more mature audiences, walking and biking signage to be posted around the city and town of Ithaca were designed to provide all citizens with intuitive and easy to understand walking and biking directions, without the learning curve associated with technology-driven solutions.
  - Two types of signs, one placed at large bus stops including a map of the nearby area and points of interest, and a second, smaller version indicating the direction of travel to various destinations.
  - Large signs (called central hubs) would be located at important points throughout the city and town of Ithaca, and the smaller signs (called navigational arrows) would enable users to easily navigate between them.
  - Signs would indicate distance to destination and provide time to destination estimates, with easy to understand symbols communicating the pertinent information.
  - Signs will also be integrated with the TIME app, allowing users to learn more about the Ithaca area during their travels.

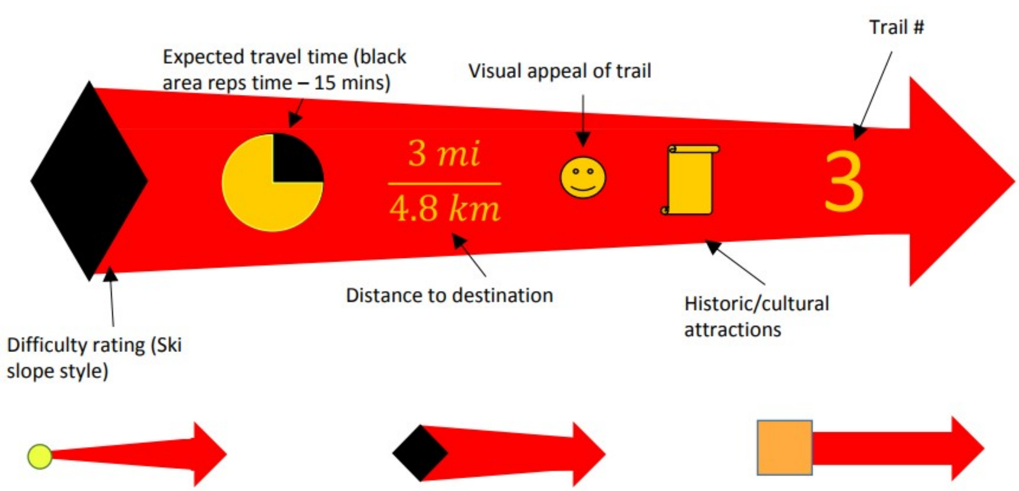


Figure 10: Enhanced Walking and Biking Signage

● Upgraded Shelter System: In light of empathy fieldwork suggesting the above discouraging factors, an upgraded shelter system was proposed. This system included three tiers of bus shelter upgrades (based on economic feasibility and ridership). These upgrades respond to the expressed needs of the TCAT users.

- o Base tier shelters (for stops with low ridership) meet the basic level needs.
- o Mid tier shelters (for stops with medium ridership) meet the basic level needs, and also include additional informational and security features.
- o Top tier shelters (for stops with high ridership) meet all of the above needs, in addition to enhanced informational user interfaces, increased community engagement opportunities, and aesthetic upgrades.

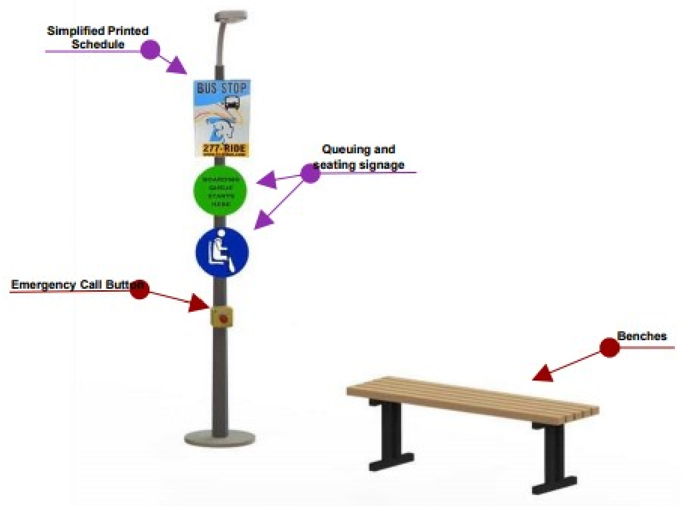


Figure 11: Base Signage Vision

Figure 12: Top Tier Shelter Vision

1.3.3 Fall 2016: Bus Shelter Renovations

Fall 2016 served as the first semester of the Bus Shelter Renovations (BSR) team project with Cornell University Sustainable Design (CUSD). The work of the BSR team expanded off the two prior spring semesters of SYSEN 5740. Noting that the vision for an updated shelter was repeated both semesters, the shelter redesign served as the entry point for the project.

Led by Nikita Dubnov (nd296@cornell.edu, Information Science 2017), the team consisted of 22 members motivated by the idea of redesigning public transportation in Ithaca. The Fall 2016 semester focused on the following:

- Developing a working relationship with TCAT and Department of Planning.
- Researching legal, site, and financial factors to building bus shelters in Ithaca.
- Conducting user research to make well informed design decisions.

Following inspirations, empathy fieldwork, ideating, and bodystorming, the following shelter concepts were selected to continue being pursued in later semesters:

- Information Accessibility
    - Visual / Bus Stop / Local Information
- Interactive Screen
- Emergency Notification System
- Lighting
- Interactive Art
- Reading
- Green Infrastructure
- Solar
- Seating

1.3.4 Spring 2017

During the Spring 2017 semester, the SYSEN 5740 class continued into its third semester of mobility redesign and the CUSD BSR team continued into its second semester.

1.3.4.1 SYSEN 5740

The Spring 2017 semester of SYSEN 5740 worked in collaboration with the CUSD BSR team, with several members interfacing across the two divisions of the project. Empathy fieldwork was conducted this semester, with fields of action divided geographically: City of Ithaca, Town of Ithaca, and remaining Tompkins County.

Following the empathy fieldwork and ideation, the following solutions were investigated:

- **Lansing Re-Route**: Investigated connecting routes #36 and #37 at the Lansing Fields, so as to increase the feasibility of traveling in rural Lansing.
    - Proposed Route #36 and #37
        - Landmarks with high relative ridership
        - Potential for park & ride
        - Keep flagging North of Route 13

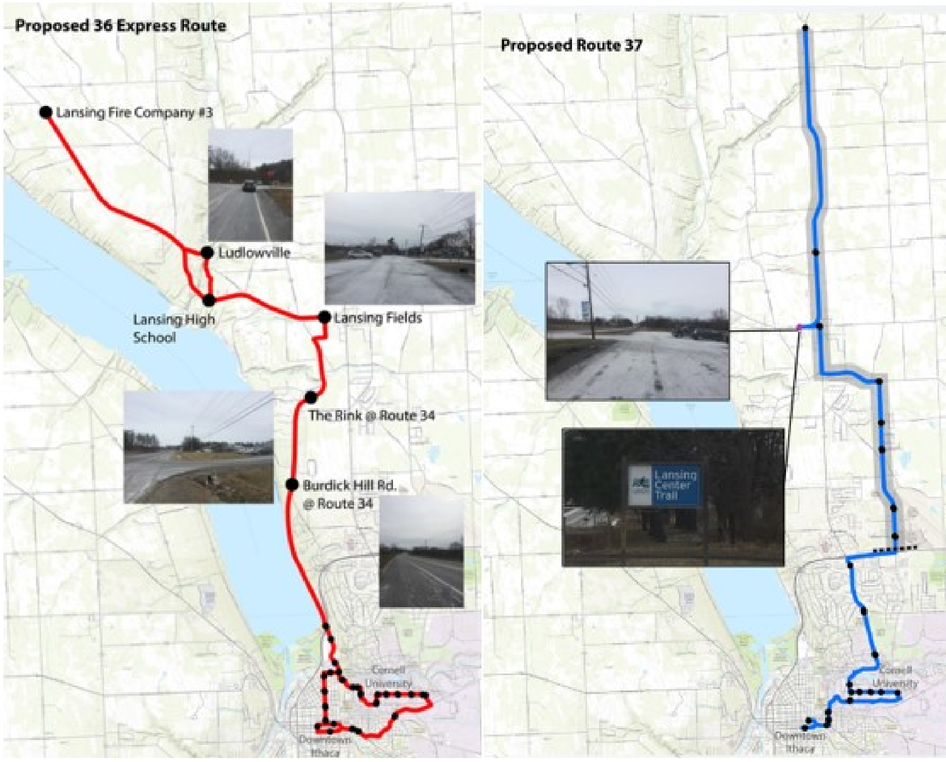


Figure 13: Lansing Re-Route Suggestions

● **Park & Ride Signs:** Signage at park & ride locations was found to be unclear, so users were left confused as to whether the lot served as TCAT park & ride. Additionally, with a 3 hour parking limit, the current implementation was not feasible for users commuting to the City of Ithaca. The team's proposed solution is shown below, which removes the parking limit and displays clear TCAT branding, removing ambiguity.

Figure 14: Redesigned Park & Ride Signage

● **Reflective Passes:** Informed from the empathy fieldwork, the status quo made it so it was difficult to spot riders at night, with the lack of visibility compromising safety. Flagging at night created an unsafe scenario for riders. Drivers reported users waving flashlights at the busses so as to increase visibility while waiting on the side of the road. Through a reflective bus pass solution, the pass could be used to catch the driver's attention, giving the rider additional security that they would not be accidently missed and an increased feeling of safety.

Figure 15: TCARD with Reflective Siding

● **New Maps:** Informed by the need for greater information accessibility. This semester explored the possibility of subway-styled mapping. By moving forward with the subway style, the team experimented how to prioritize system information visually. Information shown included the following:

- o Parking
- o Flag stop areas
- o Designated stops
- o Major destinations
- o Frequency
- o Irregular Service
- o Rural roads
- o Snow routes
- o One-seat rides

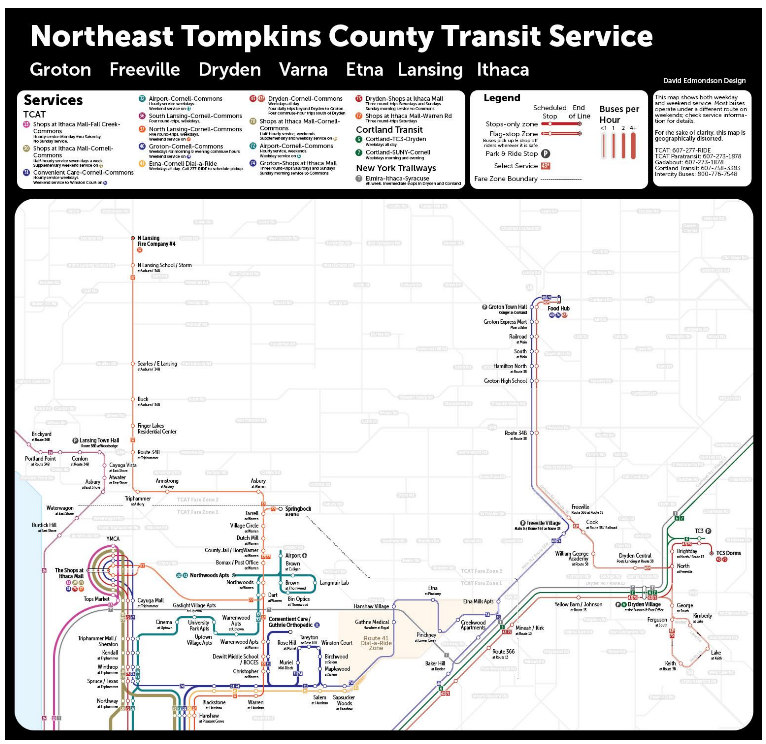


Figure 16: Quarter System Map Implementation

● **User Interface:** A tiered system of signage was proposed after observing from empathy fieldwork that users preferred minimizing interaction in obtaining their information. The ideas proposed here are grounded in simplicity and minimizing the effort required by the observer to obtain the information.

Figure 17: Proposed Tier Level of Signage

● **Social Media:** Implementation of a social media platform was investigated to include the following:

- o Real time updates of the bus status
- o Social interactions between riders
- o Connection between users and the community

● **Welcome Packet:** Empathy fieldwork revealed a common thread—populations did not know the ins and outs of riding the bus, and therefore never went out of their way to learn. Faced with the question of how to increase ridership, one solution was to develop a welcome packet for new residents along TCAT's routes.

Figure 18: Welcome Packet

● **Business Opportunities:** One team explicitly investigated business opportunities that could be pursued by TCAT. One option that appeared promising was the development of a high-end "Wine Line" to operate on a 45 minute loop over the summer, allowing users to move between wineries at 45 minute intervals.

The proposed financial structure included charging wineries a premium to be included along the route, in addition to an increased fare for riders.

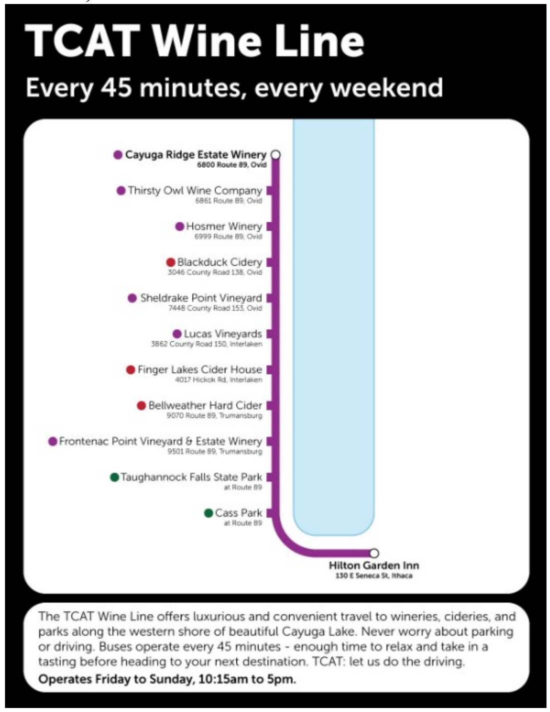


Figure 19: TCAT Wine Line Vision

1.3.4.2 Bus Shelter Renovations

In the second semester of the Bus Shelter Renovations (BSR) project, the team focused on the development of the shelter, including the physical design, in addition to solar integration and a live data display.

The solar team, working closely with a logistics team, was able to secure donation of two 280W solar panels from Renovus Solar and developed initial integration plans.

Figure 20: Solar Setup

Design for the shelter also moved forward considering the following as design criteria:

- Information
    - o Schedules and signage clarity
    - o Real-time arrivals information
- Accessibility
    - o ADA compliance
    - o Informed bus stop locations
    - o Consistent designs
- Weather
    - o Shade and cool riders in summer
    - o Maximize shelter in rain, cold
- Aesthetics and Community
    - o Reflect community's diversity and values
    - o Opportunity to integrate history, art
    - o Opportunity for "novelty", whimsy
- Safety
    - o Lighting and visibility
    - o Homeless deterrence
    - o Ease-of-maintenance and durability
- Sustainability
    - o Sustainable, safe materials
    - o Renewable energy

Three-level tiered shelters were designed to fit these goals:

Figure 21: Three Tiers of Shelter Designs

The designs followed a modular philosophy, where multiple sizes of shelter were built from a common set of elements. This included a 3'x5' "Seating module" and 5'x5' "Info wall module". The advantages of modularity were outlined as:

- Uniform look across system
- Simplified stock, construction
- (Almost) plug-and-play flexibility
- Reduced costs

The bench served as a whimsical element, connecting the shelter to the community. Inspired by the water of Lake Cayuga, it holds a light, welcoming appearance. The wood provides thermal comfort versus typical metal benches, while the ripples and tilt deter sleeping. Two implementation methods were considered, molded plywood and modular elements of plywood.

Figure 22: Bench Views

After pitching our initial designs to our stakeholders, we proceeded to develop a prototype medium shelter (to scale) located in the basement of Carpenter Hall.

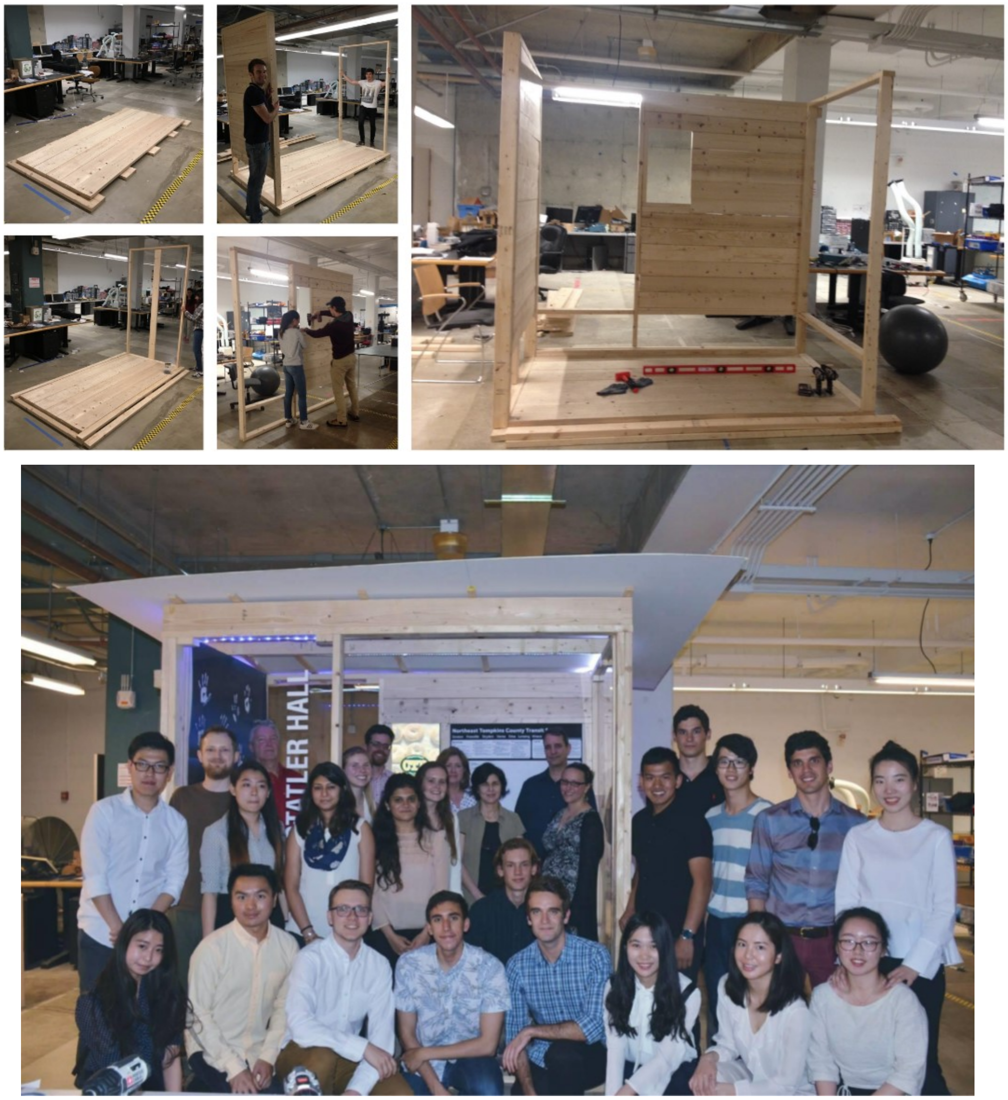


Figure 23: Wooden Prototype Medium Shelter

2 SHELTER

2.1 Shelter Design

2.1.1 Introduction

Shelter Design within Sustainable Mobility is a direct continuation of the progress achieved by predecessor team Bus Shelter Renovations. The mission of this facet of the project is to design a bus shelter system for stakeholder and partner Tompkins Consolidated Area Transit (TCAT) which can also serve as a design exemplar for similar transit systems and beyond. Some key values that drove the project's first year include modularity, adaptiveness, safety and security, comfort, inclusivity, whimsy and delight, environmental sustainability, community engagement, design innovation, and economy.

As mentioned in the prior team history section, the Bus Shelter Renovations team went through the design process in two academic semesters from Fall 2016 to Spring 2017. The first semester focused on empathy fieldwork in order to identify key opportunities and areas of improvement for TCAT bus shelters. The second semester design focus was in ideating and prototyping the high level schematics for an innovative bus shelter system. The shelter team's goal was to, using a modular dimension system, create bus shelters that can adapt in size and type. Steering around functional/programmatic considerations such as ADA standards, the modules were 3x5' and 5x5' units of space. The technology team supported the logistics of the design. In the end of Spring 2017, the team constructed a low-fidelity prototype bus shelter, Design V.0, out of plywood and acrylic panels. This was a looks-like, works-like, and feels-like realization of the design, used to show space and dimensions and demonstrate key features—such as the bench, proposed signage, and live data display.

Figure 24: Design V.0 as it would Appear in Medium Form

For Fall 2017, members of the design and technology subteams collaborated on the design development of shelter Design V.1, using the design thinking process to verify the existing design and identify new areas of improvement based on TCAT and test user feedback. The team then finalized the shelter dimensions and design, created the modular connections strategy, developed core modules (base kit-of-parts, technology, solar system, bench, etc.), and ideated creative modules. All of these tasks and goals iterate upon previous work, advancing us towards our established design criteria.

2.1.1.1 Pre-Design

The previous semester's work on Design V.0 is considered a prototype. The next stage in the design process from there was testing and iteration. Before any design development work on Design V.1 could begin, the design subteam reviewed the design thinking process and procedures for extracting valuable insights to inform the next design iteration.

Subteam members conducted interviews with TCAT users, using the in-lab prototype as an experiential mock-up tool. They observed users during these interviews. In addition, they did personal immersions as subject matter experts to further analyze the previous work. These first, second, and third person notes were then "unpacked." The interviewer/observer read out the details of their episode as other designers took notes of individual needs, insights, and surprises that they noticed—this is the unpacking of the data, the "sticky-note storm," associated with design thinking. From there, the data was modeled—similar data points were grouped together, condensing an array of data into more manageable key insights.

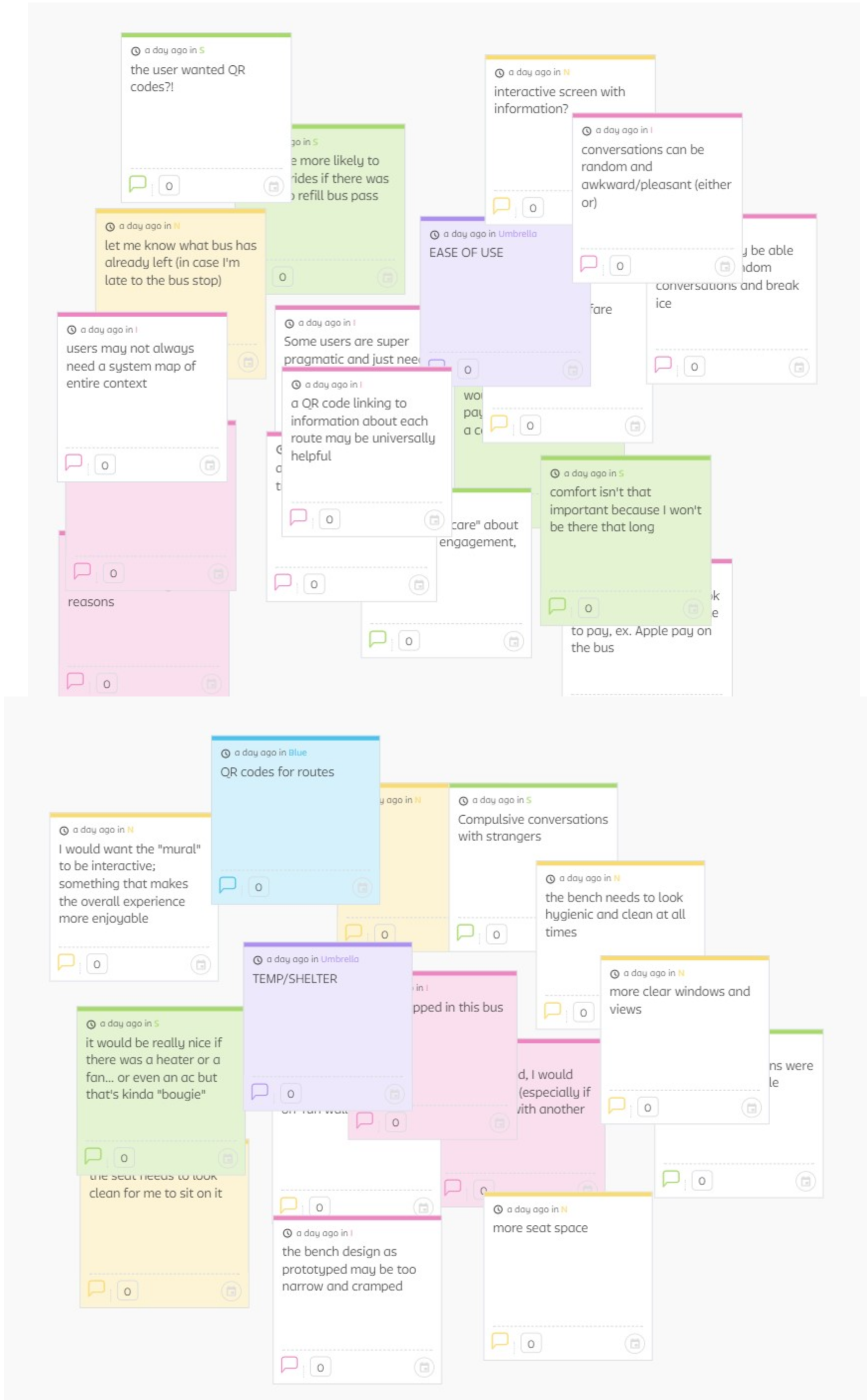
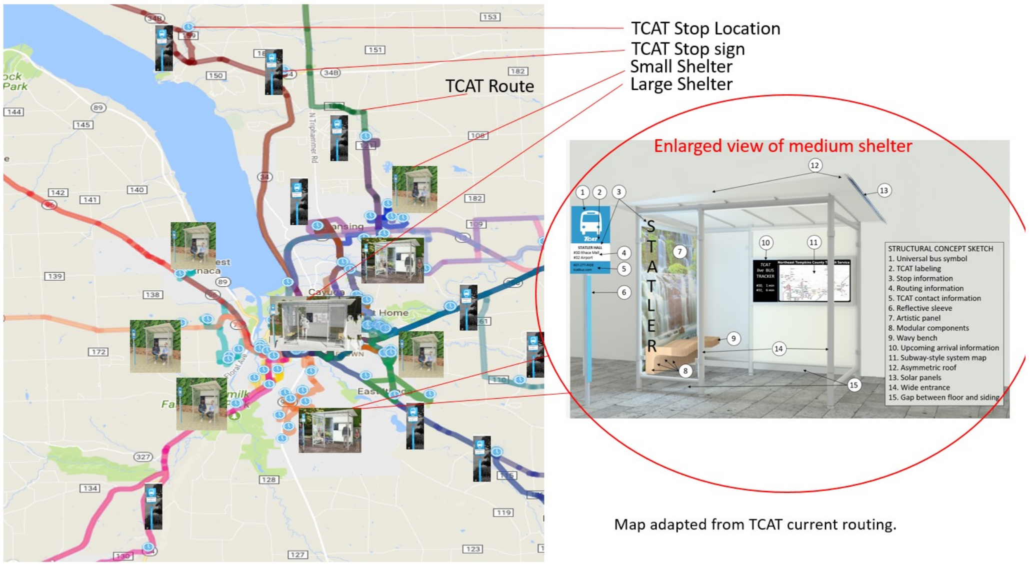
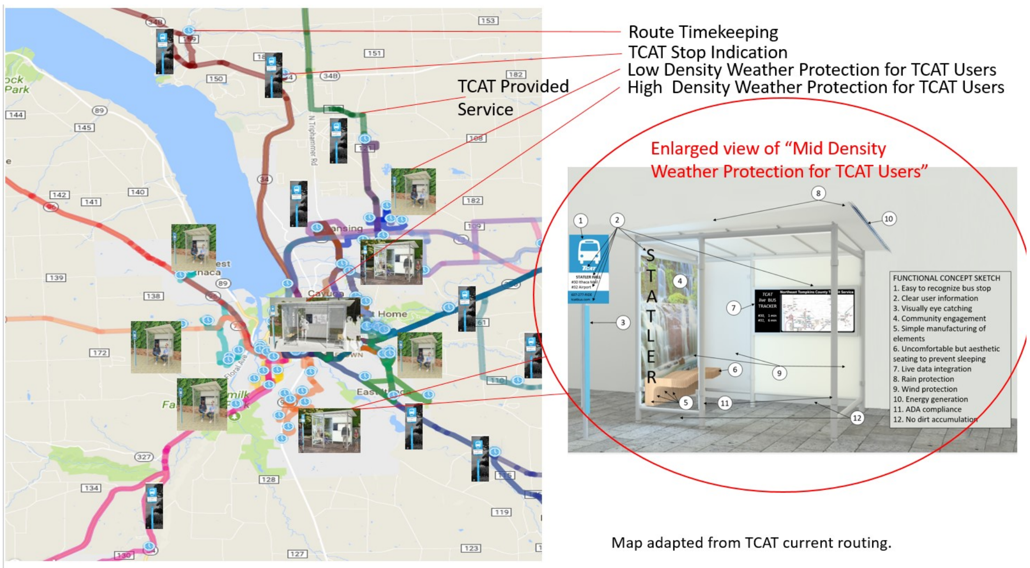


Figure 26: Unpacking Shelter V.0 Data

Following this process, team members redeveloped the shelter concept sketches so as to better reflect the systematic and modular approach informed from fieldwork.



System Index 1: Structural Concept Sketch



System Index 2: Functional Concept Sketch

From this process, there was validation of the first round of empathy fieldwork, validation of the previous design choices, incessant areas of improvement, and some newly discovered opportunities. These informed the design goals of Design V.1, as listed below:

- Need for more perceived space throughout entire experience
  - Increase vistas, width; habitable space
- Maximize protection from weather/elements
  - More barrier, protect standees, mitigate wetness
- Seat ergonomics, legibility, space/comfort
- Safety
  - Blue light, maximize vistas in/out of shelter
- Lighting
  - Validated need for increased light.
    - Determine the right amount that is both attractive and limits insects
- Modular panels
  - Message board/pin-up, custom art pieces, rider engagement, fare changer

2.1.1.2 Modularity

Design V.0 utilized 3’x5’ and 5’x5’ wall panels as the building blocks of the small, medium, and large size shelters. For Design V.1, we pushed the width from 5’ to 6’ to accommodate additional seating to support our empathy fieldwork—on last year’s prototype, people felt cramped in the 5’ design. From the fieldwork, we identified a need for more seating, a wider seat, and more habitable space. With a 6’ length, the small and medium shelter can hold four seating blocks instead of three, and the large can hold eight seating blocks, allowing us to meet the needs identified from the testing.

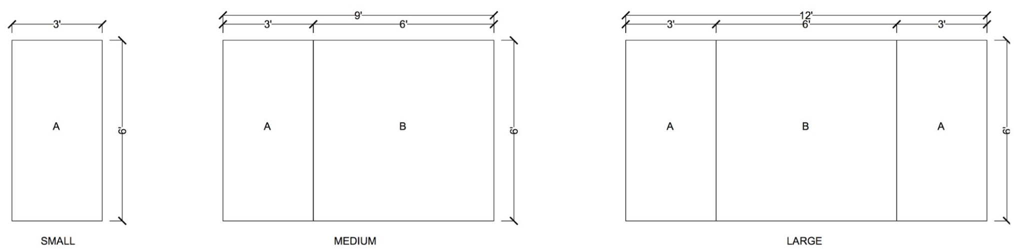


Figure 27: Modular System Organization

After finalizing the modular building blocks, we applied the system to the shelter construction detail. First, we decided to use 3”x3” square posts as the main structural frame. Given that ADA require the opening to be 36”, we applied a 37” length to the distance between the inside of two posts. This means that the 37” length includes the panel and panel-to-post connections.

With all the things taken into consideration, the final dimension of small shelter is 3’-7”x6’-11”, medium is 6’-11”x10’-3”, and large is 6’-11”x13’-7”.

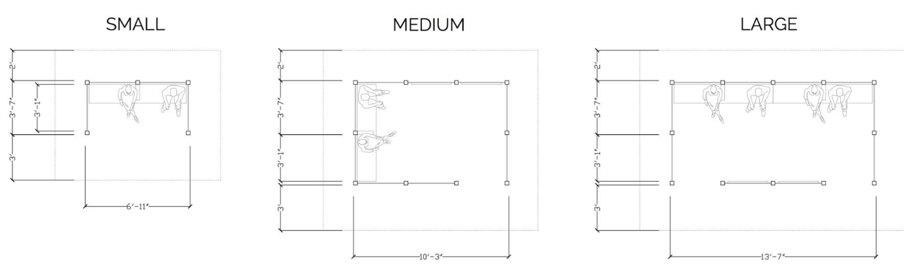


Figure 28: Final Shelter Dimension

The modular system poses numerous advantages over a non-modular design. Through a modular system, there are numerous ways of configuring the small, medium, and large shelters so that each can be tailored to its specific site. Below are a few examples of the possible variations generated by this modular system. Note for small shelters, there is only one configuration. Each configuration presented is also wheelchair accessible with 5’ turning radius taken into account.

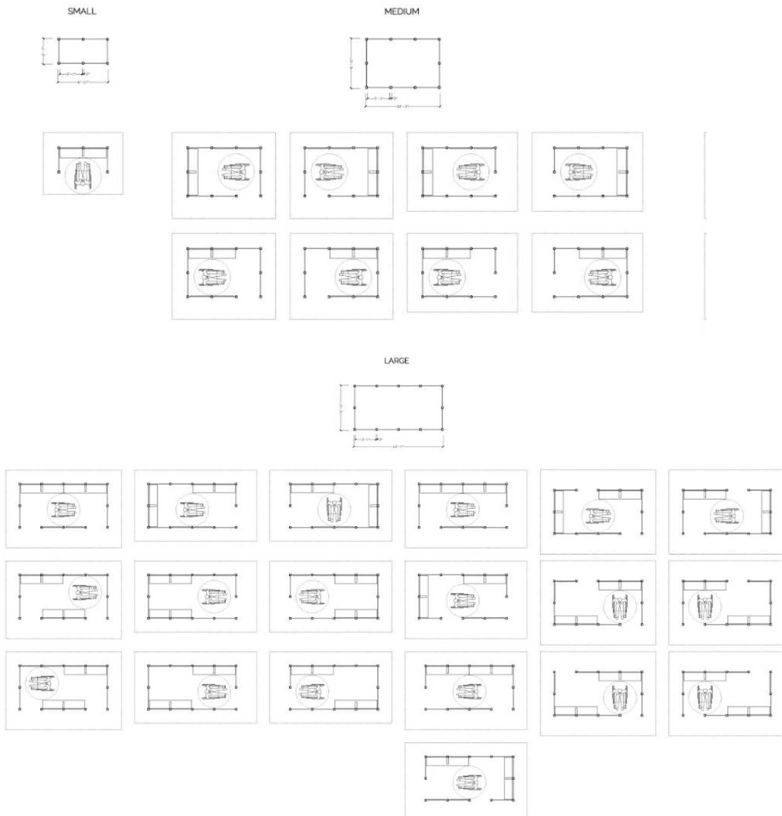


Figure 29: Index of Modular Variation

2.1.1.3 Bench

The new bench design negotiated with a few factors the previous design did not account for including ease of manufacture, color, aesthetic, handrail and connection with the t-slot structure. The bench also accommodates the solar panel battery in its support, protecting and camouflaging the equipment. The bench can be doubled to fit the modular condition of the shelter design. The new handrail is a separate element that fastens directly to the t-slot post instead of the bench, allowing the bench to have either a free seating arrangement or a more rigid one.

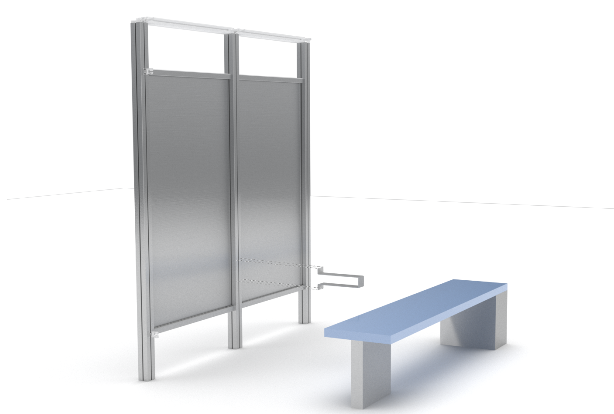


Figure 30: Elements of Bench Design: Back Post, Handrail, Bench with Battery Storage

Figure 31: Medium Shelter with Bench Installed

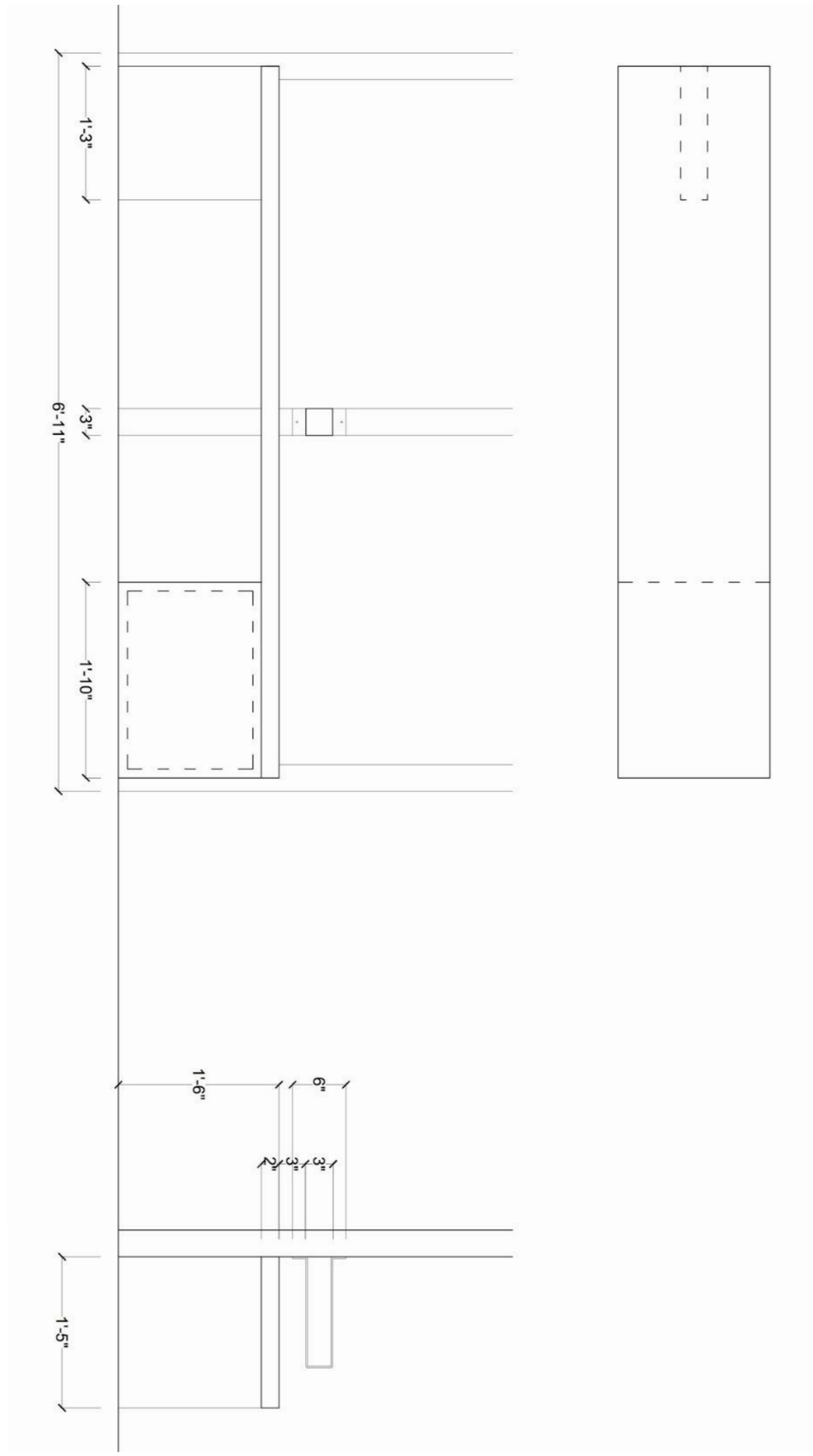


Figure 32: Final Bench Dimension

2.1.1.4 Appearance

As a result of the modular system, each shelter can be easily tailored to embody the specific characteristics and needs of the location. The realization of varied typology while maintaining consistent branding is especially valuable considering the diverse implementations required for implementing an urban to rural network.

Figure 33: Shelter in Urban and Rural Setting

For example, shelters could be covered by panels of artwork to promote local artists, covered with green vegetation to speak to nature and sustainability, integrated with high levels of technology, or any combination of the above. Through this variation of type, we are able to better connect with and meet the needs of the diverse communities of the Tompkins County, all while maintaining consistent branding.

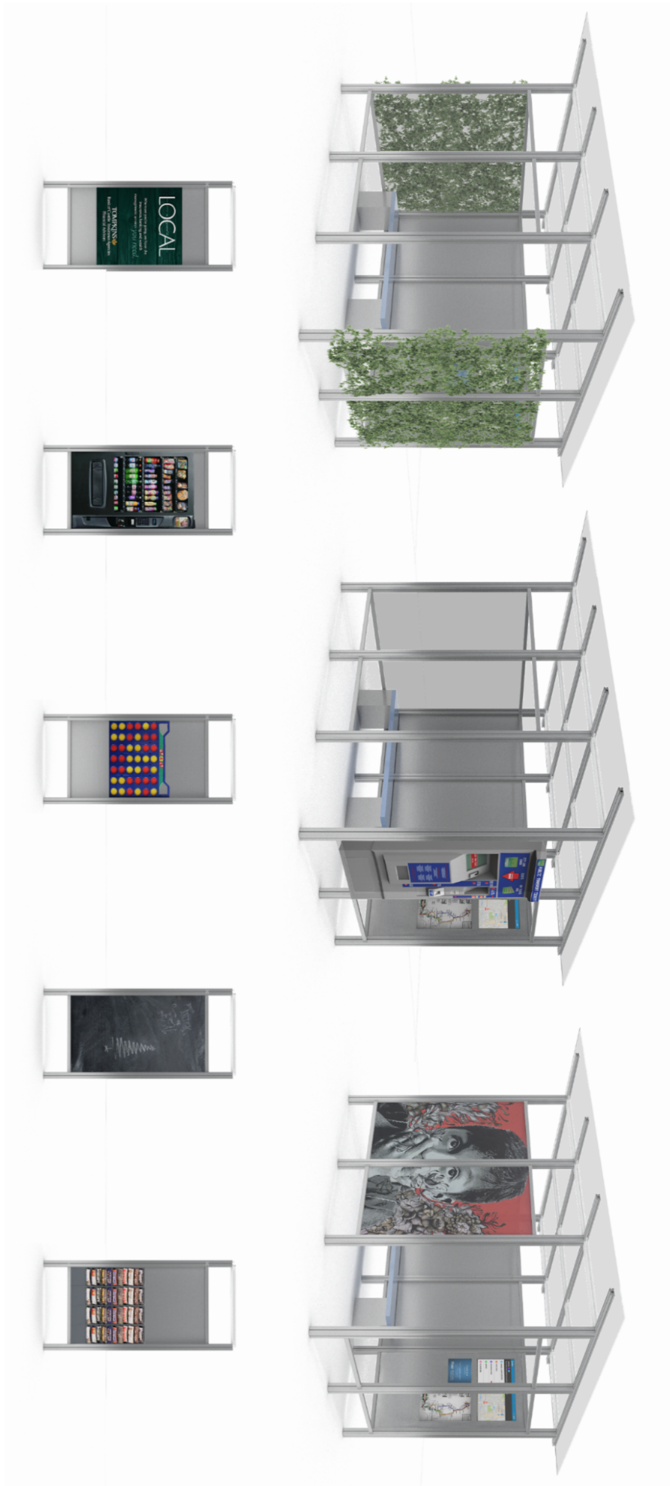


Figure 34: Examples of Shelter and Panel Variations

2.1.2 Structural Frame

2.1.2.1 Modularity

Modularity is both a functional building block of our design, while also serving as one of the factors making our shelters unique. Modularity allows the shelter to be adaptable to diverse locations with the least number of components possible.

In order to realize the technical requirements of modularity, the team selected a highly versatile building block that could be used for every shelter, similar to a Lego brick, that would be structurally sound enough to last 10+ years.

For this reason we decided to use a T-slot design (also known as 80/20) as the building block. T-slots are mainly used in factory settings, where companies need to quickly and easily create structures to support heavy machinery. T-slot frame members can easily be connected together via their slots through a variety of commercially available joint methods. T-slots are available from hundreds of manufacturers who follow the same standard, making each component and joint compatible, while also driving the price low. Furthermore, the buyer can select how many of the four faces should have slots, which creates the option to only have slots where they are needed, rather than on every face, thus adding to the shelter's aesthetic appeal.

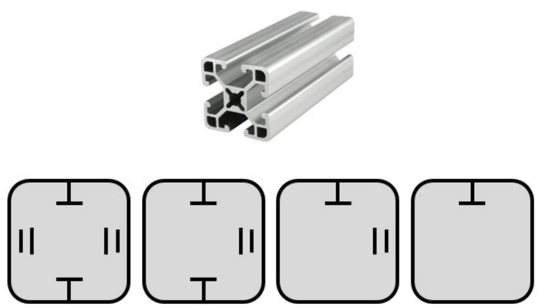


Figure 35: T-Slot Variations

We have decided to follow the 80/20 15-series standard to build the shelter. The 15 stands for 1.5", which is the dimensioning for Design V.1's subframe members. All of the frame components can be purchased through one manufacturer, decreasing the cost of the shelter significantly. The vertical posts that support the structure will be custom extrusions which abide by the same 80/20 15-series standard. To support a greater load, the vertical posts would be thicker than 1.5", but still be compatible with the 1.5" subframe bars. The custom extrusion will be 3"x3" and will have a much simpler profile in order to increase its load capacity and also decrease manufacturing costs. Structural analysis is still required on these components, and will be conducted in detail next semester.

2.1.2.2 Frame Joint Connections and Mechanisms

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

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

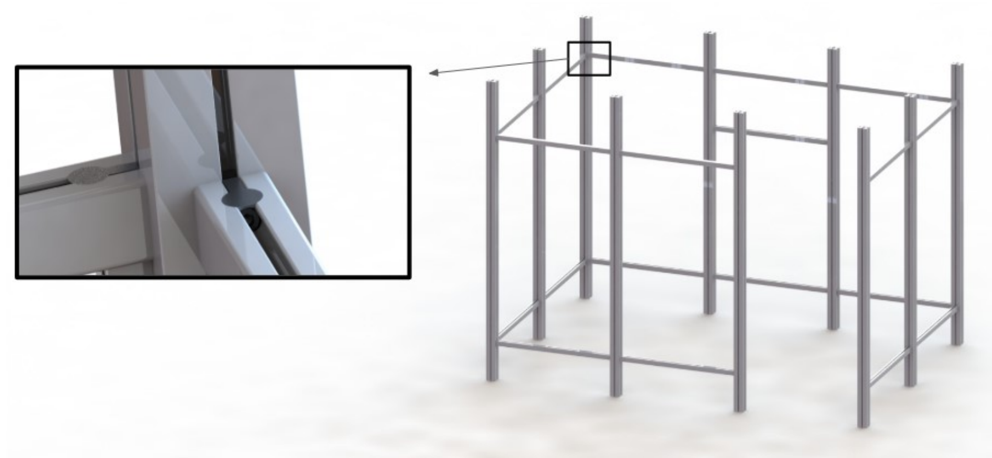


Figure 36: Butt-Fastener joint method

2.1.2.3 Full Frame ANSYS Analysis

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

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

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

2.1.2.4 Tube Structure ANSYS Analysis

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

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

1. Import the Solidworks part into Spaceclaim.
2. Use the Prepare → Extract tool and select everything, yielding a set of lines.

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

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

Use Cases						
Use Cases	Design Priority	Loading Priority	Loading Type	Loading Location	Support Location	Load (approximate)
User sits on the bench	3	3	Distributed Load	Bench	Bench Support/Mount	600 lb
User lies on the bench	1	1	Distributed Load	Panels	Frame Mount and Joints	2 lb
User puts bag on the bench	1	2	Distributed Load	Panels	Frame Mount and Joints	600 lb
User brings large luggage inside	1	0	Point Load	Roof	Roof Contacts and Support Beams	200 lb
User with chairwheel uses disabled area	3	0	Distributed /Point Load	Roof	Roof Contacts and Support Beams	200 lb
User takes shelter from rain	3	3	Distributed Load	Roof	Roof Contacts, Support Beams, and Structure	4000 lb
User avoids from being exposed to the sun inside	1	0	Point Load	Panels	Structure Supports, Panel Connections	400 lb
User chats inside	1	0	Distributed Load	Bench	Structure Supports, Panel Connections	300 lb
User eats inside	1	0	Distributed Load	Bench	Bench Support/Mount	10 lb
User drinks inside	1	0	Distributed Load	Bench	Bench Support/Mount	200 lb
User spills drinks inside	1	0	Point Load	Panels	Panel Supports	1 lb
User throws trash inside	2	0	Point Load	Panels	Panel Supports	Momentum
User leans on side panel	3	3	Distributed Load/Bending	Solar panel	Solar Panel Supports	200 lb
User puts up flyer/ad inside	3	1	Point Load	Display screen	Display Screen Supports	
User hangs off roof overhang	2	3				
User climbs on top of roof	2	3				
Snow falls on roof	3	3				
User kicks side panels	2	3				
Rock hits panels	3	1				
Wind blows on side panels	3	3	Distributed Load	Panel	Panel Panel Supports	.22 psi
User puts pressure on solar panel	2	1				
User hits display screen	3	1				
User vandalizes bench	3	0				
User vandalizes panel	3	0				

System Index 3: Shelter Loading Use Case Table

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

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

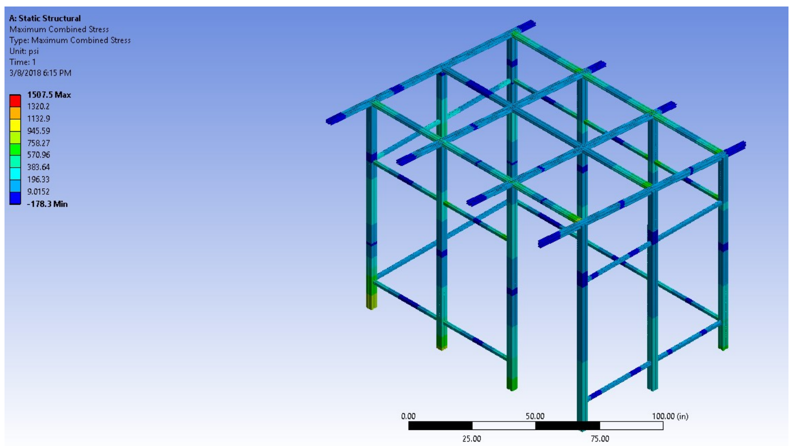


Figure 37: Shelter structure Maximum Combined Stress results under snow loading conditions

Figure 37, shows that the maximum stress experienced by the shelter structure is 1507.5 psi. Compared to the 28 ksi lower bound maximum tensile stress of Al-6105 there is a significant factor of safety and the structure is not under any compromise. Figure 38 below, shows the maximum stress under all sorts of loading (leaning, pushing, pulling, and hanging) and the resulting maximum stress is 1662.2 psi which like above is also of no concern. The scale is exaggerated for clearer visuals of the deformation of the structure, but the highest stressed areas of the structure are near the joints between subframe and mainframe and at the shelter foundation mounts.

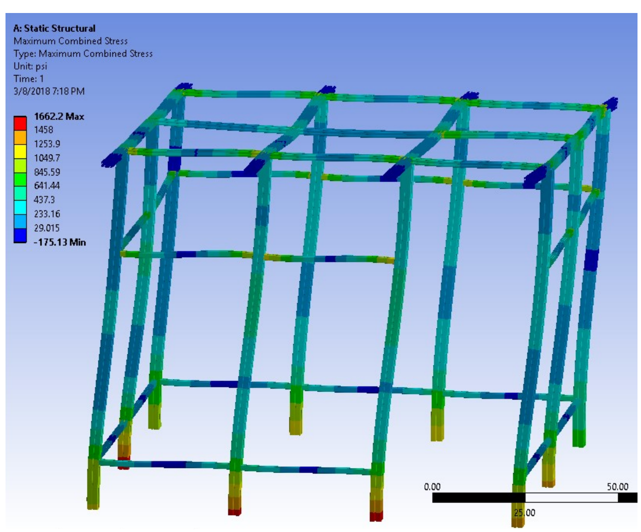


Figure 38: Shelter structure maximum combined stress results under various loads including snow loads

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

2.1.2.5 Joint ANSYS Analysis

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

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

To ensure the different joint scenarios were evaluated and the results were recorded in an organized manner, we generated an analysis databook to control the inputs and outputs of the analysis. The databook creates an informational slot for each of the joint locations which is split up based on levels. Figure 39 shows the nomenclature for the databook and how all the joints analysis will be covered.

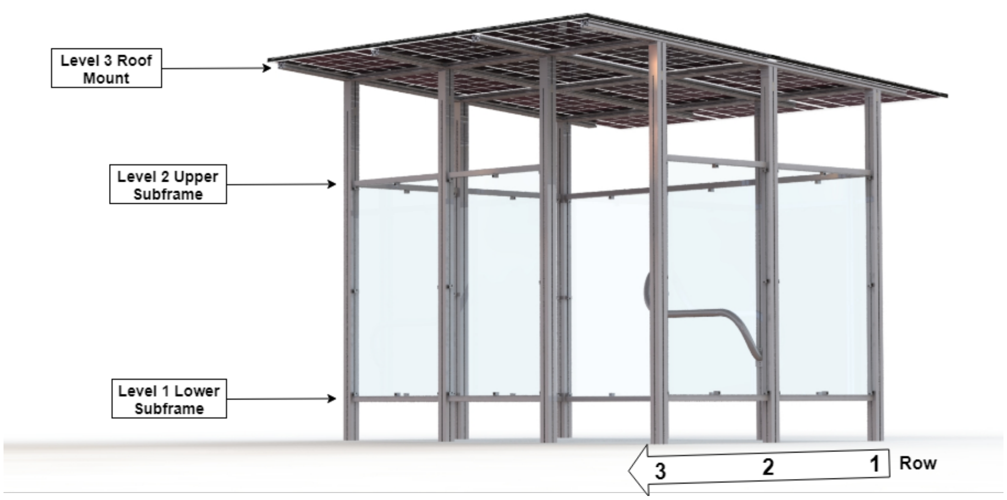


Figure 39: Nomenclature description for the ANSYS Databook with rows describing the joint location and the levels indication the sheet in the Excel file

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

The excel data book resembles the 2D top view floor plan of the shelter as shown in Figure 40. This better helps identify the location of joint results to improve user simplicity. Figure 41 shows a completed example of the databook at subframe member (2,5,4) which is the upper level subframe member located in the front next to the left of the entrance.

Level 1 - Joint connects at lower subframe level. 12" off the leveled foundation											Formatting - type(x,y,z)				Post (Main Frame Post) Subframe (Subframe member) Mount (Roof Mount) Roof (Roof Support member)		(x,y,z) x = Level (Which Sheet) y = row (backside being 1) z = column (based on value in array)			
Backside																				
Post(1,1,1)			Subframe(1,1,2)			Post(1,1,3)			Subframe(1,1,4)			Post(1,1,5)			Subframe(1,1,6)			Post(1,1,7)		
Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results
Subframe(1,2,1)			Bench						Bench									Subframe(1,2,7)		
Forces	Analysis	Results																Forces	Analysis	Results
Post(1,3,1)																		Post(1,3,7)		
Forces	Analysis	Results																Forces	Analysis	Results
Subframe(1,4,1)																		Subframe(1,4,7)		
Forces	Analysis	Results																Forces	Analysis	Results
Post(1,5,1)			Subframe(1,5,2)			Post(1,5,3)			Subframe(1,5,4)			Post(1,5,5)			Entrance			Post(1,5,7)		
Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results	Forces	Analysis	Results				Forces	Analysis	Results

Figure 40: Empty example of the ANSYS Databook for Level 1 (Lower Subframe)

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

Figure 41: Filled out example between subframe member (2,5,4) and the main post (2,5,5)

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

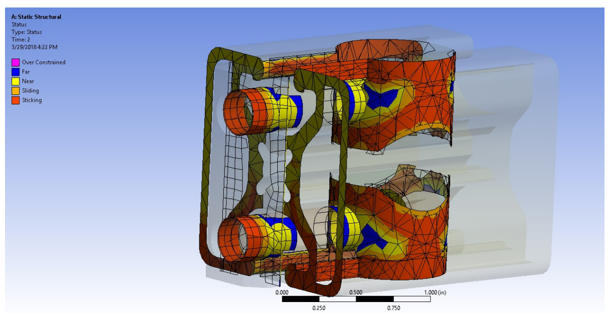


Figure 42: Contact results on the subframe member under significant loading of structure in all directions

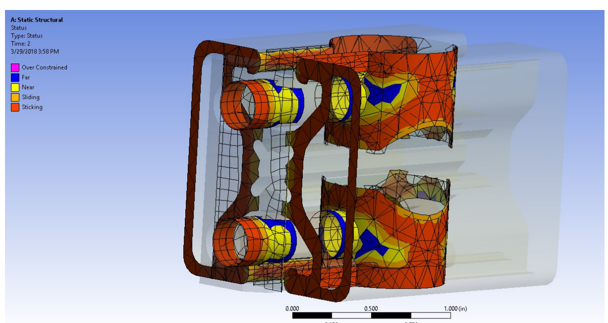


Figure 43: Contact results on the subframe member under snow loading only of structure

The contact tool in ANSYS generates both quantitative and qualitative results that both can lead to interesting conclusions. Conducting the analysis with a frictional coefficient of 0.15 between aluminum and steel and 0.2 between two aluminum surfaces yields the results seen in Figure 42 and 43. These frictional coefficients seem lower than usual to account for any sort of potential lubricant and design safety. Figure 42 and 43 show the comparison in the “sticking” of the subframe to the main post. The contact tool defines sticking as a solid bond comparable to a proper weld. Sliding indicates that the surfaces are in contact but does not offer structural support. In the specific scenario shown in the two figures, the subframe member would remain in place under both loading cases. Figure 42 indicates that loading forces in the member may create some bending in the subframe member but remains partially bonded with not visuals of disconnection from the main post.

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

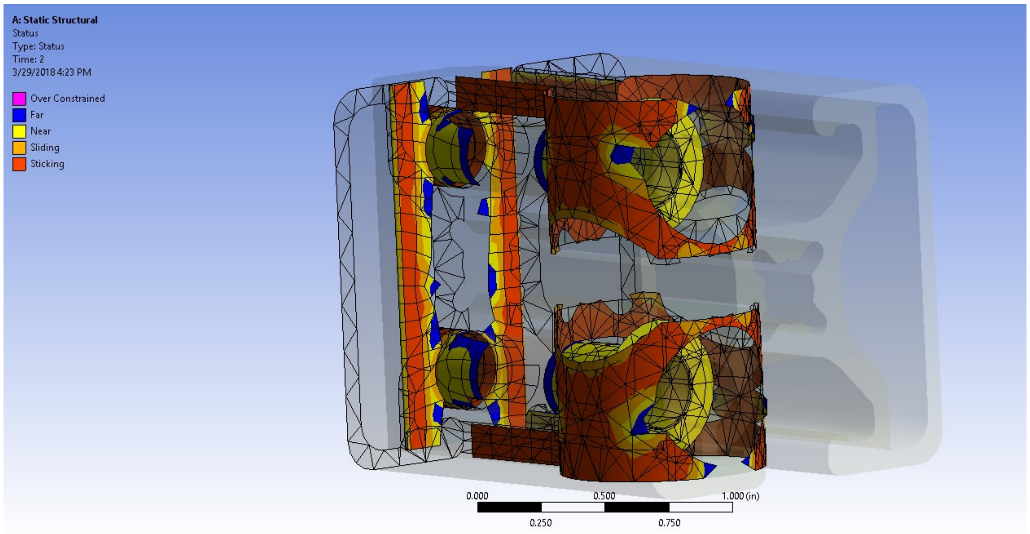


Figure 44: Contact results on the subframe member

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

2.1.2.5 Results and Conclusions

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

2.1.3 Side Panels

2.1.3.1 Material Selection and Analysis

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

Thickness	Holes	(Laminated) Tempered Glass			Polycarbonate		
		Max stress (psi)	Yield stress (psi)	Factor of safety	Max stress (psi)	Yield stress (psi)	Factor of safety
.25 in	3 by 3	9542.9	5148.84	0.54	10093	9021.34	0.89
	4 by 3	6457.2		0.79	6657		1.36
	5 by 3	6199.6		0.83	6381.1		1.41
.375 in	3 by 3	4168.9	5148.84	1.26	4464.9	9021.34	2.02
	4 by 3	2867.6		1.8	2992.8		3.01
	5 by 3	2659.3		1.94	2775.2		3.25

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

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

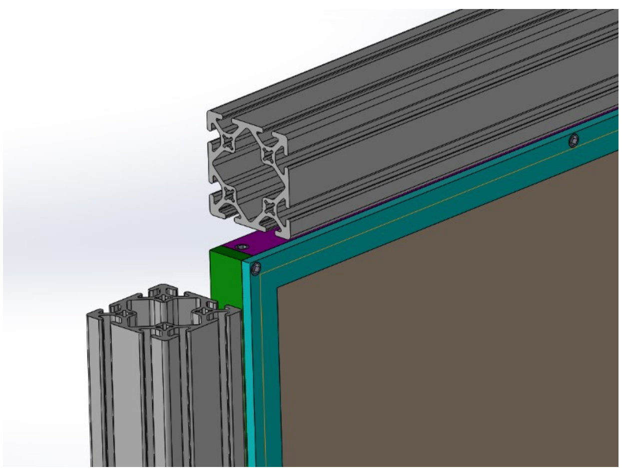
Side Panel Material Decision Matrix

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

System Index 4: Side Panel Material Decision Matrix

2.1.3.2 Panel Connection Design

Having considered several options, such as C-clamps and mounting blocks, we decided to design a mounting frame of our own onto which the panel would sit. This frame would in turn be connected to the T-slot aluminum extrusion as depicted in the diagrams below. The frame, all T6 aluminum 6061, can be broken down into the inside frame that gets connected to the T-slot and the outer frame. The inside frame is an assembly of two long, aluminum bars that form the length and two short bars that form the width. The two sets are designed to mesh on top of one another before they are screwed together hence realizing a firm joint. The outer frame is one whole rectangular piece that is fastened to the inner frame and holds back the panel in place. It is held by six Allen screws along its length and four along the width. We chose to go for this self-made design because it is less expensive, easier to assemble and minimizes aesthetic impact. With this design, it is easier to maintain and service the panel and its frame without having to remove the roof. The renders are as shown in Figure 45.



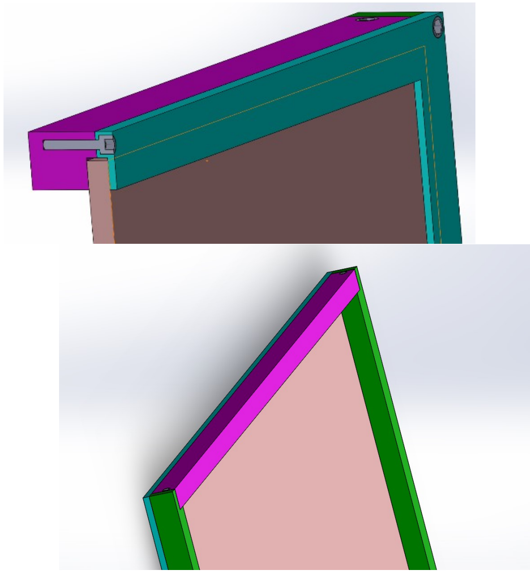


Figure 45: Contact results on the subframe member

2.1.3.3 Panel ANSYS Analysis

Our next task is to carry out a finite element analysis on the entire assembly of the panel and its frame under different loading conditions such as wind force or force exerted by a person's arm leaning on the panel. Our goal in doing this will be mainly to determine whether panel can be held in place by the frame and the gasket lining without sliding off. We have sent some of our questions to Yossi Bronsnick, an expert engineer from Taitem, who will be able to assist us on how to execute the test on ANSYS.

2.1.4 Roof Structure

2.1.4.1 Appearance and Dimensioning

The roof plays an integral role in providing cover, supporting weight, and aesthetics of the shelter. Our initial design for our shelter prototype showed an angle of 15 degrees in the roof, so as to maximize solar energy absorbed. The figure below shows the side profile of a prototype shelter with a roof angle of 15 degrees. Aside from its unappealing appearance, we determined that the gap between the roof and the top of the posts would also allow for precipitation to easily enter the shelter even with overhang on the side—an undesirable effect for users. Thus, we decided to investigate the roof angle further to determine a solution that would better meet the needs of our system.

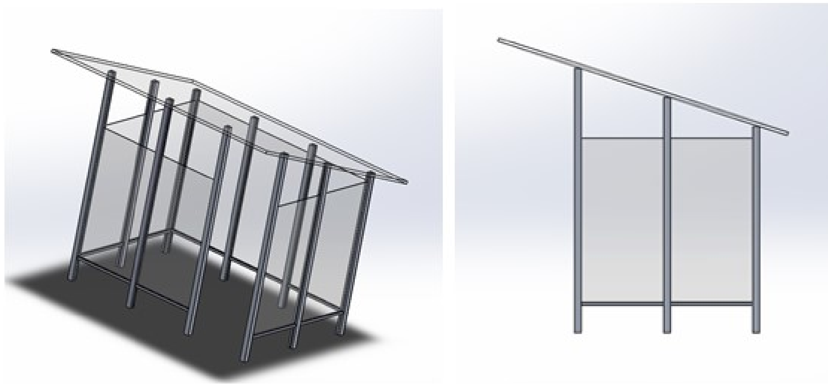


Figure 46: Side Profile of Initial Shelter with Steep Roof Angle

Via solar simulation to be discussed in an upcoming section, the impact of the roof angle in Ithaca was deemed near negligible for our purposes. Thus, the roof angle was decreased to 4.5 degrees. The slight angle aids in preventing build-up of natural materials, such as leaves, snow, and rain water, whereas also allowing for the shelter to be oriented in all directions, which a step angle of inclination would not allow for.

A proper roof overhang ensures that precipitation does not roll under the roof and into the shelter. Initial plans for the roof were to have 2' of overhang in the front and 1' of overhang around the sides and back. This would provide enough shelter for those standing in front of the shelter rather than under and provide extra waiting space. However, we have decided to move away from a fixed distance at this time. The finalized dimension will be based on material sizing and will be anywhere from 1' to 2'. This flexibility allows for lenience when costing the best solution.

For the initial roof structure design, T-slots should again be implemented as the roof structure to allow for easy integration and customizable roof attachments. Initially we chose 1.5"x3" T-slot bars for the roof. The roof support structure consists of long bars across the main frame posts and transverse supports approximately 3' apart creating a grid like system. However, after analyzing snow loads, a larger cross section bar should be used.

In Ithaca, snow loads are approximated to apply a force of about 40 lb/ft^2 on the ground and with a grid system of about 9 ft^2 in the roof, a back of the envelope estimate can be made that each 3" bar would be experiencing a distributed load of approximately 90 lbs. Examining the figure below shows that a 1.5"x3" could cause issues under maximum loading meaning the 3"x3" posts would be necessary for the roof support structure.

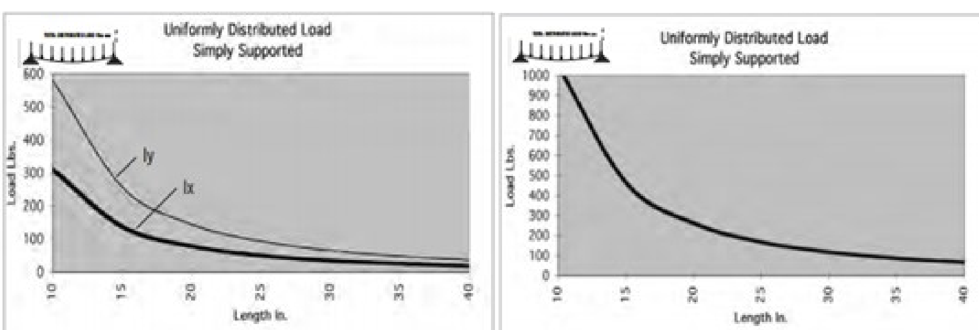


Figure 47: Load Distribution of T-slot (1.5"x3" vs 3"x3" from left to right) [1]

The roof panels would be attached directly to the T-slots on top. A cover between the panels can be easily implemented since the posts offer plenty of attachment room.

2.1.4.2 Roof Panel Material Selection and Analysis

Similar to the side panel selection, a decision matrix was used for roofing material selection as well. Contrary to the side panel selection thought process, different factors were weighted higher for various reasons. Unlike the side panels, where translucency, scratch resistance, and shatter resistance were among the top factors of consideration, the roofing material had different preferred qualities, like durability, yield strength, weather resistance, density, and cost. The full roof panel material decision matrix is shown below.

Roof Material Decision Matrix

Design Method		Polycarbonate Panel		Aluminum Sheet Panel		Steel Sheet Panel	
Metric	Weight	Normalized	Final	Normalized	Final	Normalized	Final
Lifespan	4	10	40	7	28	6	24
Scratch Resistance	1	5	5	10	10	10	10
Shatter Resistance / Max Load	5	7	35	8	40	10	50
Appearance	4	10	40	4	16	7	28
Weight/Density	4	10	40	7	28	5	20
Cost	5	10	50	7	35	8	40
Weather Resistance / UV Stability	2	5	10	10	20	8	16
Sustainability / Green Impact	5	4	20	10	50	10	50
Total		61	**240**	63	**227**	64	**238**

System Index 5: Roof Panel Material Decision Matrix

Unlike the side panels which act as a wind barrier and give the shelter its form, the roof needs to withstand snow and solar panel loads. Due to these loads, the roof panel material needed to be selected for durability and sturdiness.

According to the decision matrix, the top choice and recommended material for the roof is yet again polycarbonate sheets; however, similar to the side panel decision matrix, the outcome was close between various materials. Although steel and aluminum sheeting boasted strong tensile strengths and high yield strengths within their material properties, polycarbonate did as well. At the end of the day, the numerical strength and resistance towards loading is irrelevant as long as it can withstand all our load cases with a satisfactory factor of safety.

The ANSYS analysis performed on all three materials that were being considered (polycarbonate, steel sheeting, aluminum sheeting) all passed our various load cases, which rendered them all acceptable materials for the roof. What ultimately allowed polycarbonate to win the decision matrix was its low density, its weather resistance, and its aesthetic appearance. While the side panels would likely be transparent polycarbonate, the polycarbonate roof can range from any color as well as any level of transparency, making it the most aesthetically versatile material option. This can allow it to be customizable at each location if desired, giving the shelter a broader sense of character and style. Furthermore, by having both the side panels and the roof being made of the same material (for the barebones shelters), it reduces the amount of different types of materials needed to complete the shelter.

Since the shelter package options will come in either a solar + LCD display or a barebones option, the type of material for the roof will change depending on which is selected for any given shelter. For the barebones option, which does not have solar panels or electronics in the shelter, the roof materials will be the polycarbonate that was discussed above. However, for the solar shelter which contains all electronics (such as our showcase shelters), the roof will be made of transparent solar panels, which will be discussed at length in the Solar section of this report.

2.1.4.3 Roof Frame & Panel ANSYS Analysis

The ANSYS simulations for the roof was generated on top of the shelter structure since the roof panels distribute snow loading across the roof frame. Since the ANSYS model was restructured in SpaceClaim for the purpose of using the beam tool, the roof was recreated as mid-surfaces in SpaceClaim and snow loading was applied to the roof panels in this method. Initially the roof was modeled as 4mm aluminum panels and only snow loading is initially assumed for the roof.

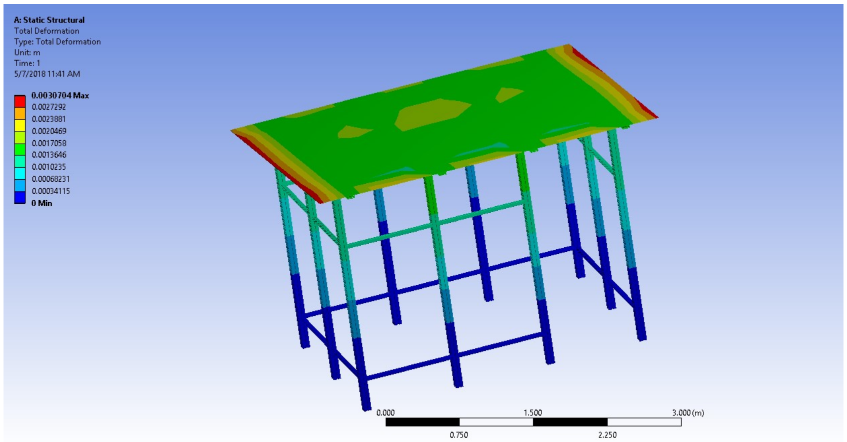


Figure 48: Roof deformation under snow loading only using ¼" Al6061-T6 Plates

Figure 48 shows that the maximum deformation for the initial aluminum panels is approximately 0.12 inches and occurs at the side overhang of the panels. These results indicated that the analysis was modeled correctly and the roof frame properly supports the roof at all locations except for the distant overhangs. Simulations were then run on polycarbonate panels due that being the final roof material choice to draw conclusions about the design of the roof.

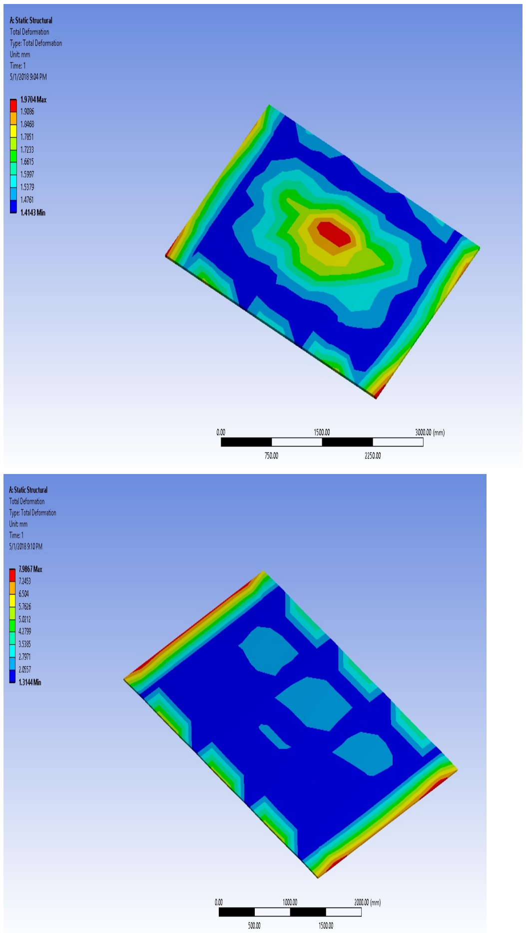


Figure 49: Comparison of total deformation between 1" thick (left) polycarbonate panels and ½" thick (right) polycarbonate panels

Figure 49 shows that the deformation for the ½" polycarbonate panels is about 0.3 inches which is a visible deformation. The 1" panel has a 0.07 inch deformation that occurs more in the center rather than along the side overhang. These results indicate that a ½" panel may have too much deflection in the roof and this issue would need an alternative solution such as additional T-slot supports extending out beneath the overhang.

2.1.4.3 Results and Conclusions

From the above results, a ½" polycarbonate panel for the roof would require additional supports for the side overhang. Future analysis would require a cost benefit analysis for an upgrade to a 1" thick panel to see if installing side supports would be cheaper. However, our tentative decision a ½" panel would be much more aesthetically pleasing and thus support options should be explored. Furthermore, in the case of the showcase solar panels from Lumos, there would be no side overhang which eliminates the issue of deformation at these locations.

2.1.5 Foundation

2.1.5.1 Solar Panel Mounting Scheme and Analysis

Like the prior material and joint selection decisions, mounting the solar panels was also approached systematically.

To mount the solar panels, several elements were taken into account including efficiency of the solar panel at a given angle, appearance, and weather resistance. A decision matrix, included below, with possible mounting schematics was drafted and used to select the optimal mount. Discussed mounting options included having a mount track the sun and adjust its angle to maximize efficiency, having a pole mount to raise the panel above the roof to improve weather resistance, and having the roof itself angle adjustable to orient each shelter with its optimal angle. A decision matrix utilized weights for particular attributes in order to scale with the value the stakeholder places in each attribute. Then each attribute was ranked for mounting the solar panels and the total number was used to make the final selection.

Solar Panel Mounting Decision Matrix

Design Method		Pole(roof)		Flat		Adjustable Roof		Sun Tracker		Pole(ground)	
Metric	Weight	Normalized	Final	Normal	Final	Normal	Final	Normal	Final	Normal	Final
Angle Adjustment	2	8	16	1	2	8	16	10	20	5	10
Cost	4	3	12	7	28	1	4	1	4	7	28
Modularity	3	4	12	8	24	1	3	5	15	5	15
Appearance	5	1	5	10	50	4	20	3	15	5	25
Ease of Implementation	2	5	10	7	14	1	2	2	4	5	10
Durability	4	8	32	2	8	5	20	5	20	5	20
Maintainability	3	5	15	3	9	5	15	5	15	5	15
Total		34	**102**	38	**135**	25	**80**	31	**93**	37	**123**

System Index 6: Solar Panel Mounting Decision Matrix

As informed by the decision matrix, due to little effect in solar efficiency, these features were phased out of the design: ease of maintenance, and appearance, mounts. Instead, the solar panels would lay flat on the surface of the roof, and in the case of several panels as in the case of the showcase shelters, these panels would be adjacent to each other to prevent snow and other damages.

2.1.7 Maintenance Strategy

Moving forward with the design and cost of the shelters, we have begun looking into possible maintenance strategies to lessen the time burden on TCAT, especially in regards to maintenance of the solar panels and shelter snow removal.

An estimated 10-15 shelters can be cleaned each day per person spending 20-30 minutes on one. In the event of snowfall, hosing the roof with warm water would be the recommended method and add an additional 5-10 minutes to shelter maintenance.

Another concept to conduct more research on is an “Adopt-a-Bus Shelter” program proven successful in areas such as Nashville, Tennessee. A local company or organization would “adopt” a bus shelter location for a donation or signed commitment to send volunteers to clean up the area every week, for which TCAT or CUSD could verify community service hours. The group or organization could potentially gain marketing exposure if their name were to be included on the TCAT webpage or a plaque on the shelter. These ideas will be further investigated in the upcoming semester.

2.2 User Experience Design

2.2.1 Introduction

The goal of the UX (User Experience) design subteam is to design/redesign information systems in TCAT using human-centered design processes. This includes live data displays, maps, bus passes, and time tables. Their solutions and process from the Spring 2018 solution are presented in the following sections.

After extensive consideration of our project deadlines and team skill set, the UX design team decided to focus on the live data display this semester. The goal is to design a real-time data display for TCAT bus shelters that is easy to read and fits well with the TCAT brand identity.

2.2.2 Explorations

2.2.2.1 Sketches

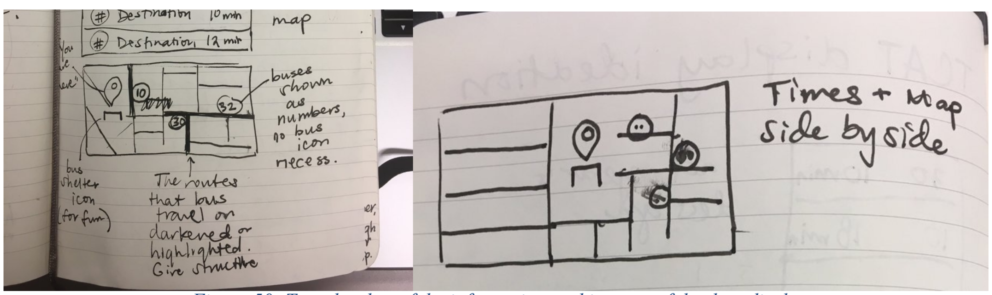


Figure 50: Two sketches of the information architecture of the data display

To start the design process, we sketched out different explorations of how the information would be organized. The general content that was available to us is:

- Bus arrival times
- Bus location

We explored three main ways of displaying the data—showing just the bus times, showing bus times only for *x* seconds and then showing a map for x seconds, or showing both the times and the map, side by side, at the same time.

We ultimately decided that to show both the times and the map at the same time because we felt that having both kinds of information available can reinforce understanding, and better associate time with distance. Additionally, we felt that having the bus times alternate with the map was displaying too little information at a time.

2.2.2.2 Medium and High Fidelity Mockups

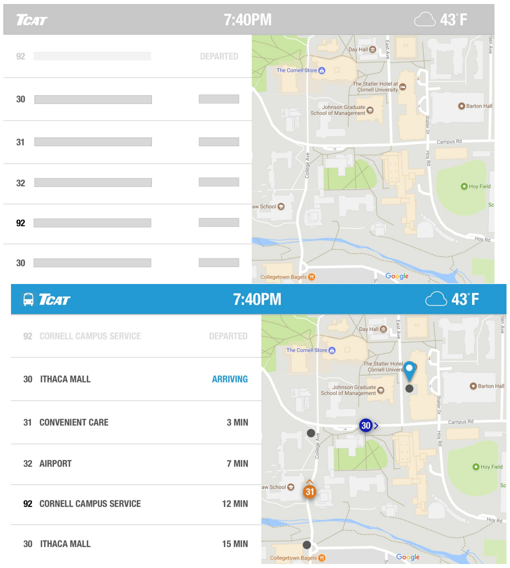


Figure 51: Left: Medium fidelity screen that shows some detail on the structure. Right: A high fidelity screen that shows all details.

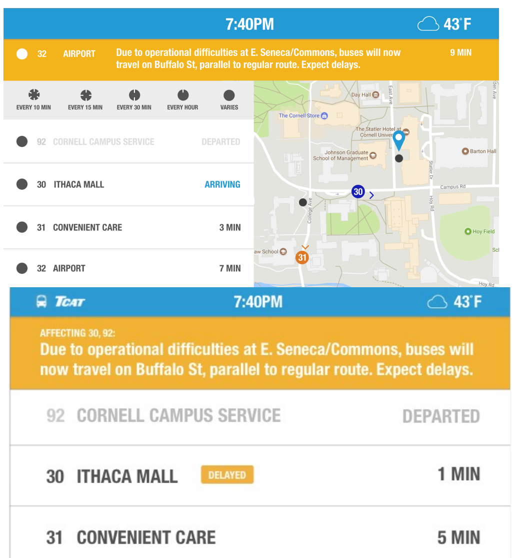


Figure 52: Further explorations on how to show announcements and display time information. Left: Displaying time intervals. Right: Indicating delayed buses.

In this phase of the semester, we not only considered what kinds of information should be displayed, but also how they should be displayed. More specifically, we thought of giving more insight in bus times in cases when users miss their bus. We agreed that it would be useful to show the time intervals for each bus (e.g. indicate that the 30 comes every 30 minutes). Ultimately, this idea was not very feasible because many TCAT buses do not arrive at consistent intervals and the idea was not impactful enough to justify pursuing it.

Additionally, we considered the idea of indicating whether an upcoming bus was delayed or not. Although the idea is very feasible, we figured that the arrival times could update when the bus is delayed.

2.2.3 Design Iteration 1: Before Usability Testing

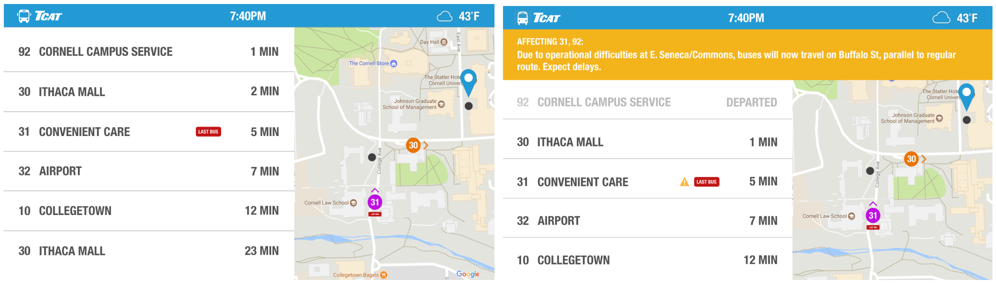


Figure 53: Left: Iteration 1 without an announcement bar. Right: Iteration 1 with an announcement bar.

After a period of exploring designs, we decided on to move on with the designs shown above. The features in this data display design include:

- Bus time arrivals
- Bus location map
- TCAT announcement bar
- Bus departed indicator
- Last bus indicator

We provided a space on the screen for TCAT-related announcements because increased transparency between TCAT and their users may mitigate frustration and anger when the user is dealing with a bus delay and has no idea why it is happening. Additionally, this is a relatively common feature to have in other transportation system data displays, and perhaps something that TCAT themselves would find beneficial in terms of efficient communication.

If a user doesn't know that their bus is delayed, they naturally become frustrated. To avoid this, we wanted to design a way to make it obvious to the user when their bus is delayed. At first, we explored ways of implementing rotational delay notifications. In this sense, any delayed bus would be allotted its own delay notification at the top of the screen. If there were more than one delayed buses at any point in time, the delay notification would rotate through each of these notifications cyclically.

After more research and deliberation, we realized that this wasn't necessarily the best way to design the notification since oftentimes one operational difficulty delayed multiple buses. Instead of having one notification for each delayed bus, we grouped all buses affected by the same operational difficulty under one umbrella notification. This allowed for a simpler, less crowded interface.

Within the notification, we included information regarding the delayed buses, and the reason for their delays. We kept the microcopy minimal and concise to ensure readability and clarity.

Lastly, we added a "Last Bus" icon to indicate that for today, that bus is the last one of its route. This will reduce the frustration felt when users accidentally wait for a long time for a bus number that is no longer in service for that day.

2.2.4 Usability Testing

After creating each mockup of the information display screen, the designs were shown to real users such as students and Ithaca residents to receive feedback that would guide design revisions and future changes. The design team's initial explorations were based on user research and hypotheses generated from past interviews. However, further user testing found some issues with our current design such as:

- The screen seemed oversaturated with colors making it difficult for users to distinguish important colored elements from the rest of the display.

- The bus symbols on the map were difficult to see amidst the details and colors already existing on the Google map.
- The listing showing a "Departed" bus seemed like an unnecessary piece of information.
- The notifications bar did not show the affected bus numbers prominently enough.
- There seemed to be little consistency between the way the bus numbers were presented in the time listings, the notification bar, and on the map.

2.2.5 Design Iteration 2: After Usability Testing

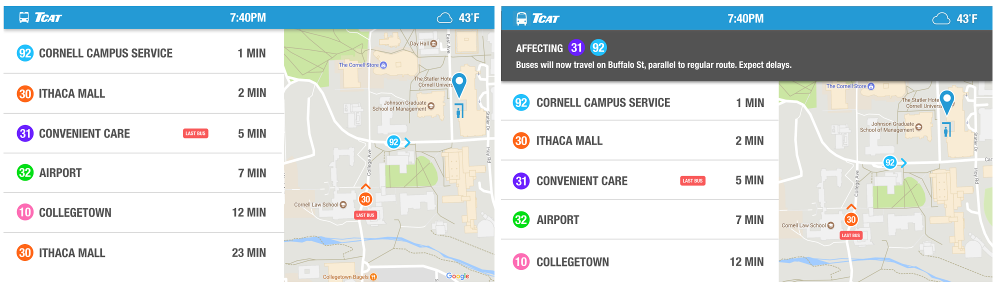


Figure 54 : Iteration 2, developed from the feedback from usability testing

After reviewing user feedback and ideating our own solutions in Sketch and on paper, new mockups were generated and once again tested with users. Our second iteration features several new improvements to tackle the above problems. In particular, we cut back on unnecessary colors and symbols and increased the size of the most important pieces of information like the affected bus numbers in the notification bar and the symbols on the map. In addition, we standardized the way bus numbers were represented across the screen by assigning each number to a uniquely colored symbol.

This uniquely colored symbol also applied to the delay notifications at the top of the screen. Since users thought the bus numbers in the notification bar weren't very clear and blended into the rest of the copy within the notification, the implementation of colored, circular bus number symbols resolved this issue neatly and ensured consistency across the screen.

We also minimized the amount of text within the notification itself. Users had said during user testing that they didn't really care about *why* the bus was delayed—they just wanted to know whether it was delayed. So we edited the microcopy to remove this unnecessary information, to ensure the notification reflected only the vital essentials of what the user wanted to know about the bus delay.

2.2.6 Solar Data Visualization

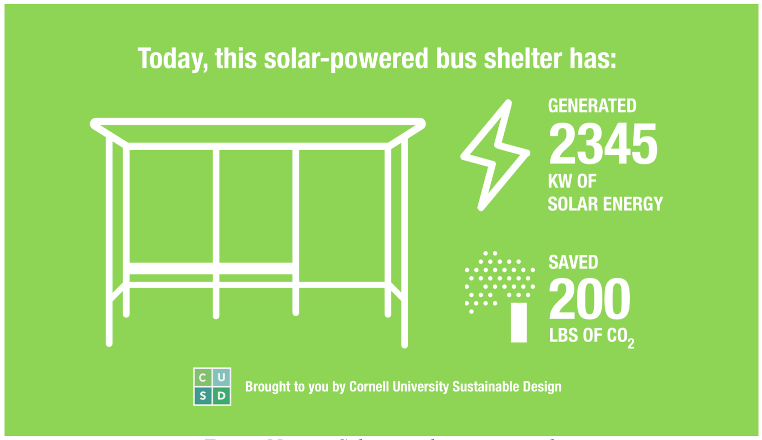


Figure 55 : Solar visualization example

This semester, the UX design team worked with the solar team to design a solar data visualization. The purpose of this visualization is to show the important solar data from the solar panels in a meaningful way to effectively inform the community about TCAT sustainable bus shelters.

Originally, the plan was to include the solar data into the same screen as the bus arrival times. However, we quickly realized that that would result in information overload. Therefore, we opted for designing a specific solar data screen that would show every *x* seconds. We designed it so that it will show not only the amount of solar energy generated, but also how much nonrenewable energy was saved as a result. The latter data would change into different, interesting units, such as cars taken off the road, coal burned, e.t.c. The data would also be live and updating regularly.

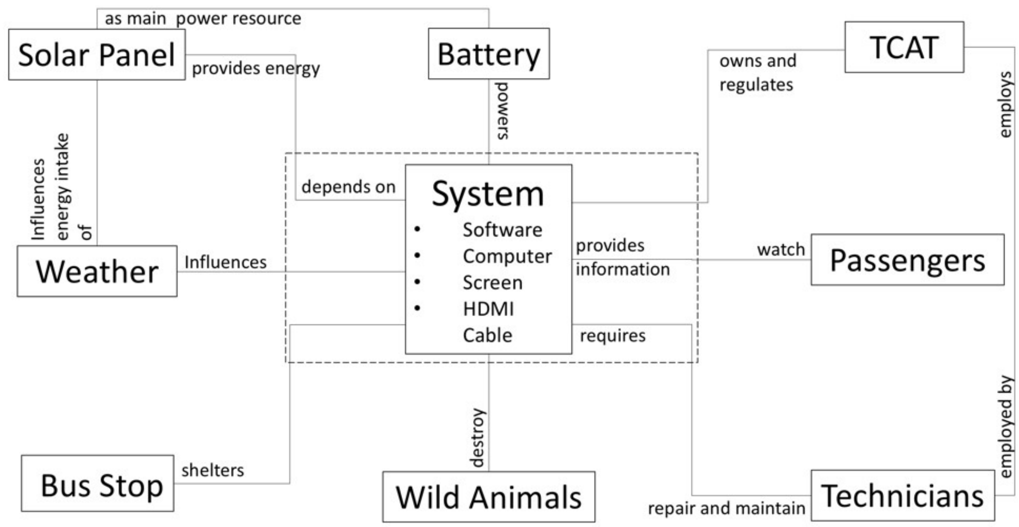
2.2.7 Conclusion and Looking Forward

Moving forward, we will run another round of usability testing on our second iteration to get more feedback. With the solar data, we want to visually refine our solar data visualization design and also conduct a bit of usability testing to verify the effectiveness of the design. We look forward to also testing out our designs on an LCD monitor to test out the design’s dimensions, legibility, and visibility.

2.2.8 Information Display

2.2.8.1 Introduction

The Information Display sub-team’s goal for spring semester was to take the foundational, unrefined information display system that we constructed in the fall and continue building it out into a functional and attractive platform. With a mix of software and hardware, we wanted to improve on the initial version of a system that takes real time information from TCAT’s API, handles it on a custom webpage, and displays it on a screen for riders to see. The system context is described in the diagram below.

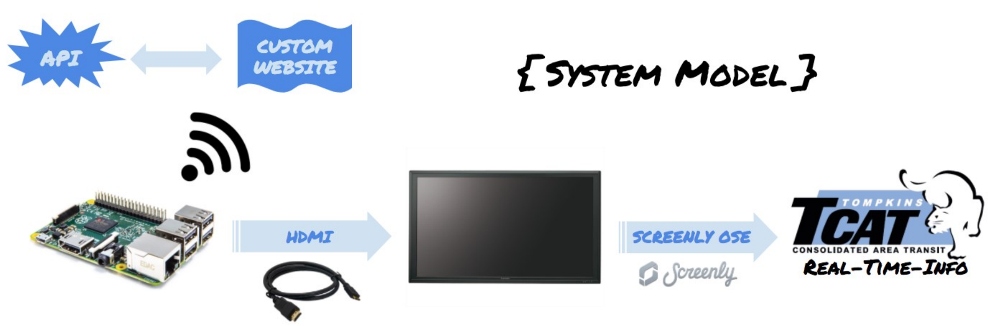


System Index 7: Live Data Display System Context Diagram

2.2.8.2 Information Architecture

In early 2017, TCAT hired the company Availtec to create an Application Programming Interface (API) that allows for external developers to access robust operational information about buses, stops, routes, and departures. This data updates in real-time and includes a wide range of geolocation and temporal information. Upon receiving access to TCAT's API, our team integrated this information with the Google Maps API to create a live display of current transit environments in Tompkins County.

There are two primary elements in our system, depicted below: a software component and a hardware component. For the software component, we developed a website that uses the TCAT API to pull data from their database and then displays bus locations and current timetable information. In order to present this data on a screen, we used a Raspberry Pi that had been loaded with the open-source software Screenly to access and display our webpage to the LCD screen. We hosted our site using the cloud service provider Heroku, which allowed for the majority of processing to occur on our web server rather than on the power-limited Raspberry Pi.



System Index 8: Information Display Structural Concept Diagram

2.2.8.3 Acquiring & Handling the Real Time Information

While TCAT's API provides a wide assortment of different functions, we made use of a few main API calls in constructing our live display. The AJAX calls to the API's query the database to return data in the form JavaScript Object Notation(JSON) objects. The below are a list of API calls currently used in the display system:

1. - /Vehicles/GetAllVehicles - This API call returns JSON objects which holds the objects such as VehicleID, RouteID, as well as a bus's current Latitude and Longitude.

2. /StopDepartures/Get/{id} - This API call retrieves information about the buses that are scheduled to depart from a specified stop and also returns a collection of JSON objects. For us, the most useful attributes held by these objects were: EDT (Estimated Departure Time), SDT (Scheduled Departure Time) and ADT (Actual Departure Time), and their "Arrival" counterparts (ETA, STA, and ATA).

3. /PublicMessages/GetCurrentMessages - This API call returns JSON Objects containing Alert Messages that describe any current unusual traffic our route situations. These objects contains attributes such as the message, the priority, and any routes affected.

The results of these API calls are stored on our web server, where we then process the data and convert it into a displayable format. The AJAX calls return the data asynchronously, and accordingly we structured our code to accommodate for receiving different pieces of information at different times.

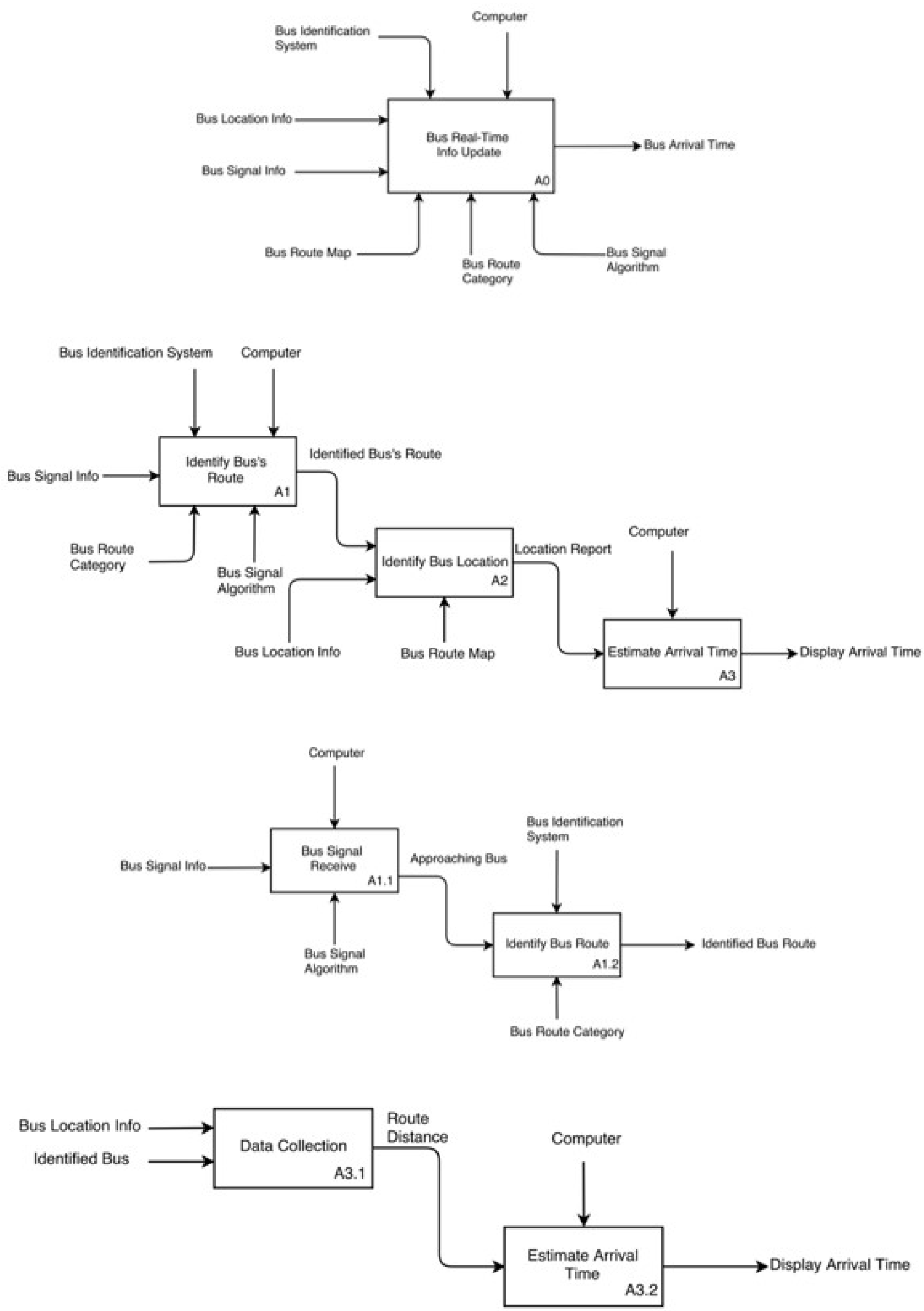
```
$(document).ready(function () {
  var token = 'Bearer e5159b89-86c1-3cca-8412-59de037c674b';
  $.ajax({
    url: 'https://gateway.api.cloud.wso2.com:443/t/mystop/tcat/v1/rest/Vehicles/GetAllVehicles',
    type: 'GET',
    dataType: 'json',
    beforeSend: function(xhr) {
      xhr.setRequestHeader("Authorization", token);
    },
    //data: 'json=' + escape(JSON.stringify(createRequestObject)),
    success: function(msg) {
      //var markers = [];
      var data = JSON.stringify(msg);
      console.log(msg);
      MapRoute(msg);
      setTimeout(function(){
        location.reload();
      }, 10000);
      $("#orders").text(data);
    },
    error: function(XMLHttpRequest, textStatus, errorThrown) {
      alert(errorThrown);
    }
  // }).done(function(data) {
  //  alert(data);
  });
});
```

Figure 56: A screenshot of an example API call (/Vehicles/GetAllVehicles) utilized in HTML/Javascript to produce a live visual of buses

Once our website receives and processes the necessary information from the TCAT servers, we use the Google Maps API to generate a map of Tompkins County and then place markers to indicate bus locations based on their latitudes and longitudes. Additionally, the site analyzes the departure data and creates a timetable that shows expected bus arrival time and bus departure time for the various routes that go through a given stop. The website updates the map and timetable sections every few seconds, performing new API calls and revising the display with the updated information.

Separately, we also used Yahoo!'s Weather API (query.yahooapis.com) to pull current weather information for Ithaca. Yahoo!'s API returns JSON objects containing weather data, which our site then uses to display the temperature and the current weather (e.g. raining, cloudy, sunny, etc.) in the top corner of the site.

Functional steps can be viewed through the systems diagram IDEF0, below. IDEF0 is a tool to develop and explore a function into details and orders. It divides a function into several steps and only by completing the previous step can go through the next step and finish the function. Each edge of IDEF0 resembles an input, output, control/constraint and resource/mechanism.



System Index 9: Live Data Display IDEF0

2.2.8.4 Displaying the Real Time Information

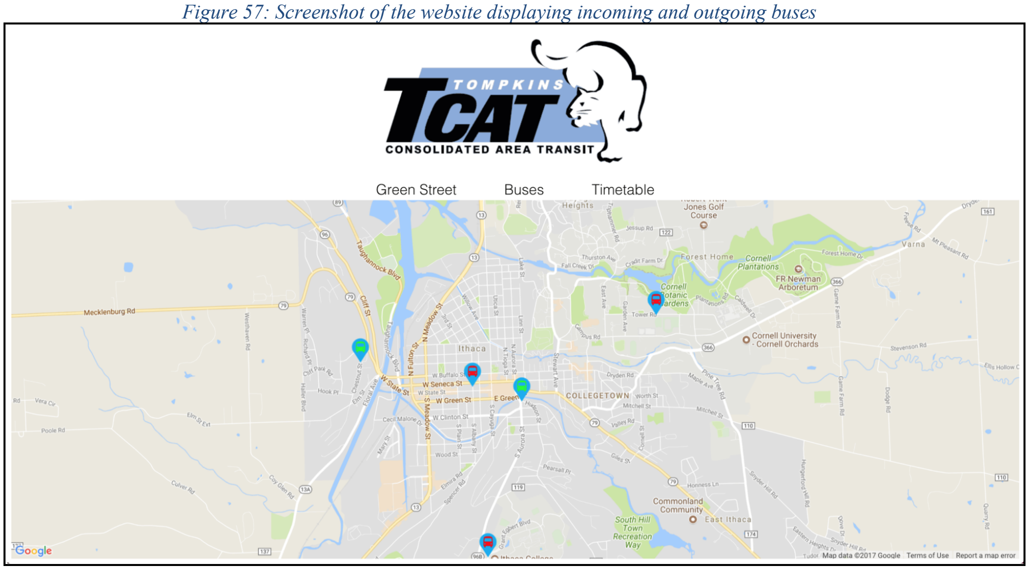
Last semester, we worked closely with the design team to ideate several different potential screen layouts for our display system. Firstly, we considered an all-encompassing screen: both the map and the timetable would be displayed on the same page, so that a rider would be able to view all the information at once. The second layout we considered was having two separate pages for the two elements; every few seconds, the website would automatically switch to the other screen. The advantage of this multi-screen layout would be that there would be more screen real estate for each page, which would allow for more detailed views into both the map and the timetable. Finally, the last layout we considered was simply having a static page displaying the timetable information. This format would be geared towards riders who were already familiar with the TCAT system, and knew what routes they needed to take to get to their destination.

This semester, we resolved to implement the first choice of the three different screen layouts: one screen display incorporating all the elements required. We have designed and developed the time, weather, service alerts, map and timetable to be all shown on one screen at the same time. This makes the information available in one instance. There were two primary drivers behind this decision: user feedback, and the size of the screen we would be using. We determined that our final LCD screen would be a 32" display, which can easily show both a timetable and a map simultaneously.

We used a web development stack of HTML, CSS, JavaScript, and AJAX calls to create our data display system. Since we decided on the single-screen design, we first needed to modify last semester's code to display both the map and the timetable on the same page (last semester's design can be seen in Figure 47 and Figure 48). With a our baseline design implemented, we then iterated on our system, adding new features (service alerts, weather widget, clock, TCAT logo, etc.) and realizing the layout scheme conceptualized by the design team. As we iterated on our design, we sought feedback from users and made improvements to our design where users saw drawbacks. The final iteration of our site for this semester can be seen in Figure 50.

We have also refined, modularized, and generalized the code from last year so that the code can be implemented in any bus stop with very minimal changes. The code is versatile enough to be extended for future addition of new bus stop from TCAT, as well as for the future implementation of new features.

Figure 57: Screenshot of the website displaying incoming and outgoing buses



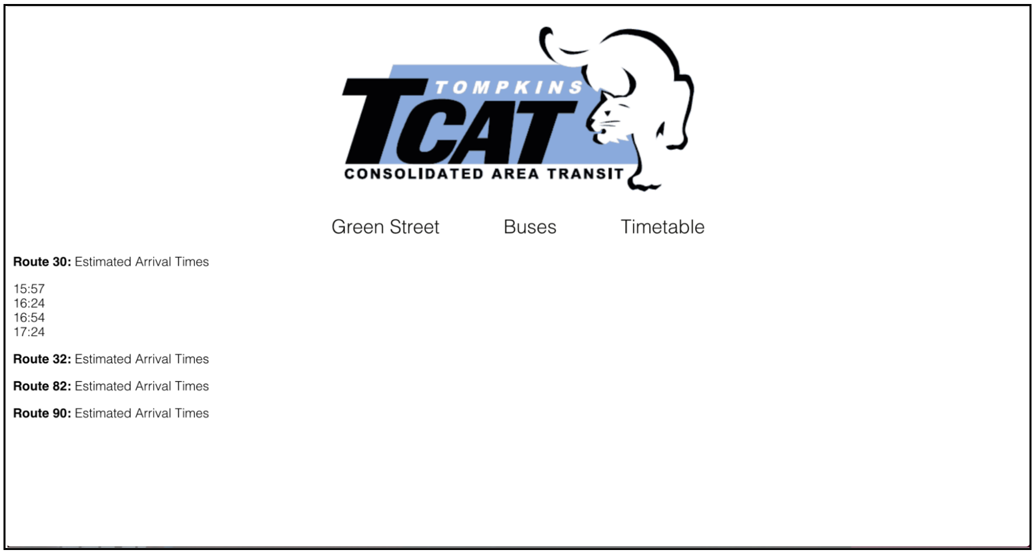


Figure 58: Screenshot of the website displaying a timetable of incoming routes and their estimated arrival times

A medium fidelity iterative mock-up of the screen is shown below.

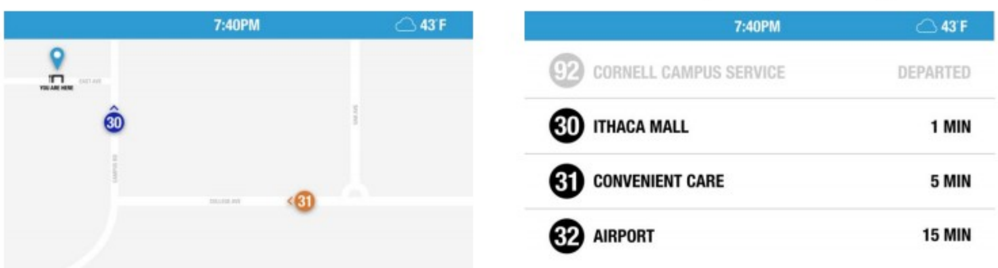


Figure 59: Data display medium fidelity mock-up

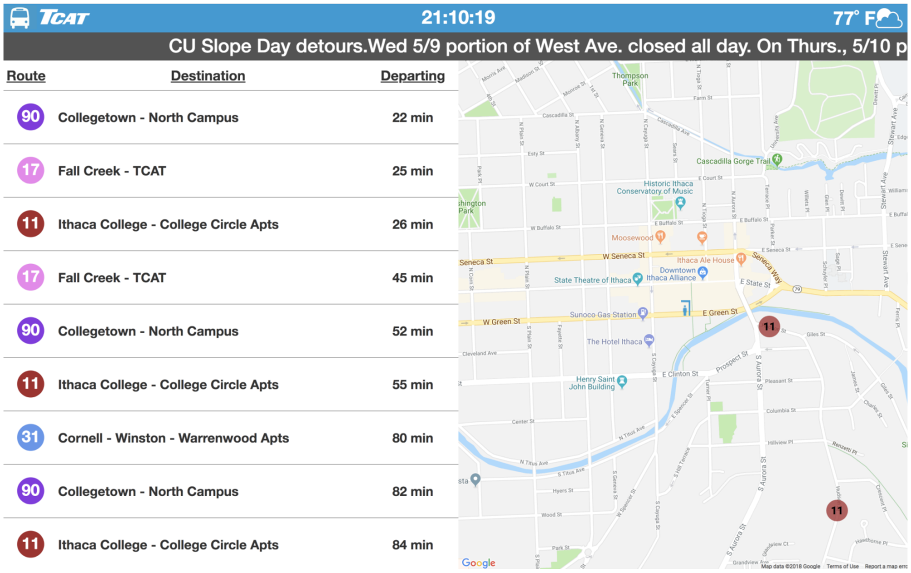


Figure 60: Data display website end-of-semester screenshot

In determining the final implementation of the screen, an Analytical Hierarchy Process was used so as to systematically prioritize the display's goals, balancing alternatives.

1	Easy to read		Reliability		Information to display			Other(Durable, Bakcup)	
	0.25		0.3		0.25			0.2	
2								Durable of the screen	Strongness of the system
								0.1	0.1
3	the screen displays the real time info successfully	Passengers can easy to understand the real time info on the screen	Wifi supporter can process the bus real time info	Screen wil survive in cold weather	Computer successfully receive the accurate real time info from the	Advertisements on the screen will attract people	People will find the emergency number all the time	There will be enough battery even the solar panel doesn't work	Screen can be attached with wifi supporter
4	0.6	0.4							
5			0.6	0.4					
6					0.4	0.3	0.3		
7								0.6	
8									0.4
	=0.25*0.6	=0.4*0.25	=0.3*0.6	=0.4*0.3	=0.25*0.4	=0.3*0.25	=0.3*0.25	=0.6*0.1*0.2	=0.1*0.4*0.2
9	**0.15**	**0.1**	**0.18**	**0.12**	**0.1**	**0.075**	**0.075**	**0.12**	**0.08**

System Index 10: Live data display analytical hierarchy process

2.2.8.5 Information Display Conclusion & Looking Forward

We were very pleased with the amount that we have achieved this semester, and the semester ended on a positive note. We were able to settle on and implement an appealing, useful data display system for CUSD's TCAT shelters. There are still a few design elements to incorporate (arrows indicating which direction the bus is facing, circles in the service alert area to clearly show which routes are affected by the alert, etc), but on the whole the site is essentially ready for use. Next semester should be primarily focused on integrating the display system with the shelter infrastructure to include energy data from the solar controller, and potentially adding the capacity to display advertisements on the site.

2.2.9 Long-Distance Light Indicators

The long-distance light indicator, as the name suggests, is a light indicator placed on the perimeter of the bus shelter to alert a distant or nearby passengers when a bus will be arriving.

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

A signal system could help solve this issue. With the visual signal, bus riders can decide the best time for their arrival to minimize their time spent at the bus stops and guarantee a randevu. A quick glance at the bus shelter can instantly tell a rider whether to walk or run towards the bus stop, thereby reducing the opportunity of missing their intended bus, and ultimately increasing the number of TCAT ridership by minimizing missed bus trips. That said, we are in contact with the Smart Vision Lights company about mass producing their product T-slot LED lights, which slide seamlessly into T-slots.

Below is a picture of the T-SLOT extrusion lights:

Figure 61: T-SLOT extrusion lights

Smart Vision lights are adaptive LED light illuminators with an intense and uniform light pattern that offer considerable energy savings over fluorescent lighting options. Mounting is easy in that the T-slot unit slides into the extrusion with no need for extra mounting accessories. With the ability to direct-connect up to 6 modules, lengths of 300 mm to 1800 mm are achievable in 300 mm increments.

Figure S1 is a visual representation of what the T-SLOT LED lights on the bus shelter would look like:

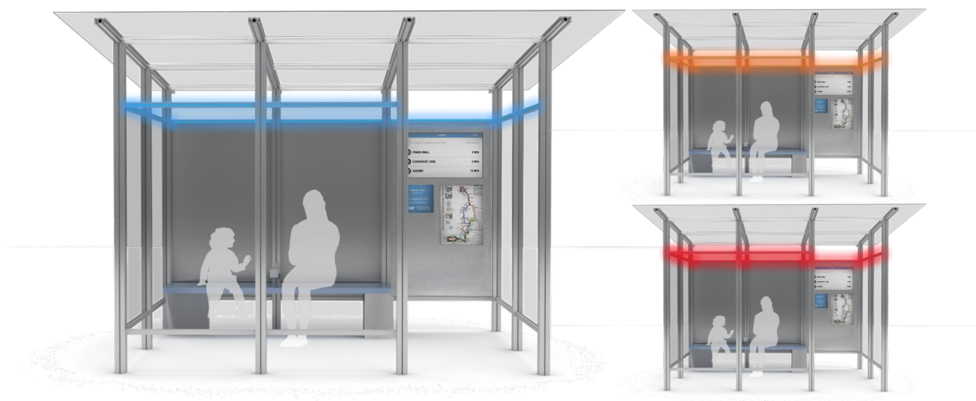


Figure S1: Light indicators on the bus shelter perimeter

According to Springer, a study found that users' urgency perception—both intuitive and attentive—was highest when color was used and the blink rate of LED lights was high. The study concluded that the use of red color with high blink frequency of the LED notification light is most effective in conveying urgency information.

Based on that reasoning, the T-SLOT LED lights will change color based on how close a bus is to the station. In particular, blue indicates that a bus is two minutes away from arrival; orange indicates that a bus is one minute away from arrival; and finally, red indicates a bus is 30 seconds away from arrival.

2.3 Solar

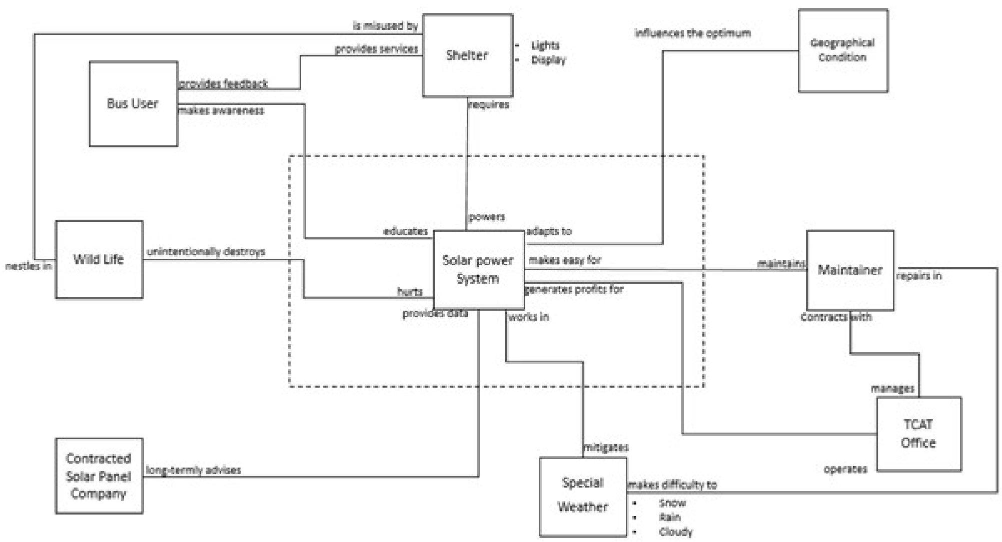
2.3.1 Introduction

As we applied modular properties to the shelter design, we applied a similar approach to solar integration among TCAT'S shelters. The bus shelters range over a large span of area within Tompkins County with differing variabilities in usage ranging from remote small shelters, medium shelters with occasional usage, and large shelters with frequent usage. TCAT expressed interest in establishing off-grid solar systems at the remote, small bus shelters to provide lighting, since only a small percentage of TCAT's larger shelter models were grid-tied. Cornell students rely heavily on the TCAT transit system, and as a result there are a multitude of bus shelters located on the campus that have a grid-tie already incorporated to provide lighting. With a goal of building our first shelter on Cornell's campus, our team began to develop a showcase version of our shelter which would implement a larger solar panel system to promote both Cornell and TCAT's image of sustainability, as well as powering additional appliances such as an LCD display.

We decided to divide solar implementation into categories of solar usage where the remote, smaller bus shelters will function by an off-grid system, and on the other end of the spectrum, the large bus shelters in highly populated areas would incorporate a showcase of solar technology. All of the shelters in between would be a variation of the off-grid system, since TCAT expressed a desire to lessen the number of shelters currently with a NYSEG meter.

2.3.2 Context Diagram of Solar Power System

The system context diagrams represent how the system interacts with the external environments and activities. The interaction between the system and the external factors, environments, and activities provide solid understanding of the requirements and constraints for the system. The following context diagram constructed for the solar power system includes the external entities: shelter, geographical condition, maintenance, TCAT office, special weather, the contracted solar panel company, wildlife, and bus users. Specifically, in the solar power system, the context diagram is extremely useful to understand how the solar power system interacts with rest of the subteams in the shelter design. For instance, the solar power system shall be used to power the loads in the shelter: lights and display, while the shelter structural design is required to provide support for the solar power system in terms of its weights and dimensions. In addition, the solar power system shall consider the extreme weather in Ithaca when selecting for performance criteria of the system. The interaction of maintenance and bus users to the system are considered through the process of the system design.



System Index 11: Solar Context Diagram

The circuit schematic representing the wiring of the various electronic components involved in the shelters is shown below. The schematic is different for medium sized shelters as well as large sized shelters. This is because of the battery count, as well as the number of solar panels in each scenario. In the medium sized shelters there are six solar panels and one battery pack (see Figure 63). On the other hand, in the large sized shelters there are eight solar panels and two battery packs (see Figure 64). As you can see in the diagrams for the wiring the general idea is that the solar panels transfer energy to a charge controller which regulates the output as it is connected to the battery pack. The output is DC so is converted to AC by the inverter as then the current travels to the various components like the LCD monitor the Wifi Router which is in turn is connected to the Wifi module. There is a voltage divider which steps down the voltage by 5 V, which is then supplied to the two Raspberry Pis. The one on the top powers the IR sensor.

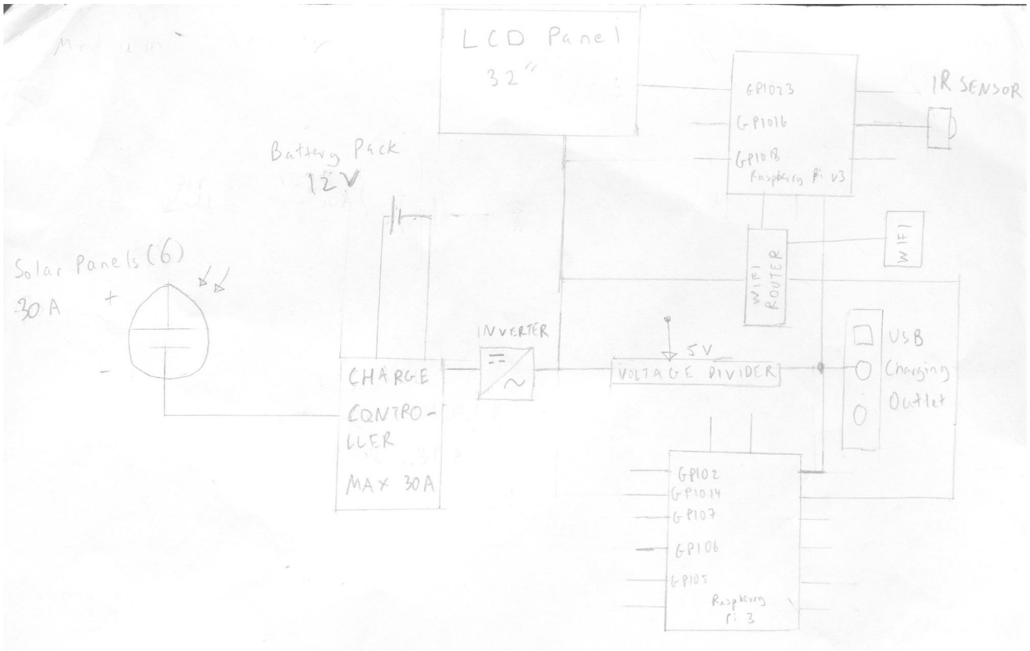


Figure 63: Medium sized shelter circuit schematic

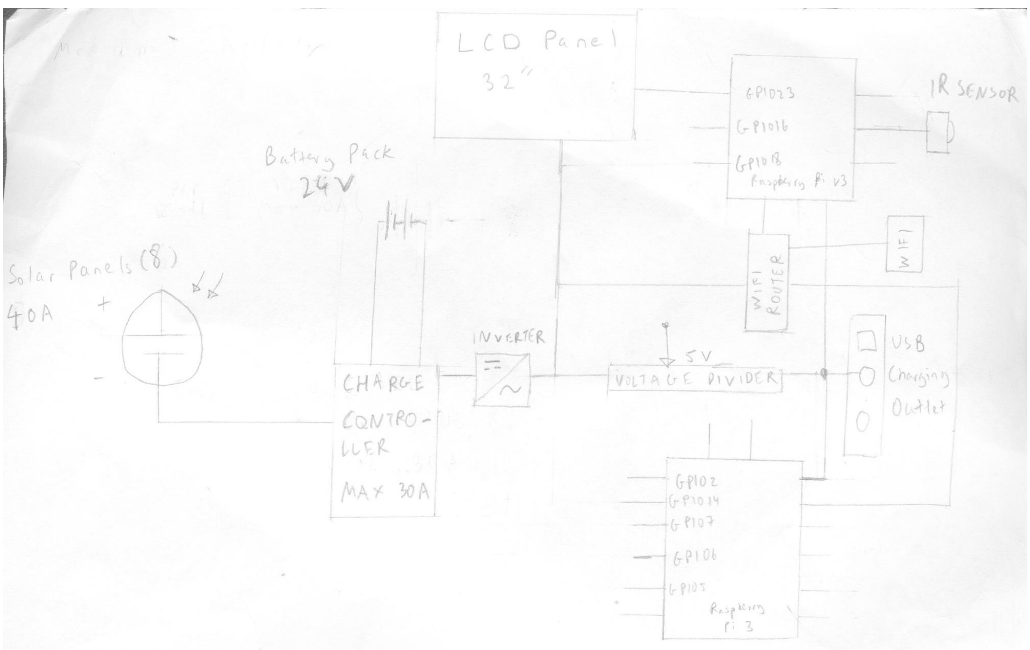


Figure 64: Large sized shelter circuit schematic

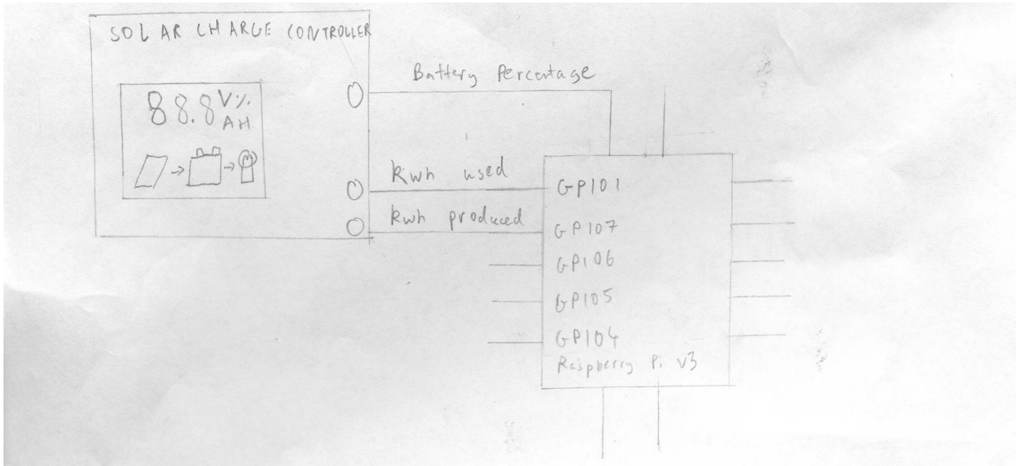


Figure 65: Serial connection between Raspberry Pi and charge controller

The diagram above represents the serial connection where data such as battery percentage and kilowatt-hour used and produced is transferred to the Raspberry Pi from the charge controller.

2.3.3 CVP & Logline

A large component of our work was in communicating our process to TCAT, so as they would trust the results of our analysis. As a primary communication tool, a customer value proposition (CVP) and log lone were both developed so as to quickly communicate the value of our work, as included below.

Log Line:

A solar energy power system provides a clean and sustainable energy source for powering electric components for the bus shelter through the use of a solar panel on top of the shelter roof. The inclusion of the solar panel enables the education of sustainability to the community through showing the live data of power generation on the display.

CVP

It was identified that the top needs of the system for the system were the following: the power source shall be clean energy source; power system shall be affordable in long-term run; power system shall be easily maintained; power system shall be sustainable and continuously improved in terms of its efficiency and reliability.

In order to meet the need of having a clean energy source, the solar panel was added.

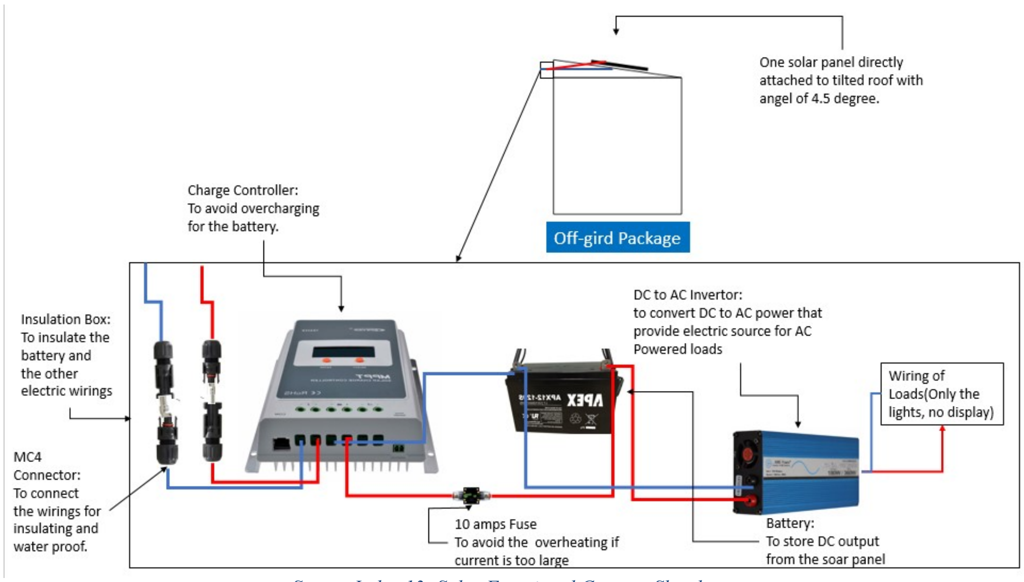
In order to meet the need of long term affordability, the functionality of selling back to the electricity company when electricity is overproduced was added.

In order to meet the need of sustainability education, the functionality of recording and displaying the electric usage information on the display was added.

System Index 12: Logline and CVP for Solar

2.3.4 Off-Grid Package

The off-grid package consists of a solar panel flatly attached to the roof of the shelter. The electric wiring system includes a charge controller, fuses, battery, and DC to AC. The following concept sketch illustrates the functional design of the off grid package. The off-grid package is similar to the grid-tied package, except there is only one battery instead of two. The off-grid package is designed with one solar panel and one battery to power a 20 W light without backup power. This decision is explained via calculations on the following pages.



System Index 13: Solar Functional Concept Sketch

2.3.4.1 Off-Grid Electric Loads & Components

The off-grid model's solar setup is designed to provide lighting, which was deemed the only necessary electronic amenity for stops with minimal use. The off-grid system will be set up to offer two separate light systems. The first lighting system is referred to as the "security" lighting. It will be on from dusk to dawn, about 10 hours per day in total. The security lights are 10 W, and produce roughly 600 to 700 lumens, equivalent to the amount of light produced by a "low-beam" car headlight. This system's function will primarily be to illuminate the stop, and provide a sense of safety. Additionally, the off-grid stops will include a second system of 10 W lights, which will be motion activated. Once users enter the stop, this secondary light source will power on, providing close to 1300 lumens, or around the strength of a "high-beam" car headlight. The secondary system will provide the light necessary for the users to clearly read system maps, and is estimated to be on for roughly three hours a night.

The simplicity of these systems allows for the implementation of minimal electrical components. Each off-grid stop will be fitted with one solar panel and battery, as well as a simple charge controller and inverter system which will produce the necessary power to run the light systems mentioned above.

2.3.4.2 Off-Grid Package Feasibility

In order to understand whether the off-grid package design is feasible to power the required loads: the 10 W safety load and additional 10 W motion-activated load, the solar subteam completed a power production feasibility analysis. The calculation in this analysis involves two parts: the total AC real power production (in Watt hours) and the total power required for lights (in Watt hours).

In addition, to understand whether the battery selection is feasible in terms of the longevity of running the off-grid power system without energy input. This analysis is important because it helps the team to understand how many days the solar power system would work in extreme sceneries that have no any solar energy input to the system.

The AC Real Power Production:

$$\boldsymbol{Written\ Power\ on\ the\ Solar\ Panel = 280W;}$$

$$\boldsymbol{Number\ of\ Solar\ Panel\ in\ the\ Off-Grid\ Package = 1}$$

$$\boldsymbol{1\ DC\ Power\ in\ watts\ hour = 4\ AC\ Power\ in\ watts\ hour}$$

$$\boldsymbol{The\ AC\ Energy\ Loss = 30\%}$$

$$\begin{aligned}\boldsymbol{Total\ AC\ Real\ Power\ Prodution}\\ &= \boldsymbol{Written\ Power \times Number\ of\ Solar\ Panel\ \times DC\ to\ AC\ Power\ Ratio}\\ &\times \boldsymbol{AC\ Energy\ Loss = 280\ wh \times 1 \times 4 \times (1-30\%) = 780\ wh}\end{aligned}$$

The above calculation result gives that the AC real power production of the off-grid package is 784 Wh.

The Total Power Required for Lights:

$$\boldsymbol{Wattage\ of\ Security\ Light = 10\ watts}$$

$$\boldsymbol{Security\ Light\ Operational\ Hour = 10\ hours}$$

$$\boldsymbol{Wattage\ of\ Additional\ Lights\ with\ Motion-activated\ Profile = 10\ watts}$$

$$\boldsymbol{Additional\ Lights\ Operational\ Hour = 10\ hours}$$

$$\boldsymbol{Estimated\ Utilization\ of\ Additional\ Lights = 30\%}$$

$$\begin{aligned}\boldsymbol{Total\ Power\ Required\ for\ Lights}\\ &= \boldsymbol{Wattage\ of\ Security\ Light \times Security\ \ Light\ Operational\ Hour}\\ &+ \boldsymbol{Wattage\ of\ Additional\ Lights\ with\ Motion-activated\ Profile}\\ &\times \boldsymbol{Additional\ Lights\ Operational\ Hour}\\ &\times \boldsymbol{Estimated\ Utilization\ of\ Additional\ Lights}\\ &= \boldsymbol{10\ watts \times 10\ hours + 10\ watts \times 10\ hours \times 30\% = 130\ wh}\end{aligned}$$

The above calculation result gives that the total power required for lights in the off-grid package is 130 Wh.

Result of Power Production Feasibility Analysis:

The surplus of power production is 650 Wh, which means the AC real power production of the off-grid package exceeds the power required in the off-grid package. Therefore, the power production of the off-grid design is feasible to power the lights requirement for the small bus shelter modulus.

Off-Grid (Daily):
Total AC Real Power Production : 780Wh
–
Total Power Required for Lights: 130Wh

The Surplus of Power Production: = 650

Feasibility Analysis on the Battery Selection

$$\textit{Capacity of Battery} = 120Ah$$

$$\textit{Number of Battery} = 1$$

$$\textit{Percentage of Capacity Reducted for Battery Protection} = 40\%$$

$$\textit{Percentage of Capacity Loss} = 15\%$$

$$\textit{The voltage of the loads} = 12V$$

$$\textit{The total Capacity Required} = \frac{\textit{The Power Required for Loads}(wh)}{\textit{Voltage of the Loads }(v)} = \frac{130wh}{12v} = 11\ Ah$$

$$\begin{aligned}\textit{The Real Battery Capacity} &= \textit{Capacity of Battery} \times \textit{the Number of Battery} \\ &\times \textit{the Percentage of Capacity Reducted for Battery Protection} \\ &\times \textit{Percentage of Capacity Loss} = 120Ah \times 1 \times (1 - 40\%) \times (1 - 15\%) = 61Ah\end{aligned}$$

Result of Battery Selection Feasibility Analysis:

The capacity required to power the lights is 11 Ah. The real battery capacity in the off-grid design is 61Ah, which is 5.6 times the capacity required for the off-grid system. This calculation result means that if there is no solar energy input, such as extreme weather, for a fully charged battery, the off-grid system should be able to work at least 5 days.

Off-Grid (Daily):

$$\frac{\textbf{Real Battery Capacity : 61Ah}}{\textbf{Total Capacity Required: 11Ah}} = 5.6$$

2.3.5 Showcase Packages

2.3.5.1 Translucent Solar Panels

The team has been in contact with a solar company based out of Colorado that sells translucent solar panels. The panels contain 60 cells (6 by 10) and generate 285 Watts each. The panels are unique in that they can double as a roof structure, which eliminates the need for spending on roofing and panels on the medium and large grid tied panels. The panels will allow for natural light, and can also generate power, an innovative two-for-one system.

The large shelter will contain eight of the LSX panels, for a grand total of 2,280 Watts generated, while the medium shelter will have six panels totaling 1,710 Watts generated. Each of the panels costs approximately $500 including racking systems. If the price is too large for a given shelter, Lumos also offers “blank” panels which are completely transparent and contain no solar cells. These would decrease the amount of solar energy generated, but would also greatly reduce solar costs.

Lumos has worked on similar projects in the past and is more than willing to help out in any way they can. If the shelters are purchased in bulk, it would be possible to get decreased rates.

2.3.5.2 Solar Panel Simulations

The proposed design for the large and medium shelters is to have two solar panels in series and each branch connected in parallel. The large shelter will have 8 total panels, while the medium shelter will have 6 total panels. Each Lumos LSX panel is rated to be 10 A and 40 V, so the medium and large shelters will have output of 30 A and 80 V, and 40 A and 80 V respectively.

By using Rhino and Grasshopper simulation software, we were able to forecast the incoming solar radiation on each solar panel given the location at A-Lot on Cornell's campus with our roof pitch of 4.5 degrees. Below is an image of the result.

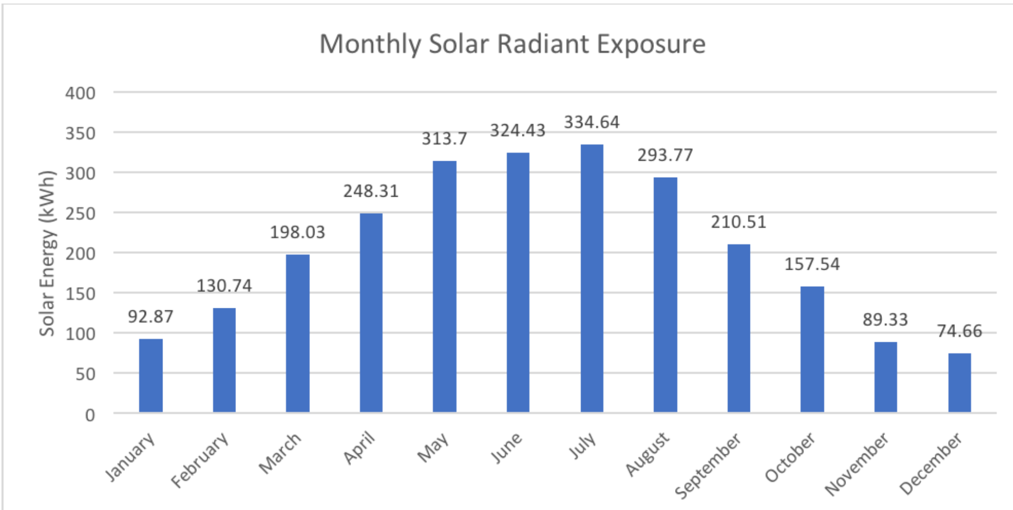


Figure 66: Data collected on one 3'-3" x 6'-6" solar panel

2.3.5.3 Simulation Analytics

The first step in our calculations was to assess all of the possible loads our solar panel system will have to sustain. These appliances would be relevant for both the medium and large shelters for the same approximate time frames. The length that each appliance was assumed to be powered on was determined by assuming TCAT operates 21 hours a day and that our incorporated IR sensor would diminish the amount of time appliances such as lights and charging outlets. To solve for the amount of energy used by the appliance, the wattage rating of the device is multiplied by the number of hours the device is assumed to be on. There is a 30% energy loss considered in our calculations due to inefficiencies due to the innate resistivity of wires and power conversion in devices. The W-h rating for each device is then totaled to solve for the total daily energy consumption of the medium and large shelters as 3.868 kWh.

Type of Load	Watts	W-h	**Time Assumed On (hr)**
LCD	90	1080	12
LCD Encloser	8	96	12
LED Lights	60	1260	21
Motion Sensor	7	28	24
Charging Outlet	20	60	3
2x Rasberry Pi's	20	240	12
Wifi Router	20	240	12
Total	218	2976	
30% Energy Loss		892.8	
Total with loss		**3868.8**	

Figure 67: Loadings per component and total daily energy consumption table

By taking the amount of incoming solar energy for a panel each month, multiplying by the number of panels per shelter, and multiplying by an efficiency factor of 19% for the LSX solar panels, we can determine the amount of energy expected to be produced monthly. The loads are calculated to be daily, so the energy produced must be divided by 31 days to achieve a daily average. We would prefer to see that the total power produced on a daily average during the month will be greater than the power consumed. By assuming a purchase rate of energy of $0.10 / kWh and sell back of $0.13 / kWh as stated on National Grid's website, we can solve for the projected yearly energy cost for both the medium and large shelters.

Month	Power Consumed (kWh)	Power Produced Per Panel (kWh)	Total Power Produced (kWh)		Net (kWh)		Profit Per Year ($)	
			Medium Shelter	Large Shelter	Medium Shelter	Large Shelter	Medium Shelter	Large Shelter
January	3.869	0.569	3.414	4.552	-0.455	0.683	-1.83365	2.75249
February	3.869	0.801	4.806	6.408	0.937	2.539	3.77611	10.23217
March	3.869	1.214	7.284	9.712	3.415	5.843	13.76245	23.54729
April	3.869	1.521	9.126	12.168	5.257	8.299	21.18571	33.44497
May	3.869	1.923	11.538	15.384	7.669	11.515	30.90607	46.40545
June	3.869	1.989	11.934	15.912	8.065	12.043	32.50195	48.53329
July	3.869	2.051	12.306	16.408	8.437	12.539	34.00111	50.53217
August	3.869	1.801	10.806	14.408	6.937	10.539	27.95611	42.47217
September	3.869	1.291	7.746	10.328	3.877	6.459	15.62431	26.02977
October	3.869	0.966	5.796	7.728	1.927	3.859	7.76581	15.55177
November	3.869	0.548	3.288	4.384	-0.581	0.515	-2.34143	2.07545
December	3.869	0.4575	2.745	3.66	-1.124	-0.209	-0.3379	-0.84227
						Total:	182.96665	300.73472

Figure 68: Revenue stream from solar power electricity generation

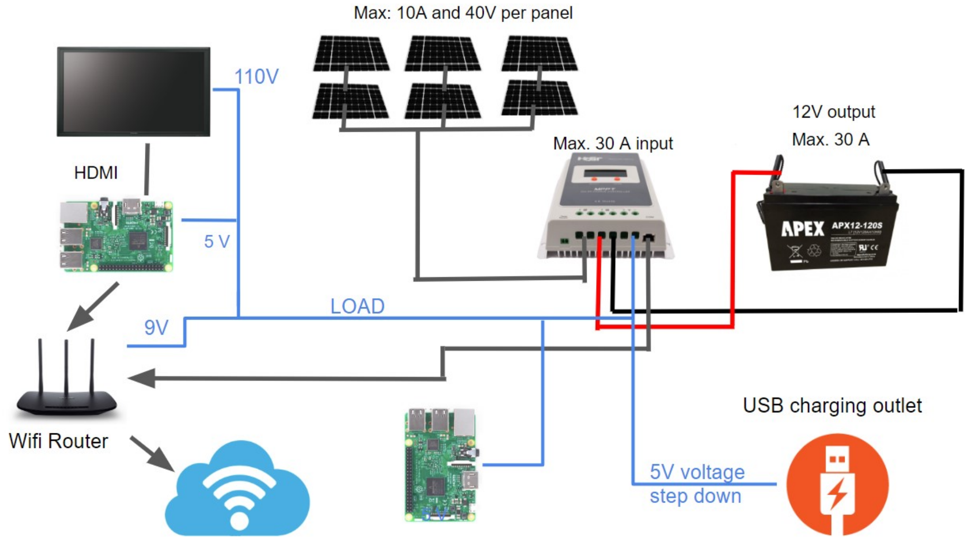


Figure 69: One line diagram of all components in a Smart shelter

In order to connect our solar panel system to the internet to monitor the shelter's battery level and power output, we decided to incorporate two Raspberry Pi's along with WIFI router. The one Raspberry Pi is responsible for parsing the serial line communication data from the charge controller to save a database for maintenance records via an online server, while the other Raspberry Pi will control the LCD display to update the images shown on the screen.

We have been encountering technical difficulties implementing modbus communication between the solar charge controller and the raspberry pi, which have led us to believe that the charger controller we ordered for prototyping has a defective serial communication port. We have ordered a new charge controller and will proceed to connect it to our Raspberry Pi.
While waiting for the new charge controller to be delivered, we have begun developing the parsing code to acquire the needed information from the charge controller by using similar projects as a reference on GitHub. Once the charge controller arrives, we will begin testing and debugging our code and begin establishing a web database that will store data from the charge controller chronologically.

2.3.5.4 LCD Monitor / Enclosure

When it came to decision-making in terms of choosing the best LCD monitor as well as the enclosure we decided to do that based on two major factors: the cost in terms of dollars as well as the wattage which is the power consumed by the component. All the enclosures we looked at were weatherproof and had some sort of thermostatic heater that would regulate the temperature for the LCD monitor housed inside the enclosure. Below is an analysis chart employed to assess which of the enclosures found were the best.

Enclosures	Cost in $	Wattage
PDS-32-W-L-US	1795	34 W
U3200HDL	2599	165 W (w/o heater)
https://www.deertv.com/products/32-43-outdoor-tv-enclosure?variant=51876334483	588	Less than 8W
http://www.thetvshield.com/tv-display-enclosures/residential-outdoor-tv-enclosures/30-40-outdoor-tv-enclosures/the-tv-shield-30-40-weatherproof-tv-enclosure/	549.99	Unknown

Figure 70: Table of potential enclosures for the LCD Monitor and some specifications

Although the last enclosure had the lowest cost in terms of dollars, it was not very aesthetically pleasing. However aesthetics are an important metric, so keeping that in mind we went with the “deertv” enclosure (see below).

Figure 71: DeerTV LCD enclosure

For the LCD Monitor, we have settled on the Sceptre 32" Class HD (720P) LED TV (X322BV-SR). This is the most cost effective as it is worth $89.99 and has maximum power consumption of 90 W.

Figure 72: Various cell patterns for the same physical size of the solar panel supplied by Lumos

2.4 Business

2.4.1 Cost Structure and Estimates

A new cost breakdown was developed this semester to account for the updated supplies list and shed light on how much each size of the shelter would cost. We found that even with the additions of electronic and solar components to our medium and large shelters, the cost of the final product would still be under the average cost of a comparable shelter on the current market (upwards of $10,000 each).

	Large + Solar + LED	Medium + Solar + LED	Small	Medium Barebones
Subframe Components	958	784	1,140	610
Roof Frame Components	1,425	1,140	924	799
Side Panels	1,630	1,473	1,473	796
Mainframe Components	1,467	1,223	1,223	1,141
Roof	-	-	784	979
Electronic Components	1,956	1,422	-	-
Solar Panels	2,464	1,848	-	-
Cost Per Unit	**$9,899.55**	**$7,889.89**	**$5,543.89**	**$4,325.10**

Figure 73: Cost estimate of the different shelter sizes

Below are our sales projections for the next five years for each of the shelter models, which we used to inform our income statement project as well.

Sales	2019	2020	2021	2022	2023
Small	-	13,840	20,760	34,601	48,441
Medium Barebones	-	26,611	44,351	62,092	62,092
Medium + Solar + LED	-	25,248	50,495	75,743	100,991
Large + Solar + LED	31,679	31,679	47,518	47,518	63,357
Large Shelter Advertising	6,500	13,000	22,750	32,500	45,500
Total Sales	**38,179**	**110,377**	**185,875**	**252,453**	**320,380**

Figure 74: Five year sales projections for each shelter model

2.4.2 Business and Financial Models

We used the following business model canvas to define the vision and competitive value of our product, finding that our strengths lie primarily with our partnership with TCAT and having them as early adopters.

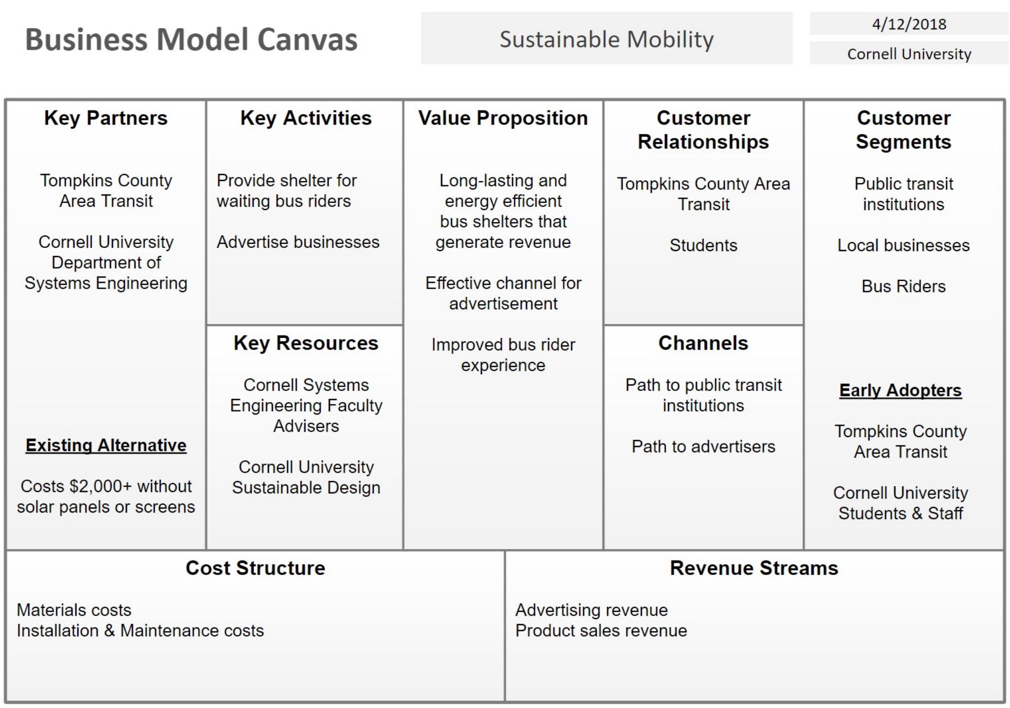


Figure 75: Business model canvas

Below is a projected income statement, which doesn't currently include revenue from advertising and solar sources. Current estimates put solar revenue at $227.96-$349.82 a year depending on the size of the shelter, and advertising revenue at up to $3,250 based on research on similar products. These revenue sources may balance out maintenance fees incurred by the shelters. Further development of a comprehensive advertisement model and maintenance costs are recommended for Fall 2018.

Income Statement	Year				
$	2019	2020	2021	2022	2023
Sales	38,179	110,377	185,875	252,453	320,380
Cost of Goods Sold	19,799	60,861	101,953	137,471	171,800
Gross Profit	**18,379**	**49,516**	**83,922**	**114,982**	**148,580**
Selling, General and Administrative Expenses (SG&A)	6,640	26,280	37,800	44,520	44,720
Research and Development Expenses (R&D)	35,000	30,000	25,000	25,000	25,000
Depreciation and Amortization (D&A)	-	-	-	-	-
Earnings Before Interest and Taxes (EBIT)	**(23,261)**	**(6,764)**	**21,122**	**45,462**	**78,860**
Interest Expense	1,250	1,250	1,250	1,250	1,250
Earnings Before Taxes (EBT)	**(24,511)**	**(8,014)**	**19,872**	**44,212**	**77,610**
Provision for Income Taxes	-	-	4,173	9,285	16,298
Net Income	**(24,511)**	**(8,014)**	**15,699**	**34,928**	**61,312**

Figure 76: Five year projected income statement

2.4.3 Grants and Sponsorships

In the Spring 2018 semester, the most significant award application was the Engineering Innovation competition particularly the Pao award for social innovation. The basis of the award is to grant $10,000 to a product that brings social innovation (benefits to a community) while having a sustainable business model. Below is our application for the award which was submitted April 20th alongside a short video "pitch."

The video pitch was a two and a half minute video that outlined the points mentioned in the application in a fun and concise manner. Sustainable Mobility was selected to move on to the final presentation round on May 7th, and the results are still to be determined. Some critical feedback for the project was to better identify the correlation of the shelter to an increase in ridership, and to develop a more expedited business model to target a larger market.

In addition, the Business subteam has been working with members of the CUSD Executive Board to create a sponsorship packet that will help CUSD teams to build structured partnerships with corporations. This initiative is in the finalization stage.

3 Lansing Routing

3.1 Fall 2017 & Work Progress to Date

Over the Summer of 2017, TCAT presented us with the task of defining the Lansing problem. Ridership on the 36, 37 and 77 routes was noticeably lower than other areas of similar population demographics. They shared their ridership data and it was clear that ridership for these routes had consistently been low for a few years as compared with other routes. We were tasked with determining why this was, as well as what could be changed to increase ridership. This task presented itself as a great opportunity to integrate Systems Design Thinking with Quantitative Methods, the integration of which is never done. The integration of complex human centered design and the mathematically rigorous process of quantitative analysis made this project all the more challenging and exciting because something like this had never been tried before.

Fall 2017 was initially spent working as one subteam, but we later divided into multiple teams. We first conducted traditional research (fact finding), finding as much information on Lansing as possible. Through our research we discovered two major items of interest; a report on transportation in Lansing from a past Design Connect project and the Lansing Comprehensive Plan. We then divided Lansing into separate fields of action for fieldwork. Next, we divided into teams of three and went out into the community to collect empathy data in the form of immersions, interviews and observations. After that, we divided into two groups, Systems Design Thinking and Quantitative Methods. The Systems Design Thinking group unpacked the empathy episodes and modeled the emotional data, while the Mathematical Modeling team worked to use algorithms and discrete numerical data to model the system and find possible improvements.

Spring 2018 was largely spent on improving our works from Fall 2017. We started the semester by working with our previous empathy fieldwork results to create 16 potential scenarios for the bus routes. We then rated each scenario by feasibility, complexity, accessibility, and efficiency. From here, we narrowed the 16 potential scenarios down to 3. At this point in the semester, we presented our findings so far to TCAT and several officials from the town and village of Lansing. We had a very successful presentation and received feedback from both TCAT and Lansing for where to proceed next. Using their feedback, we did some new empathy fieldwork in the locations that they seemed most interested in. We also developed new hotspots for Lansing based on this feedback.

Next we created a survey designed for the riders on Route 36 and Route 37. We initially distributed these to riders via getting on the buses and waiting at stops, but we did not get as many responses as we were looking for. Thus, over the course of the next week or so we sent a different team on every bus ride over the course of several days. Please note that we were not able to get any teams on the early morning routes. This, in combination with the survey being displayed on the TCAT website and being distributed through Michael Long, the Lansing Town Planning Consultant, resulted in over 70 responses. We then examined the data and performed statistical analysis of it, before finally coming to several recommendations for what TCAT ought to do to address the Lansing problem.

The initial solution process is shown in below Figure 77, while a high level view of the overall process is presented in Figure 78.

Figure 77: Initial Solution Process

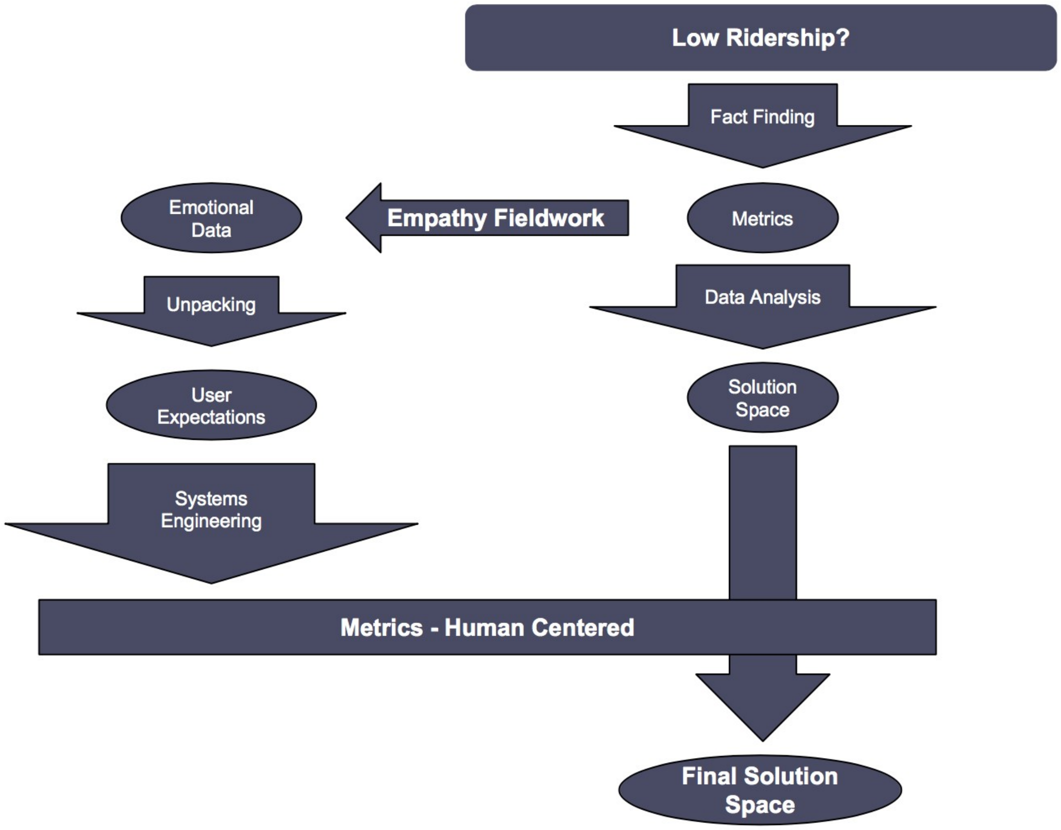
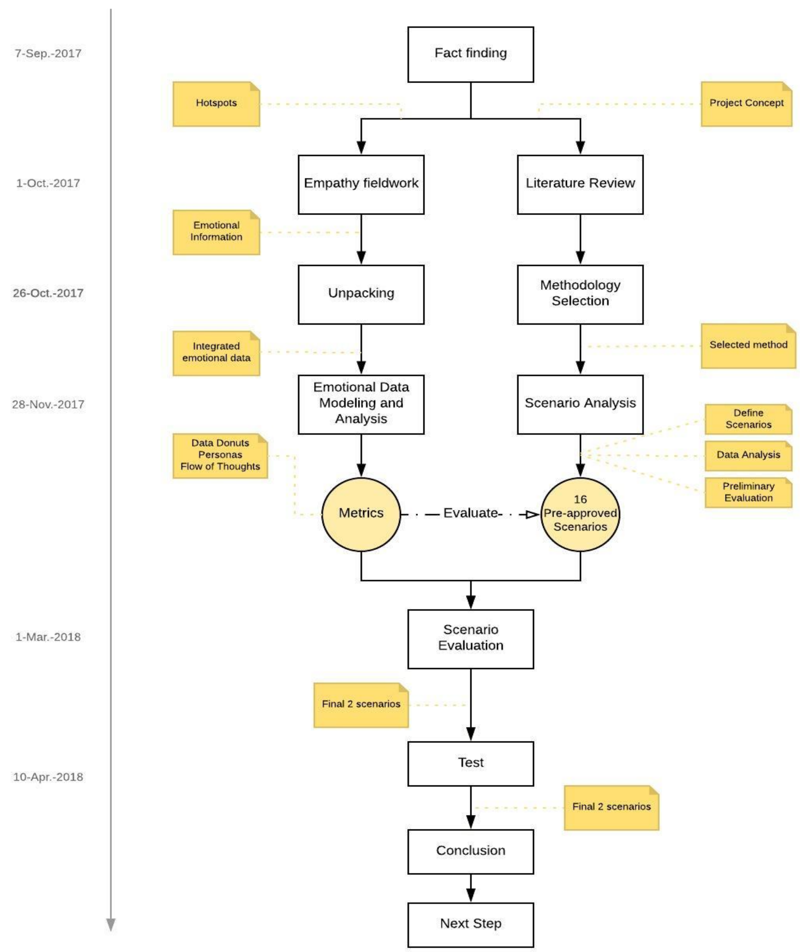


Figure 78: High Level View of our Process



Looking ahead to Fall 2018, we plan to integrate the findings from Systems Design Thinking and Scenario Analysis into the ideation phase. From there, we will collaborate with TCAT to find the most serviceable courses of action for the Lansing area.

3.1.1 Fact-Finding

Our traditional research phase consisted of the process known as fact finding.

Fact finding consisted primarily of individual research, with us coming together intermittently to share and examine all of our resources. This was especially helpful given our variety of different majors and backgrounds, enabling us to develop an understanding of Lansing and its surrounding areas.

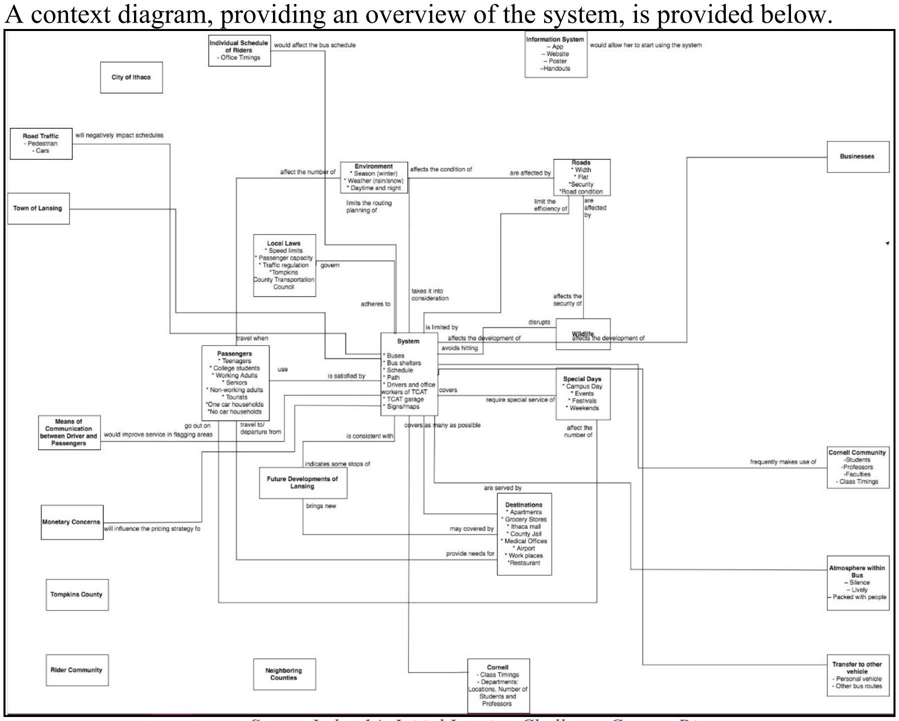
Some of the most useful data stemmed from a report developed by a separate Cornell group, Design Connect, that looked at transportation issues in Lansing in 2014. The report was devoted to general transportation, providing excellent data about potential TCAT modifications. This report is titled: Transportation Issue Assessment and Best Practices Guide Town of Lansing, New York.

Another informative document that aided our research was the Lansing Town Comprehensive Plan, which had recent government statistics and information on the type of people we could expect to find in Lansing. The Comprehensive Plan also included a section about future transportation aspects and mentioned the results of the previous Design Connect team.

Both the Design Connect report and the Comprehensive Plan provided us with a solid background on Lansing and its current transportation usage.

Ultimately, the discovery of the Design Connect report and the Comprehensive Plan led us to a Lansing Town Hall Comprehensive Plan Meeting. Here, we were able to discuss possible future communication with the Town Planning Board in regard to our project, and any future development in Lansing that we should consider as well. We were also able to talk with residents who were at the meeting, and they were able to provide us with crucial feedback for suggestions about how to improve the current bus route system.

A context diagram, providing an overview of the system, is provided below.



System Index 14: Initial Lansing Challenge Context Diagram

3.1.2 Systems Design Thinking

3.1.2.1 Empathy Fieldwork

Empathy fieldwork is a design process that employs three methodologies: immersion, engagement, and observation, in order to inform the design by better understanding the people we are designing for. The immersion portion of the process placed our team members into the shoes of the diverse demographic that uses the routes. In order to do so, we rode Route 36, Route 37, and Route 77, which make up the main components that service Lansing at different times of day. During the immersion experience we focused on our emotions and user experience in order to better understand the bus network on a personal, human-scale. By envisioning ourselves to be someone who routinely uses the bus, we were able to contextualize our bus trips, taking notes and pictures, in order to identify our own emotions and thoughts throughout our experience. The engagement portion of the process was approached from a second person perspective. The purpose of engagement is to conduct interviews in order to discover the stories and perspectives of users. For this portion of empathy fieldwork, we conducted interviews with people in the existing Cornell community who use the Lansing bus routes and conducted random interviews with people while taking the buses. For the final part of empathy fieldwork, we observed the people using the bus from a third-person perspective. We observed the behaviors of our fellow bus riders, taking note of how people interact with their environment as well as each other.

3.1.2.2 Lansing Fields of Action and Hotspots

In order to maximize our empathy fieldwork, we broke down the regions of Lansing and the different bus routes that service it, identifying them as individual fields of action. The fields of action selected were: 1) Rural Lansing 2) Lansing Town Center 3) Commercial Hub 4) Route 77 5) Route 37 6) Route 36 and 7) Analogous Setting.

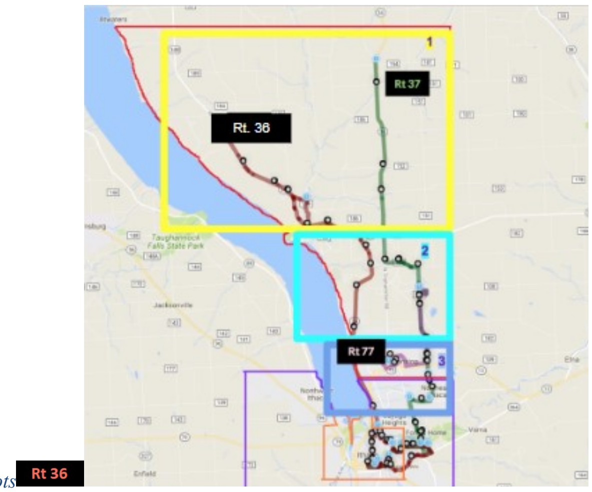


Figure 79: Lansing Hotspots

In order to be as efficient as possible with our empathy fieldwork, we researched and designated predicted "hotspots", or places we believed to be centers of activity. These were generally cafes, commercial centers, or places of local governance, but we also considered the park and ride areas and the transportation nodes as hotspots. As we performed empathy fieldwork, it was not uncommon for our hotspot focuses to change as we learned more about the system and the local community.

3.1.2.3 Fieldwork

Our team split into sub-groups of three, with each team appling the empathy fieldwork process to a specific field of action. One subgroup was assigned to each bus route, and those team members employed the immersion, engagement, and observation methods in order to gather information on the bus routes. Other sub-groups took on geographic regions, seeking both formal and informal community centers, utilizing the empathy fieldwork process in order to contextualize the Lansing community's existing relationship with the bus routes and the Lansing community values.

3.1.2.4 Unpacking Empathy Fieldwork

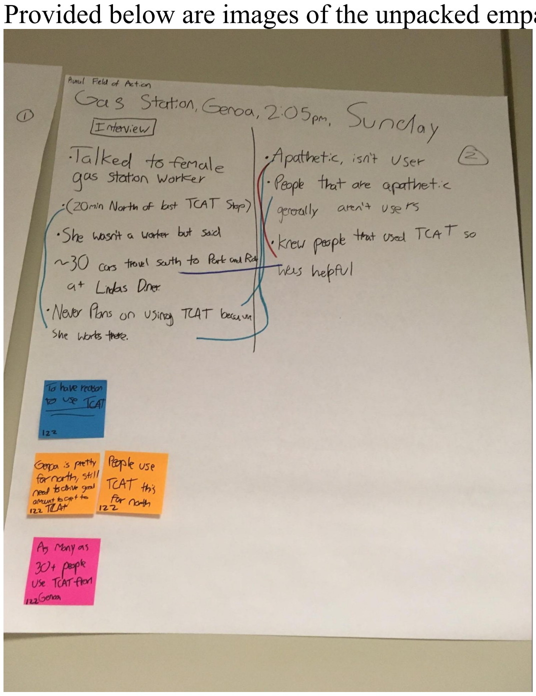
After the end of the empathy fieldwork process, the group members for each field of action regrouped, and began to unpack the information obtained during the fieldwork. In this process, each empathy fieldwork group created multiple poster sheets (shown on the following pages), detailing their experiences with each empathy episode in both words and pictures. Each empathy episode was categorized according to the three modes of empathy: immersion, engagement, and observation. On each of these sheets, the top half is split into two columns. These two columns reflected different aspects of each mode of empathy, with the left being more factual and observation-based, and the right being more based on inference and conjecture. For immersion, the left column contained facts, and the right column contained our own emotions. For observations, the left column contained the what and how of that particular situation, while the right column detailed why that event occurred. For engagement, the left column describes how the interviewee acted and how they spoke, while the right column details their feelings and beliefs.

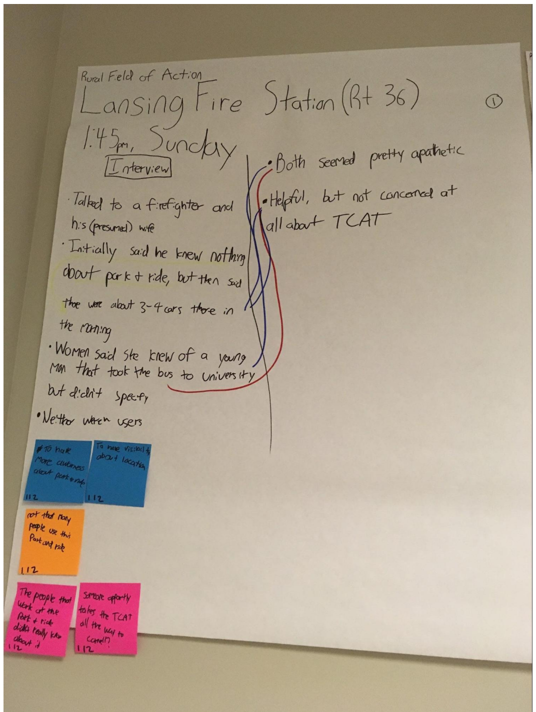
After recording these findings down on the top half of the poster sheet, team members used color-coded markers to highlight and classify the connections and contradictions between the statements recorded on a particular sheet.

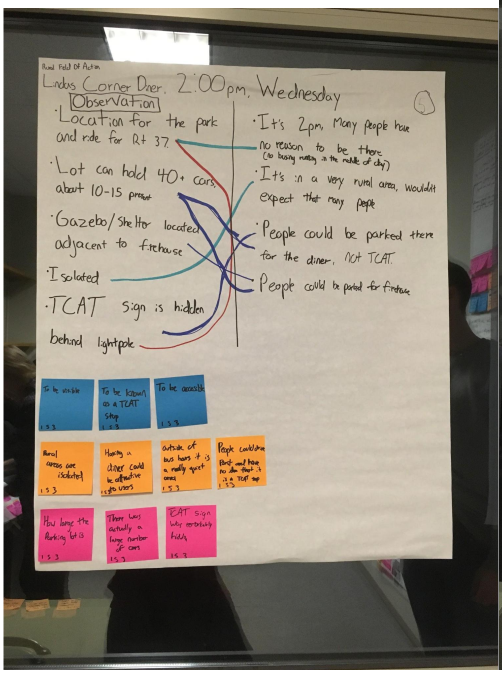
Pages 90-98 contain images of the unpacking of the empathy fieldwork.

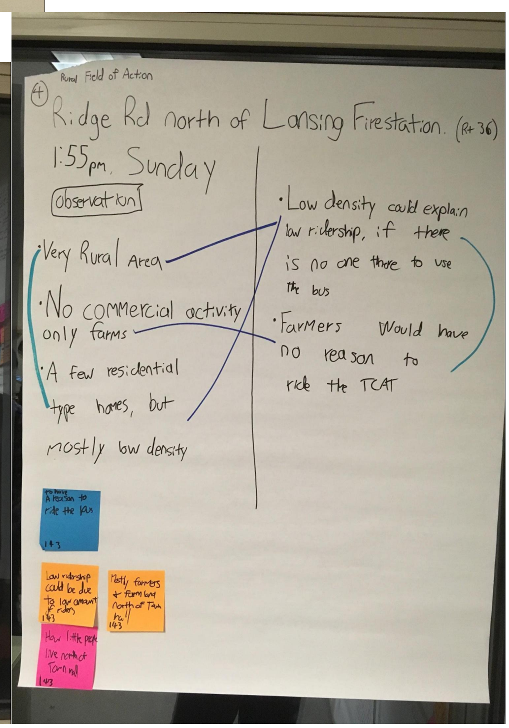
Rural Lansing

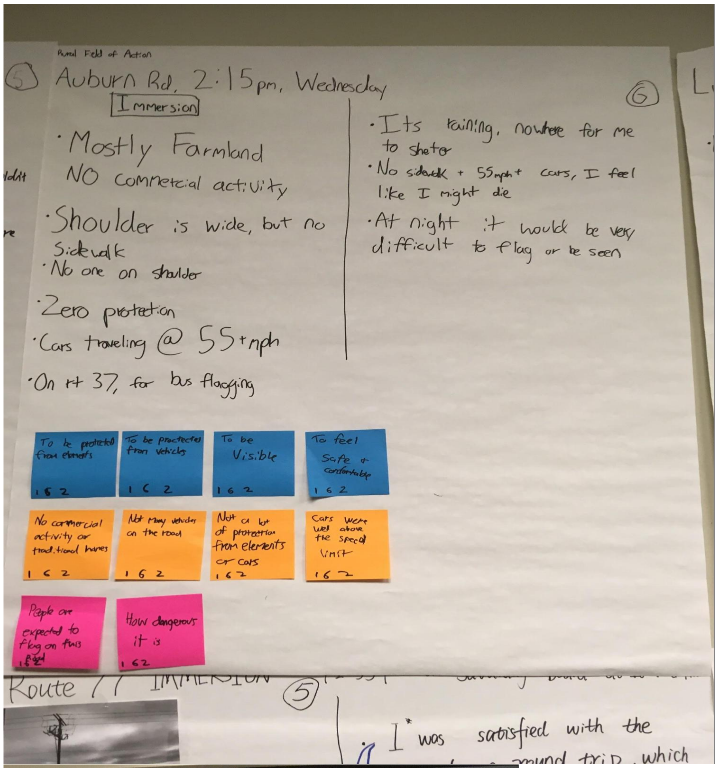
Provided below are images of the unpacked empathy data for Rural Lansing.

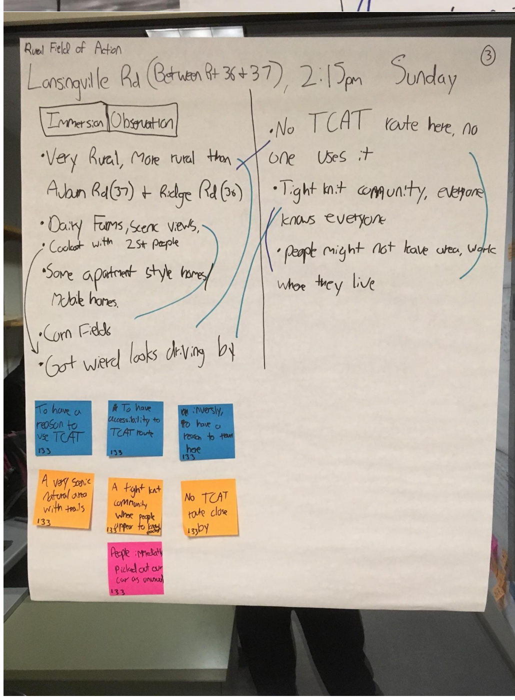


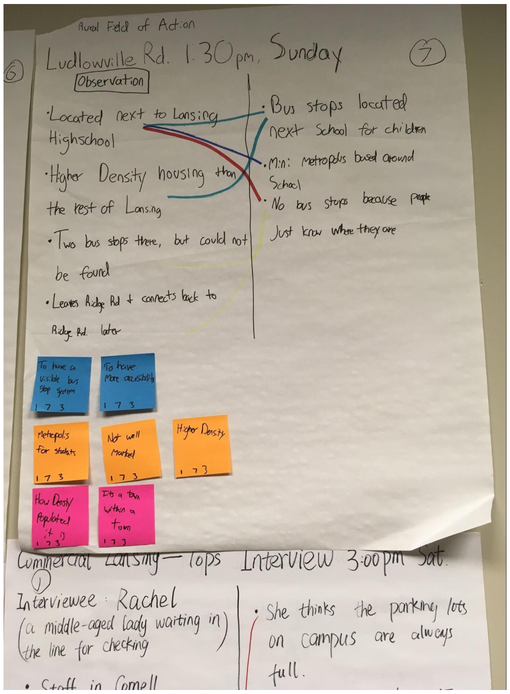

Rural Field of Action
Lansing Fire Station (Rt 36)
1:45pm, Sunday
Interview
·Talked to a firefighter and his (presumed) wife
·Initially said he knew nothing about park + ride, but then said there were about 3-4 cars there in the morning
·Women said she knew of a young man that took the bus to university but didn't specify
·Neither were users
·Both seemed pretty apathetic
·Helpful, but not concerned at all about TCAT
not that many people use the Park and ride
1.1.2


Rural Field of Action
Ludlowville Corner Diner. 2:00pm. Wednesday
Observation
·Location for the park and ride for Rt 37
·Lot can hold 40+ cars about 10-15 present
·Gazebo/Shelter located adjacent to firehouse
·Isolated
·TCAT sign is hidden behind lightpole
·It's 2pm, many people have no reason to be there
·It's in a very rural area, wouldn't expect that many people
·People could be parked there for the diner, not TCAT
·People could be parked for firehouse
To be visible
To be known as a TCAT stop
To be accessible
Rural areas are isolated
How large the parking lot is


Rural Field of Action
Ridge Rd north of Lansing Firestation (Rt 36)
1:55pm Sunday
observation
·Very Rural Area
·No commercial activity only farms
·A few residential type homes, but mostly low density
·Low density could explain low ridership, if there is no one there to use the bus
·Farmers would have no reason to ride the TCAT

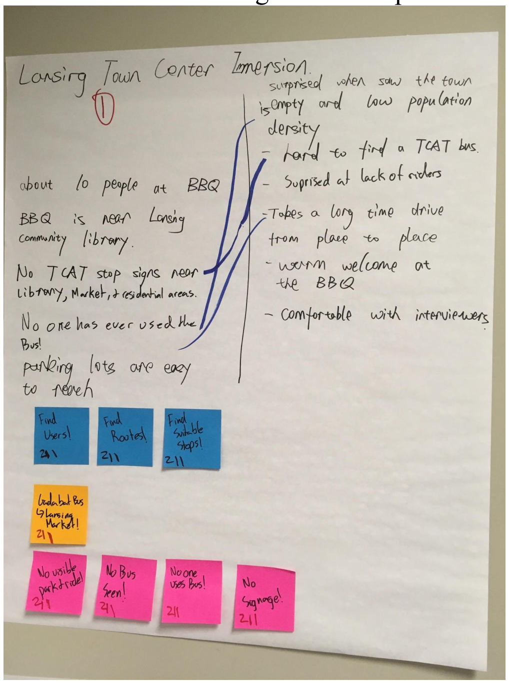

Rural Field of Action
Auburn Rd, 2:15pm, Wednesday
6
Immersion
·Mostly Farmland
NO commercial activity
·Shoulder is wide, but no Sidewalk
·No one on shoulder
·Zero protection
·Cars traveling @ 55+mph
·On rt 37, for bus flagging
·Its raining, nowhere for me to shelter
·No sidewalk + 55mph+ cars, I feel like I might die
·At night it would be very difficult to flag or be seen
To be protected from elements
To be protected from vehicles
To be Visible
To feel Safe + comfortable
No commercial activity or traditional homes
Not many vehicles on the road
Not a lot of protection from elements or cars
Cars were well above the speed limit
People are expected to flag on this road
How dangerous it is
Route 77 IMMERSION
5
I was satisfied with the

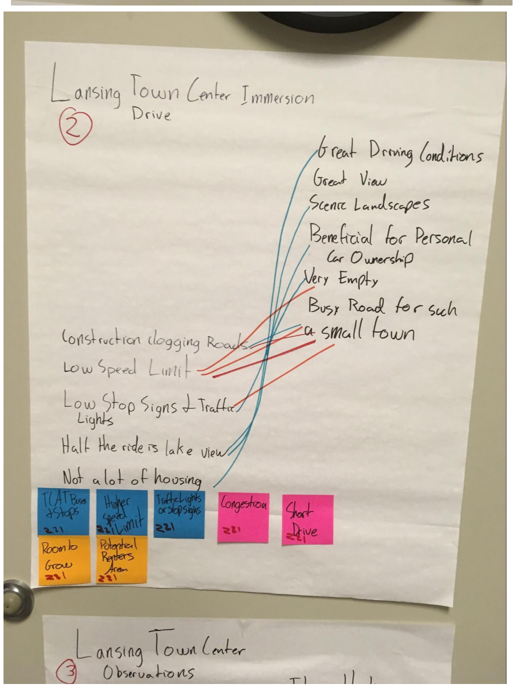

Rural Field of Action
3
Lansingville Rd (Between Rt 36 + 37), 2:15pm Sunday
Immersion | Observation
·Very Rural, More rural than Auburn Rd (37) + Ridge Rd (36)
·Dairy Farms, Scenic views,
·Cookout with 25+ people
·Some apartment style homes/ Mobile homes.
·Corn Fields
·Got weird looks driving by
·No TCAT route here, no one uses it
·Tight knit community, everyone knows everyone
·People might not leave area, work where they live
To have a reason to use TCAT
To have accessibility to TCAT route
No TCAT route close by

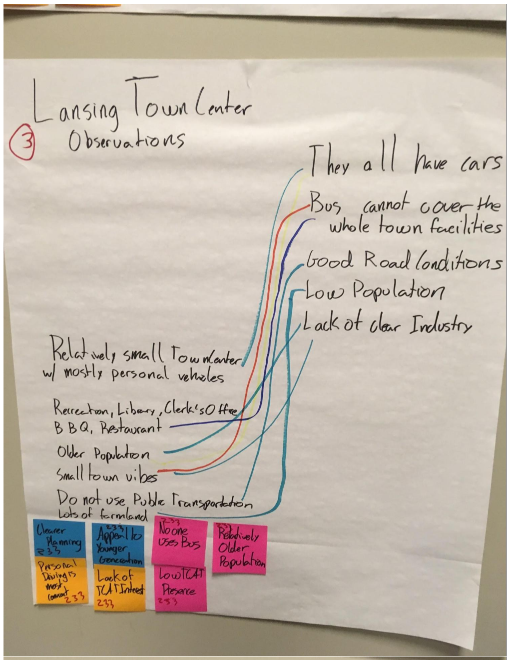


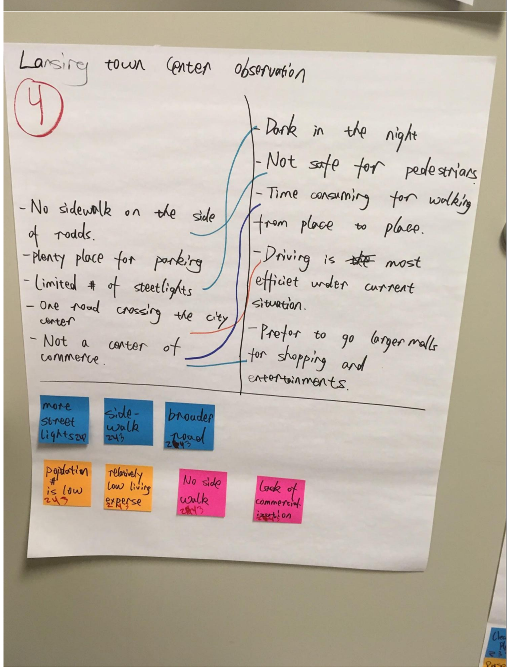
Lansing Town Center

Provided below are images of the unpacked empathy data for the Lansing Town Center.



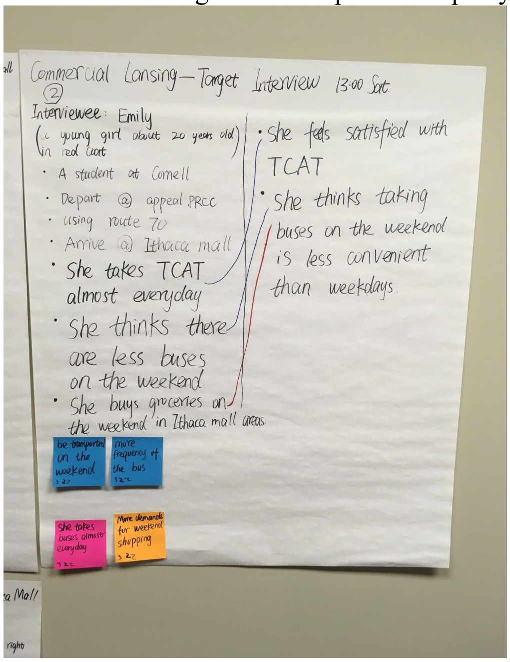




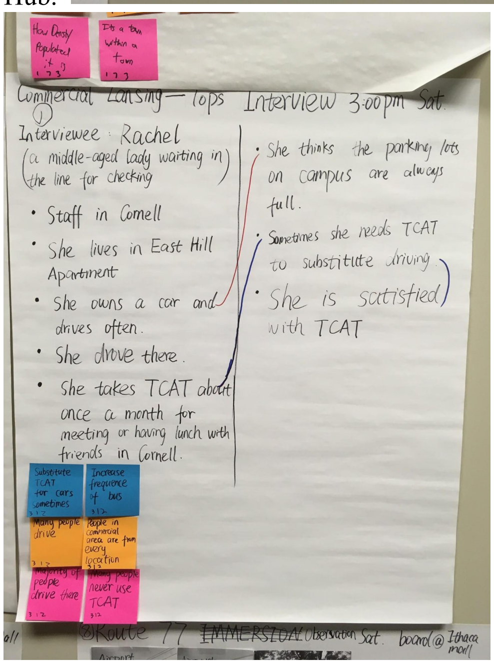


Lansing Commercial Hub

Provided below are images of the unpacked empathy data for the Lansing Commercial

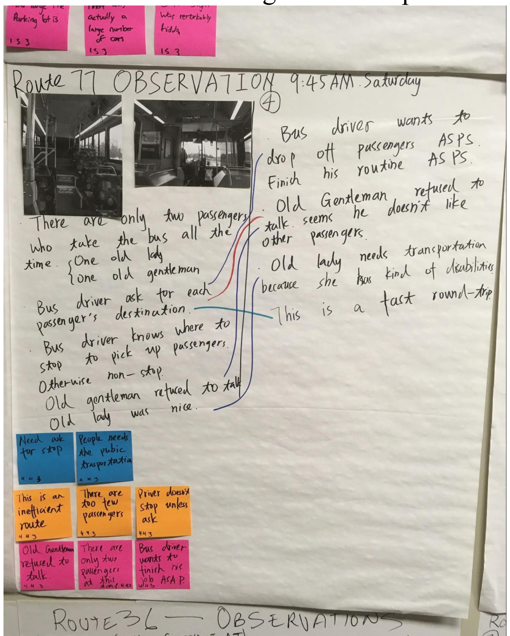


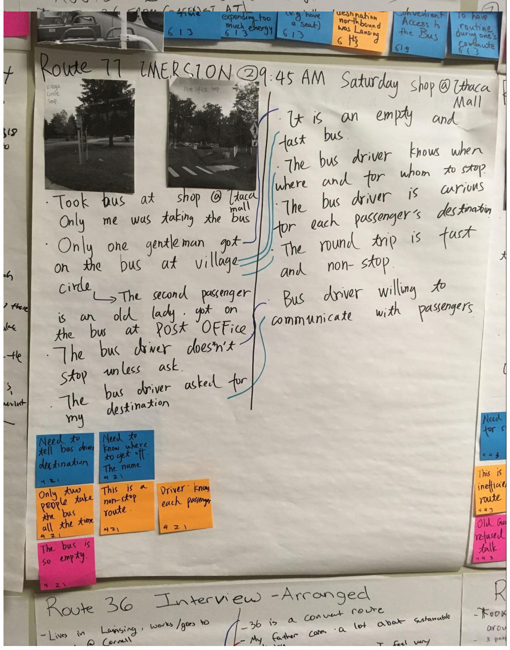
Hub.

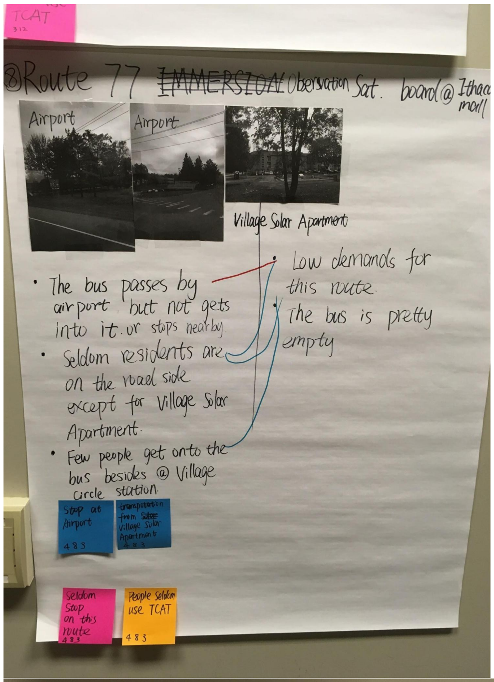


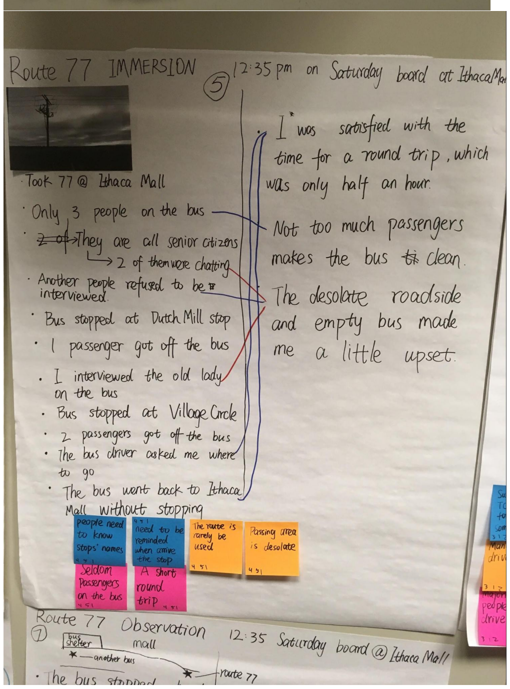
Route 77

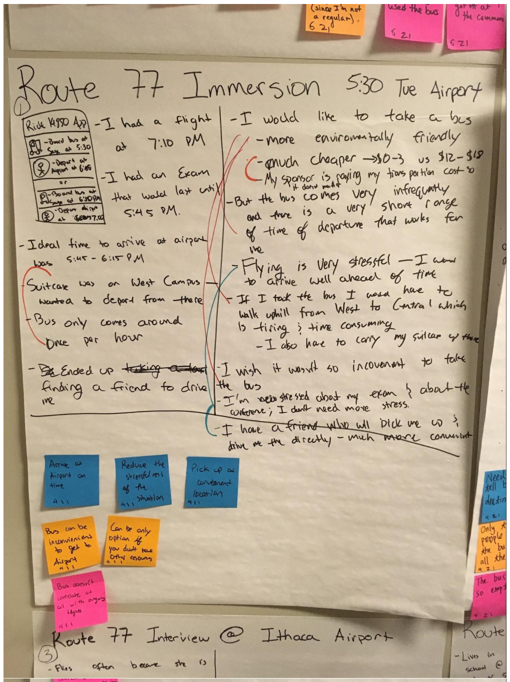
Provided below are images of the unpacked empathy data for Route 77.

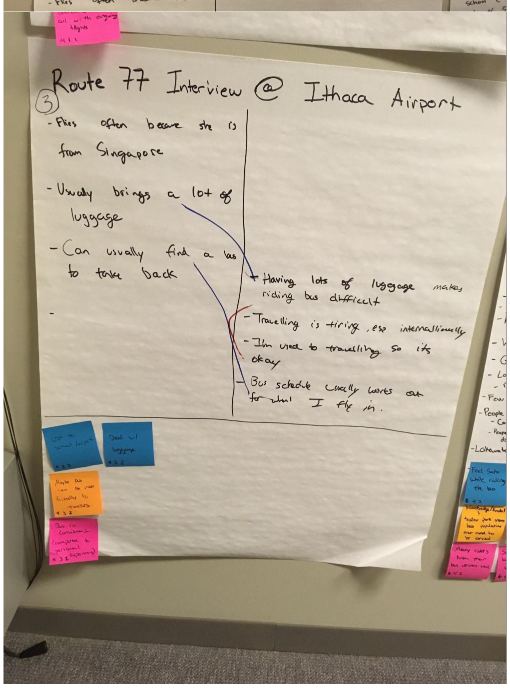


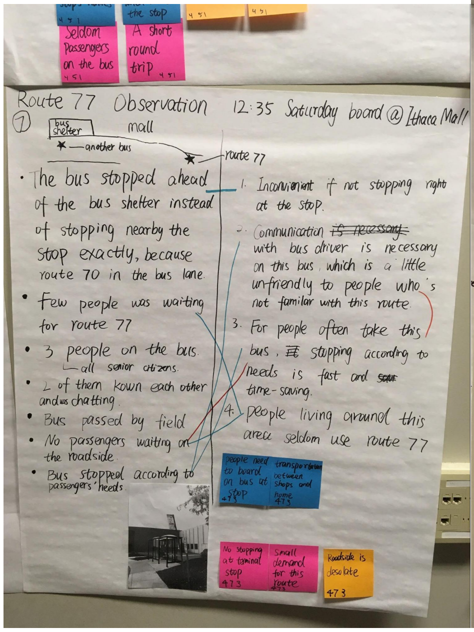


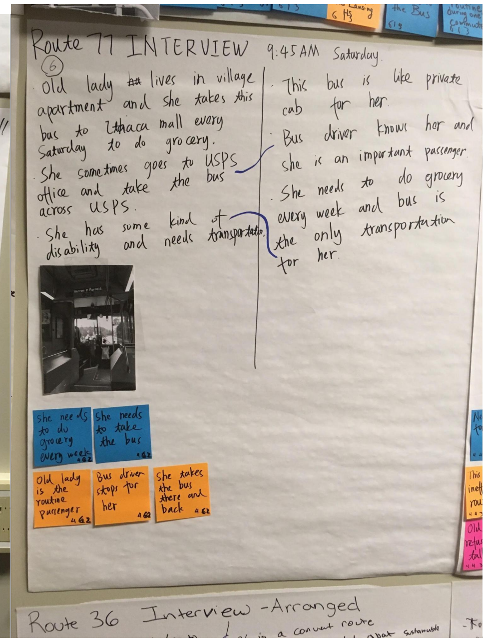

TCAT
Route 77 ~~IMMERSION~~ Obersvation Sat. board @ Ithaca mall
Airport
Airport
Village Solar Apartment
Low demands for this route
The bus is pretty empty
The bus passes by airport but not gets into it or stops nearby
Seldom residents are on the road side except for Village Solar Apartment.
Few people get onto the bus besides @ Village circle station.
Stop at Airport
Seldom Stop on this route
People seldom use TCAT


Route 77 IMMERSION
12:35 pm on Saturday board at Ithaca Mall
Took 77 @ Ithaca Mall
Only 3 people on the bus
They are all senior citizens
2 of them were chatting
Another people refused to be interviewed
Bus stopped at Dutch Mill stop
1 passenger got off the bus
I interviewed the old lady on the bus
Bus stopped at Village Circle
2 passengers got off the bus
The bus driver asked me where to go
The bus went back to Ithaca Mall without stopping
I was satisfied with the time for a round trip, which was only half an hour.
Not too much passengers makes the bus clean.
The desolate roadside and empty bus made me a little upset.
people need to know stops' names
need to be reminded when arrive the stop
The route is rarely be used
Passing area is desolate
Seldom passengers on the bus
A short round trip
Route 77 Observation 12:35 Saturday board @ Ithaca Mall
another bus
route 77


Route 77 Immersion 5:30 Tue Airport
-I had a flight at 7:10 PM
-I had an Exam that would last until 5:45 PM.
-Ideal time to arrive at airport bus 5:45 - 6:15 PM
-Suitcase was on West Campus wanted to depart from there
-Bus only comes around once per hour
-Ended up finding a friend to drive me
-I would like to take a bus
-more environmentally friendly
-much cheaper
-But the bus comes very infrequently and there is a very short range of time of departure that works for me
-Flying is very stressful
-I wish it wasn't so inconvenient to take the bus

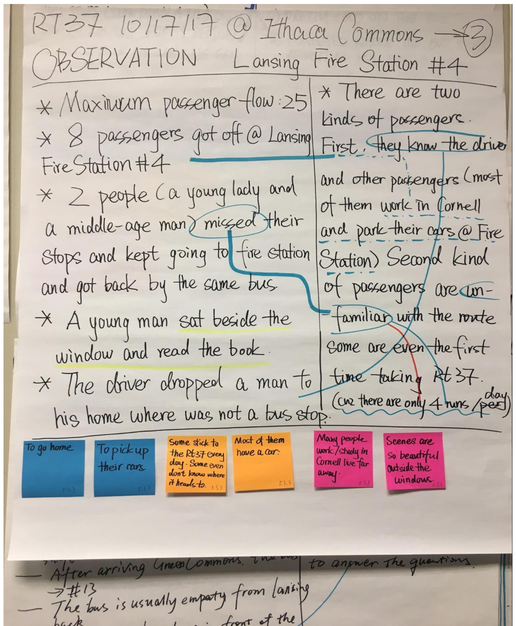

Route 77 Interview @ Ithaca Airport
-Flies often because she is from Singapore
-Usually brings a lot of luggage
-Can usually find a bus to take back
-Having lots of luggage makes riding bus difficult
-Travelling is tiring
-I'm used to travelling so it's okay
-Bus schedule usually works out for what I fly in.

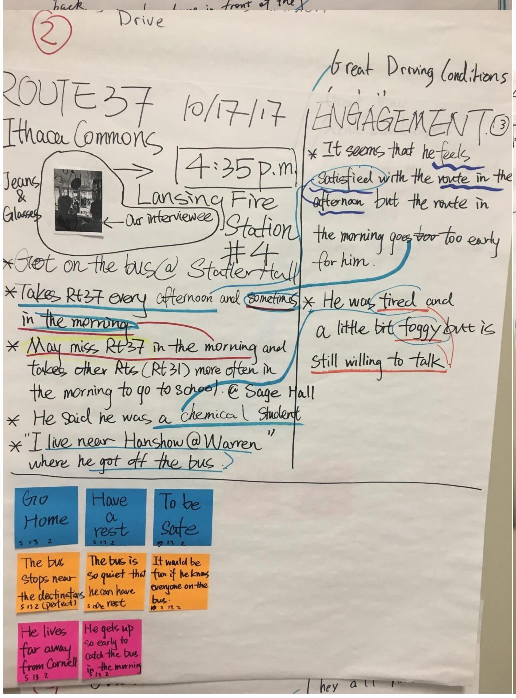


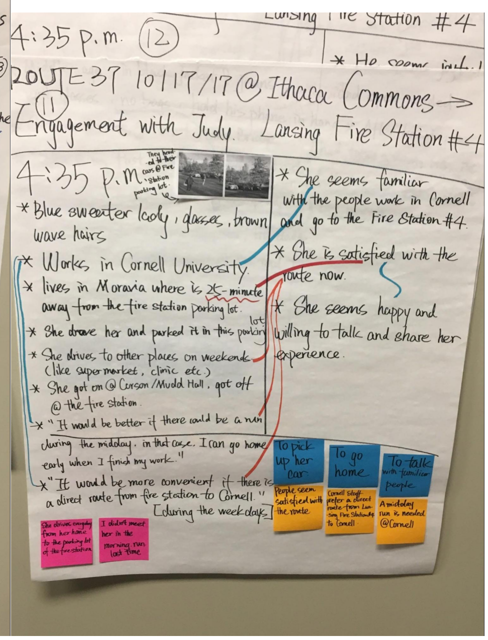


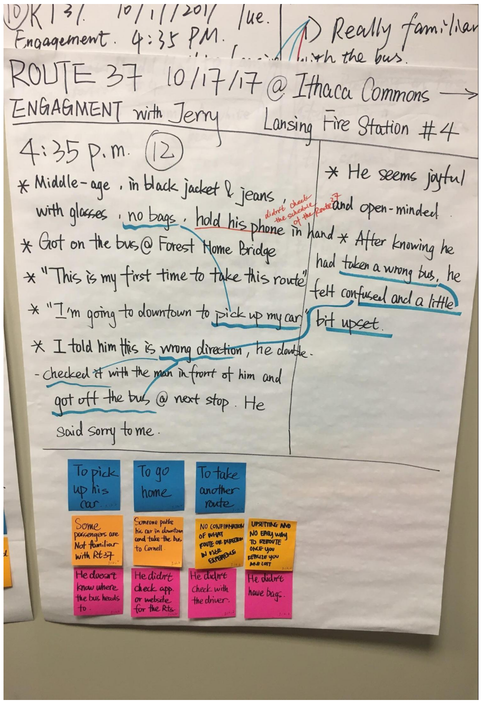
Route 37

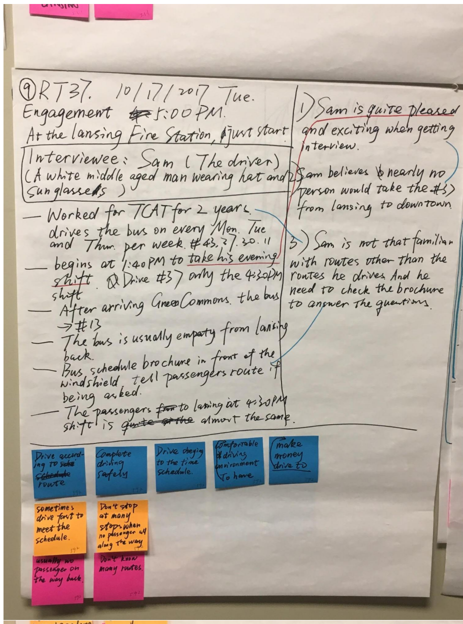
Provided below are images of the unpacked empathy data for the Route 37.

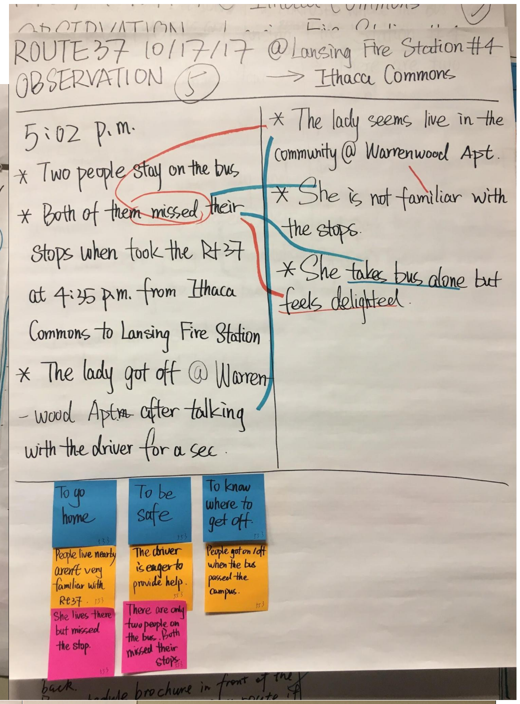

RT37 10/17/17 @ Ithaca Commons → Lansing Fire Station #4
OBSERVATION
* Maximum passenger flow: 25
* 8 passengers got off @ Lansing Fire Station #4
* 2 people (a young lady and a middle-age man) missed their stops and kept going to fire station and got back by the same bus
* A young man sat beside the window and read the book
* The driver dropped a man to his home where was not a bus stop.
* There are two kinds of passengers. First, they know the driver and other passengers (most of them work in Cornell and park their cars @ Fire Station) Second kind of passengers are un-familiar with the route some are even the first time taking Rt37. (as there are only 4 runs/day)
To go home
To pick up their cars
Some stick to the Rt37 every day. Some even don't know where it heads to
Most of them have a car.
Many people work/study in Cornell live far away.
Sceneis are so beautiful outside the windows.
After arriving Green Commons
The bus is usually empty from Lansing back

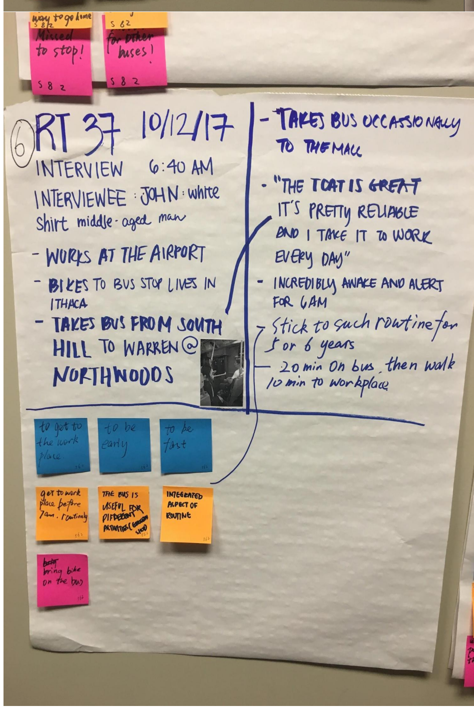

Drive
ROUTE 37 10/17/17
Ithaca Commons → Lansing Fire Station #4
4:35 p.m.
Jeans & Glasses
Our interviewee
* Got on the bus @ Statler Hall
* Takes Rt37 every afternoon and sometimes in the morning
* May miss Rt37 in the morning and takes other Rts (Rt31) more often in the morning to go to school @ Sage Hall
* He said he was a chemical student
* "I live near Hanshaw @ Warren" where he got off the bus.
Great Driving Conditions
ENGAGEMENT
* It seems that he feels satisfied with the route in the afternoon but the route in the morning goes too early for him.
* He was tired and a little bit foggy but is still willing to talk.
Go Home
Have a rest
To be Safe
The bus stops near the destinations
The bus is so quiet that he can have a rest
It would be fun if he knows everyone on the bus
He lives far away from Cornell
He gets up so early to catch the bus in the morning

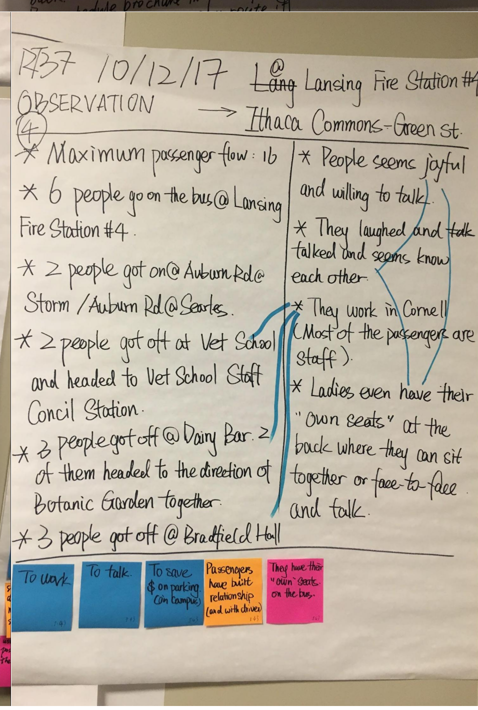

ROUTE 37 10/17/17 @ Ithaca Commons → Lansing Fire Station #4
Engagement with Judy
4:35 p.m.
* Blue sweater lady, glasses, brown wave hairs
* Works in Cornell University
* lives in Moravia where is 25 minute away from the fire station parking lot.
* She drove her and parked it in this parking lot
* She drives to other places on weekends (like super market, clinic etc)
* She got on @ Carson/Mudd Hall, got off @ the fire station
* "It would be better if there could be a run during the midday. in that case, I can go home early when I finish my work."
* "It would be more convenient if there is a direct route from fire station to Cornell" [during the weekdays]
* She seems familiar with the people work in Cornell and go to the Fire Station #4.
* She is satisfied with the route now.
* She seems happy and willing to talk and share her experience.
To pick up her car
To go home
To talk with familiar people
People seem satisfied with the route
A midday run is needed @ Cornell

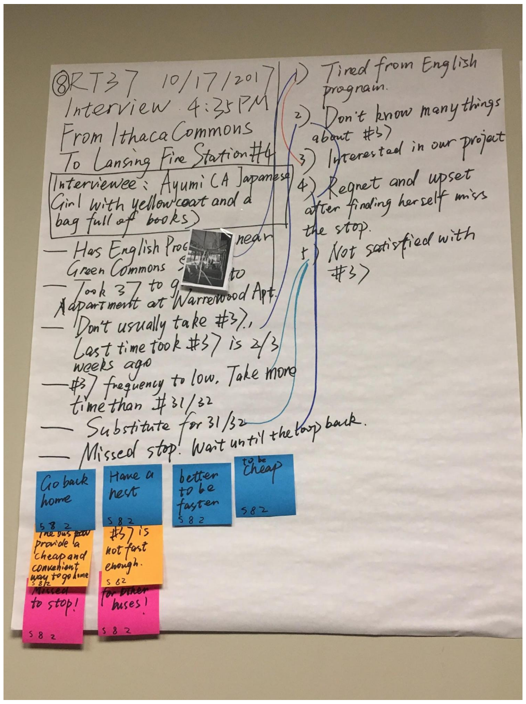

ROUTE 37 10/17/17 @ Ithaca Commons → Lansing Fire Station #4
ENGAGMENT with Jerry
4:35 p.m. 12
* Middle-age, in black jacket & jeans, with glasses, no bags, hold his phone in hand
* Got on the bus @ Forest Home Bridge
* "This is my first time to take this route"
* "I'm going to downtown to pick up my car"
* I told him this is wrong direction, he double-checked it with the man in front of him and got off the bus @ next stop. He said sorry to me.
* He seems joyful and open-minded.
* After knowing he had taken a wrong bus, he felt confused and a little bit upset.
To pick up his car.
To go home
To take another route
Some passengers are Not familiar with Rt37
Someone parks his car in downtown and take the bus to Cornell.
NO CONFIRMATION OF WHAT ROUTE OR DIRECTION IN USER EXPERIENCE
UPSETTING AND NO EASY WAY TO REROUTE ONCE YOU REALIZE YOU ARE LOST
He doesn't know where the bus heads to.
He didn't check app. or website for the Rts.
He didn't Check with the driver.
He didn't have bags.

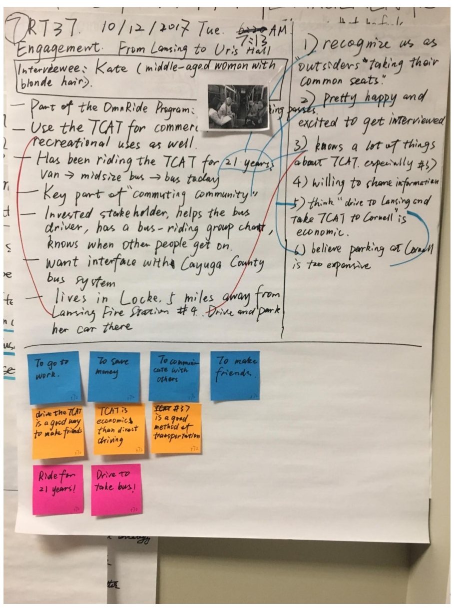

⑨RT37. 10/17/2017 Tue.
Engagement 5:00PM.
At the lansing Fire Station, just start.
Interviewee: Sam (The driver)
(A white middle aged man wearing hat and sunglasses)
— Worked for TCAT for 2 years.
drives the bus on every Mon. Tue and Thur. per week. #43, 37. 30. 11
— begins at 1:40PM to take his evening shift. Drive #37 only the 4:30PM shift
— After arriving Green Commons. the bus → #13
— The bus is usually empty from lansing back.
— Bus schedule brochure in front of the windshield, tell passengers route if being asked.
— The passengers to lansing at 4:30PM shift is almost the same.
1) Sam is quite pleased and exciting when getting interview.
2) Sam believes nearly no person would take the #37 from lansing to downtown.
3) Sam is not that familiar with routes other than the routes he drives. And he need to check the brochure to answer the questions.
Drive according to ~~Schedule~~ route
Complete driving safely
Drive obeying to the time schedule.
Comfortable driving environment To have
make money drive to
sometimes drive fast to meet the schedule.
Don't stop at many stops when no passenger all along the way
usually no passenger on the way back.
Don't know many routes.


ROUTE 37 10/17/17 @Lansing Fire Station #4
OBSERVATION ⑤ → Ithaca Commons
5:02 p.m.
* Two people stay on the bus
* Both of them missed their stops when took the Rt 37 at 4:25 p.m. from Ithaca Commons to Lansing Fire Station
* The lady got off @ Warrenwood Apt. after talking with the driver for a sec.
* The lady seems live in the community @ Warrenwood Apt.
* She is not familiar with the stops.
* She takes bus alone but feels delighted.
To go home
To be safe
To know where to get off.
People live nearby aren't very familiar with Rt37.
The driver is eager to provide help.
People got on/off when the bus passed the campus.
She lives there but missed the stop.
There are only two people on the bus. Both missed their stops.


way to go home
Missed to stop!
for other buses!
⑥ RT 37 10/12/17
INTERVIEW 6:40 AM
INTERVIEWEE: JOHN: white shirt middle-aged man
- WORKS AT THE AIRPORT
- BIKES TO BUS STOP LIVES IN ITHACA
- TAKES BUS FROM SOUTH HILL TO WARREN @ NORTHWOODS
- TAKES BUS OCCASIONALLY TO THE MALL
- "THE TCAT IS GREAT IT'S PRETTY RELIABLE AND I TAKE IT TO WORK EVERY DAY"
- INCREDIBLY AWAKE AND ALERT FOR 6AM
- Stick to such routine for 5 or 6 years
- 20 min On bus, then walk 10 min to workplace
to get to the work place.
to be early
to be fast
get to work place before 7am. routinely
THE BUS IS USEFUL FOR DIFFERENT ACTIVITIES
INTEGRATED ASPECT OF ROUTINE
bring bike on the bus

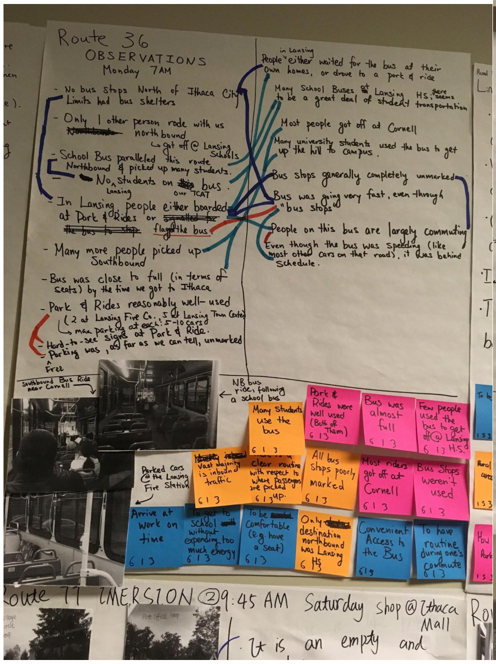

RT37 10/12/17 @ Lansing Fire Station #4
OBSERVATION ④ → Ithaca Commons-Green St.
* Maximum passenger flow: 16
* 6 people go on the bus @ Lansing Fire Station #4.
* 2 people got on @ Auburn Rd @ Storm / Auburn Rd @ Searles.
* 2 people got off at Vet School and headed to Vet School Staff Concil Station.
* 3 people got off @ Dairy Bar. 2 of them headed to the direction of Botanic Garden together.
* 3 people got off @ Bradfield Hall
* People seems joyful and willing to talk.
* They laughed and talked and seems know each other.
* They work in Cornell (Most of the passengers are staff).
* Ladies even have their "own seats" at the back where they can sit together or face-to-face and talk.
To work
To talk.
To save $ on parking. (on campus)
Passengers have built relationship (and with driver)
They have their "own" seats on the bus.

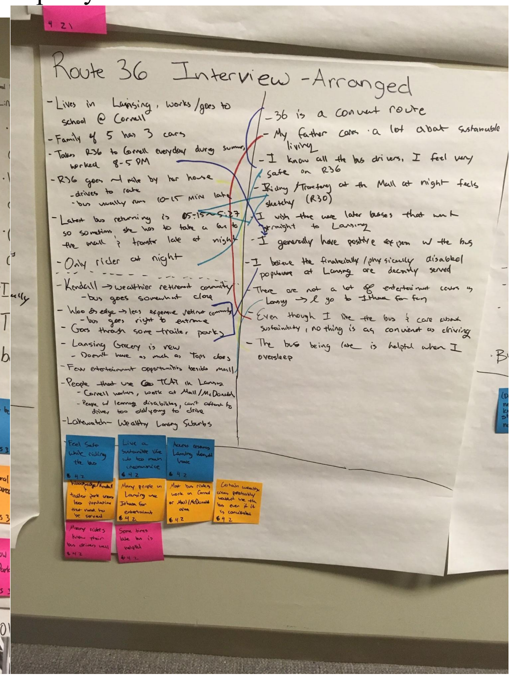

8 RT37 10/17/2017
Interview 4:35PM
From Ithaca Commons
To Lansing Fire Station #4
Interviewee: Ayumi (A Japanese Girl with yellow coat and a bag full of books)
— Has English Prog near Green Commons
— Took 37 to go to Apartment at Warrenwood Apt.
— Don't usually take #37, Last time took #37 is 2/3 weeks ago
— #37 frequency to low, Take more time than #31/32
— Substitute for 31/32
— Missed stop! Wait until the loop back.
1) Tired from English program.
2) Don't know many things about #37
3) Interested in our project
4) Regret and upset after finding herself miss the stop.
5) Not satisfied with #37
Go back home
Have a rest
better to be fasten
to be Cheap
#37 is not fast enough.
to stop!
buses!

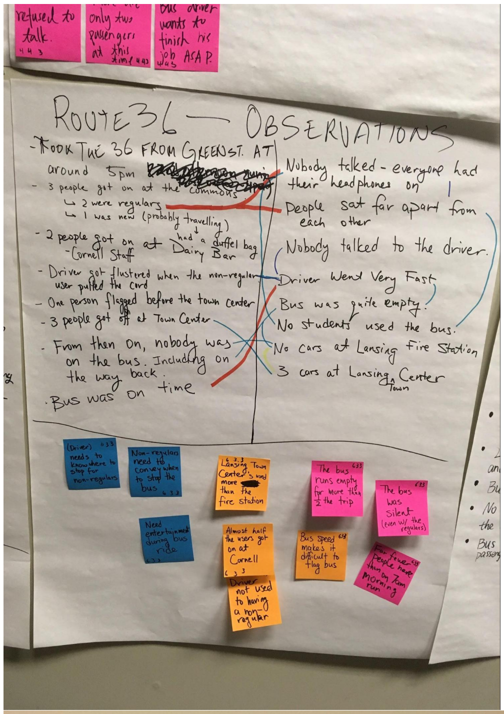

7 RT37. 10/12/2017 Tue. 7:13 AM
Engagement. From Lansing to Uris Hall
Interviewee: Kate (middle-aged woman with blonde hair).
— Part of the OmniRide Program:
— Use the TCAT for commerc recreational uses as well.
— Has been riding the TCAT for 21 years; van → midsize bus → bus today
— Key part of "commuting community"
— Invested stakeholder, helps the bus driver, has a bus-riding group chat, knows when other people get on.
— want interface with Cayuga County bus system
— lives in Locke. 5 miles away from Lansing Fire Station #4. Drive and park her car there
1) recognize us as "outsiders" taking their common seats."
2) Pretty happy and excited to get interviewed
3) knows a lot of things about TCAT. especially #37
4) willing to share information
5) think "drive to Lansing and Take TCAT to Cornell" is economic.
6) believe parking at Cornell is too expensive
To go to work.
To save money
To communicate with others
To make friends.
drive the TCAT is a good way to make friends
TCAT is economics than direct driving
#37 is a good method of transportation
Ride for 21 years!
Drive to take bus!

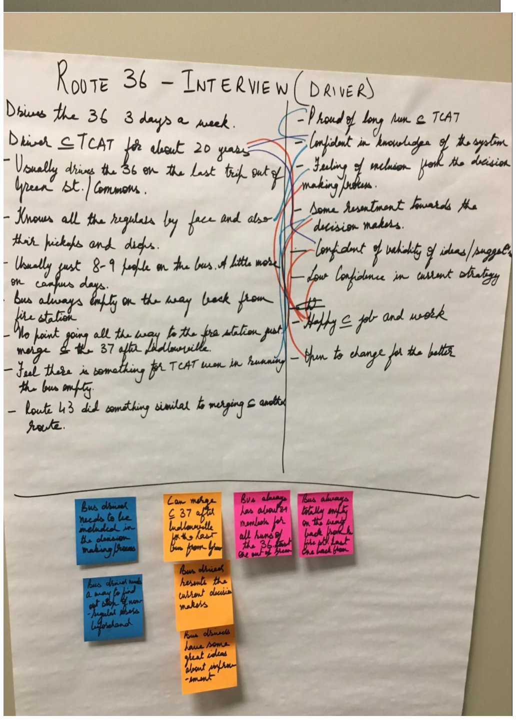
Route 36

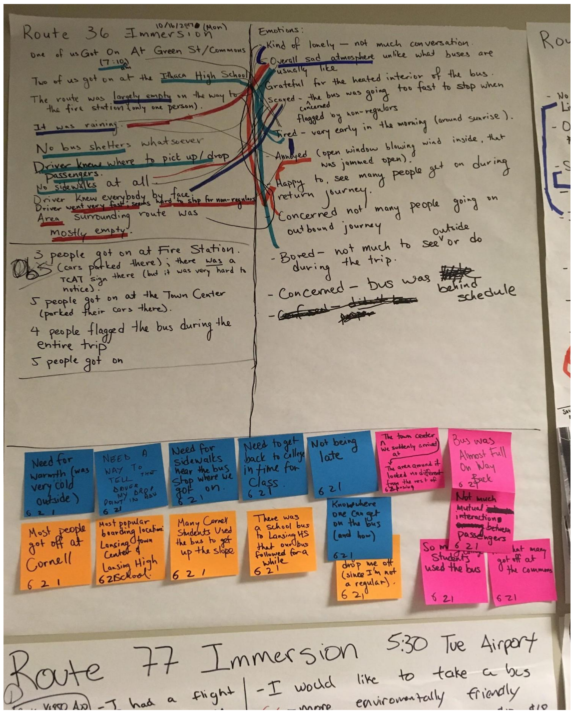
Provided below are images of the unpacked empathy data for the Route 36.






refused to talk.
only two passengers at this time
Bus driver wants to finish his job ASAP.
ROUTE 36 — OBSERVATIONS
- TOOK THE 36 FROM GREEN ST. AT around 5pm
- 3 people got on at the Commons
↳ 2 were regulars
↳ 1 was new (probably travelling) had a duffel bag
- 2 people got on at Dairy Bar - Cornell Staff
- Driver got flustered when the non-regular user pulled the cord
- One person flagged before the town center
- 3 people got off at Town Center
- From then on, nobody was on the bus. Including on the way back.
- Bus was on time
Nobody talked - everyone had their headphones on
People sat far apart from each other
Nobody talked to the driver.
Driver Went Very Fast
Bus was quite empty.
No students used the bus.
No cars at Lansing Fire Station
3 cars at Lansing Town Center
(Driver) needs to know where to stop for non-regulars
Non-regulars need to convey when to stop the bus
Lansing Town Center's used more than the fire station
The bus runs empty for more than 1/2 the trip
The bus was silent
Almost half the users get on at Cornell
Bus speed makes it difficult to flag bus


ROUTE 36 - INTERVIEW (DRIVER)
Drives the 36 3 days a week.
Driver with TCAT for about 20 years
- Usually drives the 36 on the last trip out of Green St./Commons.
- Knows all the regulars by face and also their pickups and drops.
- Usually just 8-9 people on the bus. A little more on campus days.
- Bus always empty on the way back from fire station
- No point going all the way to the fire station just merge with the 37 after Ludlowville.
- Feel there is something for TCAT wen in running the bus empty.
- Route 43 did something similar to merging with another route.
- Proud of long run with TCAT
- Confident in knowledge of the system
- Feeling of exclusion from the decision making process.
- Some resentment towards the decision makers.
- Confident of validity of ideas/suggestions
- Low Confidence in current strategy
- Happy with job and work
- Open to change for the better
Bus drivers needs to be included in the decision making process
Can merge with 37 after Ludlowville
Bus always has about 8-9 members
Bus always totally empty on the way back



3.1.2.5 Need, Insight, Surprises Data

At the end of the unpacking process, the statements given and connections made were synthesized into short statements on post-it notes. These fell into three categories: needs, insights, and surprises, each of which corresponded with a different colored post-it note (in the pictures below, blue is needs, orange is insights, and pink is surprises). The post-it notes from all of the groups were then removed from the poster sheets, and gathered in one location.

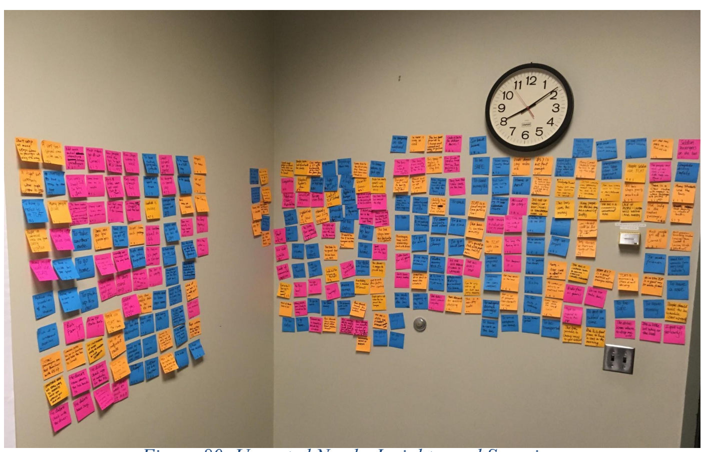


Figure 80: Unsorted Needs, Insights, and Surprises

3.1.2.6 Results Digitizing

Below are examples of the digitized unpacking episodes from empathy fieldwork (immersion, observation and engagement respectively):

4.1.1- RT 77- Immersion- 5:30PM, Tue, Airport

Ride 14850 APP
-Board bus at Sage at 5:30
-Depart at Airport at 6:00
or
-Board bus at sage at 6:00PM
- Depart at Airport at 7:00PM

- I had a flight at 7:10PM
- I had an exam that would last until 5:45 PM
- Ideal time to arrive at airport was 5:45-6:15 PM
- Suitcase was on west campus– so want to depart from there
- Bus only comes around once per hour
- Ended up finding a friend to drive.

- I would like to take a bus.
- more environmental friendly.
- much cheaper ($0~3 vs: $12~18)
- My sponsor is paying my portion cost so it doesn't
- But the bus comes very infrequently and there is a range of time of departure that works for me.
- Flying is very stressful -- I would have to arrive ahe
- If I take the bus I would have to walk uphill from w central which is tiring and time consuming.
- I also have to carry my suitcase there.
- I wish it wasn't so inconvenient to take the bus.
- I'm stressed about my exam and about the conve don't need more stress.
- I have a friend who will pick me and drive me dire more convenient.

N Arrive at airport on time | Reduce the stress of the situation | Pick up at convenient location

I Bus can be inconvenient to get to airport | can be the only option if don't have other resources

S Bus doesn't correlate at all with ongoing fights

Te
Co
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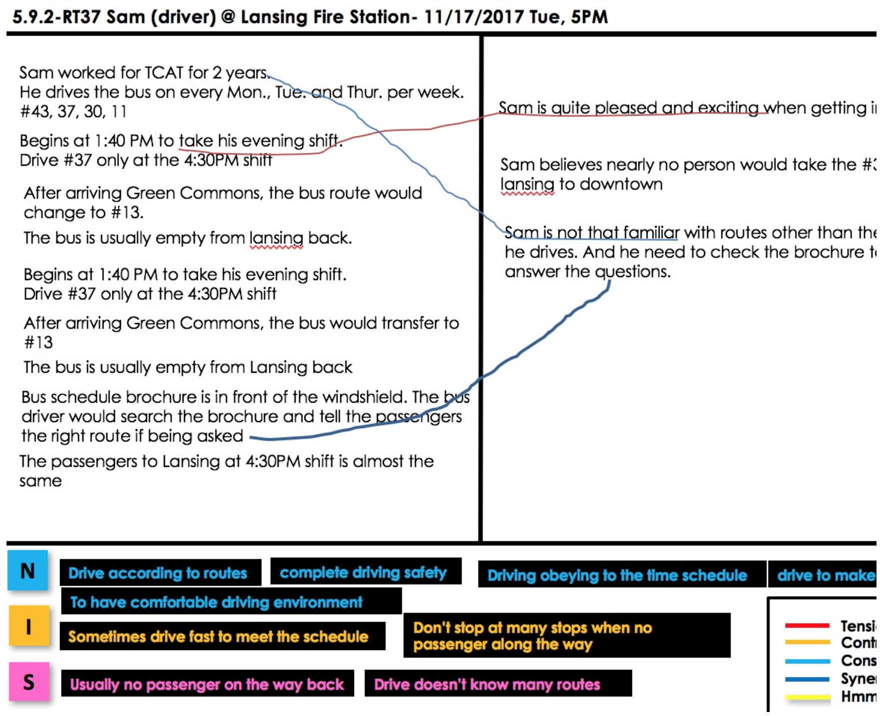
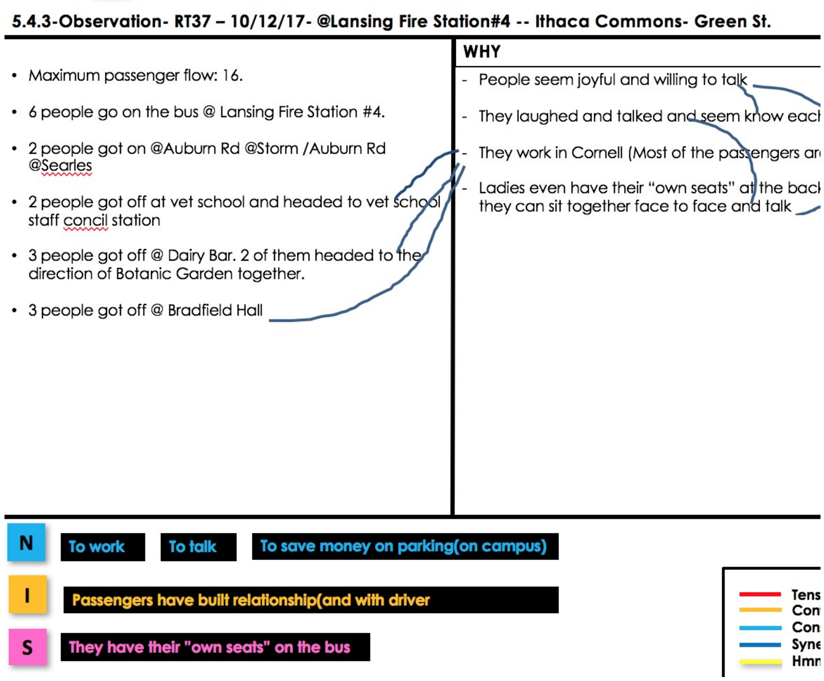




3.1.2.7 Emotional Data Modeling

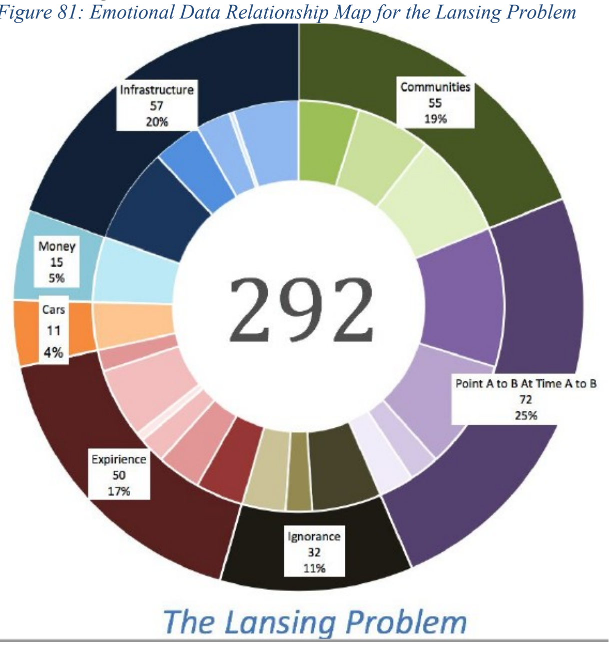
To model the emotional data collected, we categorized the needs, insights, and surprises into groups and subgroups. The goal was to search for patterns in the fieldwork data to generalize the different needs and experiences of Lansing TCAT users. We analyzed the percentage of the total data each category took and the relationships and tensions between categories.

The categories we found from our 292 data points were:

● **Point A to B at Time A to B** *25%* – Users needed to get from certain places (to/from home/school/work etc.) during specific times of day (morning/afternoon etc.)
● **Infrastructure** *20%* – The physical conditions of the buses and the bus stops affected the levels of safety and convenience the users experienced.
● **Communities** *19%* – Small communities would often develop on the bus between both the drivers and the passengers, and users expressed desire to meet people and have a friendly environment.
● **Experience** *17%* – Users were affected by their experiences planning their bus trip, the experience of the journey, and the physical amenities of the bus itself.
● **Ignorance** *11%* **–** Users were not always fully educated about the TCAT system, whether in regards to understanding how the routes worked, how the TCAT system itself worked, or not knowing what TCAT was entirely.
● **Money** *5%* – Users cared about travelling in cost efficient ways, and the bus is often one of the cheapest ways to travel.
● **Cars** *4%* – It is hard to beat the convenience of a personal vehicle, and many Lansing residents opted to drive whenever feasible.

This is visualized in the image below.

Figure 81: Emotional Data Relationship Map for the Lansing Problem



The raw data is provided in the table below.

	COMMUNITIES (55)
Identifier	**Cornell (14)**
6.1.3	Most riders got off at Cornell
6.4.2	Most bus riders work in Cornell or Mall/McDonald area
5.3.3	Many people work/study in Cornell live far away
5.5.3	People got off when the bus passed the campus
6.1.3	Many students use the bus
6.2.1	Many Cornell students used the bus to get up the slope
	Cornell staff prefer a direct route from Lansing Fire Station#4 to Cornell
5.13.2	He lives far away from Cornell
	A midway run is needed @Cornell
6.2.1	So many college students used the bus
1.7.3	Metropolis for students
6.3.3	Almost half the users got on at Cornell
5.12.2	Someone parks his car in downtown and take the bus to Cornell
1.1.2	Someone apparently takes the TCAT all the way to Cornell

	Geographic Community (17)
1.5.3	Outside of bus it is a really quiet area
1.4.3	Low ridership could be due to low amount of riders
6.4.2	Woodsedge /Kendall Trailer Park crews has population that need to be served
1.2.2	As many as 30+ people use TCAT from Genoa
1.4.3	How little people live north of town hall
6.4.2	Many people in Lansing use Ithaca for entertainment
3.2.2	More demands for weekend shopping
2.2.1	Potential renters area
3.1.2	People in commercial area are from every location
2.3.3	Appeal to younger generation
1.6.2	No commercial activity or traditional homes
1.4.3	Mostly farmers & farm land north of town hall
1.7.3	Higher Density
1.3.3	A tight community where people appear to know each one
1.7.3	How density populated it is
1.2.2	Genoa is pretty for north, still need to drive good amount to get to TCAT
1.2.3	It’s a town within a town
	Rider Community (24)
4.2.1	Driver knows each passenger
	To talk to people
5.2.1	The driver know where to drop me off
5.13.2	It would be fun if he knows everyone on the bus
6.6.2	Bus always has 8-9 members for runs of the 36
5.10.2	It's good to talk to people when taking the bus
1.2.2	To have a reason to use TCAT
5.4.3	Passengers have built relationship with driver
4.6.2	Old lady is the routine passenger
1.3.3	To have a reason to use TCAT
5.4.3	They have their own seats on the bus
5.7.2	Rider for 21 years
6.4.2	Access resources Lansing doesn’t have
4.4.3	Old gentleman refused to talk
5.10.2	"Bus family"
8.4.2	Many riders know their bus drivers well
6.2.1	Not much mutual interaction between passengers
5.7.2	To make friends
5.5.3	Driver is eager to provide help
3.2.2	She takes the bus almost every day
2.3.1	Room to grow
5.7.2	Drive the TCAT is a good way to make friends
5.2.1	The bus is a community gathering place
5.10.2	Takes the bus for 25 years
	POINT A to B AT TIME A to B (72)
	Commuting (32)
5.10.2	To go work
4.6.2	To get to work place
	To go home
5.7.2	#37 is a good method of transportation

6.1.3	Park & Rides were well used (both of them)
5.6.2	The bus is useful for different activities
4.3.2	Get to school/airport
1.4.3	To work
5.10.2	To go back home
4.6.2	She needs to do grocery every weekend
1.1.2	Not that many people use this part and ride
4.6.2	She takes the bus there and back
5.12.2	To go home
5.1.1	To be transported
7.3.3	To go home
5.7.2	To go to work
5.8.2	Go back home
5.9.2	Drive according to route
1.3.3	To have a reason to travel here
5.2.1	To be transported
5.13.2	Go home
7.3.3	To go home
4.4.3	People needs the public transportation
4.7.3	Transportation between shops and home.
5.12.2	To take another route
2.4.3	Population # is low
6.1.3	To get to school without expending too much energy
6.1.3	There is a clear routine with respect to where passengers are picked up
4.8.3	Transportation from village solar apartment
4.5.1	A short round trip
3.2.2	To be transported on the weekend
2.4.3	Lack of commercialization
	Personal Schedule (25)
4.1.1	Arrive at airport on time
3.1.2	Increase frequency of bus
6.2.1	Not being late
5.6.2	To be early
2.3.3	Clearer Planning
5.6.2	Integrated Aspect of routine
5.9.2	Drive obeying to the time schedule
5.6.2	To be fast
5.6.2	Get to work place before 7am
6.1.3	Arrive to work on time
5.9.2	Sometimes drive fast to meet schedule
5.2.1	Should meet the bus schedule
6.3.3	Far fewer people here than on 7am morning run
5.2.1	To get to school on time
5.8.2	Better to be faster
5.1.1	To arrive to workplace on time
	I didn't meet her on the morning run last time
6.1.3	To have routine during ones commute
6.4.2	Sometimes late bus is helpful
4.1.1	Bus doesn't correlate at all with outgoing flights
6.2.1	Need to get back to college in time for class
5.10.2	To be on time
4.2.1	This is a non-stop route

6.6.2	Bus driver needs to find out the stop of non-regular users
5.8.2	37 is not fast enough
	Demand (Route) (7)
4.5.1	The route is rarely used
6.4.2	Certain wealthy areas probably wouldn't use the bus even if it is convenient
4.6.2	She needs to take the bus
1.3.3	To have accessibility to the TCAT route
6.3.3	Lansing Town Center used more than the fire station
1.2.2	People use TCAT this far north
5.3.3	Don't know where bus even goes
	Transition to cars (8)
5.12.2	To pick up his car
5.10.2	Driver to take bus
5.1.1	Just one of many modes of transportation
	She drives everyday from her home to the parking lot of the fire station
5.6.2	Bring bike on the bus
5.3.3	To pick up their cars
5.7.2	Drive to take bus
	To pick up her car
	IGNORANCE (32)
	I'm on the bus but I don't know how it works (16)
6.2.1	Know where one can get on the bus
6.6.2	Bus driver has some great ideas about informing
5.12.2	He didn't check with driver
6.3.3	Driver needs to know where to stop for non-regulars
5.5.3	She lives there but missed the stop
4.4.3	Driver doesn't stop unless asked
4.2.1	Need to know where to get off
	Bus driver resents the current decision makers
5.4.3	To talk
4.2.1	Need to tell bus driver destination
5.12.2	Upsetting and no easy way to reroute once you realize you are lost
5.10.2	To communicate with others
6.2.1	Need a way to tell the driver my drop point in advance
5.7.2	To communicate with others
4.5.1	Need to b reminded when arriving to the stop
4.4.3	Need to ask for stop
	I don't know how the bus works as system (6)
6.3.3	Non-regulars need to convey when to stop the bus
5.9.2	Don't know many routes
5.12.2	Some passengers are not familiar with 37
2.1.1	No bus seen
5.12.2	He didn't check app or website for routes
5.5.3	There are only two people on the bus. Both missed their stops
	I don't know how the bus works as system (6)
3.1.2	Many people never use TCAT
2.3.3	Lack of TCAT interest
5.5.3	People live nearby aren't very familiar with 37

5.1.1	No one else really is going to Lansing
5.12.2	He doesn't know where bus heads to
2.3.3	No one uses bus
2.1.1	No one uses bus
2.1.1	Find users
4.8.3	People seldom use TCAT
2.3.3	Low TCAT presence
	EXPERIENCE (50)
	Convenience
	Scheduling Exp. (11)
6.1.3	Convenient Access to the bus
4.1.1	Bus can be inconvenient to get to the Airport
6.3.3	Bus speed makes it difficult to flag bus
1.3.3	To be accessible
4.1.1	Pick up at convenient location
5.1.1	The bus didn't stop
5.2.1	I got up so early!
1.7.3	To have more accessibility
5.10.2	The bus is on time monthly
5.13.2	He gets up so early to catch the bus in the morning
5.8.2	Missed the Stop
	Trip Experience (10)
5.13.2	The Bus is so quiet that he can have a rest
5.2.1	To have a rest
5.8.2	Have a rest
5.17.2	Have a rest
5.1.1	Have a rest on the bus
4.1.1	Reduce to the stressfulness of the situation
6.2.1	Scared to flag bus to drop me off (since I'm not a regular)
6.2.1	There was a school bus to Lansing HS that our bus followed for a while
5.2.1	Bus is a good place to have a rest in the morning
4.4.3	This is an inefficient route
	Environment (6)
1.5.2	To be protected from the elements
4.5.1	Passing area is desolate
5.4.2	Live a sustainable life w/o too much inconvenience
6.2.1	Need for warmth (was very cold outside)
1.3.3	A very scenic natural area with trails
5.3.3	Scenes are so beautiful outside the windows
	Space Experience (2)
5.12.2	He didn’t have bags
4.3.2	Deal w/luggage
	Density
	Bus Experience (16)
5.2.1	It's a little bit noisy on the bus
4.3.2	Maybe bus can be more friendly to travelers
6.3.3	The bus was silent (even w/ the regulars)
6.1.3	to be comfortable (e.g. have a seat)

5.9.2	usually no passenger on the way back
5.9.2	to have comfortable driving environment
4.2.1	Only few people take the bus all the time
6.1.3	Bus was almost full
6.2.1	Bus was almost full on way back
4.7.3	People need to board on bus at stop
4.3.2	Bus is convenient (compared to personal driving)
6.3.3	Need entertainment during bus ride
4.4.3	The are only two passengers at this time
6.3.3	The bus runs empty for more than 1/2 the trip
4.5.1	Seldom passengers on the bus
4.4.3	There are too few passengers
	Driver (5)
6.3.3	Driver not used to having non-regular
4.6.2	Bus driver stops for her
6.6.2	Bus drivers also need to be included in the decision making process
2.2.1	Higher Speed Limit
4.4.3	Bus driver wants to finish his job ASAP
	CARS (11)
	Private Vehicles (11)
2.2.1	Congestion
4.1.1	Can be only option if you don't have other resources
1.6.2	Not many vehicles on the road
6.1.3	Vast majority is inbound traffic
1.6.2	Cars were well above the speed limit
1.5.3	There was actually a large number of cars
3.1.2	Substitute TCAT for car sometimes
3.1.2	Majority of people drive there
2.3.3	Personal Driving is most convenient
5.3.3	Most of them have a car
3.1.2	Many people drive
	SAVING MONEY (15)
5.1.1	The bus save the money
5.7.2	To save money
5.9.2	drive to make money
5.2.1	The bus provides a cheap way to get to school
5.4.3	to save $ on parking (on campus)
5.2.1	To save money
5.7.2	TCAT is economic than direct driving
5.8.2	The bus provide a cheap and convenient way to go home
5.10.2	To be cheap
5.1.1	To save money ($)
5.8.2	to be cheap
5.1.1	to avoid driving and parking ($)
2.4.3	relatively low living expense
5.10.2	TCAT is a good way to save parking fees
5.2.1	The bus is cheaper than driving and parking; Cornell subsidized
	INFRASTRUCTURE (57)
	Location of Stops (22)

2.1.1	find routes
5.13.2	The bus stops near the destination(perfect)
4.8.3	Seldom stop on this route
1.6.2	People are expected to flag on road
6.2.1	Most people get off at Cornell
5.5.3	To know where to get off
6.1.3	Few people used this bus to get off at lansing
6.2.1	Most popular boarding location: lansing town center lansing high school
5.9.2	Don't stop at many stops when no passengers all along the way
2.2.1	TCAT buses don't stops
4.8.3	stop at airport
1.3.3	No TCAT route close by
	people seem satisfied with this route
4.7.3	small demand for this route
1.5.3	Having a dinner could be affective to users
4.5.1	People need to know stop's names
6.1.3	Bus stops were not used
2.1.1	Bus to lansing marked
1.5.3	Rural areas are isolated
4.7.3	No stopping at terminal stop
6.1.3	Only destination northbound was lansing HS
2.1.1	Find suitable stops
	Signage (11)
1.1.2	The people that work at park don't ride didn't really know about it
1.5.3	People could drive past and have no idea that it is a TCAT
2.1.1	No visible park
1.5.3	To be known as a TCAT stop
6.1.3	All bus stops poorly marked
1.7.3	No well marked
1.7.3	To have a visible bus stop system
1.5.3	TCAT sign was remarkably hidden
1.1.2	To have more awareness about park
2.1.1	No signage
5.12.2	No confirmation of what route or direction in user experience
	Street/surrounding infrastructure (8)
2.4.1	More street lights
1.5.3	How much the parking lot is
2.4.3	No sidewalk
2.4.3	Broader road
2.2.1	Traffic lights or stop signs
2.4.3	Sidewalk
6.2.1	Need for sidewalks near the bus stop where we get on
	Alternative/Plan-B (1)
5.8.2	substitute for other buses
	Safety (15)
5.5.3	To be safe
5.9.2	complete driving safety
4.7.3	Road side is desolate
1.6.2	To feel safe and comfortable

5.13.2	To be safe
5.1.1	To be safe
1.6.2	To be visible
6.4.2	Feel safe while riding the bus
5.2.1	Many people on the bus give me a sense of safety
5.2.1	To be safe
1.6.2	To be protected from vehicles
5.1.1	Lack of people and light while waiting causes anxiety
1.6.2	How dangerous it is
1.5.3	To be visible
1.1.2	To have vision about locations
TOTAL=	***292***

3.1.2.8 Emotional Data Analysis

By analyzing our data, we were able to see the different push and pull factors that would affect whether a Lansing resident would want to use the bus. Many users were attracted to the affordability of the TCAT system (sometimes by choice and sometimes by necessity) especially if they did not have a vehicle or other form of transportation. Many of the frequent passengers enjoyed seeing other familiar passengers and bus drivers throughout their weekly routes, which created a sense of community on the bus. However, the bus can sometimes be inconvenient due to outdated routes that do not reflect passenger needs and unreliable arrival times. This leads to many people opting for private vehicles, especially when they have busy schedules that require a lot of travelling at specific times. With so many residents opting for private vehicles, a culture has developed in Lansing where many residents are unaware of the TCAT system.

This thought process is visually shown in Flow of Thoughts below.

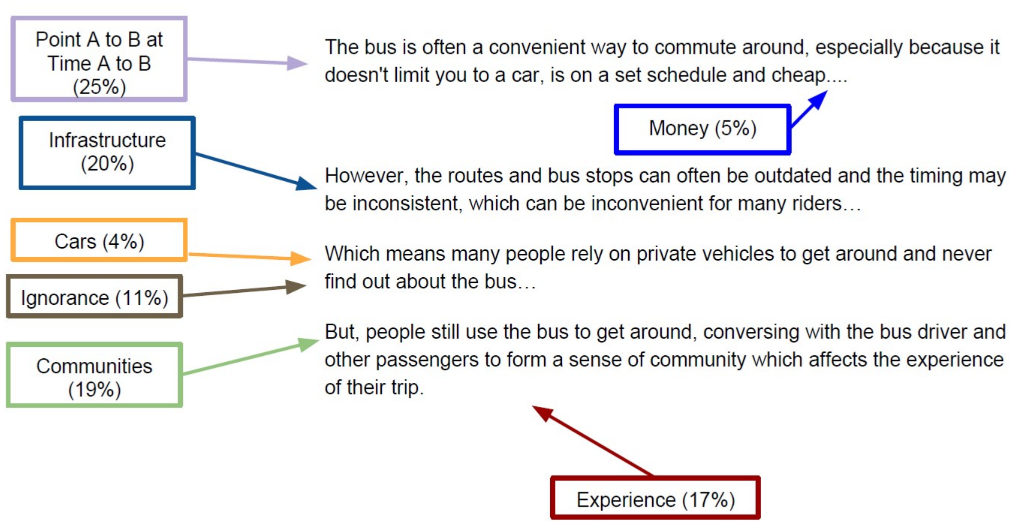


Figure 82: Flow of Thoughts

3.1.2.9 Points of Views

Our team developed three personas to reflect the different ways users experience and engage with the TCAT system. They describe a wide breadth of needs and desires of different types of residents within Lansing and helped us address how to attract different types of users to TCAT.

Our personas are included below.

Frannie Duckworth

Age*: Late 70s*

Social Life*: Lives in North Lansing, far away from the majority of the town's residents and business'. She is retired and lives alone. She enjoys riding the bus to meet new people and see her bus friends.*

Work Life: *Previously worked as a civil servant in another part of New York, but is now retired.*

Key Attributes:

- *She likes feeling independent and on her schedule.*
- *Living alone sometimes gets lonely, so she enjoys riding the bus to see people*
- *Does not have a car, relies on the bus.*

Quote*: "I love riding the bus to see my friends and get out of the house, but it can be often difficult due to the limited bus schedule."*

Mary Elmwood

Age*: 47*

Social Life*: Primarily socializes with others working in her department at Cornell University. She is single and has no kids. She is committed to her job and rarely has time to socialize and meet new people beyond the people she sees daily.*

Work Life*: Works as an administrative assistant at Cornell University, commuting down from Genoa each weekday morning, and back each weekday afternoon. Her job has a regular daily schedule, starting at 8:00am and ending at 5:00pm. However, there are some instances in which she has to stay later.*

Key Attributes*:*

- *Is a stickler for timeliness and order in her daily life.*

- *Has a car but would be open to using alternative means of transport, if she feels that they are appropriate for her*
- *Likes working for Cornell and tries to support her local businesses as much as possible*

Quote: *"I love working for Cornell and really appreciate being able to impact the lives of young people everyday. However, since I'm so busy with my work, I rarely get to meet new people. It would be great if I could use the bus to find people who live near me or work in other departments at Cornell."*

Margaret Lee

Age*: 32*

Social Life*: She is a busy mom who spends most of her time with her husband and children. When she has free time, she may get coffee with her friends, who are mothers of her children's classmates. Most of her socialization is centered around her work and family.*

Work Life*: Works at the Kendal at Ithaca as a caretaker for elderly people. Because she has to drive her kids to and from school and sometimes she has to work late hours for the residents, she always drives herself wherever she needs to go. As a result, none of her family is aware of the bus system either.*

Key Attributes*:*

- *Prioritizes the wellbeing and needs of her family*
- *Has a busy, hectic life that requires a lot of daily transportation*
- *Relies on a car to get around*
- *Does not know much about TCAT besides that it exists*

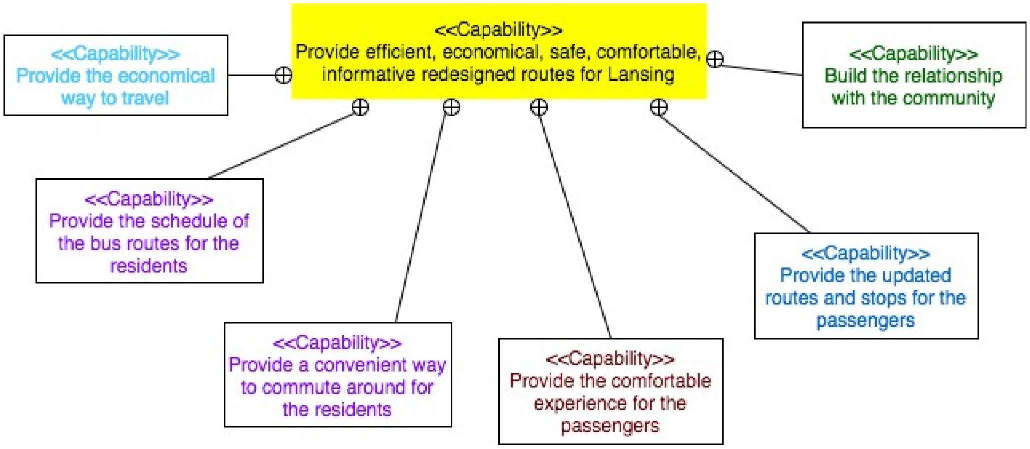
Quote*: "I live a busy life so using a car to be on my own schedule is very helpful, however I want to explore the option of using the bus to save money on gas so I can spend more on my children. With that being said, I don't know anything about the bus system and I don't know where to start!"*

3.1.3 System Diagrams

3.1.3.1 Capabilities Diagram

The capabilities diagram is a useful starting point for describing our routing system. Based on the results of empathy fieldwork, we summarized six main capabilities which need to be provided by the new routing system. The different colors of the capabilities are consistent with the donut breakdown (the flow chart) of the empathy fieldwork. According to our fieldwork, 25% of people care about the time and convenience to their destination as well as the money they saved. 20% of people would like to see the timing and path of the old routes updated. 19% of the passengers enjoy their travel on the bus where they can chat with others and build a relationship with the community. 17% of the people mentioned that they enjoy their experience when they take the bus.

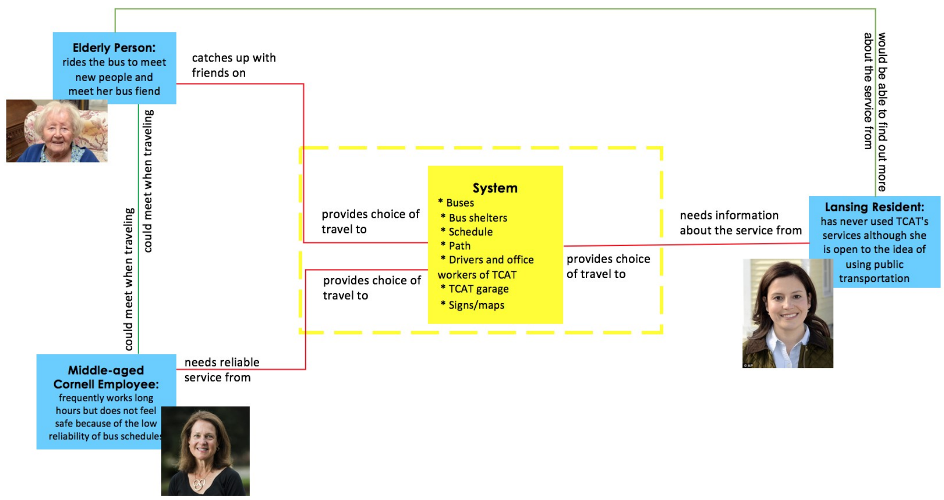
Shown below is the capabilities diagram of Lansing routing system, which shows key functions of the system.



System Index 15: Capabilities Diagram

3.1.3.2 Personal Context Diagram

The personal context diagram provides visualized relationships between the three perceived personas and our system. As stated prior, three personas (typifying the various types of TCAT users) have been developed from the empathy fieldwork and data modeling. These are recorded in blue blocks. They collectively cover most of the characteristics people related to our system possess. The system is presented as a yellow block and connected to the personas with red lines indicating their relationships. For example, they can be read as “the system provides choice of travel to elderly person.” Also, the green line indicates the relationship between the external entities. By making this diagram, the POVs we extracted have been mapped to the system through these personas. This will prove helpful in identifying use cases for the system.



System Index 16: Personal Context Diagram

3.1.4 Modeling

3.1.4.1 Previous Literature

A considerable amount of literature exists on analytic approaches for any studies if one desires to look for the work. In order to bring new insights into Sustainable Mobility project, the mathematical modeling team has looked into a wide range of previous literature written by many different professors across the globe. Amongst the many, there are two research papers that the team has been inspired by: *Design of Local Bus Service with Demand Equilibrium* by George Kocur and Chris Hendrickson, and *Multiple Period Optimization of Bus Transit Systems* by Shyue Koong Chang and Paul M. Schonfeld. Kocur and Hendrickson have analyzed bus services with ridership sensitive to bus service levels and fares, and developed closed-form solutions for the optimal route spacing, headway and fare for different objective functions. The letter written by Chang and Schonfeld has also implemented closed-form analytic solutions in order to identify fundamental optimality relations between primary characteristics the paper seeks to define. The mathematical modeling team has not necessarily followed the avenues of their research, but has learned about their analytic models for optimizing bus services with their respective variables. The team has especially examined their definitions of variables to perform their analysis. By exploring their major decision variables and mathematical functions, the mathematical modeling team has been able to begin its own analysis of TCAT's bus system for the Lansing Challenge. Although not as comprehensive as the scholars' papers, the team has dedicated a significant number of hours to produce results and potential pathways that should be further studied for the next semester of Sustainable Mobility.

3.1.4.2 Methodology

The modeling process basically follows mathematical modeling and systems engineering processes. The steps and methods are shown in the figures below.

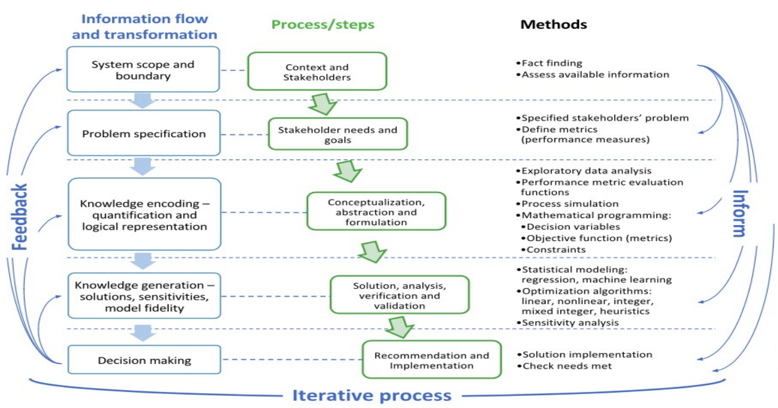
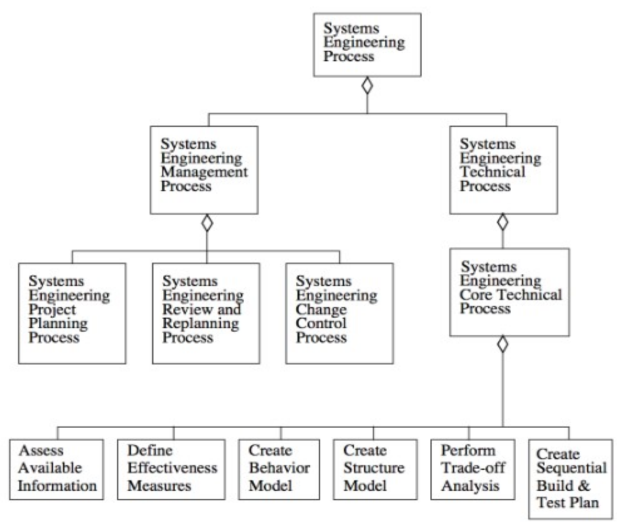


Figure 83: Mathematical Modeling Process



Systems Engineering Process (Figure 4-4, p 104, Oliver, David W., Timothy P. Kelliher, and James G. Keegan Jr. *Engineering Complex Systems*. McGraw-Hill Companies, 1997.)

Figure 84: Systems Engineering Process

The first step is clarifying context and stakeholders. This step determines system scope and boundary. Methods needed in this step are fact finding and assessing available information. The Lansing context diagram, shown earlier in System Index 16, again applies here. Our model will focus on those stakeholders.

The second step is understanding stakeholder needs and goals. This step provides problem specification. Methods needed in this step are definitions of stakeholders' problems and metrics. For TCAT, their goal is to satisfy more riders' needs, while minimizing TCAT's cost. For riders, the most pressing need is the service level of TCAT. Thus, the model will focus on improving TCAT's service level while minimizing the cost for TCAT. The specific metrics used in this model will be mentioned in the upcoming Preliminary Model section.

The third step is conceptualization, abstraction and formulation. This is the core step in our modeling process. This step includes knowledge encoding, quantification, and logical representation. Methods needed in this step are exploratory data analysis, performance metric evaluation functions, process simulation, and mathematical programming. Our modeling process is at this stage now. We received access to TCAT's ridership data and explored the data for Routes 36, 37, and 77 which serve Lansing area. We analyzed different metrics and the evaluation criteria.

To have a deeper understanding of this complex model, we first conducted a scenario analysis of Lansing area. Scenario analysis is not for our conclusive results or recommendations, but one of the methods we use to help build our mathematical model. Through scenario analysis, we can gather a deeper understanding of the relationships between metrics in the system and help to perfect the objective function in the modeling process by establishing the evaluation criteria for different scenarios. By evaluating proposed scenarios, we can get a sense of trade-offs among different metrics which will help us better develop the constraints of the mathematical model.

The fourth step includes solutions, analysis, verification and validation. This step is knowledge generation, where we produce solutions, sensitivities, and model fidelity. The methods used in this step will be statistical modeling, optimization algorithms, and sensitivity analysis.

The last step is recommendation and implementation. Methods included are solution implementation and needs checking. In this step, we will give our recommendation to TCAT, and if TCAT adopts the idea we can further evaluate and check our model. More data may arise in this stage and may result in modifications for the model.

3.1.4.3 Scenario Analysis

Due to the high complexity and uncertainty in all the objectives, decision variables and constraints, our team decided to use a scenario analysis to preliminarily explore the possible alternatives that may have impacts on TCAT service. By evaluating these scenarios with the ridership data obtained from TCAT and also the feedback from empathy fieldwork, more insights and ideas were found to make a suitable model for the problem.

As for the results, 16 scenarios were developed by the team members. Analysis was carried out on these different scenarios with respect to feasibility, complexity, accessibility and efficiency. Clear definition was given to each dimension used to describe the scenario in a certain aspect, as well as all the symbols and marks used to represent the trend, durability, cost and percentage. Through making a decision matrix containing all the proposed scenarios and values for each variable, we managed to evaluate the scenarios and are now able to see all the aforementioned features focused in a clear way.

There have been three degrees of scenarios that the team has decided to distinguish: small, medium, and large. Each scenario indicates how much of modification of the system (e.g. fuel, distance, etc.) the scenario requires in order to be implemented in real life, and how many people need to adjust to the proposed changes. The scenarios can be found on pages 118-119.

One of the small scenarios is to connect short distance of road between Lansing Town Hall and Triphammer at Auburn, therefore letting the users of TCAT transfer from one to another if they wish to do so. There is almost no effort made by users after the changes within the scenario have been applied.

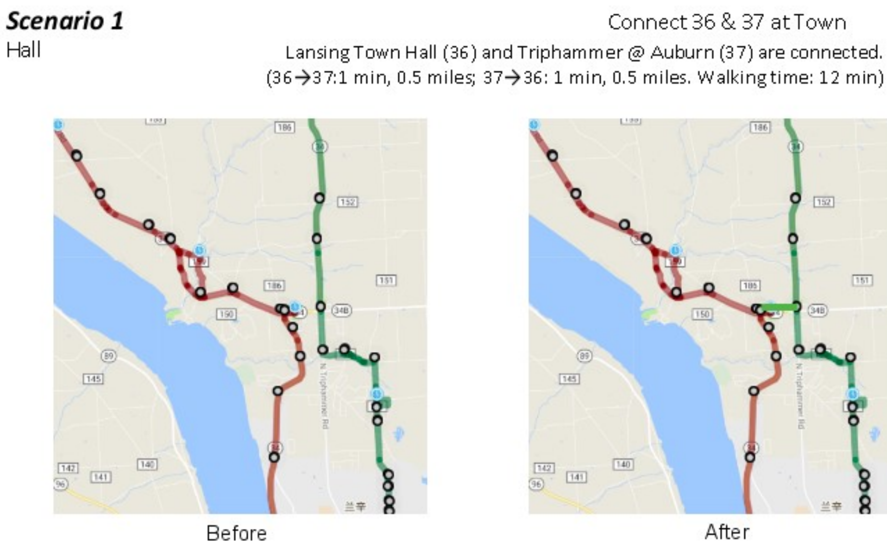


Figure 85: Example of a Small Change Scenario

One of the medium scenarios is reroute Route 37, which removes passageway through a neighborhood to travel faster through North Triphammer Road. However, Route 32 would have to be modified in order to cover the region that the Route 37 forgoes in addition to a district that has not been covered before.

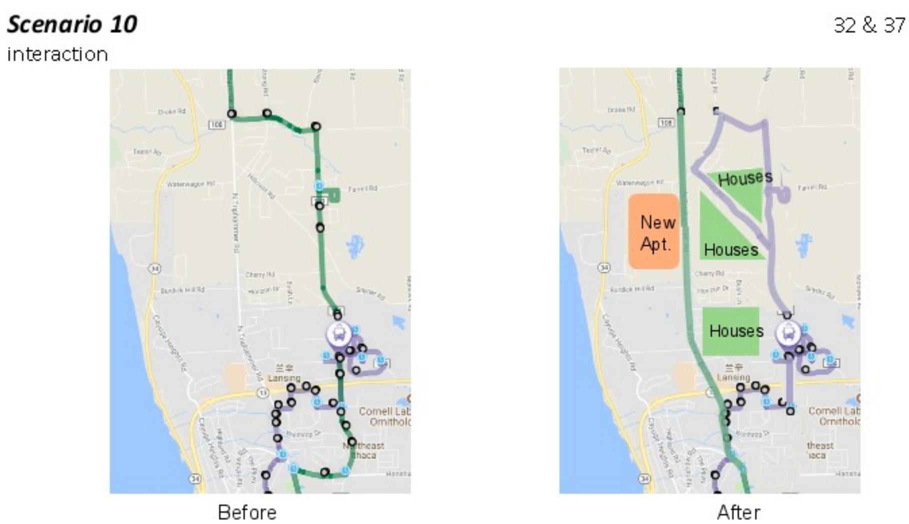


Figure 86: Example of a Medium Change Scenario

Finally, a large scenario includes a surgery of current routes and changing significant portions of existing routes to define an virtually brand new route to “efficiently and effectively” serve the main users. With a large change, we are mindful that the users of TCAT may have difficulty understanding new changes introduced by the scenario change.

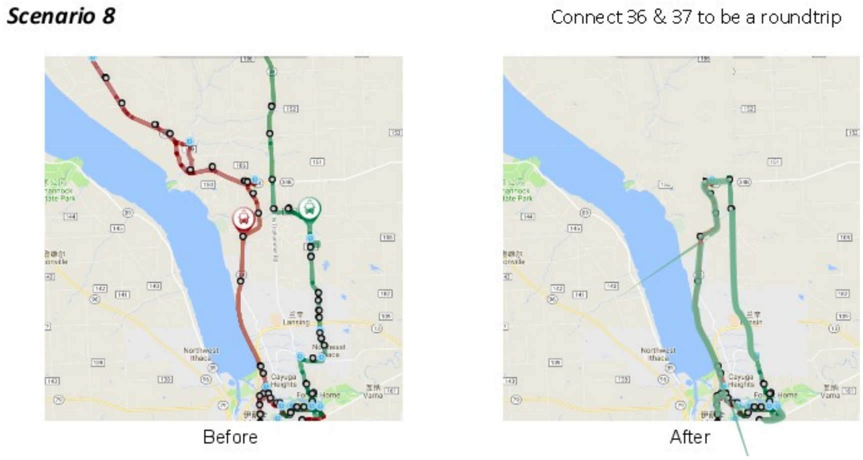


Figure 87: Example of a Large Change Scenario

Overall, the scenario analysis itself and the process of conducting it provided insight into a quantitative view of the Lansing Challenge. Among the explored scenarios, revising the current routes seems to be the most possible and feasible way to improve TCAT service. Additionally, there is room to introduce more scenarios with the additional consideration of other routes that have interactions in Lansing, such as Routes 30, 32 and 77. Also, with more updated data from TCAT and possible feedback from the TCAT office regarding the scenarios, further analysis can be made so we can continue evaluating and revising to make the scenarios more extensive and meaningful to TCAT and its users.

3.2 Spring 2018

3.2.1 Integration of Empathy Fieldwork and Scenario Analysis

Moving into the Spring 2018 semester, the team's mandate was to combine the results of the mathematical modelling team i.e. the scenario analysis together with those of the Empathy Fieldwork team i.e. the empathy data relationship map. The empathy data relationship map (Donut) identifies all the major themes in information unpacked from empathy episodes. These themes reflect the needs and expectations of the people from TCAT's services and insights into their views on the current service. The scenario analysis started with listing out 16 different scenarios (modified routes) and scored each of them on metrics based on TCAT's organizational constraints and the needs of users as inferred from the ridership data provided by TCAT.

The approach we decided to follow was to transform user needs and insights identified from the empathy fieldwork into goals for the re-routing. The key needs/insights were as follows:

1. People are not aware of TCAT's services
    a. Bus stops are hard to find
2. Riders want more bus stop prompts
3. Riders feel signages could be better
4. Users feel tardiness is an issue
5. Distance to bus stop is a consideration for users
6. Users want more areas of Lansing connected to Ithaca Mall
7. Riders want service on off-days (holidays)

As is clear after going through the above, some of them are not relevant to a rerouting based solution. So we filtered out the ones that we believed were relevant and transformed them into relevant goals.

These are as follows:

1. Tardiness
2. Residential area coverage
3. Bus frequency
4. Bus stop locations (relative to residential areas)
5. Accessibility of Ithaca Mall
6. Service on off-days

A requirements table can be a useful tool here by listing out requirements in a table to help achieve a clear understanding on what the routing system should be capable of. It gives a complete picture of the routing system's required capabilities.

Index	Originating Requirements	Abstract Function Name
OR.1	The schedule of system shall be on time.	On time
OR.2	The routing of system shall cover over 80% residential area.	Range
OR.3	The system shall have as many shifts as possible.	Shifts
OR.4	The routes of system shall cover main functional area, such as supermarket, hospital.	Hot spot
OR.5	The system shall set bus stops close to residents.	Close
OR.6	The routing of system shall connect Cornell and other designed areas.	Cornell
OR.7	The system shall charge fare cheaply.	Price
OR.8	The system shall make bus stations conspicuous.	Identification
OR.9	The system shall provide more routing options to Ithaca mall.	Mall
OR.10	The schedule of system shall be flexible.	Flexibility
OR.11	The system shall keep running regularly.	Regular
OR.12	The system shall provide prompting.	Sign
OR.13	The system shall provide clear and easy understanding signals.	Readability
OR.14	The system shall have the capacity for peak hour ridership.	Capacity
OR.15	The system shall able to deliver safe services.	Safety
OR.16	The system shall provide rides for flagging stops.	Flagging
OR.17	The system shall have a fixed operating timetable.	Timetable
OR.18	The system shall follow the local transportation regulations.	Regulation
OR.19	The system shall publish its operation timetable in advance.	Publish
OR.20	The system shall provide rides for both inbound and outbound directions.	Directions

System Index 17: Routing Originating Requirements Table

After this we set out to identify metrics for each of these goals and come up with a scoring system to evaluate the 16 scenarios on these metrics. We followed the process of a Goal Question Metric(GQM) to come up with ideal and the approximate metrics for these goals.

The results are shown in Table below.

No.	Scores	1	2	3	4	5	Note

1	The schedule of system shall be on time.	late time > 15 min	late time ≤ 10 min	late time ≤ 5 min	late time ≤ 3 min	late time ≤ 1 min	Depend on the distance between every stop： the farther the distance, the lower the score.
2	The routing of system shall cover over 80% residential area.	≤30%	≤50%	≤70%	<80%	≥80%	Estimate: the buffer area of total stops/residence area of Lansing
3	The system shall have as many shifts as possible.	>1.5 hr/run	1hr-1.5hr /run	30-60 min/run	10-30 min/run	5-10 min/run	Base on the schedule
4	The routes of system shall cover main functional area, such as supermarket, hospital.	≤30%	≤50%	≤70%	<80%	≥80%	Estimate: the buffer area of total stops/Total functional area of Lansing
5	The system shall set bus stops close to residence.	>0.6 mi	0.4-0.6 mi	0.2-0.4 mi	0.1-0.2 mi	≤0.1 mi	Estimate: the distance between stop and the center of a "defined area" of residence.
6	The routing of system shall connect Cornell and other areas.	Routes connect Cornell to only some stops	Routes connect Cornell to all transit station	Routes connect Cornell to main residence	Routes connect Cornell to main functional area where people's basic demands can be met.	Routes connect to Cornell and all functional area	(no relationship with scenarios)
7	The system shall charge fare cheaply.	$2.50	$2.25	$2.00	$1.50	$1.00	refer to cost(no relationship with scenarios)
8	The system shall make bus stations conspicuous	No station	Hard to find	Not easy to find	Easy to find	Very easy to find	(no relationship with scenarios)

9	The system shall provide more routing options to Ithaca mall.	1 route	2 routes	3 routes	4 routes	5 routes	Estimate: the buffer area of total stops/Total functional area of Lansing
10	The schedule of system shall be flexible.	Less than 3 shifts a day.	Less than 6 shifts a day.	Enough shifts during peak hours	Enough shifts during day.	Enough shift all day.	Base on the schedule
11	The system shall be kept running regularly.	The bus frequency will be cancelled during holiday,	The bus frequency will be decreased during most holiday, such as labor day.	The bus frequency will be decreased heavily during holiday.	The bus frequency will be decreased slightly during main holiday, such as Christmas	The bus frequency are the same all year around.	Base on the schedule
12	The system shall provide prompting.	No prompting	Having prompting of next stop only at some stops.	Having prompting of next stop at most stops	Having prompting of next stop at every stop	Clear prompting including approaching stop and next stop at every stop	(no relationship with scenarios)
13	The system shall provide clear and easy understanding signals.	No signal	Hard to find and read	Not easy to find and read	Easy to find and read	Very easy to find and read	(no relationship with scenarios)

Scenario Evaluation Metrics Table

The color coding of the table has been color coded as follows:

- Grey represents goals and metrics that are not relevant to a routing based solution
- Blue represents the ones that can be affected by scheduling the routes more effectively
- Green represents goals that may be met by re-routing but can only be measured using approximate metrics as explained in the notes. For example: Residential area coverage may be measured using Arcgis to estimate the total residential areas overlapping with a walkable distance margin of the routing scenarios.

Although we planned to use these metrics thoroughly to evaluate the scenarios, the client shortened the deadline for delivering the final results and we had to rely on a team consensus based scoring of the scenarios on a scale of 1 to 3 (1 being the worst and 3 being the best).

Using this approach we identified 3 scenarios (2 additional scenarios were shortlisted as they stood out on one or two metrics and would make the final discussion richer) out of the 16 that stood out and that we would recommend to the client. These are presented below along with the scores on each of these metrics (the final set was derived by considering scores based on the Scenario Analysis of Fall 2017 in conjunction with the Empathy Metrics. The full table has not been presented for the sake of brevity):

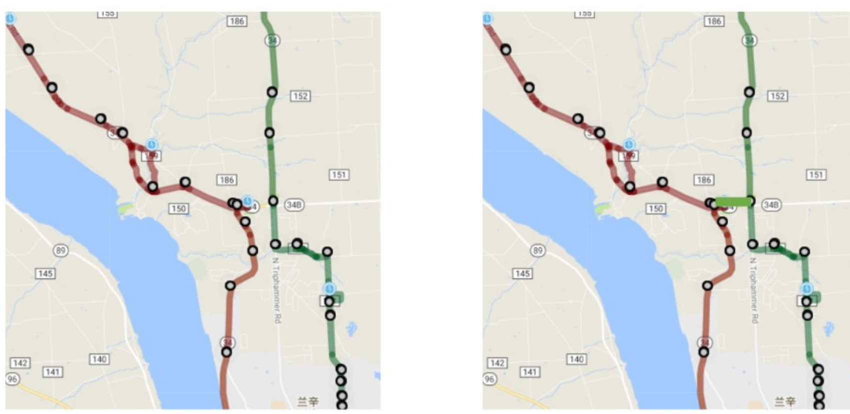
CUSD Sustainable Mobility Routing Team			Evaluation							
Classification	No.	What is your scenario?	Req.1 Punctuality	Req.2 Residential Coverage	Req.3 # of Shifts	Req.4 Functional Area Coverage	Req.5 Near to Residence	Req.9 Route to Ithaca Mall	Req.10 Flexible Schedule	Req.11 Special Time
Final Set	A (1)	Connect 36 & 37 (current demand)	2	3	3	3	3	1	1.5	1
	B (4)	Combine 37 & 77 (current demand)	3	3	3	3	3	3	1	3
	C (16)	32 serves portion of 37 which will then have a different route	2.5	2	2	2.5	2.5	3	1.5	2
Other Interesting Scenarios	11	37 goes through Ithaca Mall	2	2.5	3	3	3	3	1	3
	15	30 serves 77 on Saturday and Sunday	3	3	2	2.5	2.5	3	1.5	2

System Index 18: Scenario Evaluation Results/Decision Matrix

It is worth noticing here that out of the three final recommendations derived by combining the results of scenario analysis and empathy fieldwork, two were the same as those shortlisted by the modelling team. This indicated a strong agreement between the two approaches and increased our confidence in the results.

The three recommended scenarios are shown in the figures below (the "Previous Scenario" number refers to the scenario's index in the scenario analysis table from Fall 2017):

Recommended Scenario A (Previous Scenario 1) Connect 36 & 37 at Town Hall



Before After

Figure 88: Recommended Scenario A

Explanation: This recommendation would keep the 36 and 37 as they are except for a small diversion where each would got to the Town Hall parking lot to allow users to make a transfer and get to a destination on the route faster than having to travel down till Ithaca before making a transfer.

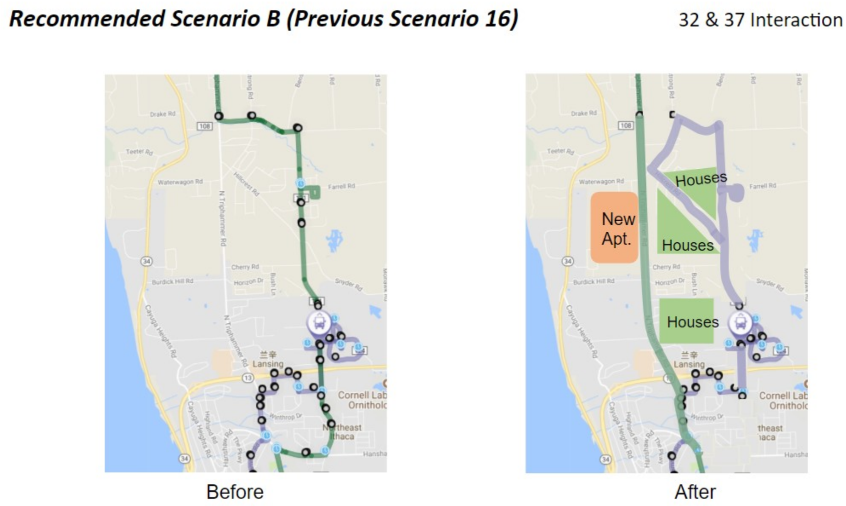


Figure 89: Recommended Scenario B

Explanation: If this recommendation were implemented, Route 32 would serve a portion of Route 37 while redirecting the 37 along North Triphammer road south of the Town Hall. Route 32 would run beyond the airport (originally its last stop) and cover the Solar Village Apartments area.

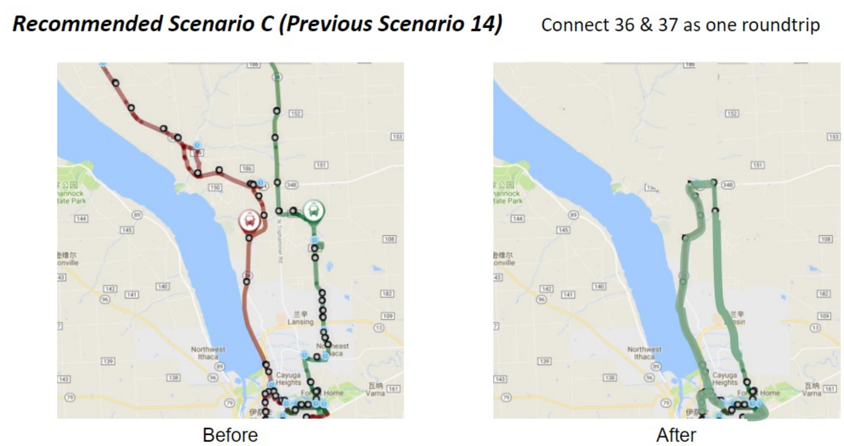


Figure 90: Recommended Scenario C

Explanation: For this recommendation we plan to replace the 36 and 37 with a loop along North Triphammer and East Shore Drive.

3.2.2 Stakeholder Feedback

The team presented these recommendations to TCAT representatives, and received feedback in the form of questions that needed further analysis. TCAT also recommended potential methods for this analysis. One potential solution that TCAT suggested team members explore would be to see if Lansing riders from the Lansing Fire Company #3 and Lansing Fire Station #4 park and ride locations would be willing and able to coordinate with each other so that they could all use one morning trip and one evening trip. They suggested that it also may be useful to see if any of those riders would be willing to make the trip to the Town Hall if there were more buses available throughout the day. TCAT representatives also suggested exploring whether Lansing residents would be willing to transfer at the Ithaca Mall if it meant much more frequent service along Triphammer and Warren Rd. Another concern raised by the representatives was how TCAT could make sure to capture riders that want to get to Cornell from the Northern Fall Creek neighborhood if the Route 36 alignment along East Shore Drive goes away. It might also be important to determine whether or not the 32 could feasibly make it to the Village Solars and back during its 17 minute long layover. TCAT representatives also suggested exploring when people would prefer to travel if there were three to six trips on weekends that go to the Lansing Town Hall.

In addition to specific questions about the effects of changing routes, TCAT representatives also had suggestions for potential adjustments to the methods for futures studies. TCAT representatives had several thoughts about empathy fieldwork methods including assessing the usefulness of tradeoff-style questions, acquiring help from social science students and faculty at Cornell, and offering an online survey version that Cornell staff and other riders could easily access. The representatives also suggested that determining and providing two to three distinct scenarios and presenting these scenarios in open public meetings could be a useful method in determining the most favored option. Finally, evaluating the scenarios using OD matrices and GTFS were strategies that TCAT representatives felt could help determine the efficacy of the final solution.

Based on the TCAT's recommendations and feedback we realized that they were leaning towards recommended scenarios B and C but needed validation of user acceptance by means of a survey. So keeping the modifications that recommended scenarios B and C would implement in mind, the team designed a survey and the process of its design is as explained in the following section.

3.2.3 User Testing

For validating user acceptance towards our recommendations we decided to go ahead with the survey but also decided to integrate it with the human centered design element of empathy testing. To explain briefly the usual surveying methodology is augmented by the surveyor looking out for user emotions and needs and recording them as empathy episodes to be unpacked and analyzed separately. In addition to this the electronic version of the survey also allowed users to the results of the survey and those of the empathy data would then be combined to provide a stronger analysis rooted soundly in both the principles of statistics and that of human centered design.

3.2.3.1 Survey Design

The survey was created with several things in mind. First, and foremost, we collaborated with TCAT to ask pointed questions that would give us the data that TCAT was looking for. Second, we included questions about the scenarios we generated to better gauge the feasibility and interest in them. Lastly, we included an additional comments section to allow the users to include any extraneous thoughts or concerns. These comments gave us valuable empathy data that we fit into our models. Finally, we also utilized the Cornell Statistical Consulting Unit to help us design an optimized and unbiased survey.

The survey questions were all answered on a Likert Scale. The Likert Scale allows the user to respond on a scale ranging from strongly agree to strongly disagree, with everything in between. The questions on the survey along with the rationale behind them are as follows:

> 1) For the 36 route, if there was only one morning and one afternoon bus on this route (ie. the bus would leave Lansing Fire Company #3 at 7:30 am instead of both 7:15 am and 7:40 am), how much would this affect your commute?
> **Aim:** This question aimed at evaluating people's reaction to a reduction in service (possible cutting off of service) to the fire station at the north end of route 36 as that would be one of the key parts of implementing our recommendations. This

mainly targeted people who did not use the park and ride at the fire station but used the route get to and from somewhere between the Lansing Town Hall and the Fire Station.

2) If you currently use the park and ride at Lansing Fire Company #3 or #4, how willing would you be to park and ride at Lansing Town Hall if it meant there would be a significant increase in service (more buses throughout the day)?
Aim: The aim of this question was similar to question except this targeted people who used their own vehicles to drive upto the fire station and then took the 36 or the 37 to travel into Ithaca. These people have the option of driving a little further till town hall and use the park and ride there. We wanted to evaluate if people were willing to do that if it meant increased frequency of service.

3) How willing would you be to taking a transfer bus at Ithaca Mall to get to work or other places if more service was provided along Triphammer and Warren roads?
Aim: If TCAT implemented Recommended Scenario B people currently using the 37 to get to offices on Warren Road (such as Borg Warner and Transonic Systems) would need to first travel down to Ithaca Mall and then make a transfer to the extended 32 and travel up again. This question aimed at assessing user opinion on the trade-off between this possibility and increased service along North Triphammer (currently not served by any route) and Warren Roads.

4) If one bus was dedicated to Lansing routes and terminated at the mall, would you prefer a loop route that only runs one way along Triphammer and Warren, if it meant much more frequent service, or would you rather have service in both directions with significantly less frequency?
Aim: Recommended Scenario B.

5) If there are 3-6 trips on Weekends that go to Lansing Town Hall from the Mall (an expanded route 77), when would you want to travel?
Aim: Weekend service of route 77.

3.2.3.2 Survey Execution

An aspect of surveying that is almost as important as its design is to identify a distribution method and locations which would ensure a representative and unbiased collection of data. These locations were based on several factors, including relevance to Lansing residents, ease of access to current bus riders, and their potential as sources of future ridership.

In addition to these physical locations, TCAT also made the survey accessible on their website, in order to reach a wider segment of Lansing residents. The survey was further distributed amongst Lansing residents through Michael Long, the Planning Consultant for Lansing.

Below are short descriptions of the survey locations we chose:

1. Route 36
Route 36 operates between the Ithaca Commons and Lansing Fire Station #3, via Cornell University, E Shore Road, and Ridge Road. It operates 5 round trips a day, with two serving the morning commute, approximately between 6:45am and 8:30am, and two full trips (and one short-turn) serving the afternoon commute, approximately between 3pm and 6pm.

2. Route 37
Route 37 operates between Ithaca Commons and Lansing Fire Station #4 via Cornell University, Pleasant Grove Road, Hanshaw Road, Warren Road, Asbury Road, Triphammer Road, and Auburn Road. with two full trips (and one short-turn) serving the morning commute, approximately between 6:30am and 9am, and two full trips serving the afternoon commute, approximately between 4pm and 6:30pm.

3. Route 32
Route 32 operates between Ithaca Commons and Ithaca-Tompkins Regional Airport via Collegetown, Cornell University, Triphammer Marketplace, and the Cornell Business and Technology Park. It operates hourly between 7am and 4pm (with an extra trip at 7:45am) and between 6pm and 9pm, and operates every 30 minutes between 4pm and 6pm.

4. Lansing Fire Station #3 Parking Lot
This is an isolated outpost on Ridge Road, surrounded by woods, farmlands, and far-flung single family homes. This location primarily serves as a park-and-ride, and is the northern terminus of Route 36. When we attempted to survey riders who parked at the fire station, we were unable to find a single rider that disembarked here at the time that we went.

5. Lansing Fire Station #4 Parking Lot
This fire station is located on Auburn Road, with single-family homes, farmland, woods, and a restaurant nearby. It serves as the northern terminus of Route 37. This location primarily acts as a park-and-ride as well. Surveying was marginally more successful here than at the other fire station; we were able to survey one rider at this location.

6. Lansing Town Hall Parking Lot
This location both serves as a good source of bus ridership, with its park-and-ride lot, municipal offices, and public library, and also has the potential to be an even greater source of ridership in the future, given the development plans for the area. We were only able to distribute the survey to one person at this location.

7. Offices Near Springbrook Apartments on Route 37
This location contains several potential sources of bus ridership, as well as possible destinations, including the newly constructed Village Solar Apartments, Springbrook Apartments, as well as a UPS Customer Center, and other companies, such as Global Phoenix Computer Technologies Solutions. However, attempts to distribute surveys there were unsuccessful. We were unable to find people outside of their homes and offices in the area, and so we were unable to distribute the surveys to them.

3.2.4 Survey and Empathy Testing - Results and Discussion

3.2.4.1 Survey Results and Basic Analysis

After the survey was completed the first thing we did was to look at the aggregated results (71 responses in total). The results are as presented below.

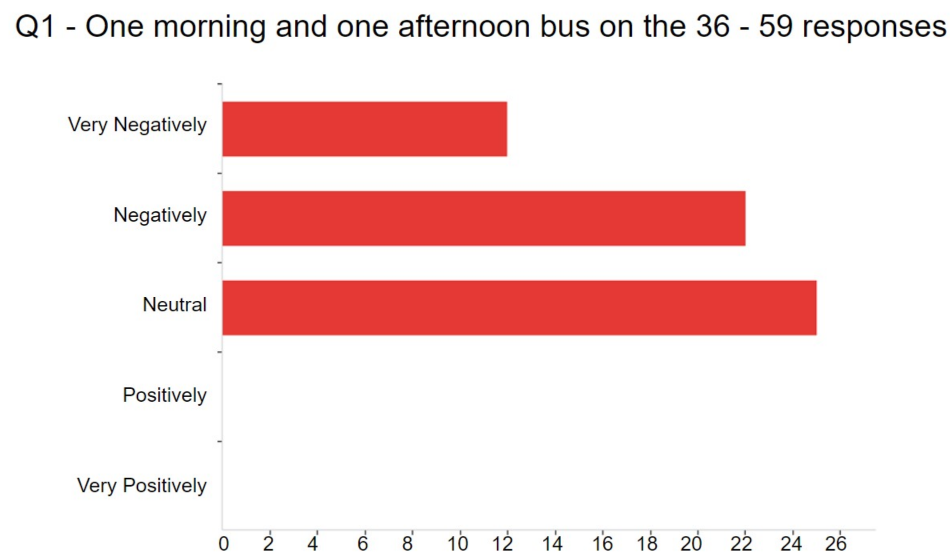


Figure 91:Bar Plot for Q1

Observation 1: Based on this plot one could conclude that people are not in favor in reduction of service to the fire station even if it means increased frequency of service up until Town Hall.

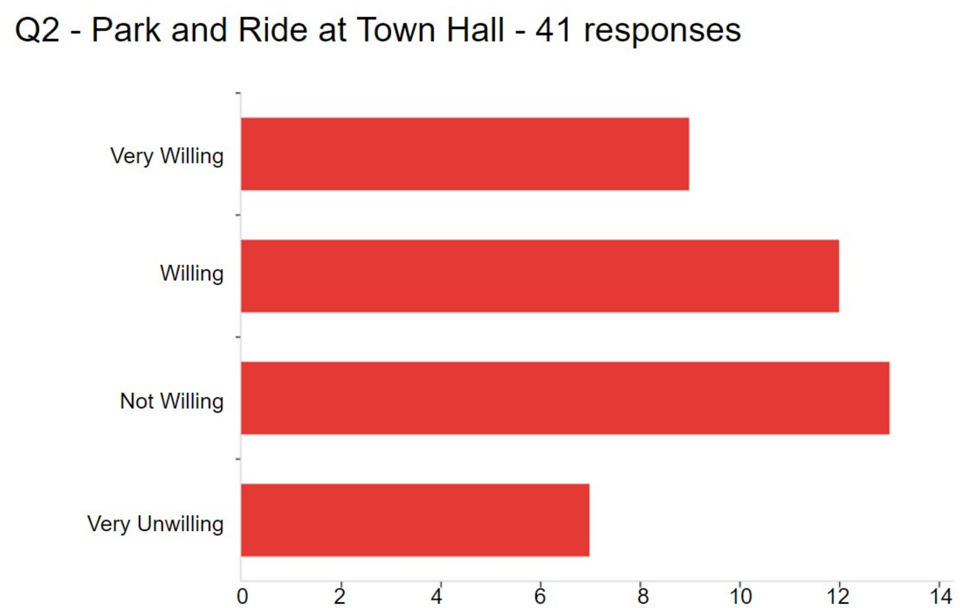


Figure 92:Bar Plot for Q2

Observation 2: The plot does not indicate a clear preference in favor of or against driving down further and parking at the Town Hall lot.

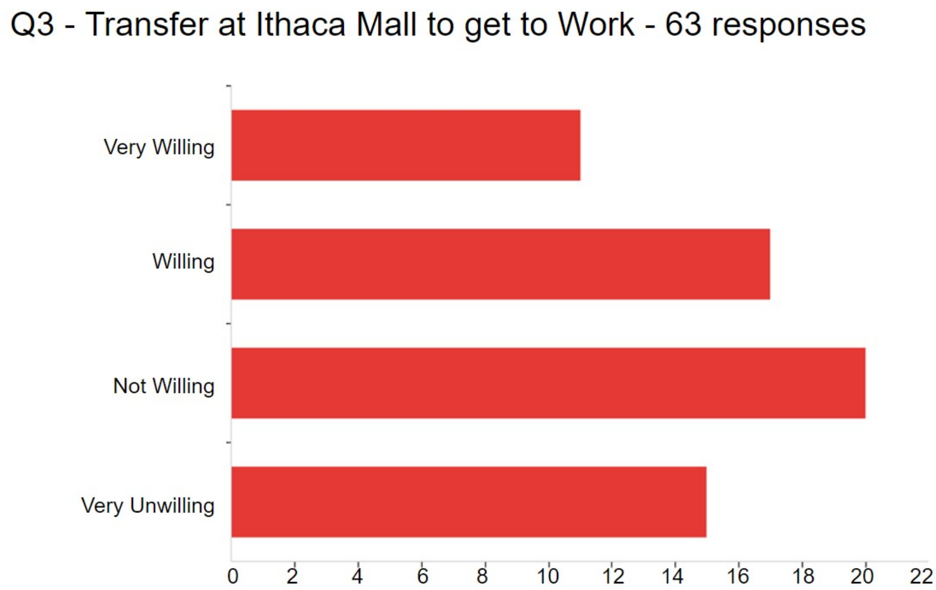


Figure 93:Bar Plot for Q3

Observation 3: Again, the plot does not make it clear what the people think about making a transfer at Ithaca Mall.

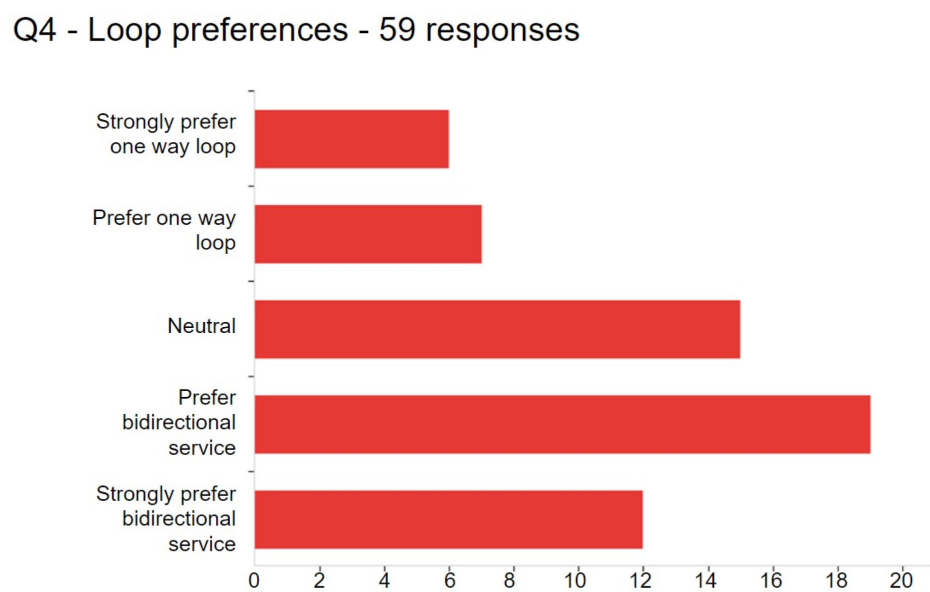


Figure 94:Bar Plot for Q4

Observation 4: This plot indicates a slight preference for a Bidirectional Service along North Triphammer and East Shore Drive as opposed to a one way loop.

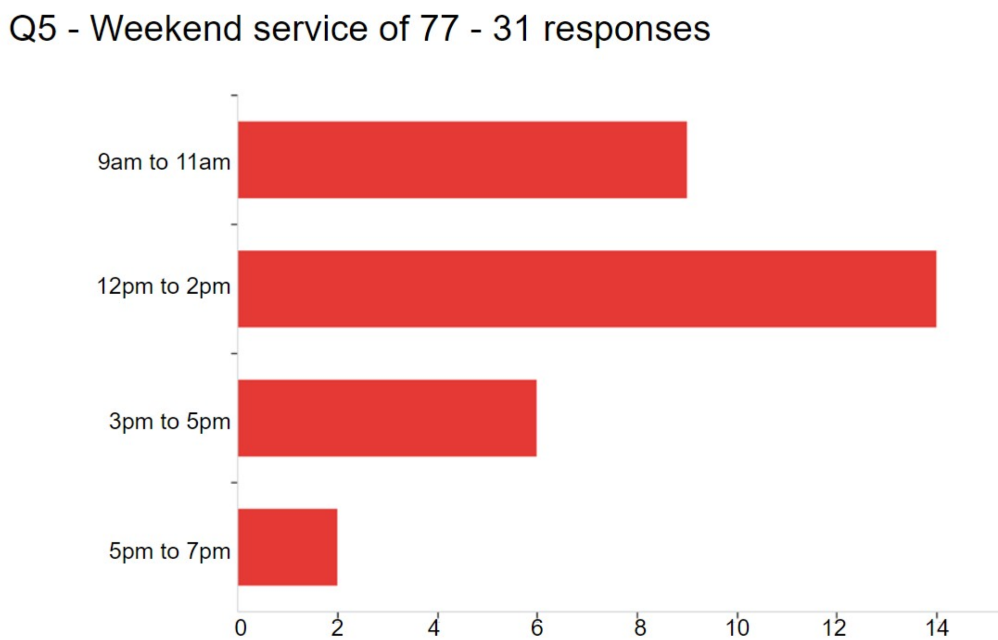


Figure 95:Bar Plot for Q5

Observation 5: This plot shows a clear preference for slots 9am-11am and 12pm-2pm for weekend service.

Although some plots do indicate some preferences or leanings they are not strong enough to inform a decision about implementing the recommendations.
We also realized that in a lot of cases the number of responses to a question were not aligned with our estimate of the people who would be affected by the changes being assessed by it. This could only mean that there were people who had just indicated their opinion of how other users might respond to the changes and did not represent the response of the affected users. To tackle this we did further analysis using clustering methods as explained in the next section.

3.2.4.1 Further Analysis based on Clustering

In order to make the data analysis more robust, we used a method of machine learning called hierarchical clustering. The algorithm employed groups the responses based on similarity in the set of questions a person chose to answer. The rationale behind this was that each set of questions would indicate a specific cluster of riders with shared concerns/needs and the preferences. And as opposed to the aggregated preference of all respondents, this method can better indicate the preferences of users targeted by each question.

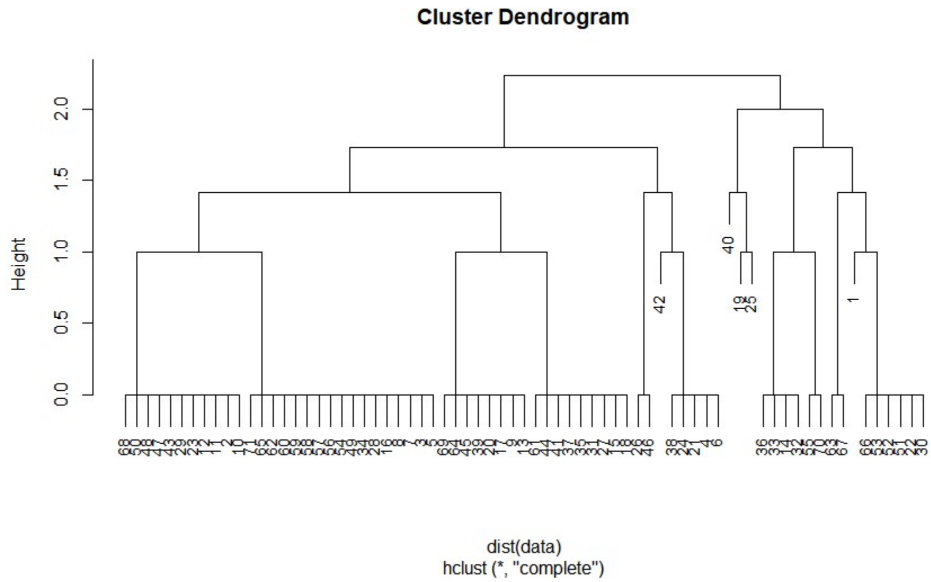


Figure 96: Cluster Dendrogram

The above figure was the cluster dendrogram from RStudio. After we got rider clusters, we tried to infer the concerns/needs represented by each cluster. We then merged those with similar needs into a larger group which we decided to call "Rider Cluster". Each of these Rider Clusters consisted of users with similar needs which could now be mapped to the questions and thus allowed us to weigh the responses based on the rider group they belonged to.

This entire process was represented in Figure 97 below:

Q1	Q2	Q3	Q4	Q5	Cluster	Number of Respondents	Total Respondents	Percentage of Total Responses	Response Cluster	Rider Cluster
					2	11	**11**	**15%**	Route 36 and 37; No interest in Weekend Service	**Riders on 36 and 37**
					4	5	**8**	**11%**	Route 37	**Riders on 37**
					11	2			Route 37; No Park and Ride	
					13	1			Route 37; No Park and Ride	
					5	8	**18**	**25%**	No Park and Ride	**Riders on 36 without Park and Ride**
					7	8			No Park and Ride	
					8	1			No Park and Ride	
					12	1			No Park and Ride	
					3	17	**21**	**29%**	No Clear Theme	**Riders without clear patterns**
					6	4			Do not like the loop or do not care	
					9	6	**13**	**18%**	Noise	**Noise data**
					14	3			Noise	
					15	2			Noise	
					1	1			Noise	
					10	1			Noise	

Figure 97:Clustering Results

As can be seen above, fifteen small clusters containing different number of respondents were generated by the clustering algorithm. We then inferred the needs indicated by the set of questions answered by each cluster which can be seen in the column titled "Response Cluster." The small cluster were then merged with other similar clusters (in terms of concerns/needs) into five larger "Rider Cluster" marked by five different colors. Four of these "Rider Clusters" most likely represent four groups of respondents with the following themes: Users of Route 36 and 37, Users of Route 37, Users of Route 36 who do not park and ride, Users with no clear theme. The last "Rider Cluster" was identified as noisy data because responses in this group were random in nature and did not indicate association with any theme. But it is interesting to note that some of the respondents from last cluster turned out to be people who had filled in written feedback but had not answered the questions i.e. that is people who preferred a more conversational style of communication as opposed to a more limited yes/no response to a set of questions.

The bar plots below show the responses of each of Rider Cluster to each question on the survey:

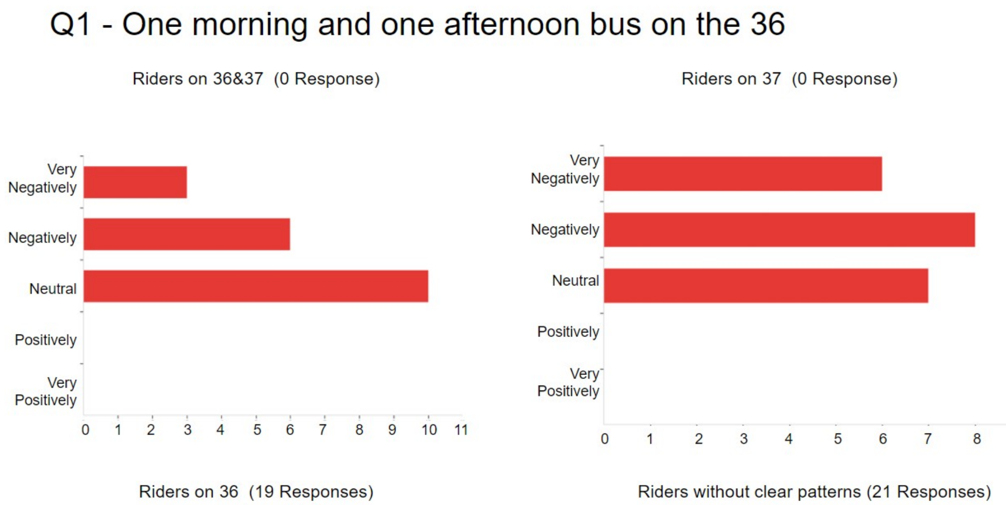


Figure 98:Q1 Cluster Wise Bar Plots

Takeaway 1: The preference is much more pronounced and it is clear that people who ride the 36 and 37 clearly do not like the idea reduced service to the fire stations.

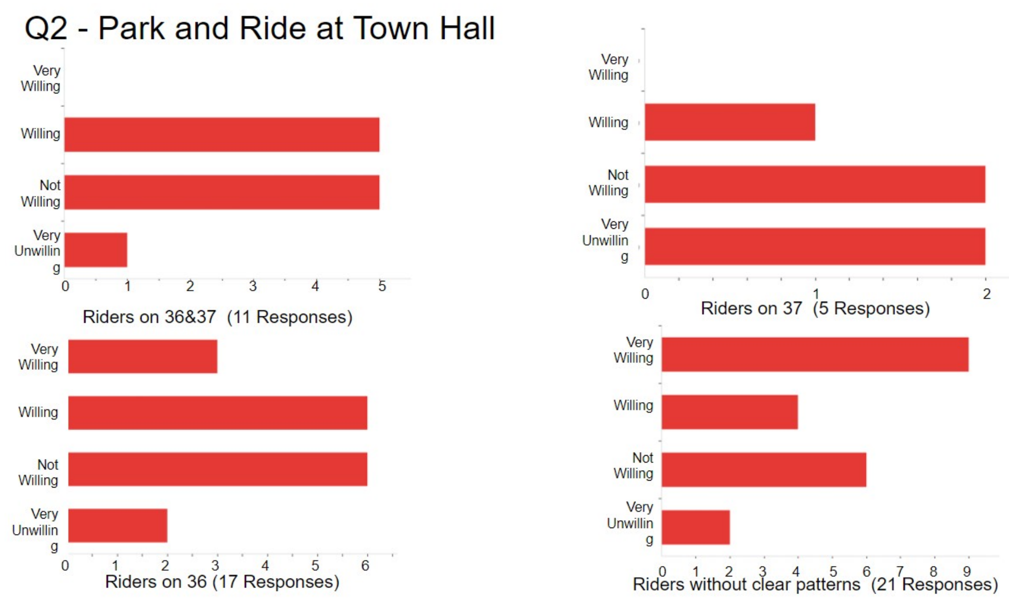


Figure 99:Q2 Cluster Wise Bar Plots

Takeaway 2: Based on the above plots one could infer that people who do park and ride, and would be affected by having to drive down further, are not in favor of it.

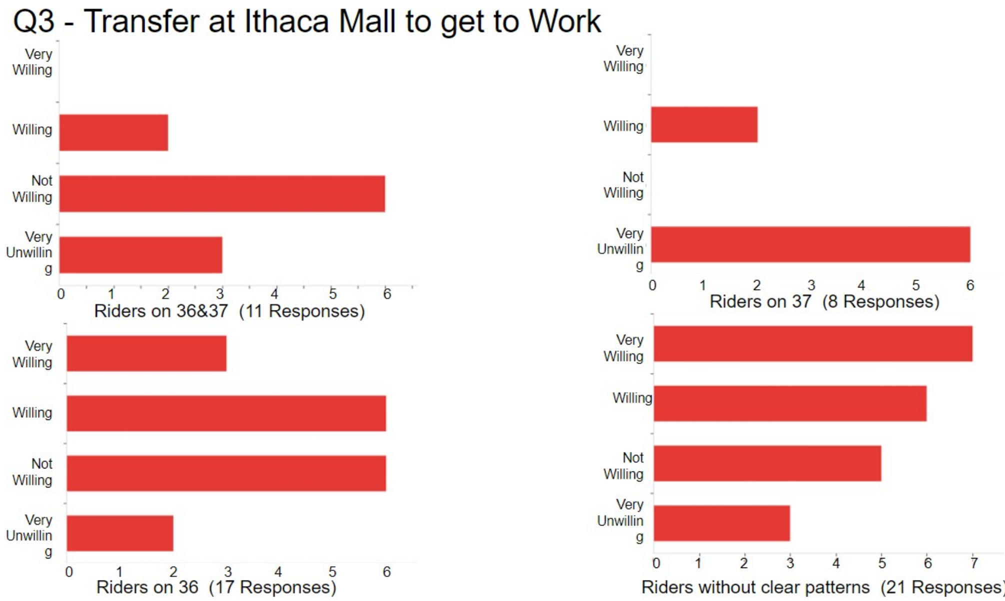


Figure 100:Q3 Cluster Wise Bar Plots

Takeaway 3: Again looking mainly at the clusters containing the users of route 37 it becomes clear that they are not in favor of having to make a transfer.

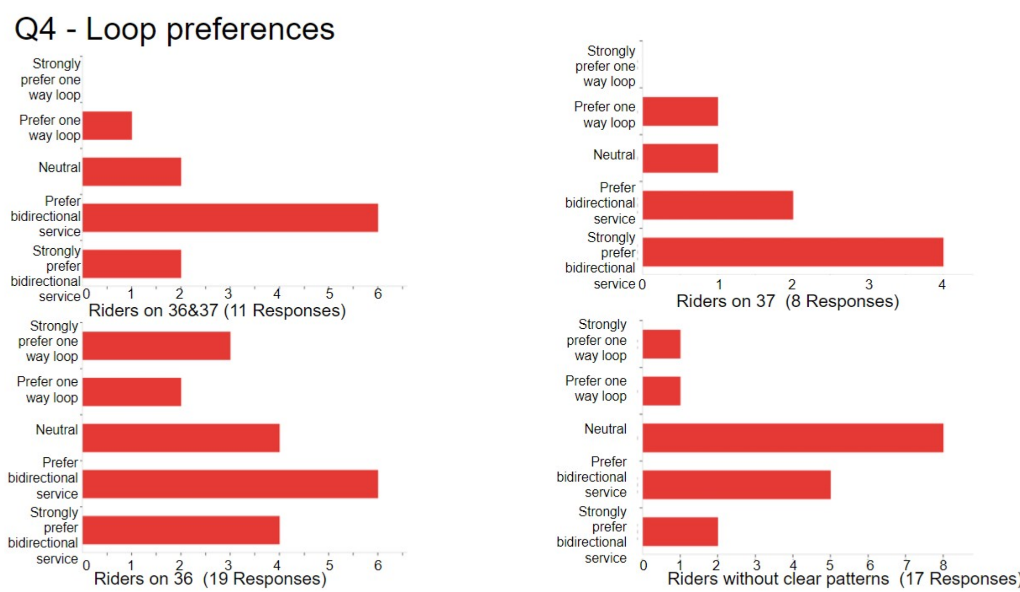


Figure 101:Q4 Cluster Wise Bar Plots

Takeaway 4: When considering each cluster having users of the 36 or 37 there is a more pronounced preference for bidirectional service.

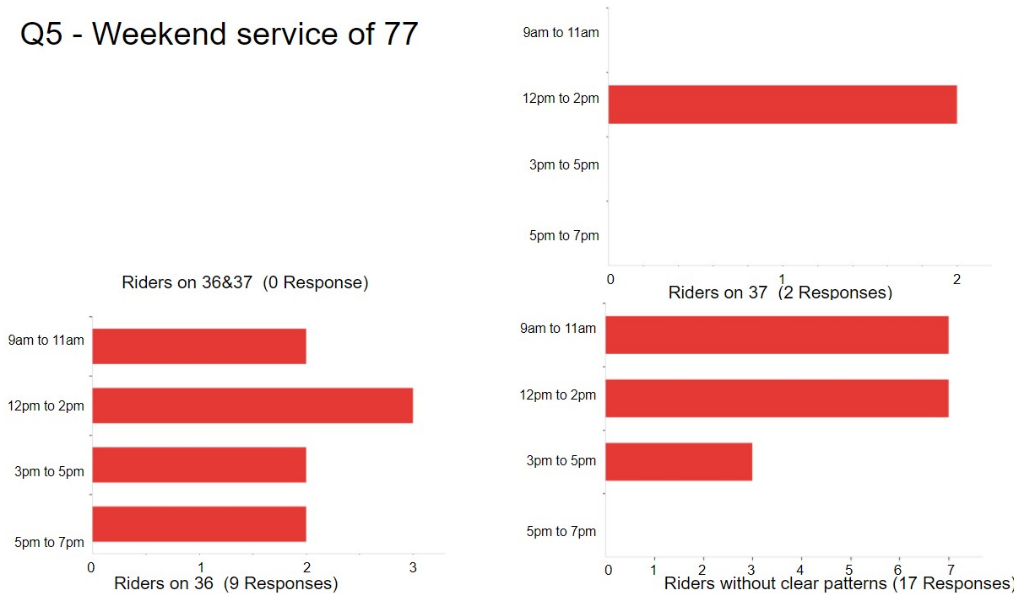


Figure 102:Q5 Cluster Wise Bar Plots

Takeaway 5: Consistent with the aggregated responses, this plot shows a clear preference for slots 9am-11am and 12pm-2pm for weekend service.

It is clear that although we could make out slight inclinations using the aggregated results the preferences are much clearer when looked at by mapping questions to the relevant clusters.

Based on the cluster analysis, we came up with the following conclusions:

1. People do not like idea of reduced service to the fire stations and are generally not willing to drive down to the Town Hall parking lot. (Takeaway 1 and 2)
2. Users of Route 37 are unwilling to make a transfer at the mall to get to destinations on Warren Road. (Takeaway 3)
3. There is a general preference for bidirectional service along Triphammer and Warren. (Takeaway 4)
4. And the most popular slots for Route 77 weekend service are 9-11 A.M. and 12-2 P.M. (Takeaway 5)

These conclusions indicated that some of our recommendations were not aligned with user preferences as validated by the survey and we needed to modify these to better serve the people of Lansing. These modifications are presented in the final section of final set of scenarios.

3.2.4.3 Emotional Modeling on Survey Results

The data analysis was also accompanied by empathy data unpacking and modelling to identify the emotional aspect of user testing. This is represented in the emotional data relationship map, Figure 103.

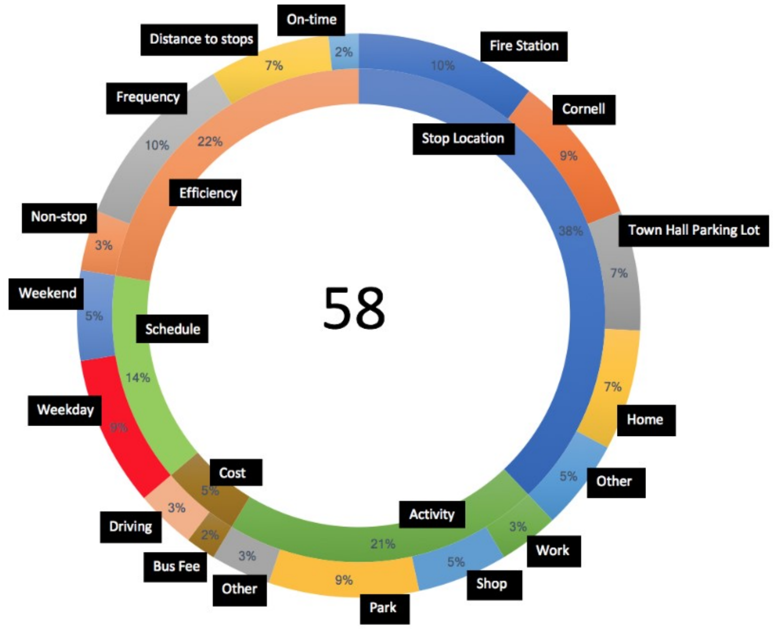


Figure 103:Emotional Data Relationship Map

This was obtained by a process very similar to the User Affinity Process using the comments and emotions identified by students who interacted with users while getting the surveys filled. These comments and emotions were then unpacked to derive needs, insights and surprises. These were then grouped by sub-themes (such as weekend service, parking and distance to stop) and broader themes (such as schedule, efficiency and stop location).

The comments and the summarized results are presented below:

User Background and Experiences	Reactions/Emotions to survey
1. Chinese old couples who take Route 37 every weekday 2. Sometimes they also take Route 30 for shopping 3. They complain on Route 32 not passing their home because previously it was changed the route 4. They do not take buses during the weekends 5. They own their car	1. Patient 2. Complaining (on Route 32)
1. Usually take Route 31,32 and 37 2. Drops out at Bradfield Hall usually 3. Does not like to transfer the buses	1. Curious 2. Happy on taking survey 3. Patient
1. Go to Fire Station (final stop) 2. Actually lives in Harbor 3. Unhappy to park at Town Hall 4. Has to drive 20 miles from Fire Station to home, pretty far 5. Has personal schedule that prefers to go to campus quickly 6. If driving to Town Hall, would rather then just drive to Cornell	1. Unhappy if Route 37 changes (hope to arrive to campus more directly) 2. 10/15 Unwilling to agree 3. Unwilling to transfer to 32 4. Unhappy about the loop (cutting off the North area
1. Live closer to Route 37, near the Triphammer Road	1. Patient 2. Interested in taking the survey
1. Only uses 37 2. Totally against new ideas 3. Has an extra 5 miles of driving to do as well as the bus 4. Lives outside Tompkins County	1. Disagreeing with the new ideas 2. Complaining about the decision 3. Unhappy
1. Totally against loop idea	1. Curious

2. Also has an extra five miles of driving to do 3. Final destination is fire station 4. Lives outside Tompkins County 5. Has concerns about parking as Lansing Townhouse parking is already full, which is why people park at fire station	2. Disagreeing 3. Unhappy
1. Disagrees with the proposal 2. Lives 20 miles away from the fire station 3. Is concerned with the idea as there are still 5 miles away from fire station to Cornell Campus 4. Also brought up the fact that the Lansing parking lot is already full but there are still more than 15 cars waiting	1. Complaining 2. Decisive in decision making process 3. Unhappy
1. Currently does not use route 36 2. Stops at fire station 3. Willing to consider the re-route 4. Only uses the bus on the weekdays	1. Curious perhaps even considerate 2. Careful 3. Uncertain
1. Wants to have both 36 and 37 stop at Lansing Town Hall 2. Believes proposed route 32 isn't helping anyone in the village 3. Does not like the idea of TripHammer Mall being the place for the transfer as the area is already being used for other things 4. Is worried about how much more money the new route (loop) will cost due to increased mileage and heating	1. Seems very dubious and skeptical. 2. Is worried about the price of gas and the possible new route 3. Unhappy with the new idea
We need this route	
1. Wants to cut out Ludlowville loop because it is hilly and dangerous due to ice and snow 2. Only one regular takes the early morning bus 3. Is also concerned about the Ludlowville loop due to Lansing schools	1. Also seems very dubious and skeptical. 2. Overly concerned with safety. 3. Unhappy with the new idea
If driving to Cornell, will park at A lot	
1.doesn't agree with question about what time of day on weekends/Lansing to the Mall which only offers one option. 2. Explains that If going to the mall, usually spend at least two hours. 3. At the same, if Route 74 substitutes Route 31 and it operates too infrequently daily, it forces passengers to stay longer in malls (which wastes some of their time potentially). 4. It's confusing to indicate that a bi-directional routes would make the bus operations in less frequency, when a one way loop means more. 5. The interviewee lives in the NE area instead of Lansing 6. The interviewee has looked at residential apartments that past the Fedex office or Dart Drive, if the buses along Warren would run more frequently or can run later at night.	1. Concerning about the changes 2. Likely unwilling
Loves the idea of a continuous hourly loop to increase service delivery.	3. Strongly willing
1. Strongly disagree with any changes to Route 36. 2. The reason is that Route 36 serves to deliver Cornell staff to work and home conveniently as it stands. 3. Since the interviewee would not take weekend buses, he/she thinks they are not useful at all to Ithaca Town Hall	1. Strong disagree/unwilling
1. Would like Lansing to provide more parking and ride lots, which might be helpful if it is hard for TCAT to arrange more services	1. Likely willing
1. Strongly disagree with the change on Route 36 in particular the one at 7:40am,	1. Strongly unwilling on a specific time slot for the bus

because he/she believes it will lead to very negative impact.	
1. New proposal will not affect this passenger, as he does not travel to upper Lansing area	1. Seems neutral about the idea 2. Not overly concerned or affected by it
1. Likes this idea due to Weekend service	1. Seems happy or okay with the idea 2. Excited by the idea of weekend service
1. Walks to East Shore Drive everyday and takes the bus back in the evening 2. Would not want to take the bus if it meant getting in the car and parking it somewhere else	1. Doesn't seem very inclined to the idea 2. Concerned about where he parks his car and how much walking he will have to do
1. Elimination of the bus going down Woodsedge is real deterrent for this passenger riding the bus more	1. Does not seem very happy with idea as new route would negatively affect his routine
1. Depends on the bus from the fire station most weekdays 2. Does not want to drive all the way to town hall as he lives in King Ferry and would inconvenience him 3. States the just one morning and evening route from and to the fire station would work for him 4. Suggests that Cornell should provide info for people who live out toward the Fire Station to let them know bus is an option	1. Does not seem happy with new routes as it is inconvenient 2. Seems curious though and suggested ideas for TCAT to do

Figure 104:Raw Emotional Data

Top Category	Number	%	Sub-Category	Number	
Stop Location	22	37.93%	Fire Station	6	
			Cornell	5	
			Town Hall Parking Lot	4	
			Home	4	
			Other	3	(A lot, Ithaca Town Hall)
Activity	12	20.69%	Work	2	
			Shop	3	
			Park	5	
			Other	2	(Fedex)
Cost	3	5.17%	Bus fees	1	
			Driving	2	
Schedule	8	13.79%	Weekdays	5	
			Weekends	3	
Efficiency	13	22.41%	Non-stop	2	
			Frequency	6	
			Distance to stops	4	
			On-time	1	
				58	

Figure 105:Summarized Emotional Data

3.2.5 Final Recommendations and Next Steps

3.2.5.1 Final Recommendations

Based on the data analysis and emotional modeling from the survey results, as well as the empathy testing data and the personas developed in Fall 2017, we came up with a set of modifications to Routes 32, 36, and 37. These modifications could help improve service if implemented independently but can also be combined in several ways to form new routes. We presented two combinations for our final recommendations to TCAT.

The modifications are as follows:

Modification 1

Figure 106: Modification 1

Explanation: As explained in the section on Stakeholder Feedback we considered Recommended Scenarios B and C for the user testing but the results indicated that a reduction in service would not be in line with user expectations of improved service even if it results in increased frequency south of the Town Hall parking lot. The next best thing would be to try and reduce TCAT's costs in running that leg of the routes, which are currently high, because there are a very limited number of riders (~10-15). This would only be possible by running smaller buses which have relatively better mileage and lower maintenance costs. This could also be implemented by tying up with a sub-contractor or a service like Gadabout.

Modification 2

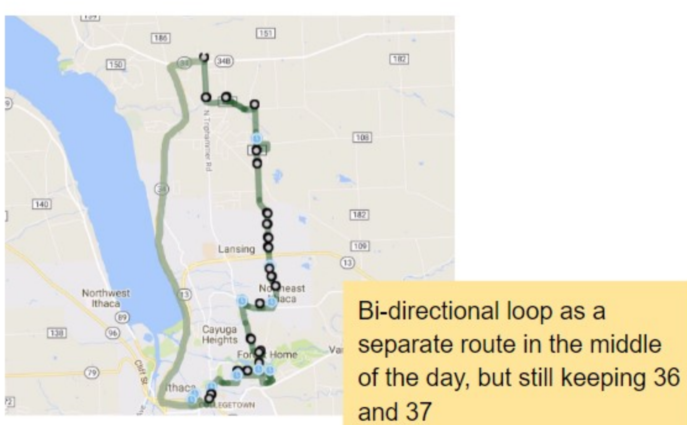


Figure 107: Modification 2

Explanation: The survey results indicated that users wanted more service throughout the middle of the day. In order to achieve this without using excessive resources, a bi-directional loop was utilized. There would still be normal service for Route 36 and Route 37. The bi-directional aspect would allow for more flexible service.

Modification 3

Figure 108: Modification 3

Explanation: The third modification involves rerouting Route 37 along North Triphammer Rd instead of along Warren Rd. Additionally, Route 32 would be expanded to cover the offices and apartments of South Lansing. This would potentially reach more users that would be traveling to Ithaca from the newly developed apartment complexes in Southern Lansing. This scenario is desirable because it does not require a lot of resources to implement and creates a more direct route to Ithaca for riders on Route 37 which is in line with our survey.

Recommendation 1

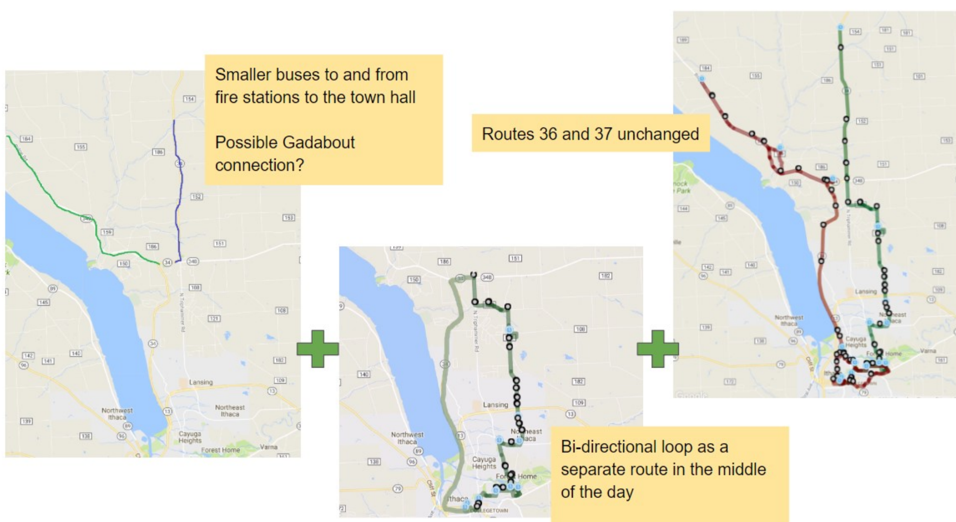


Figure 109: Recommendation 1

Explanation: The first recommendation utilizes smaller buses North of the town hall in order to cut down on costs. Additionally, it incorporates the bi-directional loop for increased midday service. The 36 and 37 routes remain unchanged.

Personas reaction

Figure 110: Personas reaction on Recommendation 1

Explanation: There is an overall positive effect on our fleshed out personas in this recommendation. Frannie has more opportunities to meet friends and be social on the smaller buses and Mary has increased service throughout the day. The recommendation has no effect on Margaret due to no changes on Routes 36 and 37.

Recommendation 2

Figure 111: Recommendation 2

Explanation: Recommendation is similar to the first recommendation in that it utilizes smaller buses North of the town hall. Additionally, it employs the modification of the Route 32 and Route 37.

Personas reaction

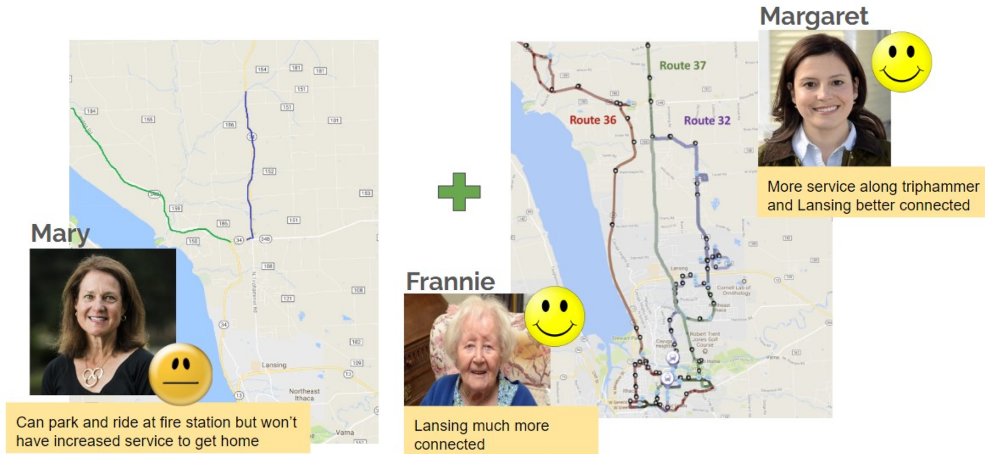


Figure 112: Personas reaction on Recommendation 2

Explanation: The second recommendation is beneficial for both Franny and Margaret as it creates a more connected Lansing, meeting their needs. For Mary, she gets to use the Town Hall as a park and ride, but the recommendation does not provide increased service throughout the day.

3.2.5.2 Next Steps and Other Promising Lines of Inquiry

Base Case Analysis to Estimate Ridership

Base cases are used as a starting point for building more complex models for the purpose of modelling real life scenarios. They are built up by first defining the quantity that needs to be estimated and identifying all factors that might impact them. In our case the quantity we need to estimate is ridership and the factors are aspects like TCAT's service constraints, people's choices, etc. We can assume that all the factors remain constant and attempt to estimate the ridership by coming up with a ratio for potential riders to actual riders for every bus stop TCAT has in Lansing. This can be done by using the data we received from them. After this we can assign new bus stops at locations that have a similar population in the immediate vicinity and apply ratios for bus stops that are similar in terms of location and the demographics of the surrounding population.

This could allow us to estimate the ridership for base cases for the recommended routing changes. These cases can then be used to build up more complex models for estimating ridership by systematically introducing other constraints. We would recommend this approach moving forward in the project as a powerful tool to get quantitative validation for the recommendations being in line with the objective of increasing ridership.

General Transit Feed Specification Data

At the suggestion of Matt Yarrow from TCAT, we examined whether or not it was feasible to use General Transit Feed Specification (GTFS) data in order to model proposed changes to TCAT routes, and the impact that these changes would have. GTFS is a unified standard for marking transit stop locations, routes and timetables, among other aspects of a public transit system. By taking a copy of TCAT's existing GTFS data and modifying it to incorporate the proposed changes, it would be possible to see not only how the proposed changes would affect the routes in Lansing, but also how other routes throughout Tompkins County would interact with these changes, and how TCAT users' trip planning would be impacted.

Although we attempted to obtain official GTFS data from TCAT officials, our requests were ultimately unsuccessful. Unfortunately, the publicly available GTFS data for TCAT on the internet was neither official, nor complete. To make this data usable, the team would have had to manually compile GTFS data for the entire TCAT system, or at least for all of the routes in the Lansing area. Due to time constraints, as well as the accuracy

issues that would come with manually compiling GTFS data, the team ultimately decided not to go ahead with using GTFS for modelling.
However, this line of inquiry is promising and could help generate OD data for Lansing and identify principal flows. These could then be used to further validate or refine our recommendations.

TCAT Report
TCAT has not released a Ridership and Statistics Report since 2014. As such, much of the information in the last report is severely outdated. The majority of the fleet, as well as many of the routes, have changed significantly. In order to understand the context of TCATs current situation and resources as a whole, it would be extremely helpful if another report was issued. It is our belief that pursuing TCAT to publish another report could provide extremely valuable data that could be used to further inform our decisions.

Appendix

Appendix 1: Sustainable Mobility team roster (Spring 2018)

SUSTAINABLE MOBILITY

BUS SHELTER RENOVATIONS

	NAME	POSITION	ROLE	MAJOR	YEAR
	BYUNG HEE CHUN	Sustainable Mobility Team Lead		Economics / Statistics	2018
SHELTER TEAM	JOAQUIN JEREZ	Shelter Design Co-Lead	Systems engineer liaision; all attachment mechanisms; prototyping of	Engineering	2019
	AARON ZHU	Shelter Design Co-Lead	Systems engineer liaision; all attachment mechanisms; prototyping of	Engineering	GRAD
	JOAQUIN JEREZ	Shelter Structure Co-Coordinator	Systems engineer liaision; all attachment mechanisms; prototyping of	Engineering	2019
	AARON ZHU	Shelter Structure Co-Coordinator	Systems engineer liasion; all attachment mechanisms; prototyping of	Engineering	GRAD
	GRACE CHENG	Shelter Architecture Coordinator	Bench prototype, modularity	Architecture	2021
	LEO ANDRIUK	Shelter	All attachment mechanisms; prototyping of attachments	Engineering	2019
	KELLEY NEVILS	Shelter	Organization and parts list; prototype/test	Engineering	2019
	AMIT AJIT VERGHESE	Shelter	Panel analysis; ANSYS; light indicators	Engineering	2019
	SOFIA VILLACRESES	Shelter	New member	Engineering	2019
	RANNIE DONG	Shelter	ANSYS/Bench	M.Engineering	GRAD
	AMI MEHTA	Shelter	New member	Architecture	2020
	MICHELLE YANG	Shelter UX Coordinator	Data display	Design	2018
	EMILY CHAN	Shelter UX	Data display	Design	2021
	SARAH CHEKFA	Shelter UX	Data display	Design	2019
	KYLE GRIFFIN	Shelter UX	Data display HTML, graphics	Computer Science	2018
	SABAH QAZI	Shelter UX	Data display HTML, graphics		
	NICK CASAZZONE	Solar Coordinator	Finalizing solar kit ideas; high tech panel research/aquisition	Engineering	2019
	AUGUST CUDECK	Solar Coordinator	Finalizing solar kit ideas; high tech panel research	Engineering	2020
	KARTIKAY JAIN	Solar	Finalizing solar kit ideas; high tech panel research	Engineering	2021
	JACK PERTSCHUK	Solar	Getting solar data to website; structuring website	Computer Science	2019
	PAUL OSUMA	Solar	New member	Engineering	2020
	VICTORIA TU	Solar	New member	Engineering	2019
	KELLY CHAN	Business	Costing, Partnerships, Sponsorship, Reimbursements - shelter	ILR	2019
	KAMAKHYA MISRA	Business	Costing, Corporate Partnerships, Sponsorship, Reimbursements - solar/ ux	AEM	2020
	YINGQING CHEN	Systems Engineer Coordinator	Attending shelter meetings and providing helps in system engineering tools	Systems	GRAD
	KIMI HUANG	Systems Engineer	Attending shelter meetings and providing helps in system engineering tools	Systems	GRAD
ROUTING TEAM	BAKULESH SINGH	Routing Lead	EFW, routing and modeling	Systems	GRAD
	MATTHEW TOMASZEWSKI	Empathy Coordinator	EFW, routing and modeling	CRP	2019
	PETER MCKENDALL	Empathy	EFW, routing and modeling	CRP	2020
	ROBERT ZHANG	Empathy	EFW, routing and modeling	CRP	2020
	SCOTT KAUFMAN	Empathy	New member	Engineering	2018
	ALEC FABER	Empathy	New member	CRP	2020
	RUJUTA DESAI	Empathy	New member	CS	2020
	ELLEN CHEN	Empathy	New member	CS	2020
	ANGELA CHEN	Empathy	New member	CRP + Info Science	2020
	YOU ZHANG	Empathy	EFW, routing and modeling	Systems	GRAD
	NANZI HUANG	Modeling Coordinator	EFW, routing and modeling	Systems	GRAD
	BAKULESH SINGH	Modeling	EFW, routing and modeling	Systems	GRAD
	RAN GAO	Modeling	EFW, routing and modeling	Systems	GRAD
	CHENXI YANG	Modeling	EFW, routing and modeling	Systems	GRAD
OVERARCHING SYSTEMS TEAM	KIMI HUANG	Systems Lead	SYSEN	Systems	GRAD
	YINGQING CHEN	Systems	SYSEN	Systems	GRAD
	RAN GAO	Systems	SYSEN	Systems	GRAD
	NANZI HUANG	Systems	SYSEN	Systems	GRAD
	BAKULESH SINGH	Systems	SYSEN	Systems	GRAD
	CHENXI YANG	Systems	SYSEN	Systems	GRAD
	YOU ZHANG	Systems	SYSEN	Systems	GRAD

Appendix 2: System tools extension

Below are the systems tools conducted during the process of this project but was not included in the final report.

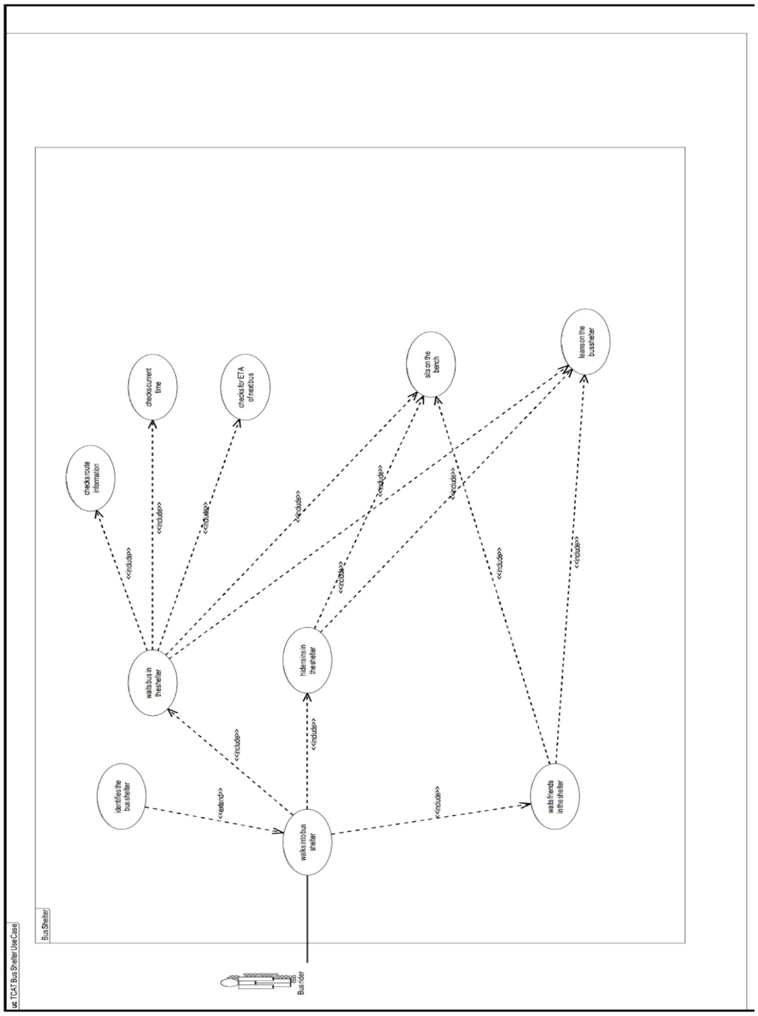
- Timeline

The Timeline/Gantt Chart table for the Spring 2018 routing team is attached below:

TCAT Routing	Deliverable	Start	Finish	Week-1	Week-2	Week-3	Week-4	Week-5	Week-6	Week-7	Week-8	Week-9	Week-10	Week-11	Week-12	Week-13
Routing				02/15/2018	02/22/2018	03/01/2018	03/08/2018	03/15/2018	03/22/2018	03/29/2018	04/05/2018	04/12/2018	04/19/2018	04/26/2018	05/03/2018	05/10/2018
Scenario Analysis																
Criterial Define		02/15/2018	02/22/2018													
Scenario Define		02/22/2018	03/01/2018													
Data Analysis		02/24/2018	03/01/2018													
Scenario Finalization		03/01/2018	03/03/2018													
Preliminary Evaluation	Pre-approved Scenarios	03/01/2018	03/08/2018													
Midterm Presentation		03/08/2018	03/08/2018													
Customer Feedbacks	Final scenario set	03/08/2018	03/15/2018													
Scenario Testing																
Survey Questionaires Making		03/29/2018	04/05/2018													
Testing Fieldwork		04/10/2018	04/19/2018													
Survey Data Analysis		04/19/2018	04/26/2018													
Final Option Define																
Final Set of Proposed Options Define		04/26/2018	05/03/2018													
Final Set of Proposed Options Analysis	Final Scheme	04/26/2018	05/03/2018													
Final Presentation		05/09/2018	05/09/2018													

- SysML Use Case Diagram

Below is a SysML Use Case Diagram for the TCAT bus shelter system:



- Map Format Decision Matrix

Below is the Map Format Decision Matrix for the Shelter UX design subteam:

		Value						Normalized Value				Final Score		
Number	Attributes	ystem map	Strip map	Booklet	Unit	in Value	ax Value	System map	Strip map	Booklet	Weight	System map	Strip map	Booklet
1	Environmental friendly	3	2	2		1	5	0.60	0.40	0.40	3	1.80	1.20	1.20
2	User-friendly	2	4	3		1	5	0.40	0.80	0.60	5	2.00	4.00	3.00
3	Contents	2	4	3		1	5	0.40	0.80	0.60	5	2.00	4.00	3.00
4	Complexity/Ease	2	4	2		1	5	0.40	0.80	0.40	4	1.60	3.20	1.60
5	Accessibility	3	3	4		1	5	0.60	0.60	0.80	4	2.40	2.40	3.20
6	Attractiveness	3	3	3		1	5	0.60	0.60	0.60	3	1.80	1.80	1.80
												11.600	16.600	13.800

Top Score		16.600
10% of Top Score		1.66

Attributes#2	Score	
nvironmental friendly	5	Map can be digitized and uses no physical material
	4	Map material can be resolved within 5 years with minimal natural material used
	3	Map material can be resolved within 5 years but requires a huge amount of natural material
	2	Map material is degradable but need more than 20 years
	1	Map material is non degradable

Attributes#3	Score	
User-friendly	5	User can find the information they're looking at first glance
	4	User can find the information they're looking for within 2 minutes
	3	User can find the information they're looking for within 5 minutes
	2	User can find the information they're looking for within 10 minutes
	1	User can't find the information they're looking for over 10 minutes.

Attributes#4	Score	
Contents	5	Includes operation schedules and routes information for all TCAT buses
	4	Includes routes information for all TCAT buses
	3	Includes routes information of one specific stop
	2	Includes information for one specific route
	1	Don't have sufficient bus information with advertisements included

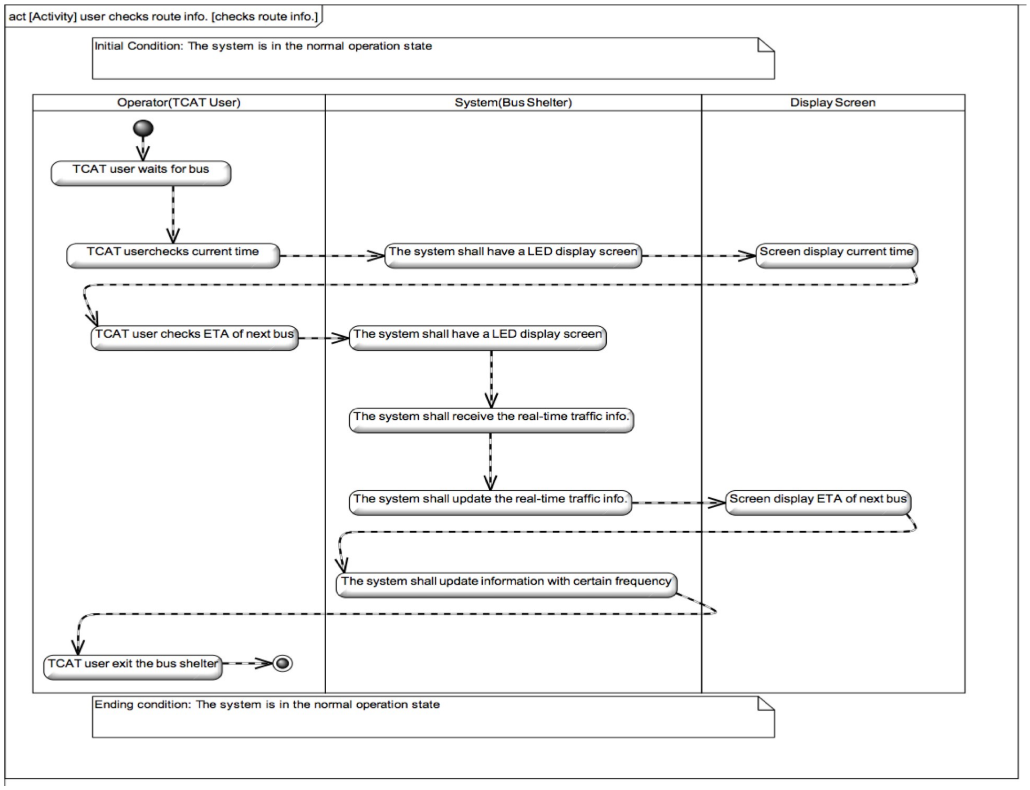
Attributes#6	Score	
Complexity	5	Map layout consists with only dots and lines in black and white colors
	4	Map layout consists with only dots and lines in under 5 different colors
	3	Map includes simplified map model with visualized routes information
	2	Map includes actual geographic maps with detailed routes information
	1	Map actual geographic maps with picture contents and massive text descriptions

Attributes#7	Score	
Accessibility	5	Map is accessible online and can be downloaded freely
	4	Map is accessible online and can be downloaded with a certain price
	3	Map is place at bus stops and users can pick them up free of charge
	2	Map is place at bus stops and users can purchase them with a certain price
	1	Map is placed in specific place and installed in fixed position

Attributes#8	Score	
Attractiveness	5	Map design can be easily recognized as a TCAT route map and makes people want to post it on their Instagram
	4	Map design is acceptable and can be recognized as a TCAT route map
	3	Map design can be easily recognized as a TCAT route map and it looks similar to the previous design
	2	Map design can be easily recognized as a TCAT route map and is impressive at first glance
	1	Map design is inappropriate and offensive

- Activity Diagram

Below is a SysML activity diagram used to visualize the shelter use case behavioral diagrams:


act [Activity] user checks route info. [checks route info.]
Initial Condition: The system is in the normal operation state
Operator(TCAT User)
System(Bus Shelter)
Display Screen
TCAT user waits for bus
TCAT userchecks current time
The system shall have a LED display screen
Screen display current time
TCAT user checks ETA of next bus
The system shall have a LED display screen
The system shall receive the real-time traffic info.
The system shall update the real-time traffic info.
Screen display ETA of next bus
The system shall update information with certain frequency
TCAT user exit the bus shelter
Ending condition: The system is in the normal operation state