
# SUSTAINABLE MOBILITY

**GRADUATE PROJECT REPORT**


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CORNELL UNIVERSITY SUSTAINABLE DESIGN

Cornell University Systems Engineering

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# 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 team brings together knowledge assets from all seven colleges of Cornell. 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 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 statistical modelling to find the most economical alternative to TCAT's current routes that also serve social needs.

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

The team is led by Kristen Vilcans, M.Eng. Systems Engineering 2017 candidate, Sirietta Simoncini, Lecturer in Systems Engineering and Wenqi Yi, Lecturer in Systems Engineering.

## 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 (SYEN 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.

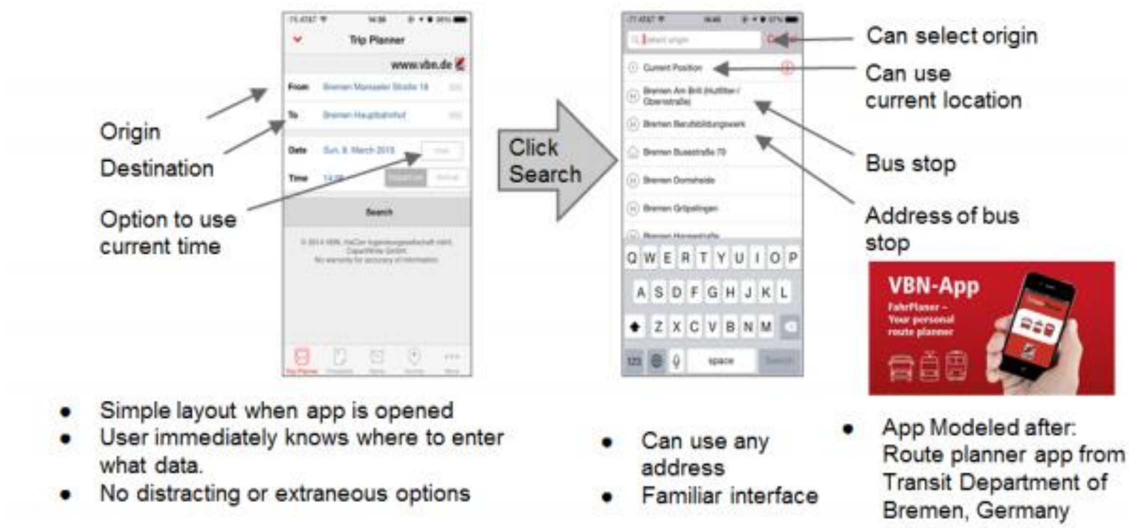



*Figure 1: TCAT Mobile App - Design of Trip Planning Screens*

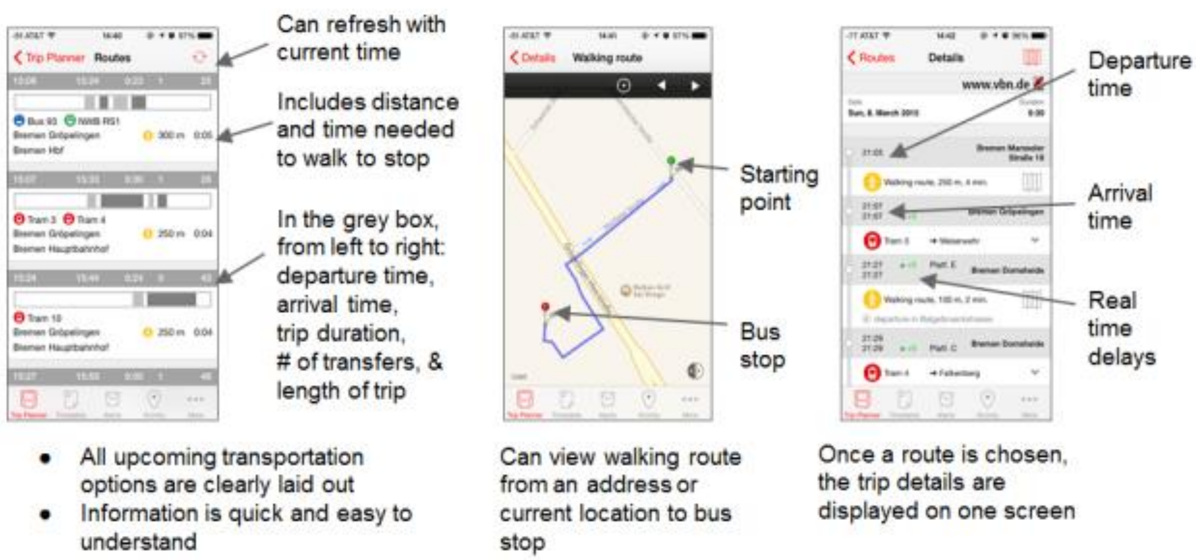



*Figure 2: TCAT Mobile App - Design of Route Selection Screen*

- **Information Design:** Four different information systems were conceptualized to provide easier and more intuitive access to information regarding the TCAT system:
    - The first idea involved developing 'linearized' route maps within the TCAT system.
    - The second idea involved simplifying schedules.

- The third idea involved developing standardized bus stops and shelters that would communicate accurate and accessible information about journeys on the TCAT.
- 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:
  - 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.
  - 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.
  - 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.
  - 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:

- 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).
- 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.
- 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.
- 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.

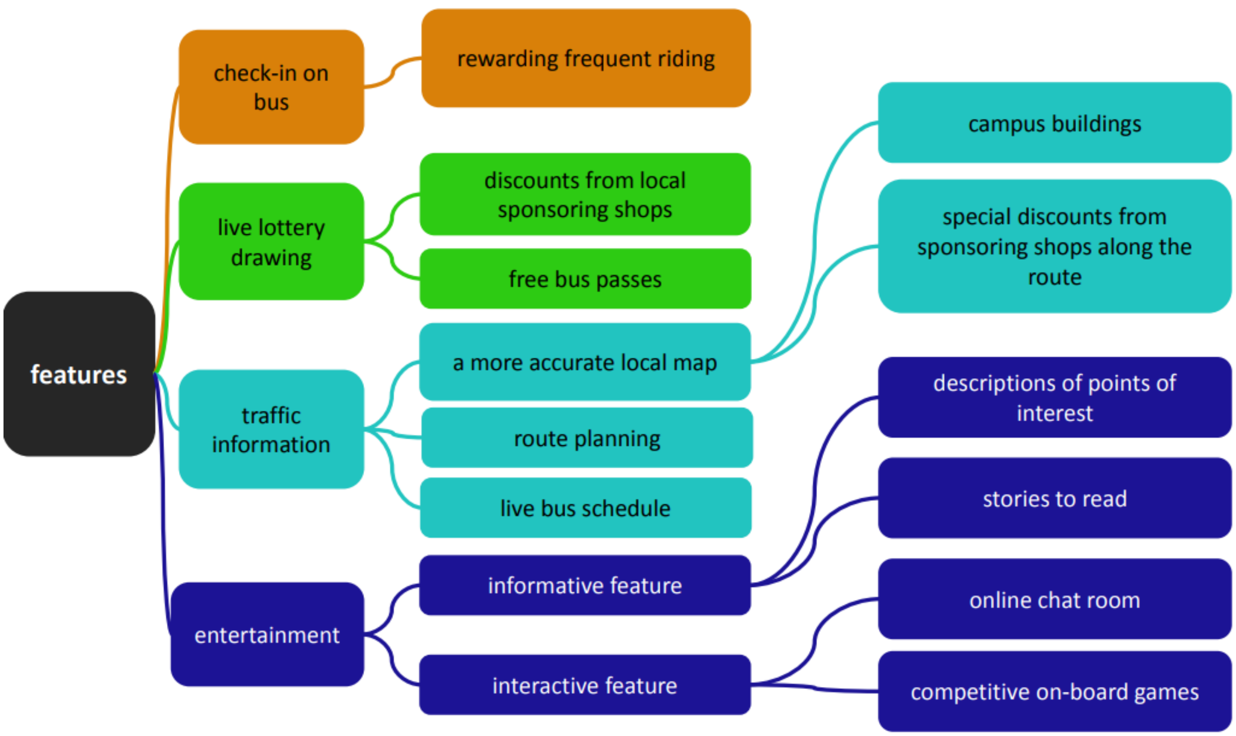
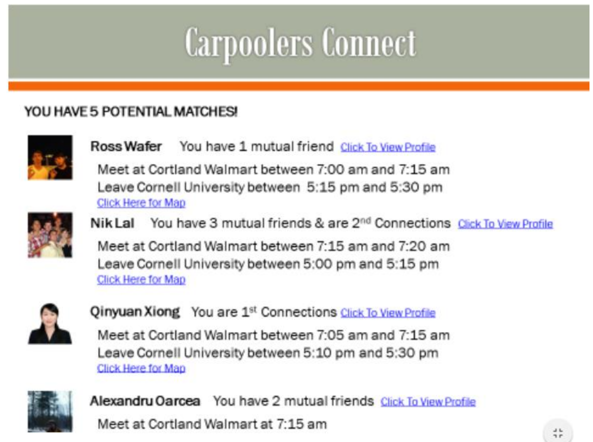



*Figure 4: Interactive Bus App Feature Breakdown*

***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:

- 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.
- 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.
  - 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:
  - 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.
  - 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.

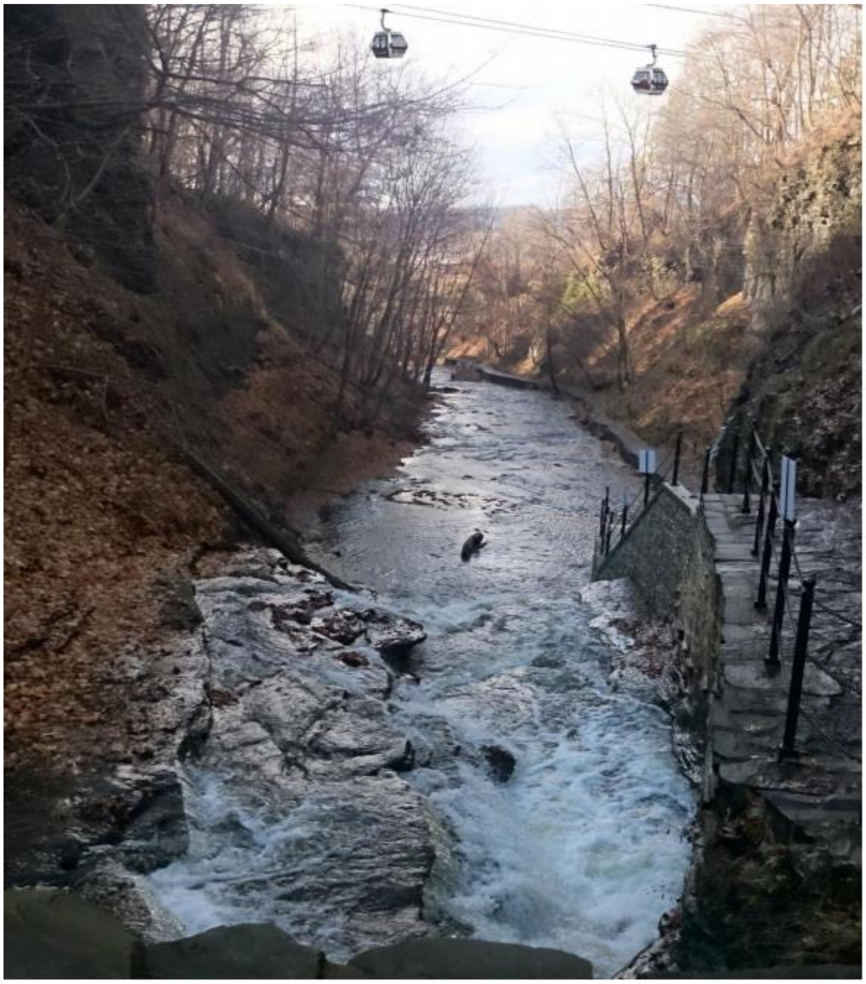


*Figure 5: Gondola Lift Vision for Ithaca*

- **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.
    - 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.
    - 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.

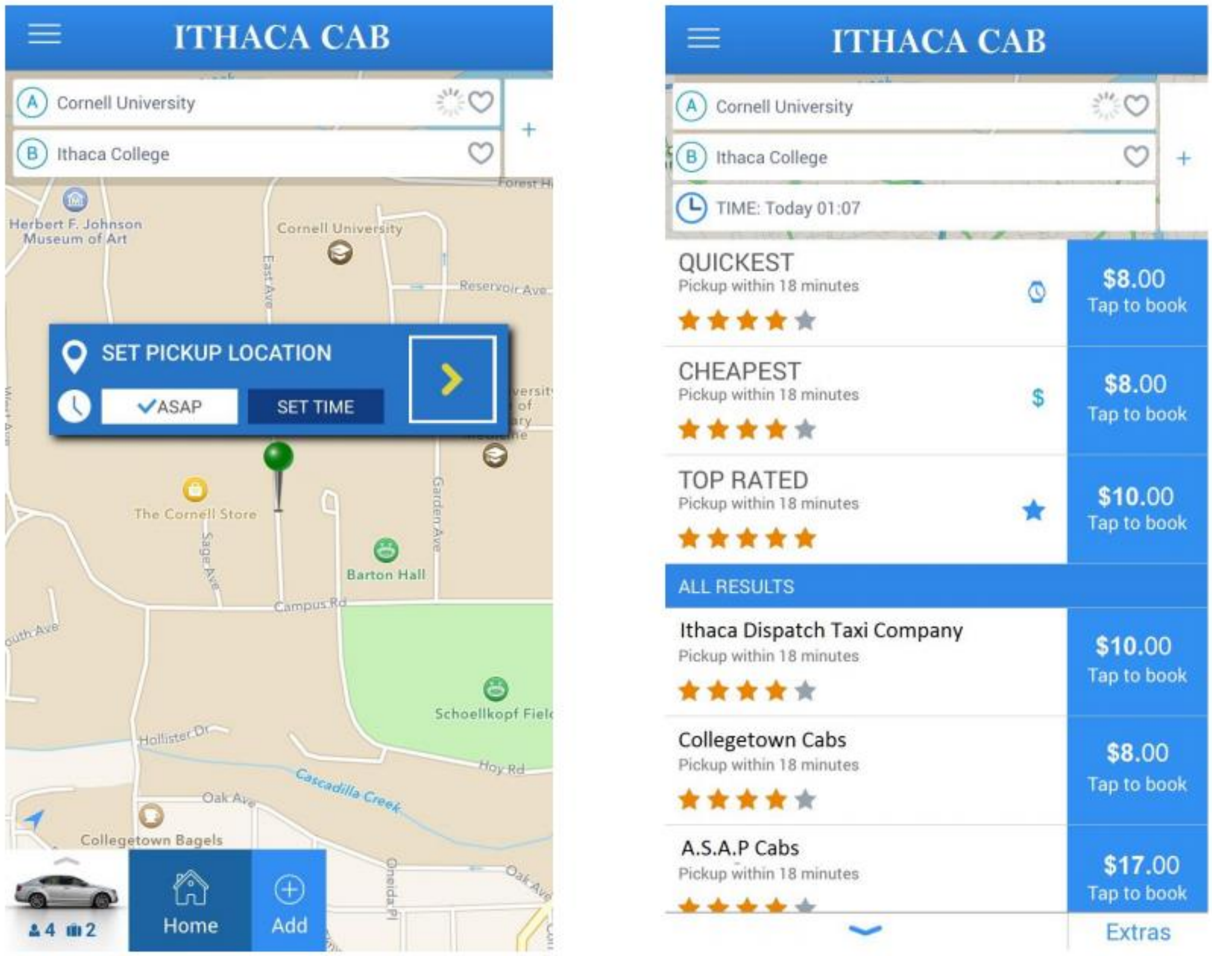



*Figure 6: Ithaca Taxi Fare Bidding Service Application*

## 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.
    - Small booklets, in two distinct sizes (as suggested by fieldwork), would be made available to users on TCAT busses

- Simplified, linear route maps and schedules, optimized to fit the booklets, would be made available at TCAT stops or on TCAT busses
- Users would collect and store in their booklets only those route maps relevant to them, thus avoiding unnecessary information and bulk
- Curated tour maps highlighting points of interest, local businesses, etc. could also be created and made available by TCAT or local organizations

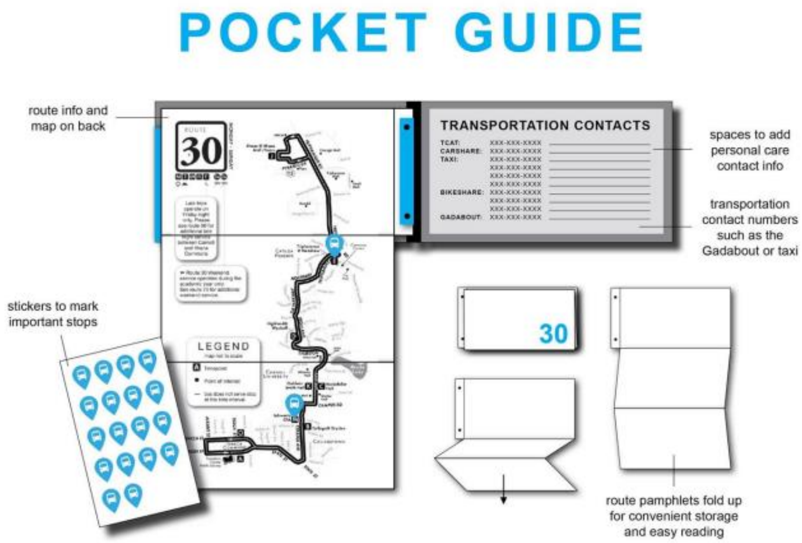



*Figure 7: TIME Pocket Guide*

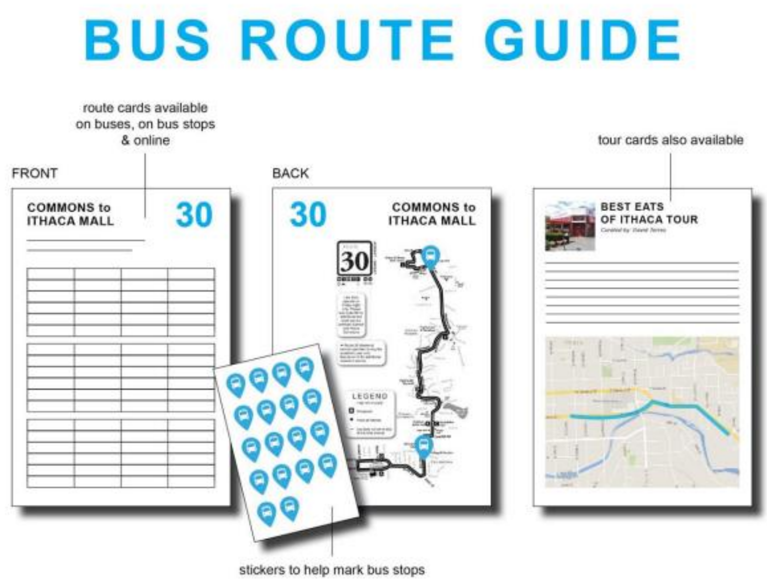



*Figure 8: TIME Bus Route Guide*

- 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.
    - 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.
    - An interactive transit map that allows users to see real-time TCAT information as well as other transit methods, routes, and information
    - Route planning will include photos of specific bus stops and information about the routes that use them.
    - 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.
    - The application will allow users to explore the Ithaca area by searching for events and destinations as well as creating and sharing tours.

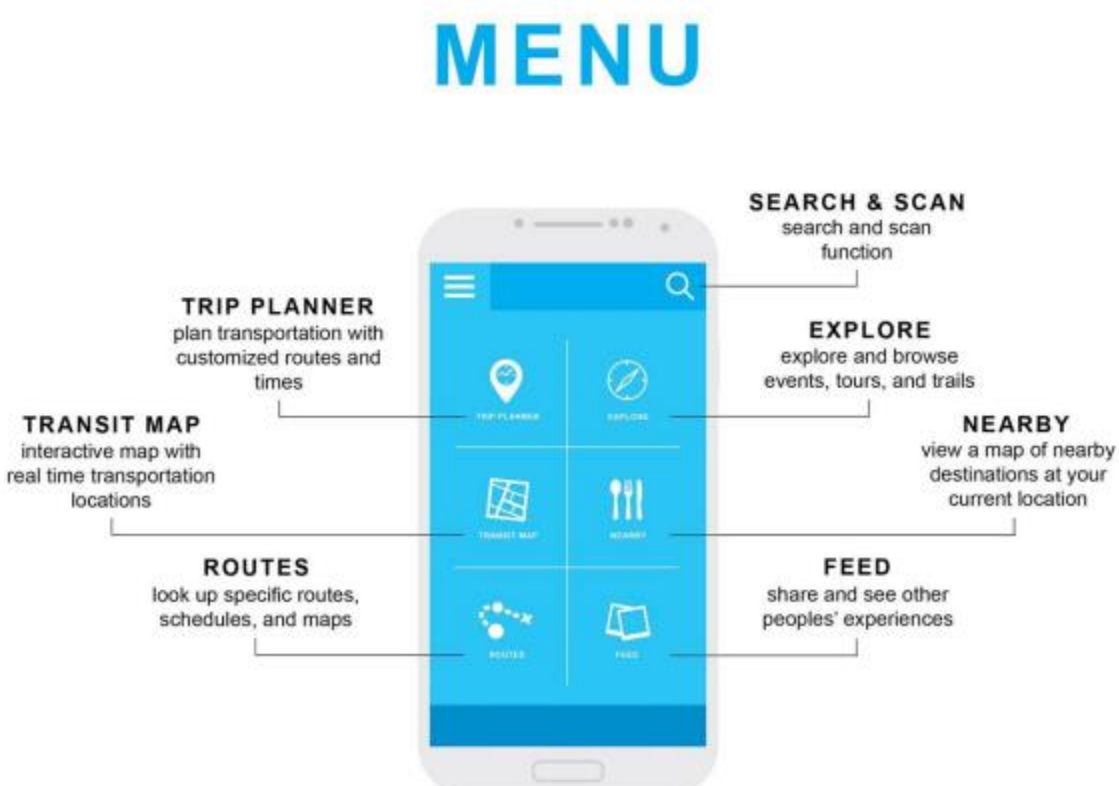



*Figure 9: TIME App*

- 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.

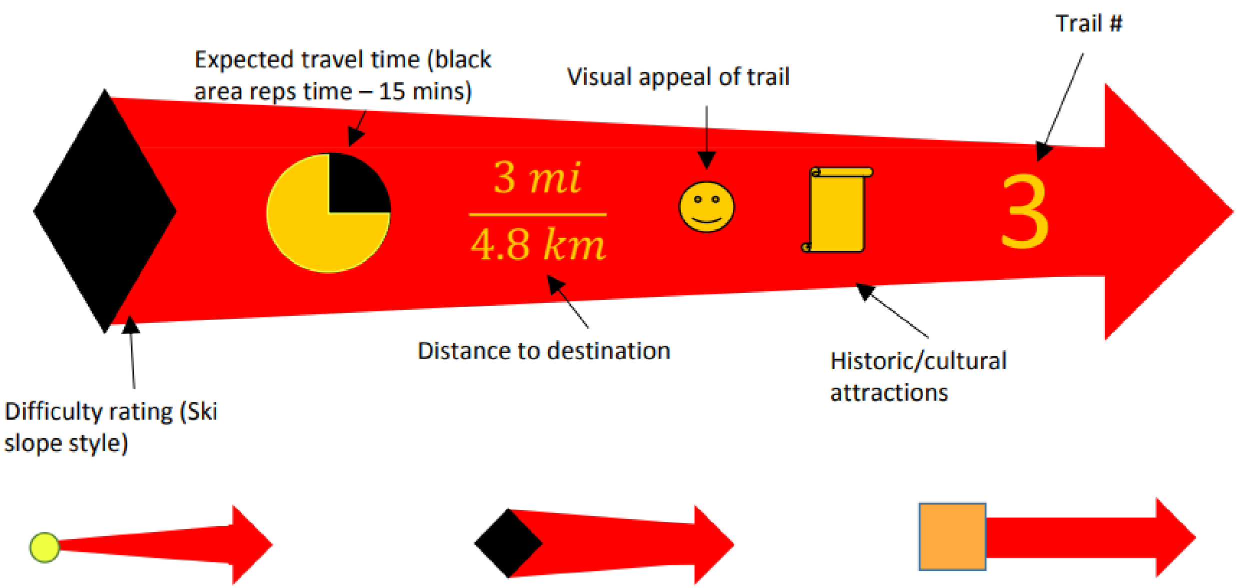



*Figure 10: Enhanced Walking and Biking Signage*

- 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.
  - Base tier shelters (for stops with low ridership) meet the basic level needs
  - Mid tier shelters (for stops with medium ridership) meet the basic level needs, and also include additional informational and security features

- 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

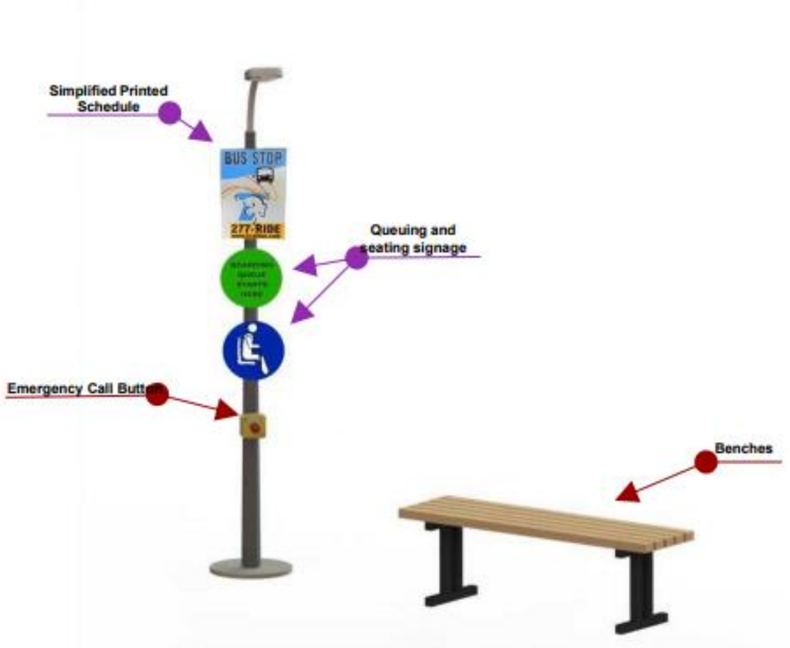



*Figure 11: Base Signage Vision*


*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 Nikita Dubnov (nd296@cornell.edu, Information Science 2017), the team consisted of 22 members motivated by the idea of re-designing 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 Information
    - Bus Stop Information
    - 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
    - Landmarks with high relative ridership
    - Potential for park & ride
    - Keep flagging North of Route 13
- Proposed Route #37
    - Landmarks with high relative ridership
    - Potential for park & ride
    - Keep flagging North of Route 13

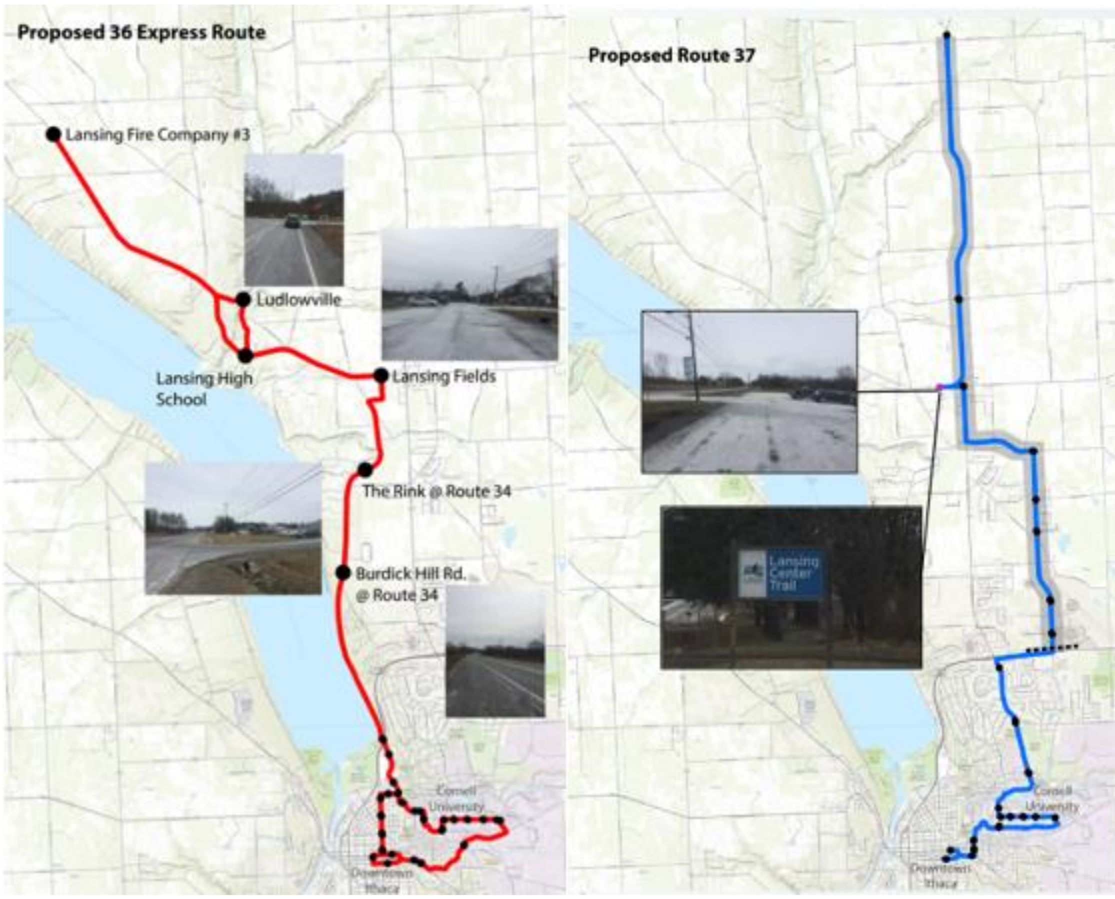



*Figure 13: Lansing Re-Route Suggestions*

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

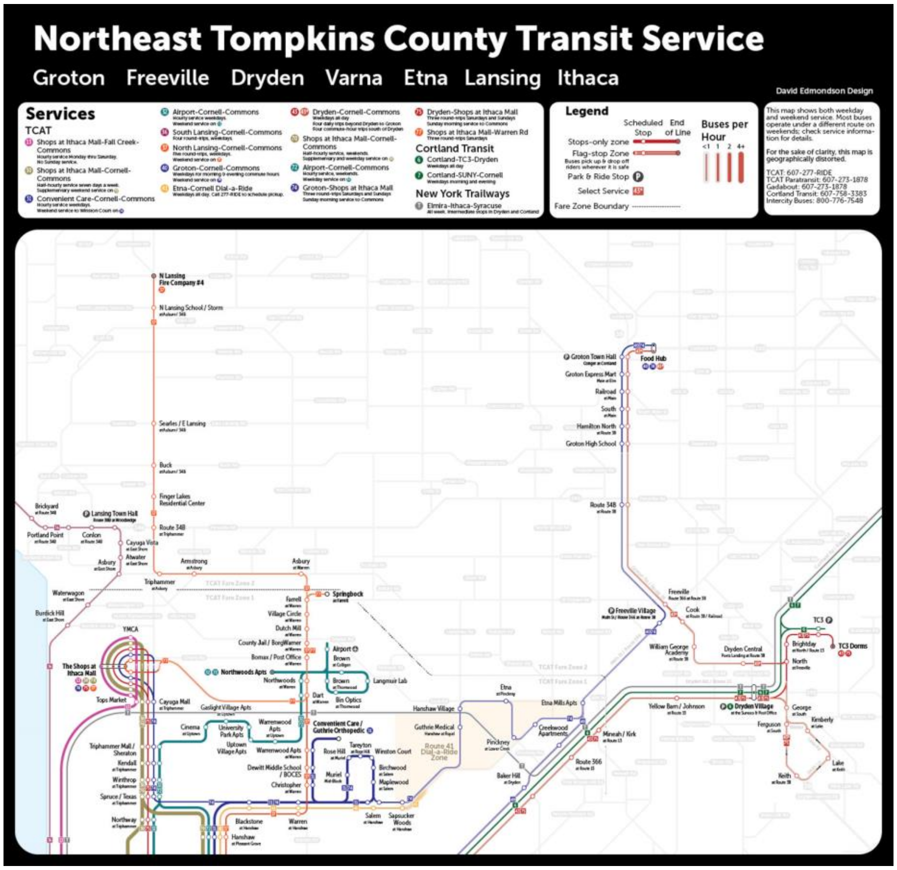



*Figure 16: Quarter System Map Implementation*

- **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.

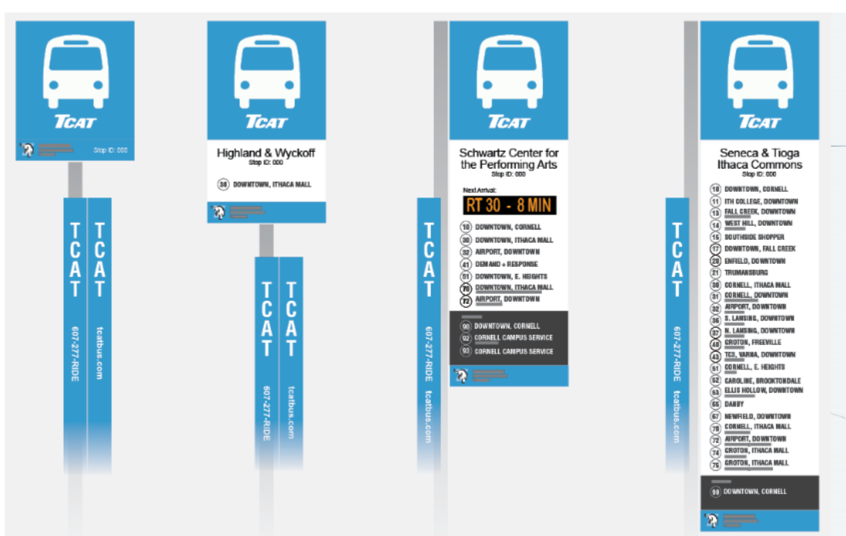



*Figure 17: Proposed Tier Level of Signage*

- **Social Media:** Implementation of a social media platform was investigated to include the following:
  - Real time updates of the bus status
  - Social interactions between riders
  - 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.

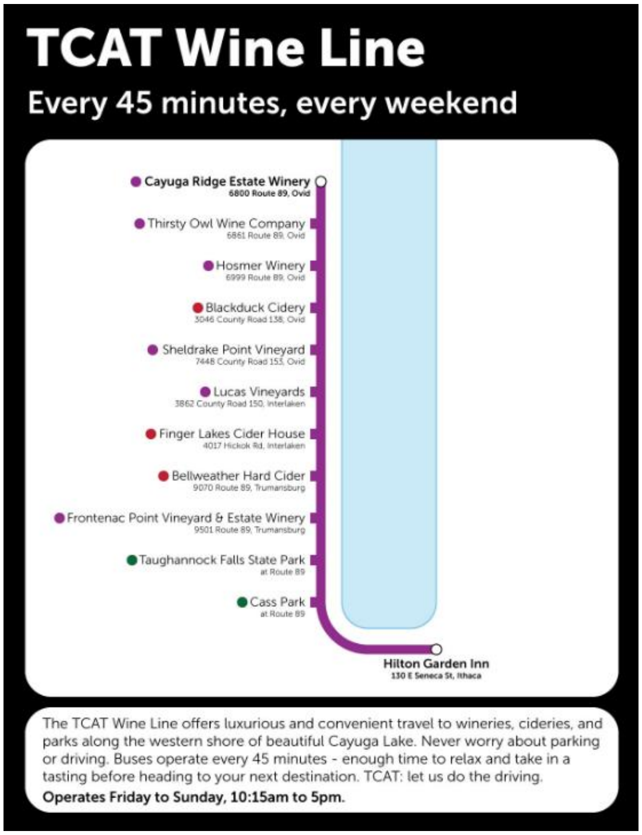



*Figure 19: TCAT Wine Line Vision*

### 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.

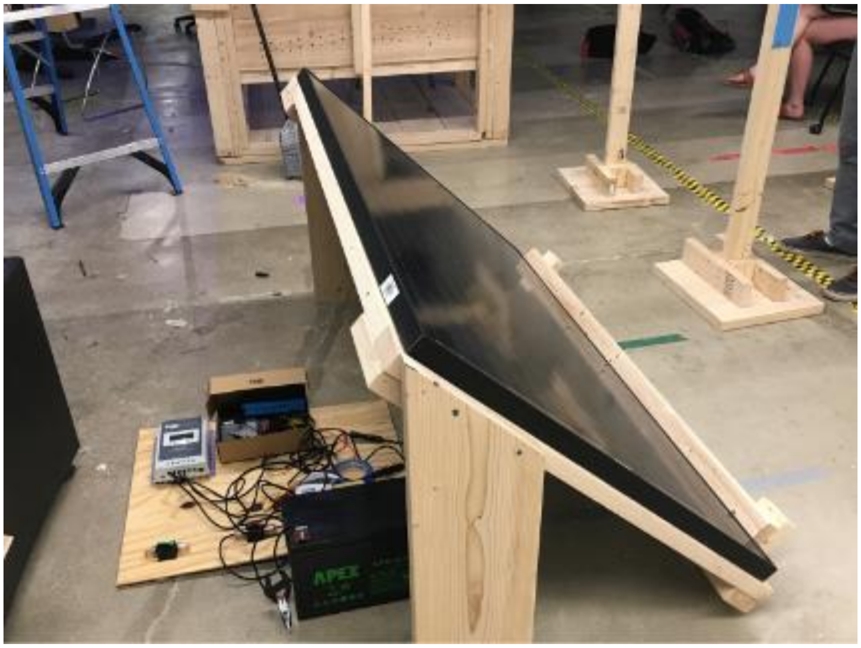


*Figure 20: Solar Setup*

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

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

Three-level tiered shelters were designed to fit these goals, shown below.


*Figure 21: Three Tier 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.

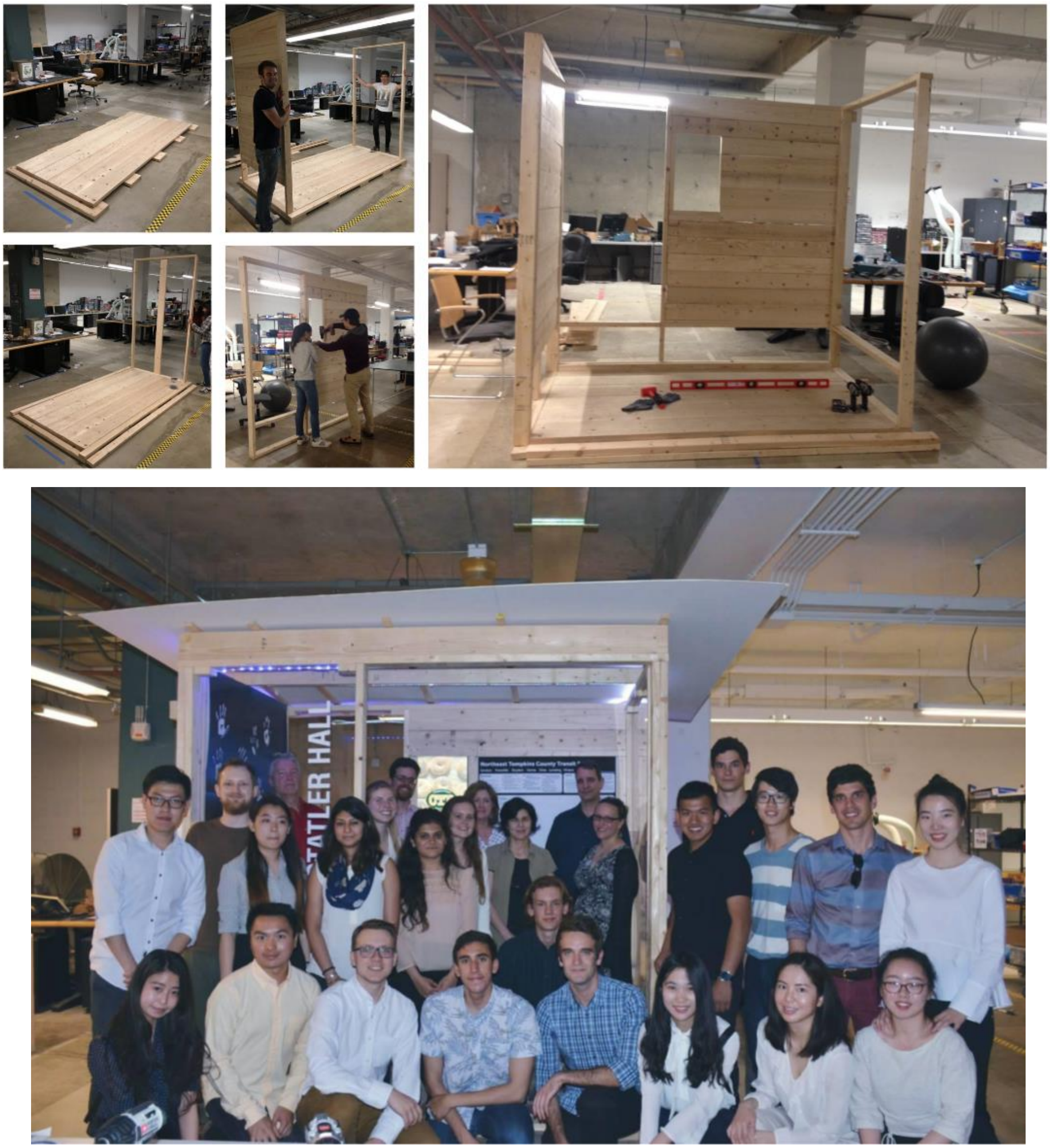


*Figure 23: Wooden Prototype Medium Shelter*

# 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, in two academic semesters from Fall 2016 to Spring 2017, went through the design process. 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*

*Figure 25: Wooden Prototype of Medium Shelter*

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.

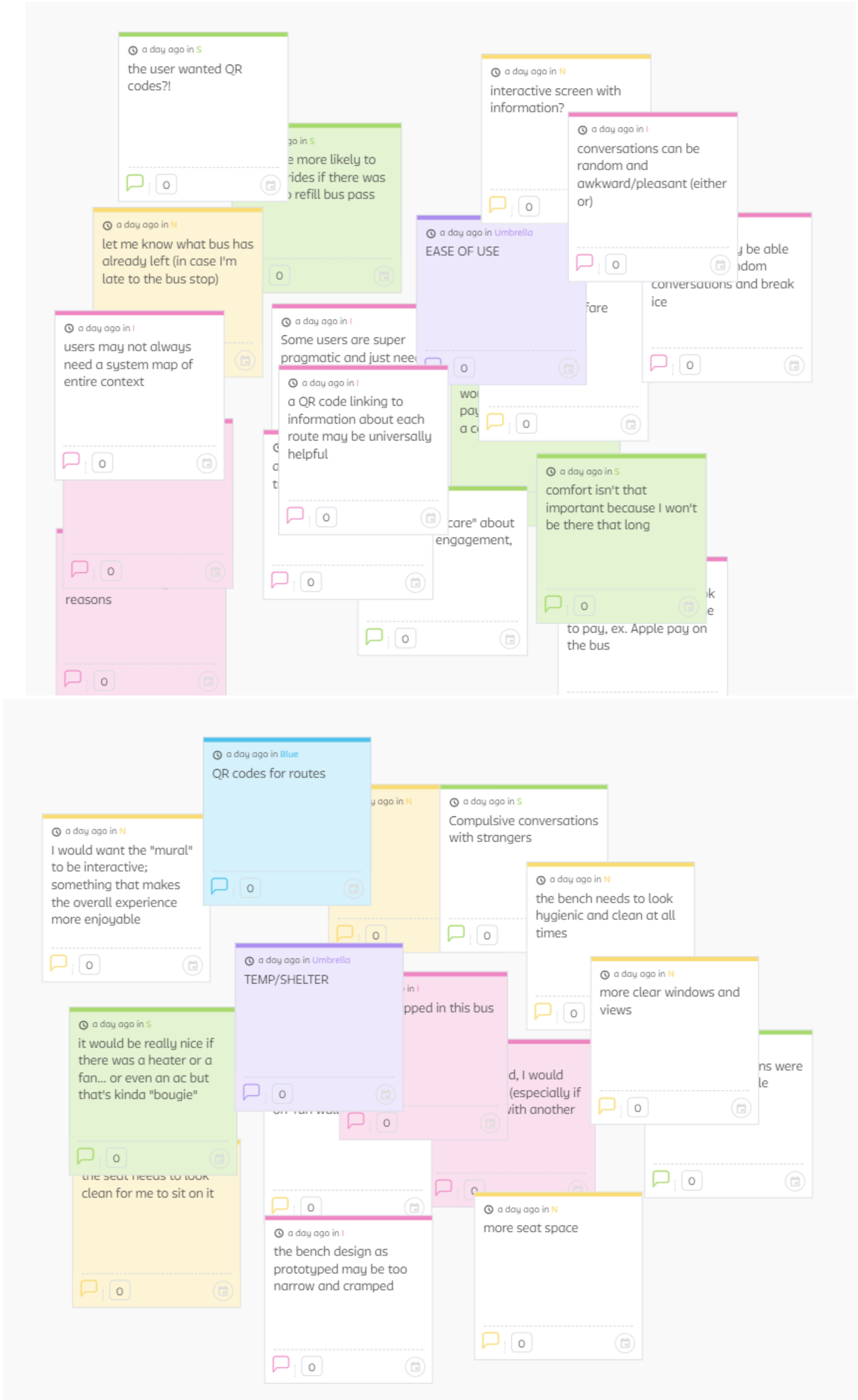
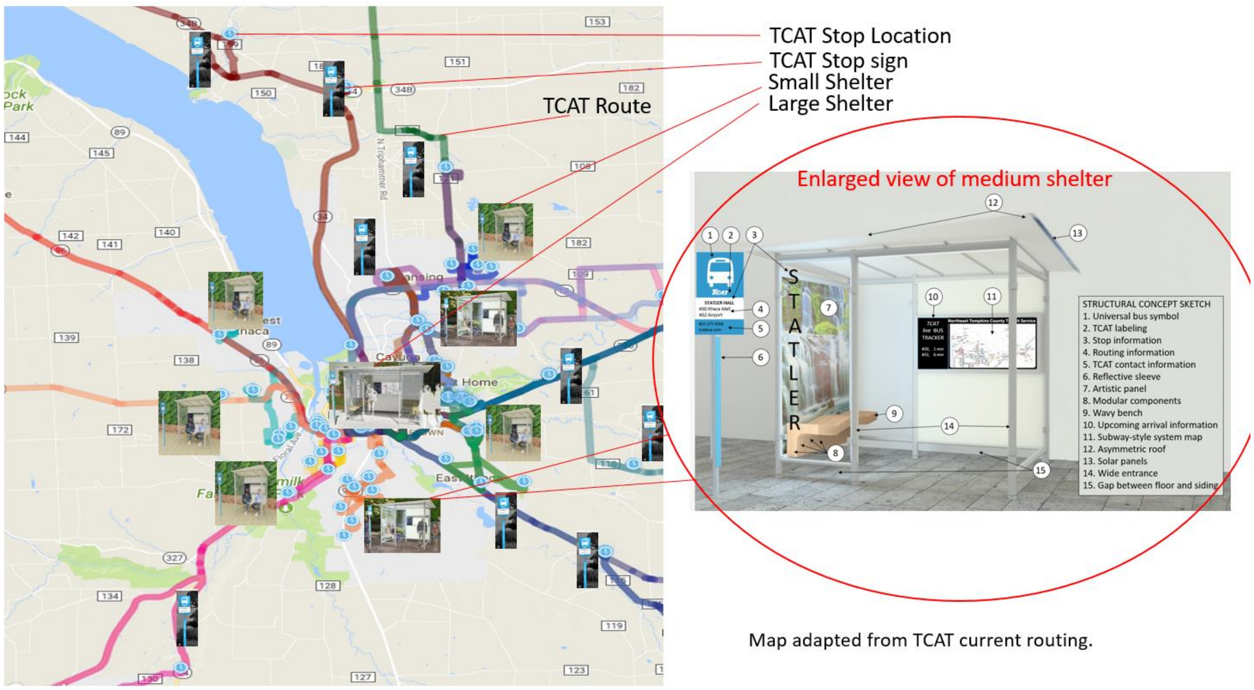
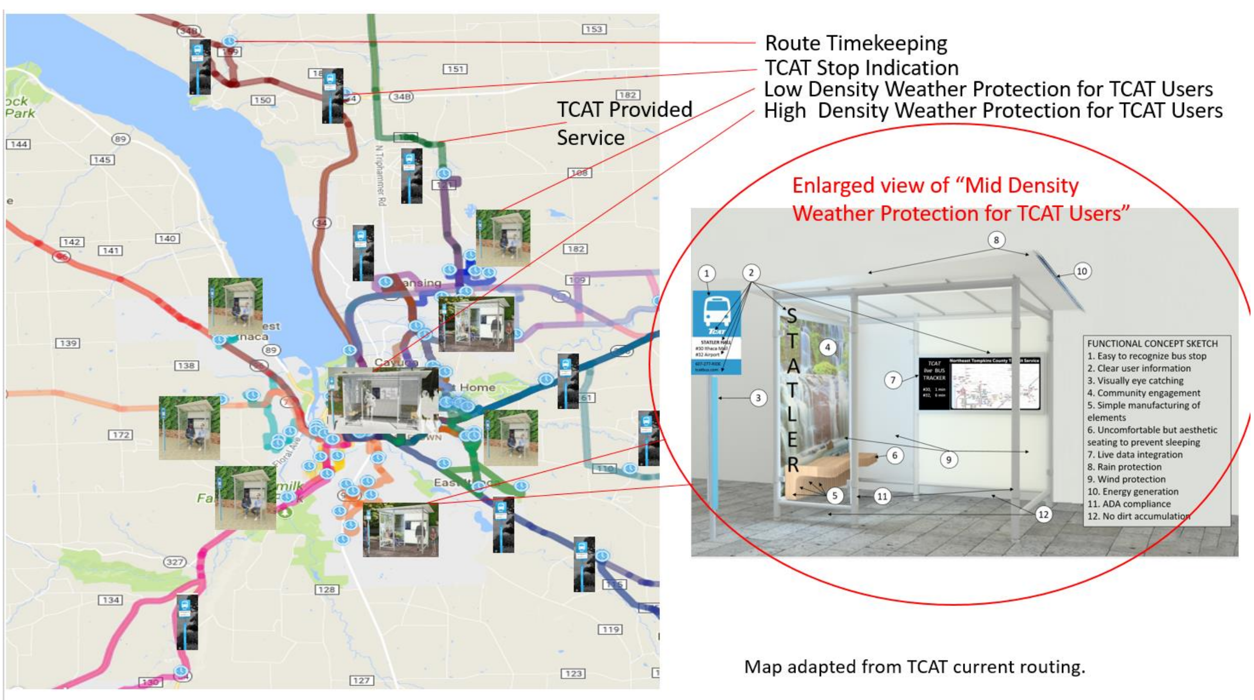



*Figure 26: Unpacking Shelter V.0 Data*

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 Ecomodernism

Moving forward with Design V.1, the team solidified a clearer vision through ecomodernism.

Ecomodernism refers to the idea that by marrying industry with environmentalist ideals, the built and natural worlds may prosper not in spite of each other, but because each depends upon the other. Ecomodernism is the greater ism to which our formal and material design belongs—the inside is characterized by ergonomic, comfortable design and organicism in form. Conversely, the exterior serves a more practical, structural purpose, represented by industrial materials and orthogonal shapes.

This concept was chosen so the structure would be a response to its environment rather than an intervention. Design V.1 utilizes organic forms to mimic the variety of natural landscapes inherent in Ithaca. These concepts can best be understood by the rendering below. The interior bench and panels will be made of molded plywood. Aluminum will be used for the frame.

*Figure 27: Ecomodernism Vision*

2.1.1.3 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.

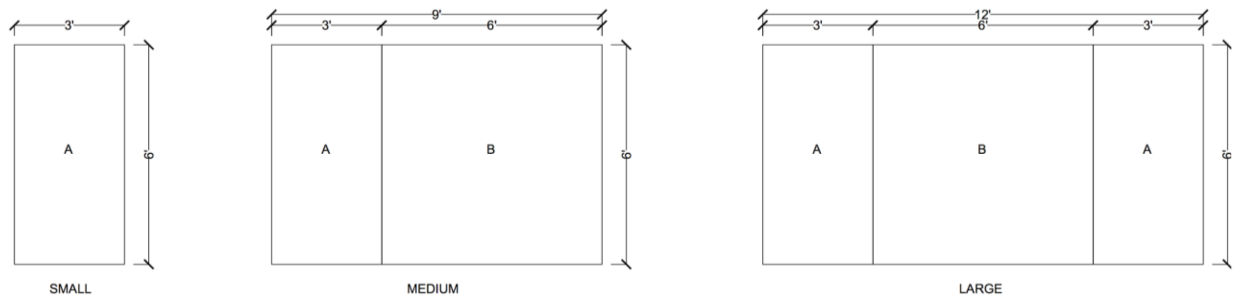



*Figure 28: Modular System Organization*

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 36” length to the distance between the inside of two posts. This means that the 36” length includes the panel and panel-to-post connections.

With all the things taken into consideration, the final dimension of small shelter was determined to be 3’-6”x6’-9”, medium was 6’-9”x10’, and large was 6’-9”x13’-3”.

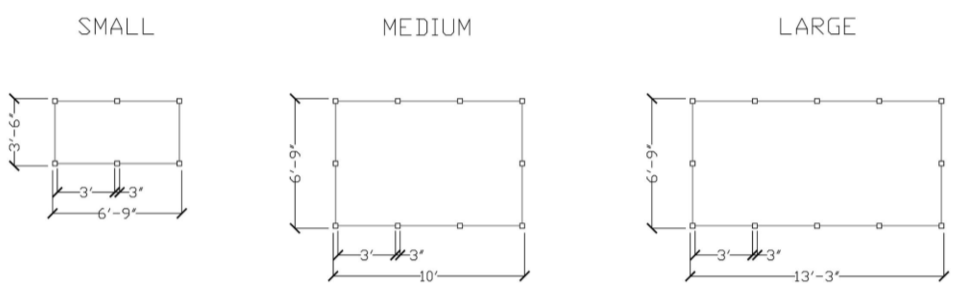



*Figure 29: Final Shelter Dimension*

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.

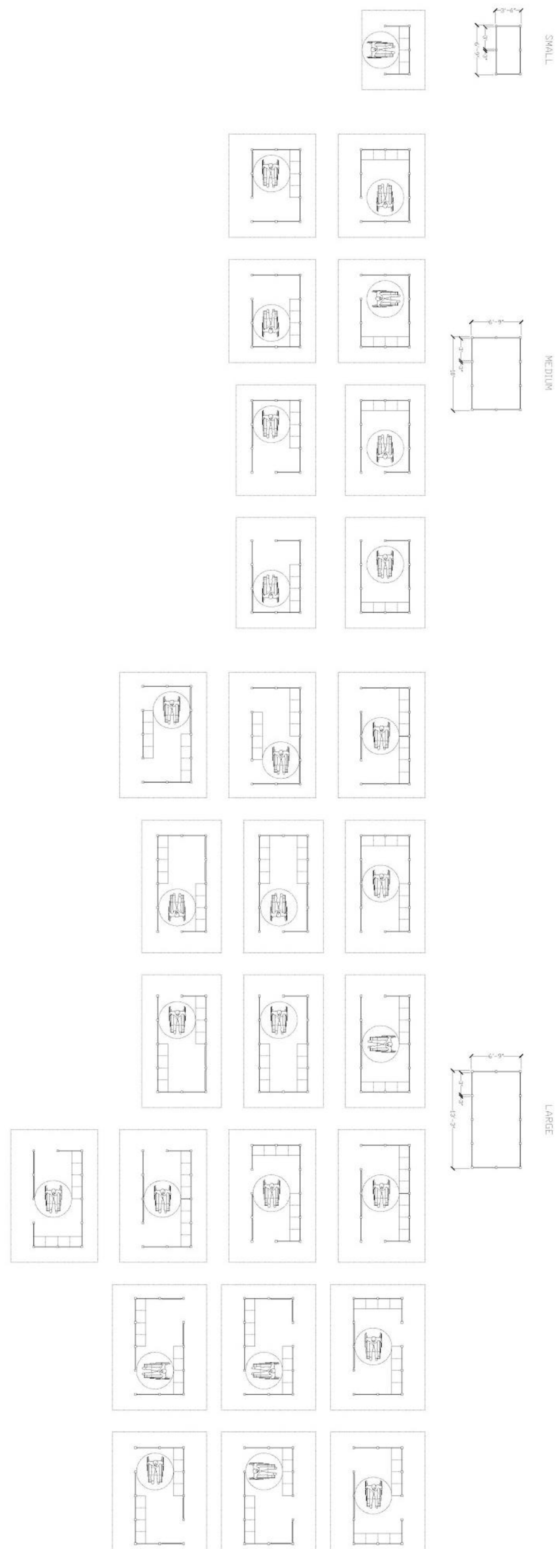



*Figure 30: Index of Modular Variation*

### 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.

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 31: Examples of Shelter 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.

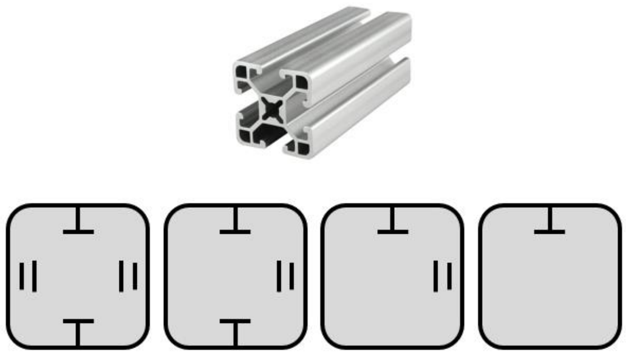


*Figure 32: T-Slot Variations*

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 Fame Joint Connections and Mechanisms

The T-slot profile of the frame members allows for seamless connections that add to the shelter's aesthetic appeal. The details of the joint connections are not completely finalized this semester, as we would like to further analyze the joints before committing to a solution.

The first two joint connections we are considering are called inner connectors. These are ideal because they do not require additional machining and are hidden within the T-slots. If the frame was held together using these connectors, there would be visible hardware, further adding to the ecomodern concept that defines our shelter. These joints hold the frame members together through friction, which presents a difficulty as we attempt to analyze its integrity. We cannot rely as heavily on finite element analysis. With a combination of more research and physical testing, we can decide on whether inner connectors are a feasible joint solution to be implemented.

*Figure 33: Inner Connectors Joint Method*

The other option is to use a bolt connection. The vertical posts, which are already custom extrusions, would have bolt holes drilled inside the slots if this joining method is selected. The 15-series T-slots are already tapped in the center hole, allowing us to connect the sub-frame bars to the vertical posts while still maintaining an (almost) seamless connection. This is a much simpler simulation for finite element analysis to guarantee that the structure is reliable, as compared to the inner connections method.

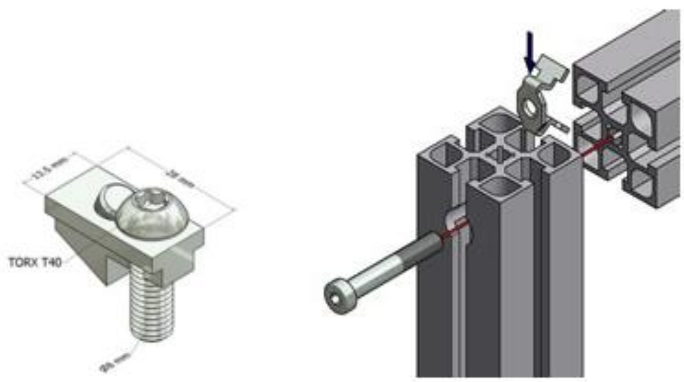



*Figure 34: Bolt Method of Joint Connection*

### 2.1.3 Side Panels

#### 2.1.3.1 Material Selection and Analysis

After collaboration and discussion between team designers and engineers, the team decided the side panels should feature both translucent and opaque materials so as to allow for both visibility and object mounting. Majority of the side panels would need to be translucent so that users would be able to sit or stand comfortably inside the shelter, while still be able to observe their surroundings outside the shelter; so as, for instance, being able to see an arriving bus. The opaque panels, on the other hand, provide an easy backdrop and mountable surface to harbor various features of the shelter like the data display, maps, or artwork. Mounting these features on an opaque material improves the overall aesthetic of the shelter itself, as compared to mounting on a translucent panel.

In order to make an informed decision regarding which type of translucent panel would function best for the shelter, a decision matrix was constructed. Criteria considered when determining which material to use were durability, scratch resistance, UV stability, appearance/transparency, shatter resistance, blunt force resistance, puncture resistance, weight/density, cost, weather resistance, and sustainability. The full decision matrix is pictured below.

**Side Panel Material Decision Matrix**

| Design Method | | Polycarbonate sheet | | Acrylic (Plexiglass)/PMMA | | Tempered Glass | | Laminated Glass | |
|---|---|---|---|---|---|---|---|---|---|
| Images | | | | | | | | | |
| Metric | Weight | Normalized | Final | Normalized | Final | Normalized | Final | Normalized | Fin |
| Durability (Lifespan) | 4 | 9 | 36 | 6 | 24 | 7 | 28 | 5 | |
| Scratch Resistance | 5 | 4 | 20 | 6 | 30 | 8 | 40 | 5 | |
| Shatter Resistance | 5 | 9 | 45 | 6 | 30 | 8 | 40 | 8 | |
| UV Stability | 2 | 5 | 10 | 5 | 10 | 6 | 12 | 6 | |
| Appearance/Transparency | 3 | 5 | 15 | 4 | 12 | 10 | 30 | 9 | |
| Blunt Force Resistance | 4 | 8 | 32 | 6 | 24 | 8 | 32 | 8 | |
| Puncture Resistance | 2 | 6 | 12 | 8 | 16 | 10 | 20 | 9 | |
| Weight/Density | 2 | 8 | 16 | 8 | 16 | 5 | 10 | 6 | |
| Cost | 5 | 7 | 35 | 6 | 30 | 4 | 20 | 3 | |
| Weather Resistance | 4 | 8 | 32 | 5 | 20 | 6 | 24 | 6 | |
| Sustanibility | 4 | 4 | 16 | 7 | 28 | 4 | 16 | 8 | |
| | | | | | | | | | |
| Total | | 73 | **269** | 67 | **240** | 76 | **272** | 73 | |

*System Index 3: Side Panel Material Decision Matrix*

Although the results of the matrix did not point to one clear solution, it can be noted that the two highest scoring materials were tempered (toughened) glass and polycarbonate sheeting.

Tempered glass is in essence a type of refined glass that is produced using extreme heating and tensile fabrication methods. It is the strongest type of glass and if impacted by an extremely powerful force, will shatter into blunt pieces. It is aesthetic and seems to be the industry standard for bus shelter side panels. Polycarbonate, on the other hand, is a type of thermoplastic that is up and coming in the use of side panel and roofing materials. Unlike glass, it is virtually shatterproof, weighs six times less, is not as expensive, and is very durable; however, it is extremely susceptible to scratching and may not be as clear as the glass. Both materials can be easily sized to a desired dimension and can both be modified with holes and other extrusions as necessary.

At this time, we are not solidified in a decision of one material over the other. The team will conduct further analysis in the coming weeks. Tempered glass is currently the front-runner due to the characteristic of scratch resistance.

A further option to be considered is an abrasion-resistant coating for polycarbonate. This treatment will make the panel scratch and graffiti-resistant, but further research regarding costs and feasibility still needs to be conducted.

As for the opaque panel, in minimizing material types in the shelter, so as to match the roofing material, Alucobond was selected, which will be covered extensively with another decision matrix in a later section regrading the roofing material selection and analysis. Important to note, is that as suppliers are contracted, cost will be further realized, which may alter this initial material selection.

#### 2.1.3.2 Panel Connection Design

With the selection of the T-slot aluminum extrusion, the panel attachment mechanism needed to be determined. Using a decision matrix to help evaluate the metrics and performances of different panel connections, we were able to compare several options, such as C-clamps, gaskets, and mounting blocks. Scores were assigned to each option for each metric depending on expected performance.

**Shelter Panel Mounting Method Decision Matrix**

| Design Method | | T slot Mounting Block | | T slot rubber gasket | | Bolted through a frame | | T slot track | | T-Slot Screw Ons | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Metric | Weight | Normalized | Final | Normalized | Final | Normalized | Final | Normalized | Final | Normalized | Final |
| Volume of Material Saved | 2 | 7 | 14 | 9 | 18 | 6 | 12 | 8 | 16 | 4 | 8 |
| Cost | 4 | 2 | 8 | 5 | 20 | 6 | 24 | 4 | 16 | 6 | 24 |
| Unique Components Required | 3 | 4 | 12 | 8 | 24 | 6 | 18 | 7 | 21 | 3 | 9 |
| Durability | 5 | 8 | 40 | 6 | 30 | 8 | 40 | 5 | 25 | 7 | 35 |
| Appearance | 3 | 8 | 24 | 9 | 27 | 1 | 3 | 7 | 21 | 6 | 18 |
| Feasability (Analysis) | 4 | 5 | 20 | 8 | 32 | 7 | 28 | 8 | 32 | 6 | 24 |
| Maximum Weight Supportable | 5 | 8 | 40 | 6 | 30 | 8 | 40 | 5 | 25 | 6 | 30 |
| Ease of Assembly | 4 | 9 | 36 | 8 | 32 | 8 | 32 | 9 | 36 | 8 | 32 |
| Manufacturability | 3 | 9 | 27 | 7 | 21 | 9 | 27 | 9 | 27 | 9 | 27 |
| Shipping and Handling | 3 | 9 | 27 | 9 | 27 | 8 | 24 | 9 | 27 | 9 | 27 |
| Maintainability | 2 | 8 | 16 | 3 | 6 | 5 | 10 | 4 | 8 | 9 | 18 |
| Disassembly/Vandalize Proof | 4 | 3 | 12 | 6 | 24 | 2 | 8 | 4 | 16 | 2 | 8 |
| | | | | | | | | | | | |
| Total | | 80 | **276** | 84 | **291** | 74 | **266** | 79 | **270** | 75 | **260** |

*System Index 4: Panel Connection Decision Matrix*

The decision matrix above shows that the overall design choice would be T-slot rubber gaskets. Its simplicity and appearance separated the connection mechanism from other options, with its seamless connections to the T-slots being an aesthetic advantage.

However, with this design a main concern became a panel's maintainability and serviceability. Through this connection mechanism, the panel would be locked into the T-slot framing system and would require the roof to be removed for a panel to be removed. Furthermore, the 3' x 7' area for the panel would require that the panel be slightly larger than 3'x7' in order to fit into the frame and gasket. The non-standard sizing could increase manufacturing complexity and affect the cost of the panels.

With TCAT's desires in mind, we adjusted the maintainability weight of the decision matrix and determined panel mounting blocks or a modified gasket system would be most fitting for TCAT's requirements. A PVC lining alternative appeared a promising solution for easier panel maintenance, but the panel supports would lie only in the top and bottom cross bars resulting in a structure that is susceptible to pushing.

Another alternative, panel mount blocks, offered the most durability and cohesion with other aspects in our design such as bench mounting. With glass manufacturers such as Syracuse Glass and Inlet Glass and Mirror in Ithaca able to accommodate custom sizing on glass and predrilled holes, the drawbacks of panel mount blocks are minimal.

*Figure 35: PVC Panel Clamp and Panel Mount Block*

### 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.

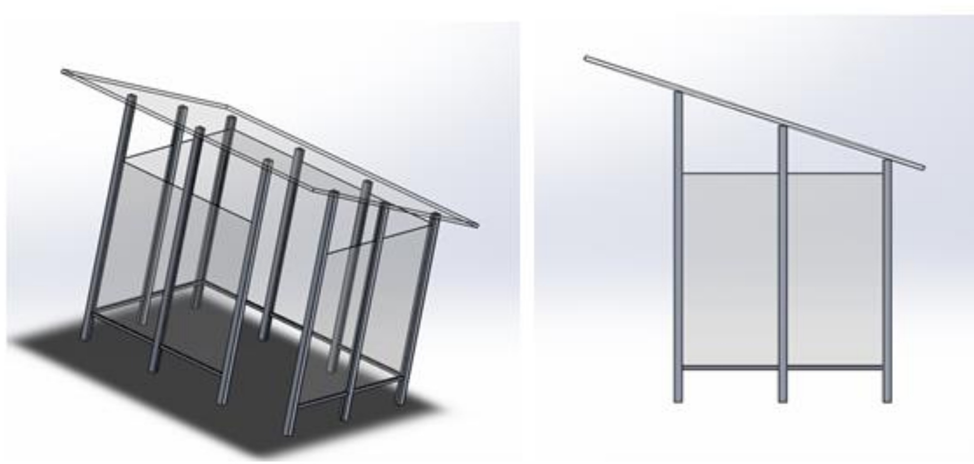


*Figure 36: Side Profile of Initial Shelter with Steep Roof Angle*

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.

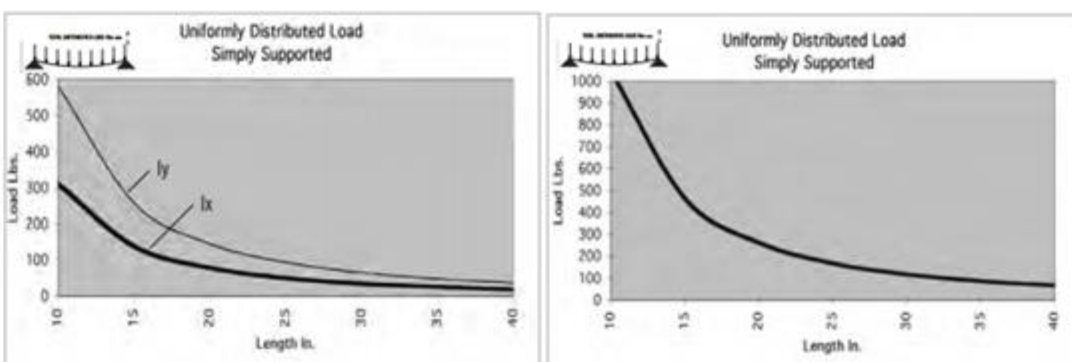


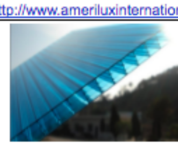

*Figure 37: Load Distribution of T-slot (1.5”x3” vs 3”x3” from left to right) [1]*

The roof panels would be attached directly to the T-slots on top. A cover between the panels can easily be 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 Panel Material Decision Matrix**

| Design Method | | Polycarbonate | | HDPE | | Aluminum Sheeting | | Alucobond | |
|---|---|---|---|---|---|---|---|---|---|
| Sources | | http://www.ameriluxinternational.c | | | | | | | |
| Images | |  | |  | |  | |  | |
| Metric | Weight | Normalized | Final | Normalized | Final | Normalized | Final | Normalized | Final |
| Durability (Lifespan) | 4 | 8 | 32 | 7 | 28 | 7 | 28 | 8 | 32 |
| Scratch Resistance | 1 | 2 | 2 | 2 | 2 | 6 | 6 | 6 | 6 |
| UV Stability | 2 | 5 | 10 | 10 | 20 | 10 | 20 | 10 | 20 |
| Toughness | 2 | 8 | 16 | 5 | 10 | 9 | 18 | 9 | 18 |
| Yield Strength | 4 | 7 | 28 | 4 | 16 | 9 | 36 | 7 | 28 |
| Weight/Density | 3 | 8 | 24 | 10 | 30 | 5 | 15 | 10 | 30 |
| Cost | 4 | 4 | 16 | 10 | 40 | 6 | 24 | 4 | 16 |
| Weather Resistance | 4 | 8 | 32 | 8 | 32 | 10 | 40 | 10 | 40 |
| Sustainablity | 2 | 1 | 2 | 6 | 12 | 6 | 12 | 4 | 8 |
| Appearance/Aesthetics | 4 | 9 | 36 | 7 | 28 | 6 | 24 | 10 | 40 |
| | | | | | | | | | |
| Total | | 51 | **198** | 69 | **218** | 74 | **223** | 78 | **238** |

*System Index 5: Roof Panel Material Decision Matrix*

Unlike the side panels which act as a barrier and give the shelter its form, the roof need 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 Alucobond, a type of aluminum sandwich panel which is comprised of two outer aluminum sheets and a low density polyethylene core. This low density core is glued to the aluminum sheets creating a rigid panel structure while vastly reducing the weight of the overall panel. When compared to other material types for the roof, Alucobond boasted the highest yield strength along with a low density, the aluminum sheets make it resistant to weather effects, and it was unanimously agreed upon that it was the most aesthetically pleasing material to look at. However, the cost of the Alucobond poses an uncertainty. Being significantly more expensive than the other choices, Alucobond could be out of the budget range. If this is the case, aluminum sheeting is the next best option for the roofing—whereas it is far cheaper, aluminum sheeting lacks the aesthetics and strength that Alucobond offers.

Moreover, all materials decided upon in the decision matrixes (for both the side panel and roofing materials) need to undergo structural analysis simulation testing in ANSYS. Only then will the team know exactly which materials are feasible for a sustainable structure given the various load cases.

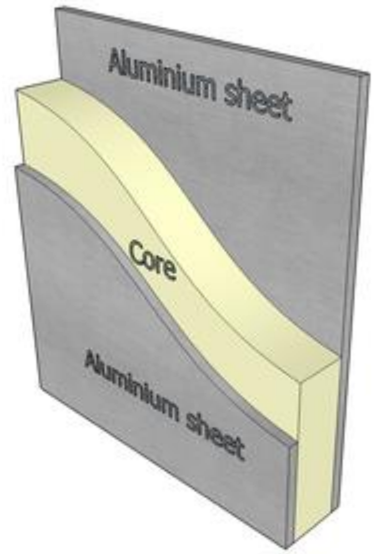



*Figure 38: Alucobond Material Schematic*

### 2.1.5 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, ease of maintenance, and appearance, mounts were phased out of the design. 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.

## 2.1.6 Electrical Housing

The original concept for the storage of the battery and its accompanying components was to attach a “backpack” of electronics to the backside of each shelter. The backpack option would work well with one battery on the off-grid stops, but with each battery close to seventy pounds, placing multiple batteries in a suspended component box would be difficult to support. In addition to this, having a battery pack extruding off the back of each stop did not add to the shelter aesthetic.


*Figure 39: "Backpack" Battery Enclosure Rendering*

There are two new ideas currently being assessed. The first is to bury the components underground within a sealed container. This option provides extra insulation for the battery, as the ground is a natural insulator, and keeps the components out of view and away from vandals. However, burying the battery will require a hole to be dug at each solar-integrated shelter location. Alternatively, a slim battery could be implemented and placed in a space between the inner and outer wall. This would bring the battery closer to the panel and loads, and would also be well hidden from vandals, but the slim batteries tend to be more expensive. Next semester's first step is to come to a conclusion and move forward on purchasing insulated enclosure options for prototyping. An example of the panel housing in a wall space is show in the image below.


*Figure 40: Technology Panel Enclosure Concept*

## 2.1.7 Structural Analysis

### 2.1.7.1 Loading Cases

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. The use cases outlined below help to inform a sound design is being pursued.

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

*System Index 7: Shelter Loading Use Case Table*

A use cases 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).

Next semester, the use cases listed will serve as the basis for our structural modeling in ANSYS and furthermore the information will ensure a systematic approach to the simulation process.

### 2.1.8 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 experience subteam is developing solutions in the realms of maps, live data displays, bus passes, and time tables. Their solutions and process from the Fall 2017 solution are presented in the following sections.

### 2.2.2 Maps

The map design subteam used the principles of user-centered design thinking to identify issues in the current TCAT maps and create prototypes that addressed possible solutions. The ultimate goal of this is to create a holistically functional and aesthetic map that can be printed and placed into shelters.

The first phase of research involved extensive empathy fieldwork to understand the needs of users. Specifically, we created an interview questionnaire that guided our understanding and consisted of questions that provided us with objective information about the interviewee's general demographic, current frustrations with existing maps, and feedback on prototypes created last semester. Interviewees consisted of Cornell University students and randomly selected individuals who lived or worked in Ithaca.

After discussing issues in current TCAT map designs, users were asked to identify ideal traits in prototype maps created last semester, shown below.

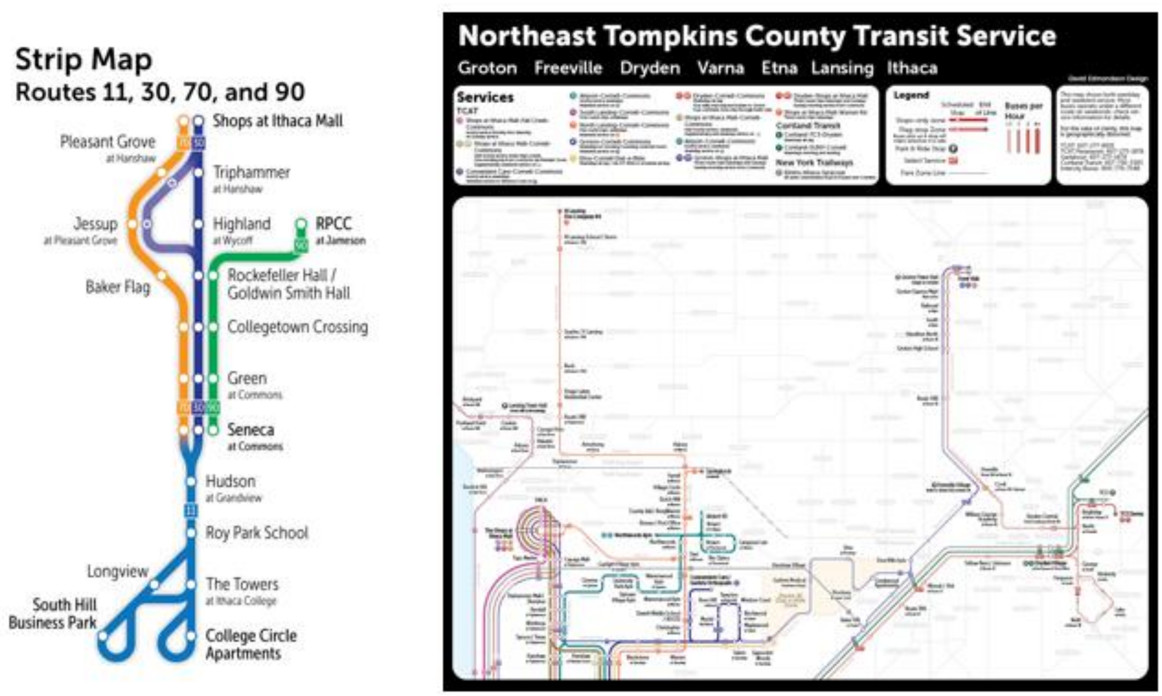



*Figure 41: Strip Map and Full System Map from Spring 2017 Semester*

After gathering information from more than thirty unique perspectives, we unpacked our data and consolidated comments that kept arising across all participants. Comments that came up most frequently were rated as being highly significant to our future design decisions.

The most important considerations from our data is summarized as such:

- The majority of users desire a new and improved TCAT map.
- The majority of users would like to see physical maps and time tables in shelters.
- If maps were placed in shelters, users would like to see a route map rather than an entire system map.
- A large population of middle to upper age users do not have access or choose not to use TCAT apps or digital resources.
- Nearly all student users interviewed agree that maps and resources found in apps such as Ride14850 and MyStopMobile are extremely helpful.
- Users liked maps that did not feel "overcrowded" with text and information.
- Users liked the use of color to distinguish routes.
- Users liked maps that used linear route lines.
- Users liked that the prototype map helped them find multiple route options to get to the same stop.
- Users liked when beginning and end of the routes were clearly identified.
- Users liked maps that suggested geography.
- Users liked maps that clearly showed all intermediary stop names.
- Users liked maps that indicated a sense of direction and a "you are here" marker.

This data, along with team feedback gathered from last semester, guided our ideation for new prototypes. Two working prototypes for possible route maps to be placed in shelters were created. One map consisted of a complete overhaul of the current TCAT maps. This was inspired by the "subway-style" aesthetic in the map created last semester. Another map consisted of a compilation of elements that preserved existing details present in the TCAT Ride Guide Maps and introduced new "subway-style" features. Feedback from stakeholders suggests that we adhere to the former approach. A higher fidelity prototype based on Figure 43 will be produced in the upcoming semester.

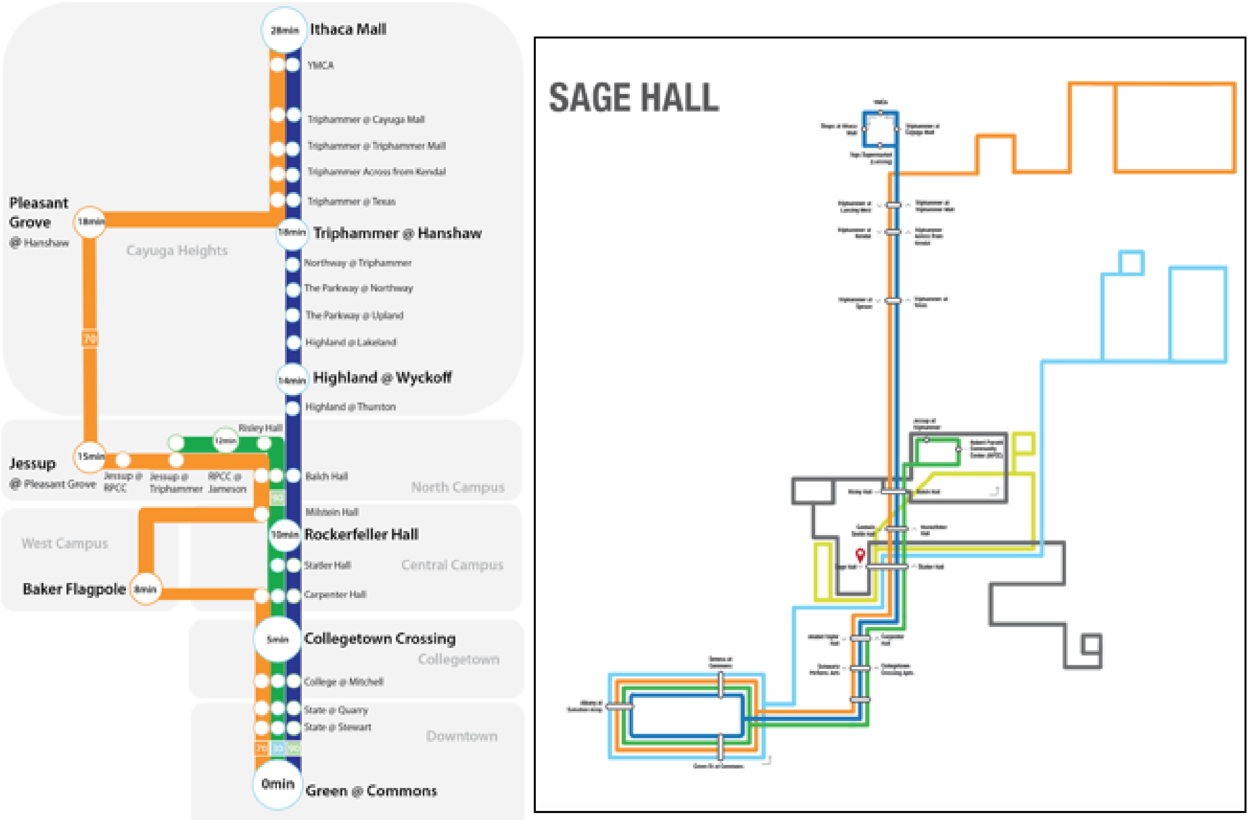



Figure 42: Two Iterations of Subway Styled Mapping

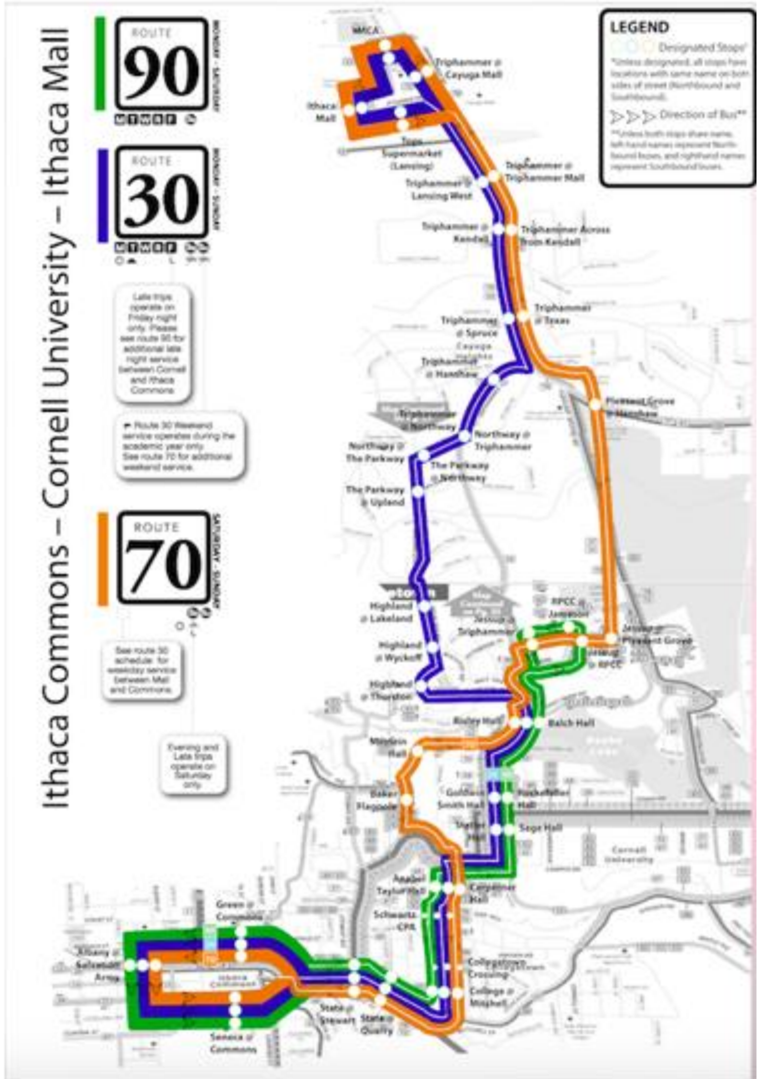



*Figure 43: Enhanced Geographic Styled Map*

## 2.2.3 Time Tables

Through our empathy fieldwork, we found that most users valued the information about time schedules when using Ride Guide maps. They reported that the current display of the bus schedules is informative but it is hard to follow. A list of time schedules takes up almost a full page, so some users thought there was an overwhelming amount of information. In addition, the current time tables on Ride Guide maps indicate information related to only the major bus stops; thus, those who wait at the unspecified bus stop(s) cannot find the necessary information.

Our team proposes three ideas to improve the current limitations of the display of bus schedules. Our first idea can be referred as "time chart". The time chart demonstrates a pattern of the bus schedule by hours. This chart is stop-specific which means the hours and minutes are only relevant to a specific bus stop – shown is Highland @ Wyckoff in Route 30.

**Highland @ Wyckoff**

*Outbound (towards Ithaca Mall)* | *Inbound (towards Green @ Commons)*

| Minutes | | | | | | Hour | Minutes | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 44 | 6AM | 42 | | | | | |
| | | | 59 | 44 | 14 | 7AM | 12 | | 42 | 57 | | |
| | | 59 | 44 | 29 | 14 | 8AM | 12 | 27 | 42 | 57 | | |
| | | 59 | 44 | 29 | 14 | 9AM | 12 | 27 | 42 | 57 | | |
| 58 | | 59 | 44 | 29 | 14 | 10AM | 12 | 27 | 42 | 57 | | |
| 58 | 28 | | 44 | | 14 | 11AM | 12 | 27 | 42 | | 24 | 54 |
| 58 | 28 | | 44 | | 14 | 12PM | 12 | | 42 | | 24 | 54 |
| 58 | 28 | | 44 | | 14 | 1PM | 12 | | 42 | | 24 | 54 |
| 58 | 28 | | 44 | | 14 | 2PM | 12 | | 42 | | 24 | 54 |
| 58 | 28 | 59 | 44 | 29 | 14 | 3PM | 12 | | 42 | 57 | 24 | 54 |
| 58 | 28 | 59 | 44 | 29 | 14 | 4PM | 12 | 27 | 42 | 57 | 24 | 54 |
| | 28 | 59 | 44 | 29 | 14 | 5PM | 12 | 27 | 42 | 57 | 24 | 54 |
| | | 59 | 44 | 29 | 14 | 6PM | 12 | 27 | 42 | 57 | | |
| | | | 44 | 29 | 14 | 7PM | 12 | 27 | 42 | 57 | | |
| | | | 44 | | 14 | 8PM | 12 | | 42 | | | |
| | | | | | 14 | 9PM | 12 | | 42 | | | |
| | | | | (friday only) | 14 | 10PM | 39 | (friday only) | | | | |
| | | | | (friday only) | 14 | 11PM | 39 | (friday only) | | | | |
| | | | | | | 12AM | | | | | | |
| *Weekend* | | *Monday - Friday* | | | | | *Monday - Friday* | | | | *Weekend* | |

Route 30

*Figure 44: An Example of "Time Chart" using Bus Schedules for Highland @ Wyckoff*

The second idea is using "time bubbles". The minutes indicated in the bigger circles refer to how long it takes from one stop to the next major stop. It gives users an approximate duration of bus ride. For example, the Route 30 bus departing from Green @ Commons will take 5 minutes to get to Collegetown Crossing and 10 minutes to get to Rockerfeller Hall. For someone who gets on the bus at Collegetown Crossing going to Triphammer @ Hanshaw, they can estimate the duration of bus ride by subtracting the minutes indicated in the bubbles.

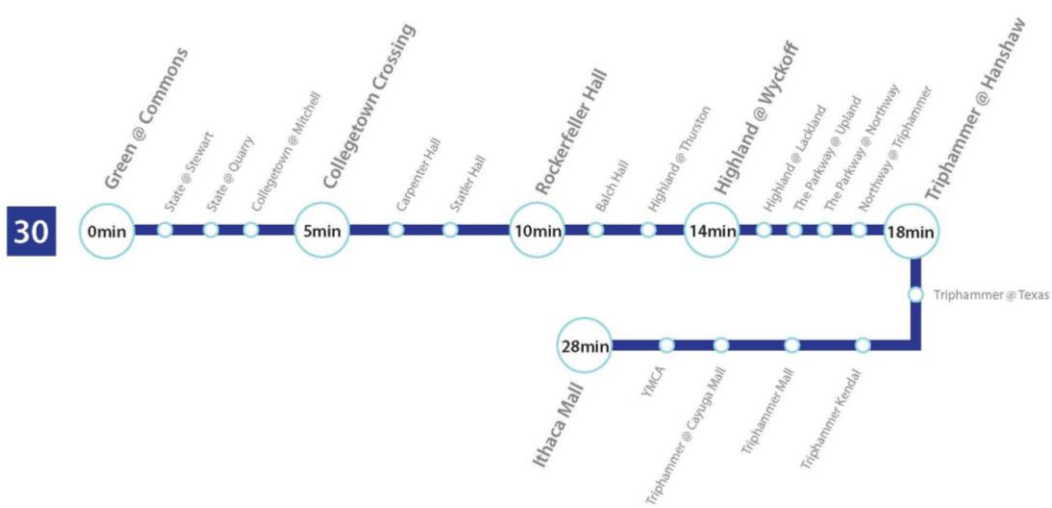



*Figure 45: An Example of "Time Bubble" using Route 30 Information*

The last idea demonstrates a stop-specific bus schedule with an indication of stop information, bus direction, and the bus schedules by hourly pattern.


# Route 30

## Ithaca Mall --> Green @ Commons

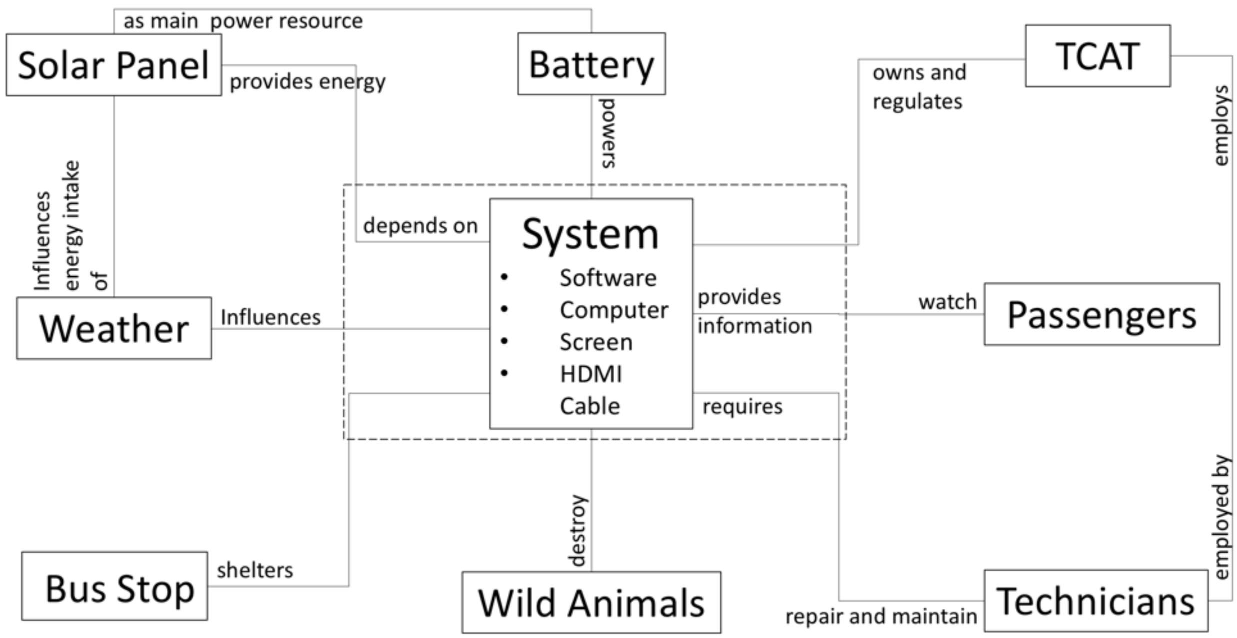
| | Monday - Friday | | | | Weekend | |
|---|---|---|---|---|---|---|
| 6AM | 42 | | | | | |
| 7AM | 12 | | 42 | 57 | | |
| 8AM | 12 | 27 | 42 | 57 | | |
| 9AM | 12 | 27 | 42 | 57 | | |
| 10AM | 12 | 27 | 42 | 57 | | |
| 11AM | 12 | 27 | 42 | | 24 | 54 |
| 12PM | 12 | | 42 | | 24 | 54 |
| 1PM | 12 | | 42 | | 24 | 54 |
| 2PM | 12 | | 42 | | 24 | 54 |
| 3PM | 12 | | 42 | 57 | 24 | 54 |
| 4PM | 12 | 27 | 42 | 57 | 24 | 54 |
| 5PM | 12 | 27 | 42 | 57 | 24 | 54 |
| 6PM | 12 | 27 | 42 | 57 | | |
| 7PM | 12 | 27 | 42 | 57 | | |
| 8PM | 12 | | 42 | | | |
| 9PM | 12 | | 42 | | | |
| 10PM | 39 (friday only) | | | | | |
| 11PM | 39 (friday only) | | | | | |
| 12AM | | | | | | |

*Figure 46: An Example of a Stop-Specific Bus Schedules with Route Information and Hourly Time Schedules*

## 2.2.4 Information Display

### 2.2.4.1 Introduction

The Information Display subteam's goal this semester was to construct a foundation for the closed information system that would display real time information to TCAT riders. With a mix of software and hardware, we wanted to conceptualize an initial version of a working system that would take real time information from TCAT's API, handle it on a custom webpage, and clearly display it on a screen for riders to see. The system context is described in the diagram below.

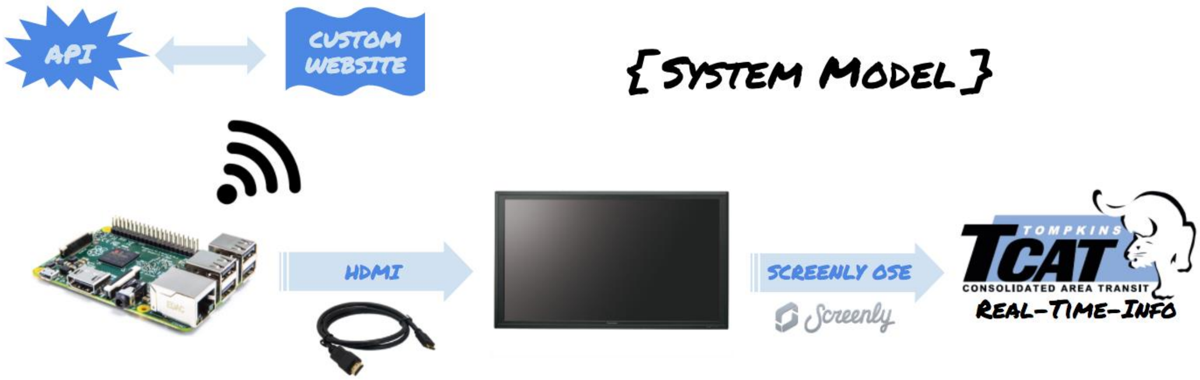



*System Index 8: Live Data Display System Context Diagram*

### 2.2.4.2 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 9: Information Display Structural Concept Diagram*

### 2.2.4.3 Acquiring & Handling the Real Time Information

While TCAT's API provides an assortment of different possible functions, we made use of two main API calls in constructing our live display: **/Vehicles/GetAllVehicles** and **/StopDepartures/Get/{id}**. The first call queries TCAT's vehicle database and returns JavaScript Object Notation (JSON) objects corresponding to all of the buses that are currently in service. These bus objects hold attributes such as VehicleID, RouteID, as well as a bus's current Latitude and Longitude. The second 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). 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.

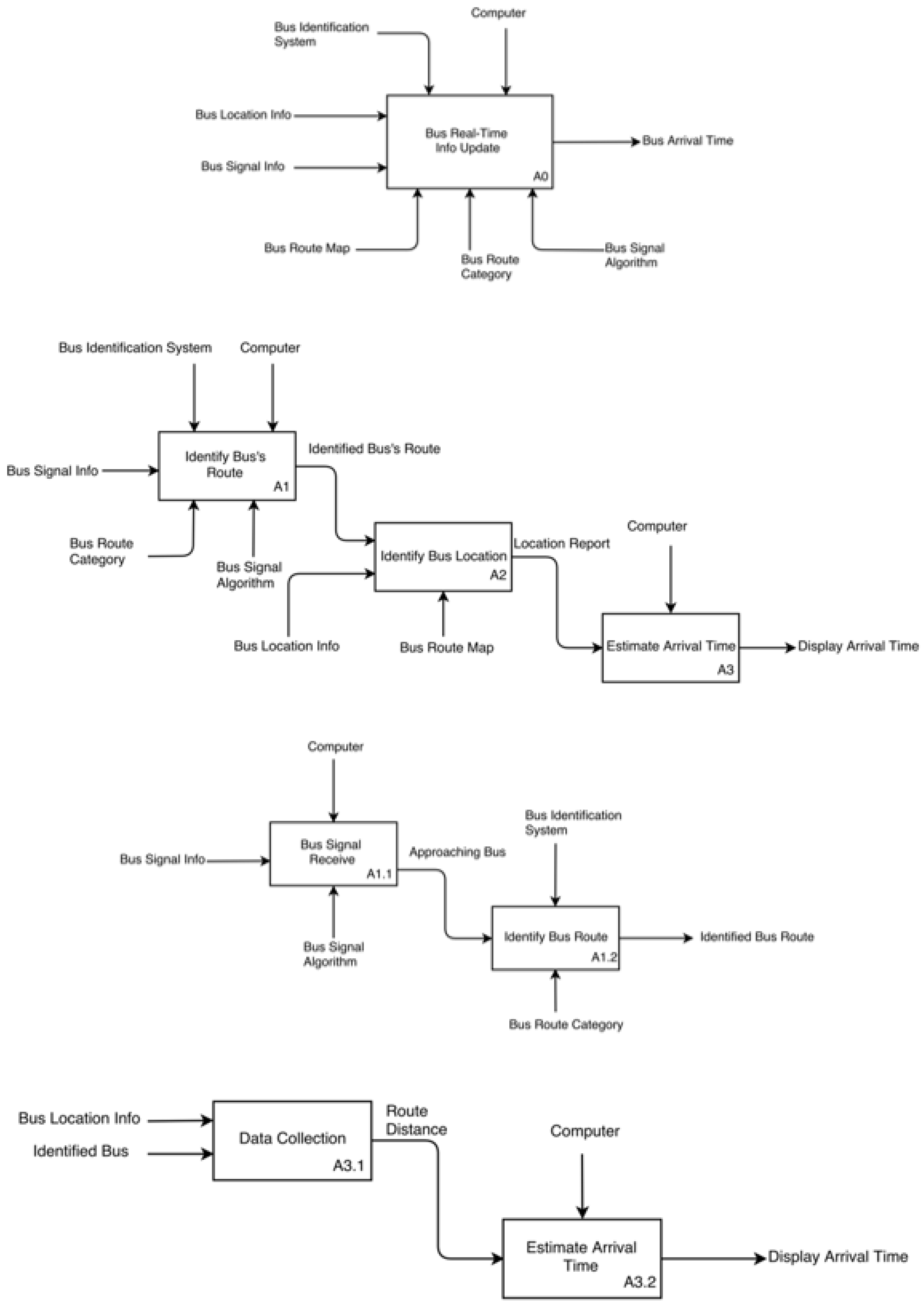
```
$(document).ready(function () {
  var token = 'Bearer e5159b89-86c1-3cca-8412-59de037c674b';
  $.ajax({
    url: 'https://gateway.api.cloud.wso2.com:443/t/mystop/tcat/v1/rest/Vehicles/GetAllVehicles',
    type: 'GET',
    dataType: 'json',
    beforeSend: function(xhr) {
      xhr.setRequestHeader("Authorization", 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 47: 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 refreshes itself every few seconds, performing new API calls and revising the display with the updated information.

Functional steps can be viewed through the systems diagram IDEF0. 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.

In the data display system, the function is to display the real time information. To complete this function, the Raspberry Pi has to first receive the approaching bus signal then identify the bus. After that it estimates the arrival time.




*System Index 10: Live Data Display IDEF0*

### 2.2.4.4 Displaying the Real Time Information

For display of the real time data, our team considered three different screen layouts to present the map and timetable. First, we worked closely with the design team to ideate 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 layout is 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. We currently have the framework for all three designs, but we are still in the process of finalizing the designs and deciding how best to represent the moving buses on the map and arrival times in the timetable.

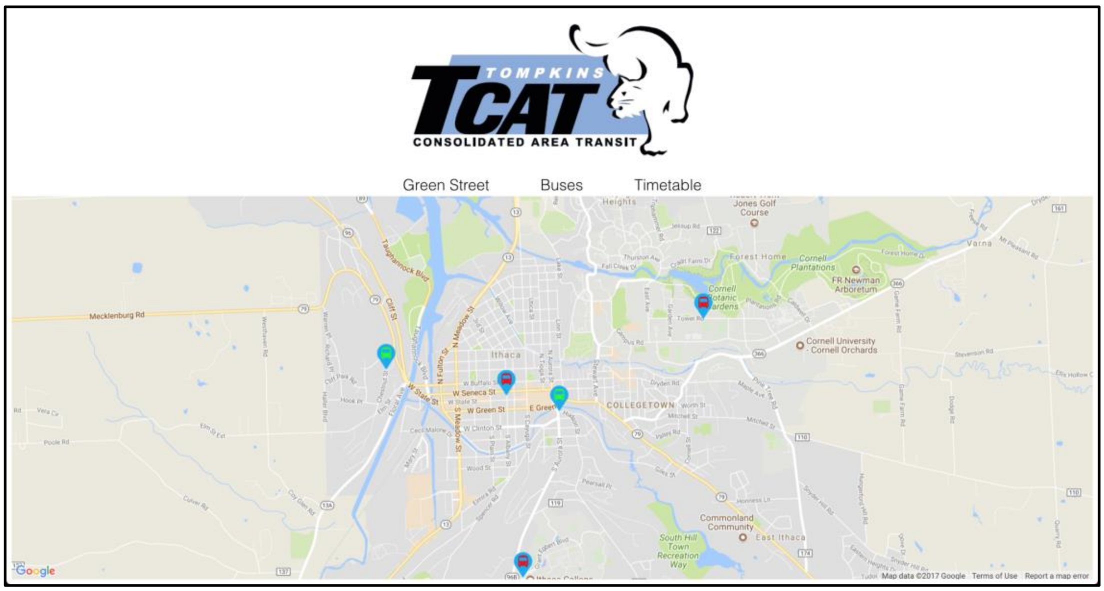



*Figure 48: Screenshot of the Website Displaying Incoming and Outgoing Buses*

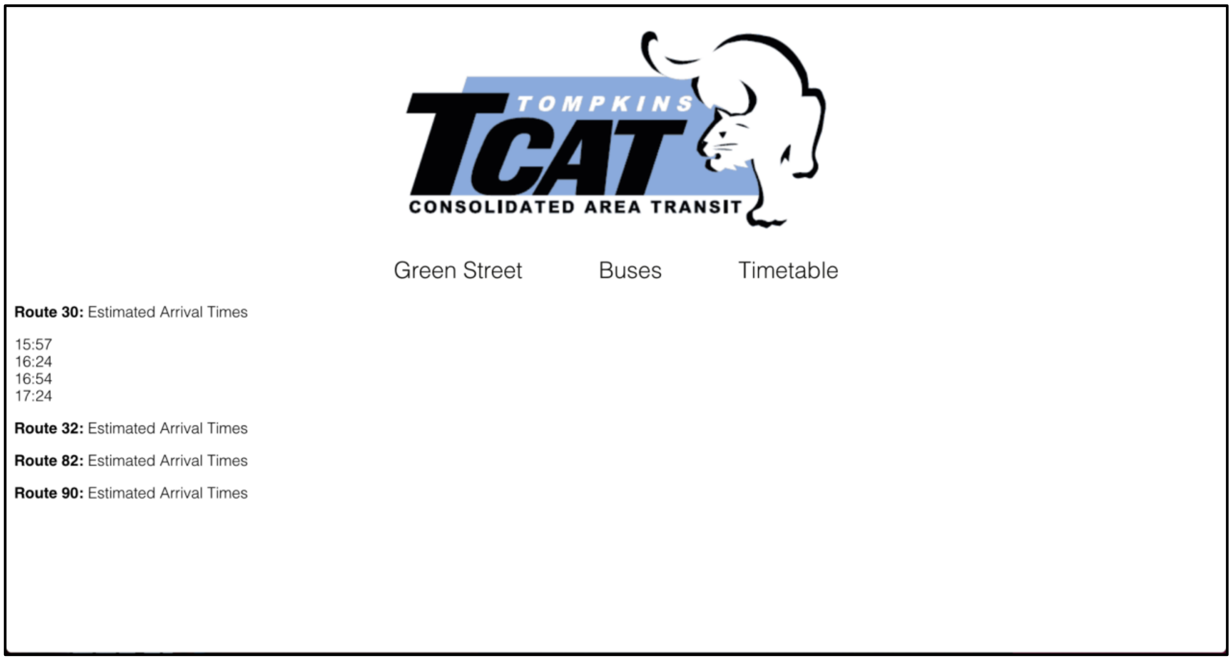



*Figure 49: Screenshot of the Website Displaying a Timetable of Incoming Routes and Their Estimated Arrival Times*

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


*Figure 50: Data Display Medium Fidelity Mock-Up*

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 11: Live Data Display Analytical Hierarchy Process*

### 2.2.4.5 Conclusion & Looking Forward

This semester ended on a positive note. We were able to effectively create an initial system for acquiring, handling, and displaying TCAT real time information to riders. It lacks a stronger infrastructure and the details of logistics, like wiring real estate and the future of website hosting, but we successfully laid a foundation for future team members to build upon. Looking forward, we would like to run multiple user tests to decide on one of the three designs for displaying the real time information on the display and to implement more CSS styling to give the website more personality.

## 2.2.5 TCard Design

Last semester, the team worked on low fidelity prototypes of a new TCard and drafted with TCAT on the idea of adding a reflective strip on the card that users can use to wave down a bus at a stop when it's dark. A proof of concept of the design is shown below.

*Figure 51: Reflective Bus Pass Proof of Concept*

This semester, we started by researching different materials for this reflective strip. We ordered a thin aluminum sticker and tested shining it in front of a car light. We found that it was difficult to see the reflection unless held directly in front of the light of a car.

We considered making card graphics with printed reflective material, called holo-sheen, however we have not tested the strength of its reflectiveness, and TCAT expressed a greater desire for adding this aspect as a sticker rather than printing such material onto the card.

In addition to redesigning the card's graphics, we realized that currently, TCAT places a large sticker on the front of each card indicating the type of card plan and zone the card is available to be used in. We drafted new graphic layout designs and utilized the opportunity to minimize their sticker use by having a section on the card to write the zone number. As for plan type, we have not found a solution to adding it in the layout without having to add a sticker (the plan type is very long and would be more exhausted to hand write on each card in contrast to writing a simple number for zone type).

In the new designs, we made wireframes for the layout of the cards, including adding a location where the reflective sticker would be placed and another where the zone number would be written. Our graphic designs have been low fidelity and more like drafts, and we planned them to be consistent with the TCAT branding. We wanted to avoid some elements of the current card design, such as the yellow color, since it does not strongly show the TCAT brand.

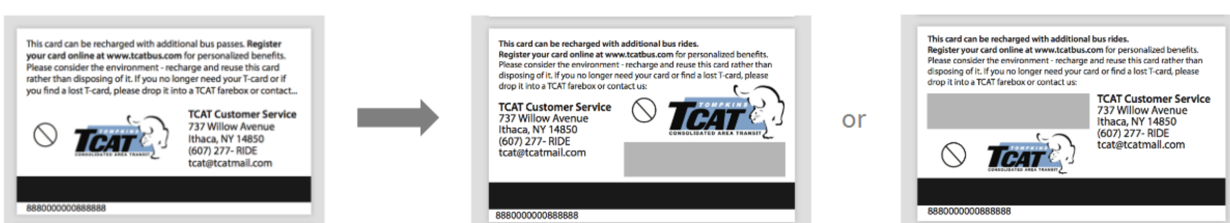



*Figure 52: TCard Integrated with Reflective Strip*

We also considered changing the one-time use cards to thinner plastic cards, much like NYC Metro cards, that aren’t as damaging to the environment when thrown away. However, TCAT employees stated that they are “only marginally cheaper and cannot be as readily re-used as the plastic ones.”

As for their logo, we have not worked on any drafts because it would be a large investment that we would prefer TCAT to give full confidence and approval for us to work on, due to their logo being widely used now and needing lots of planning and time to be replaced if redesigned.

Currently, TCAT orders their cards in bulk twice a year, at about 20,000 cards each time. The cards are printed by MagTicket.

# 2.3 Solar

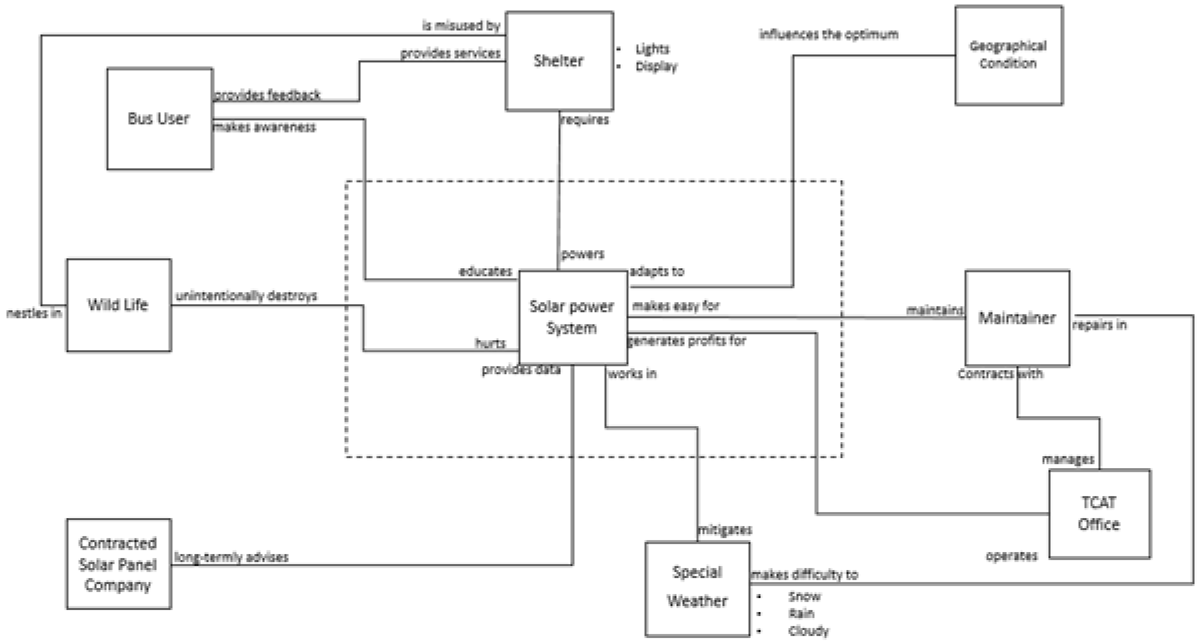
## 2.3.1 Introduction

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 usefully 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 12: Solar Context Diagram*

## 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.

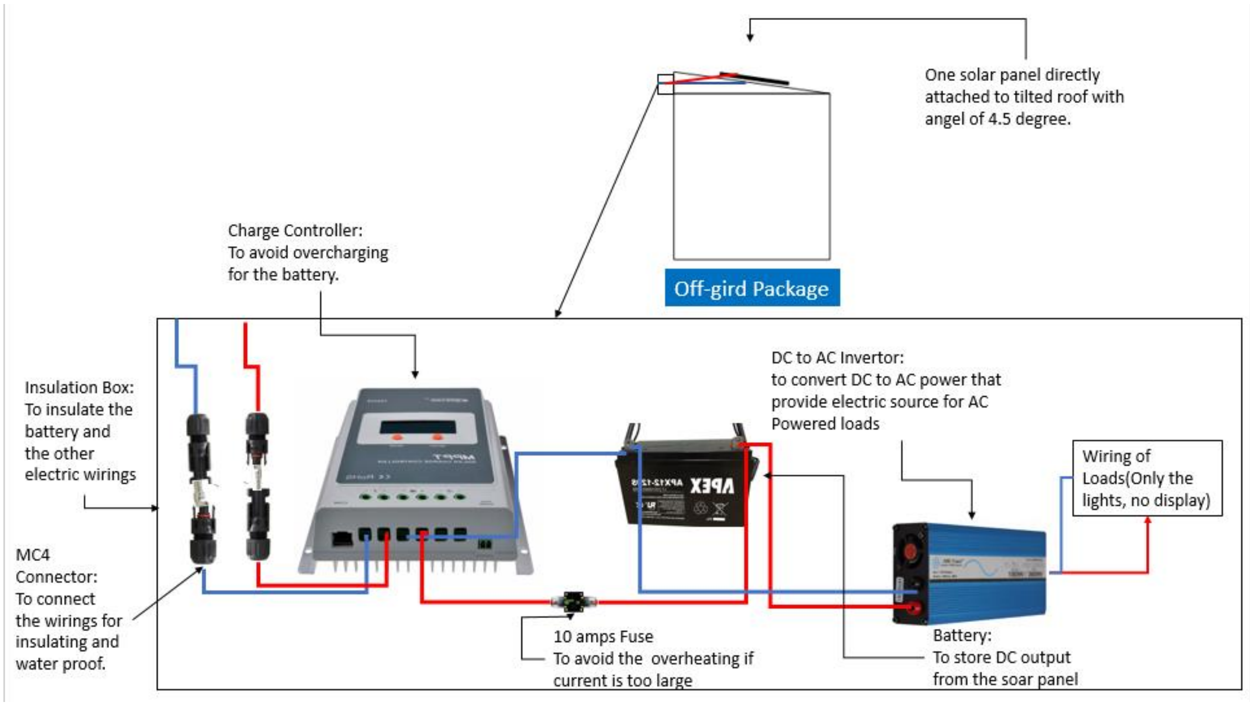
In order to meet the need of long term affordability, the functionality of selling back to the electricity company when electricity is overproduced was added.

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 13: 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 20W light without backup power. This decision is explained via calculations on the following pages.




*System Index 14: 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 10W, 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 10W 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 10W safety load and additional 10W 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:

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

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

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

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

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

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

The Total Power Required for Lights:

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

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

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

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

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

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

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

Result of Power Production Feasibility Analysis:

The surplus of power production is 650Wh, 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

$$Capacity\ of\ Battery = 120Ah$$

$$Number\ of\ Battery = 1$$

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

$$Percentage\ of\ Capacity\ Loss = 15\%$$

$$The\ voltage\ of\ the\ loads = 12V$$

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

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

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 shall be able to work at least 5 days.

$$\frac{\text{Off-Grid (Daily): Real Battery Capacity : 61Ah}}{\text{Total Capacity Required: 11Ah}} = 5.6$$

## 2.3.5 Showcase Package

### 2.3.5.1 Showcase Electric Loads & Components

The Showcase model requires a more advanced system, given that it has a load requirement three times greater than the off-grid stop. It will have three power-drawing systems. The first and second systems are like that of the off-grid stops: there is a 10-watt system that will remain on from dusk to dawn, that will produce the 700 lumens necessary to make the stop appear safe and inviting. The secondary light system, which will activate with a motion sensor, requires 20 watts. Being that the Showcase is larger than the off-grid stop, it will require more lights to fully illuminate the larger area. The 20-watt system will produce roughly 1800 lumens, which should allow for reading in the shelter. The showcase stops will also include a 30-watt LCD screen that will operate for 21 hours each day, displaying solar data and general TCAT information.

To accommodate the increased power requirement, the showcase stops will be fully equipped with solar technology. Currently, the showcase shelter can hold six domestic solar panels, each measuring 65”x40”. This design will likely be implemented, unless any of the innovative translucent or transparent solar panel options proves to be more lucrative. The stops will be outfitted with 2 batteries as well as a charge controller and inverter, in addition to the lighting and LCD components.

#### 2.3.5.2 Showcase Package Feasibility

In order to understand whether the showcase package design is feasible to power the required loads: 10W safety load, 20W motion-activated load, and 30W display 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 Watts hours) and the total power required for lights and display (in Watts hours).

In addition, even though showcase package is grid-tied, which would have electric input from the grid in days that there is no solar energy input, the team is still interested in knowing the longevity of system running only on the solar power. The goal of the showcase is to run at least one day without solar power energy input. On days that have excessive solar power production without battery capacity available, the excessive power would be sold back to the grid.

The AC Real Power Production:

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

$$Number\ of\ Solar\ Panel\ in\ the\ Off-Grid\ Package = 6$$

$$1\ DC\ Power\ in\ watts\ hour = 4\ AC\ Power\ in\ watts\ hour$$

$$The\ AC\ Energy\ Loss = 30\%$$

$$\begin{aligned} Total\ AC\ Real\ Power\ Prodution \\ &= Written\ Power \times Number\ of\ Solar\ Panel \times DC\ to\ AC\ Power\ Ratio \\ &\times AC\ Energy\ Loss = 280\ wh \times 6 \times 4 \times (1-30\%) = 4704\ wh \end{aligned}$$

The above calculation result gives that the AC real power production of the showcase package is 4704Wh.

The Total Power Required for Lights and Display:

$$Wattage\ of\ Security\ Light = 10\ watts$$

$$Security\ Light\ Operational\ Hour = 10\ hours$$

$$Wattage\ of\ Additional\ Lights\ with\ Motion-activated\ Profile = 20\ watts$$

$$Additional\ Lights\ Operational\ Hour = 10\ hours$$

$$Estimated\ Utilization\ of\ Additional\ Lights = 50\%$$

$$\begin{aligned} Total\ Power\ Required\ for\ Lights \\ &= Wattage\ of\ Security\ Light \times Security\ Light\ Operational\ Hour \\ &+ Wattage\ of\ Additional\ Lights\ with\ Motion-activated\ Profile \\ &\times Additional\ Lights\ Operational\ Hour \\ &\times Estimated\ Utilization\ of\ Additional\ Lights \\ &= 10\ watts \times 10\ hours + 20\ watts \times 10\ hours \times 50\% = 200\ wh \end{aligned}$$

The above calculation result gives that the total power required for lights in the showcase package is 200 Wh.

$$\textit{Wattage of Display} = 30\ \textit{watts}$$

$$\textit{Display Operational Hour} = 21\ \textit{hours}$$

$$\begin{aligned}\textit{Total Power Required for Display} &= \textit{Wattage Display} \times \textit{Display Operational Hour} \\ &= 30\ \textit{watts} \times 21\ \textit{hours} = 630\ \textit{wh}\end{aligned}$$

The above calculation result gives that the total power required for display in the showcase package is 630 Wh.

### Result of Power Production Feasibility Analysis:

The surplus of power production is 3874wh which means the AC real power production of the showcase package exceeds the power required in the showcase package. Therefore, the power production of the showcase design is feasible to power the lights and display requirement for the large high-tech bus shelter modulus. The excessive power production shall first be storred to the battery if there is capacity available, if not shall be sold back to the national grid.

**Showcase (Daily):**
**Total AC Real Power Production : 4704Wh**
**−**
**(Total Power Required for lights: 200Wh**
**+**
**Total Power Required for Display: 630Wh)**

---

**The Surplus of Power Production: = 3874**

### Feasibility Analysis on the Battery Selection:

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

$$\textit{Number of Battery} = 2$$

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

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

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

$$\textit{The total Capacity Required} = \frac{\textit{The Power Required for Loads}(wh)}{\textit{Voltage of the Loads }(v)} = \frac{(200+630)wh}{12v} = 69\ Ah$$

$$\begin{aligned}&\textit{The Real Battery Capacity} \\ &\quad = \textit{Capacity of Battery} \times \textit{the Number of Battery} \\ &\quad \times \textit{the Percentage of Capacity Reducted for Battery Protection} \\ &\quad \times \textit{Percentage of Capacity Loss} = 120Ah \times 2 \times (1 - 40\%) \times (1 - 15\%) = 122Ah\end{aligned}$$

Result of Battery Selection Feasibility Analysis:

The battery capacity required to power lights per day is 69 Ah. The real battery capacity in the off-grid design is 122Ah, which is 1.8 times the capacity required in the showcase system. The calculation results mean that if there is no solar energy input for fully charged battery sets, the showcase system shall be able to work at least one day.

**Showcase (Daily):**

$$\frac{\textbf{Real Battery Capacity: 122Ah}}{\textbf{Total Capacity Required: 69Ah}} \; \textbf{=1.8}$$

## 2.3.6 Translucent/Transparent Solar Panels

Earlier generations used to incorporate PV (photovoltaic) devices such as solar panels by directly mounting them on top of the building roof with minimal aesthetic consideration and only power consideration. However, more recently, building integrated PVs have started to gain attention in the market as they directly replace the corresponding building part, hence improving the functionality of the device, lowering cost. For instance, clear glass solar panels have started to replace windows in order to also obtain solar power. Due to the seamless integration of BIPVs on mechanical structures, the idea of utilizing such solar panels on the showcase shelters will be discussed in the section below.

### 2.3.6.1 Discussion:

Certain companies such as Tesla have already started to utilize such technologies by creating "solar roofs," which are basically solar panels that also function as the roof. However, they are opaque in nature. In contrast, we had the idea of doing a similar concept, but with either translucent or transparent solar panels. To go about doing this we created a decision matrix of the various translucent/transparent solar panel manufacturers that sell such BIPVs to decide which manufacturer would be the best to meet our project conditions. See in the figure below for the decision matrix.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Measurements | | | | | | | |
| | Frameless Solar Panel | | | | Clear Window Solar Panel | | | |
| Charactersics | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 | |
| Price | | | 78x98in | | | | | |
| Unit Size | 65.5"X41"X1.1 | 66.9 in x 39.4 i | 300*300mm t | 300*300mm t | Any | NA | 1200 x 600 x 7 mm | |
| Unit Power | 285W | 330W | Max:400W | Max:300W | 28W/m^2 | NA | Up to 85W | |
| Waterproof | Yes | Yes | No | No | NA | NA | NA | |
| Ease of Installation | Yes | Yes | Yes | Yes | Yes | NA | Yes | |
| Customeraztion | No | No | Yes | Yes | Yes | NA | Yes | |
| Asthestic | Yes | Yes | No | No | Very Yes | NA | Very Yes | |
| Distribution Location | | | | | | | | |
| Efficiency | 16.50% | 19.40% | NA | NA | NA | NA | 12% | |

*System Index 15: Solar Roof Decision Matrix*

As can be seen from the decision matrix we found out that option 2 was the most suitable. The reason for this was because out of all the 7 options only option 1 and 2 turned out be waterproof which was a necessity for our design. On top of this, when we compared the power produced per unit area between options 2 and 1 we found that option 2 produced a higher amount, majorly because it was bifacial which meant that it absorbed solar energy from both sides of the panel. In addition to this as can be seen from the decision matrix above, it also had a higher efficiency of 19.4% as compared to the 16.4% of option 1. Overall, option 2 had both higher power and higher efficiency compared to the opaque solar panels we had initially planned to apply from Renovus.

The option 2 solar panels are produced by Lumos. The particular cell model option 2 describes is known as the GSX Bifi Module System. After contacting the sales manager, Ryan Schaub, we found out that the panels come only in one physical size but in custom cell patterns. This means for the same physical size they have different amount of cells and hence different ratings of power and light transmittance.

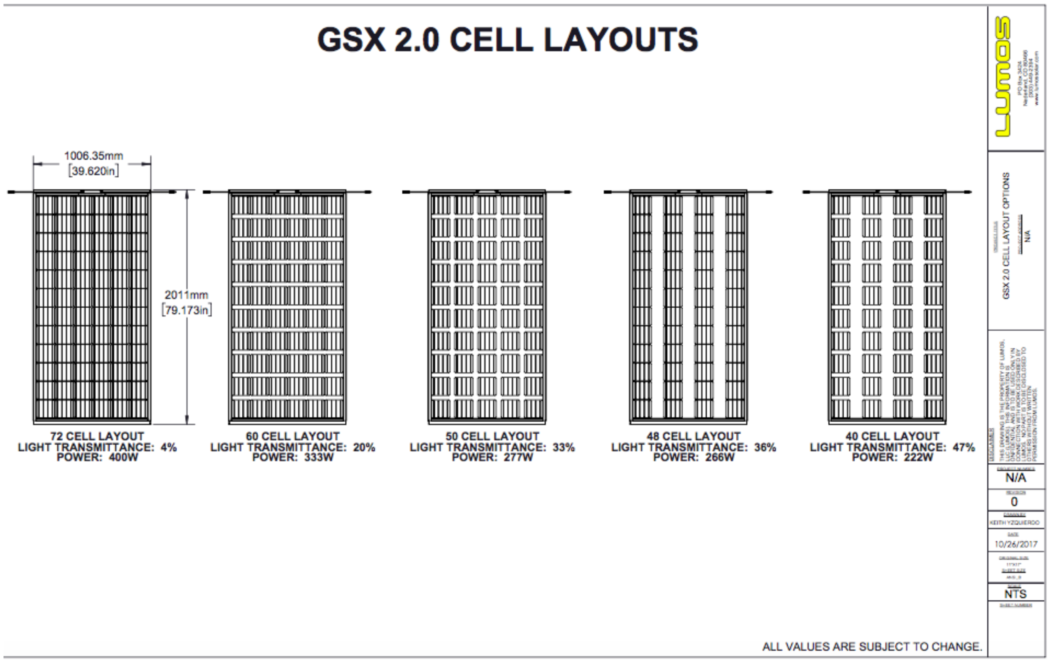



*Figure 53: Various Cell Patterns for the Same Physical Size of the Solar Panel Supplied by Lumos*

A great benefit of these panels is that they can withstand a high snow load, wind speed as well as they have high hail resistance making them weatherproofed. Although they do not provide custom module sizes, the sales manager claimed that custom infill glass can been used when required to cover up any space.

For our target solar panel dimension of 114" deep x 144" wide the following are the panels Lumos can supply to fit our needs in terms of physical size and the translucent appearance of the panels we aim to achieve for the showcase shelters:

2 LSX modules deep in Portrait = 131" x 4 LSX modules wide = 164.5"
3 GSX modules deep in Landscape = 119" x 2 GSX modules wide = 159"

Moving on, we hope to contact them on the next steps of setting up these panels if we decide to go ahead with them after analyzing their cost and performance feasibility.

# 3 Lansing Routing

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 less than other areas of similar population demographics. 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 Statistical Modeling, the integration of which is never done.

The first part of the semester was spent working as one subteam. We first conducted traditional research (fact finding), finding as much information on Lansing as possible. Then we 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 Statistical Modeling. The Systems Design Thinking group unpacked the empathy episodes and modeled the emotional data, while the Statistical Modeling team worked to use algorithms and discrete numerical data to model the system and find possible improvements.

Moving forward next semester, we will integrate Systems Design Thinking findings and the Statistical Modeling findings in the ideation phase. From there, we will collaborate with TCAT to find the most serviceable courses of action for the Lansing area.

## 3.1 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.

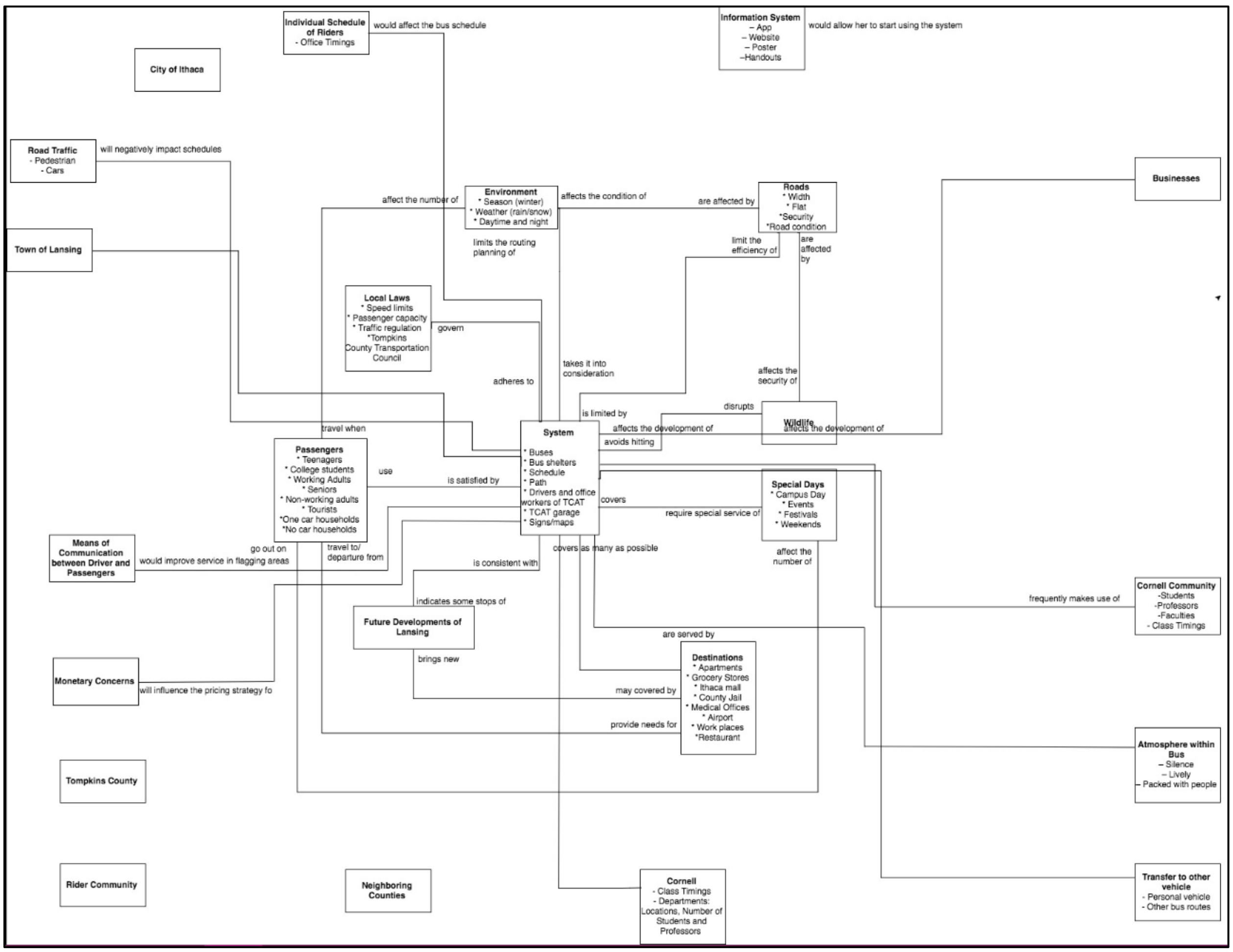
Some of the most useful data stemmed from a report developed by a separate Cornell group, Design Connect, that looked at transportation issues in Lansing in 2014. The report was devoted to general transportation, providing excellent data about potential TCAT modifications. This report is titled: Transportation 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 these 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 16: Initial Lansing Challenge Context Diagram*

# 3.2 Systems Design Thinking

## 3.2.1 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 road route 77, route 37, and route 36 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.

### 3.2.1.1 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.

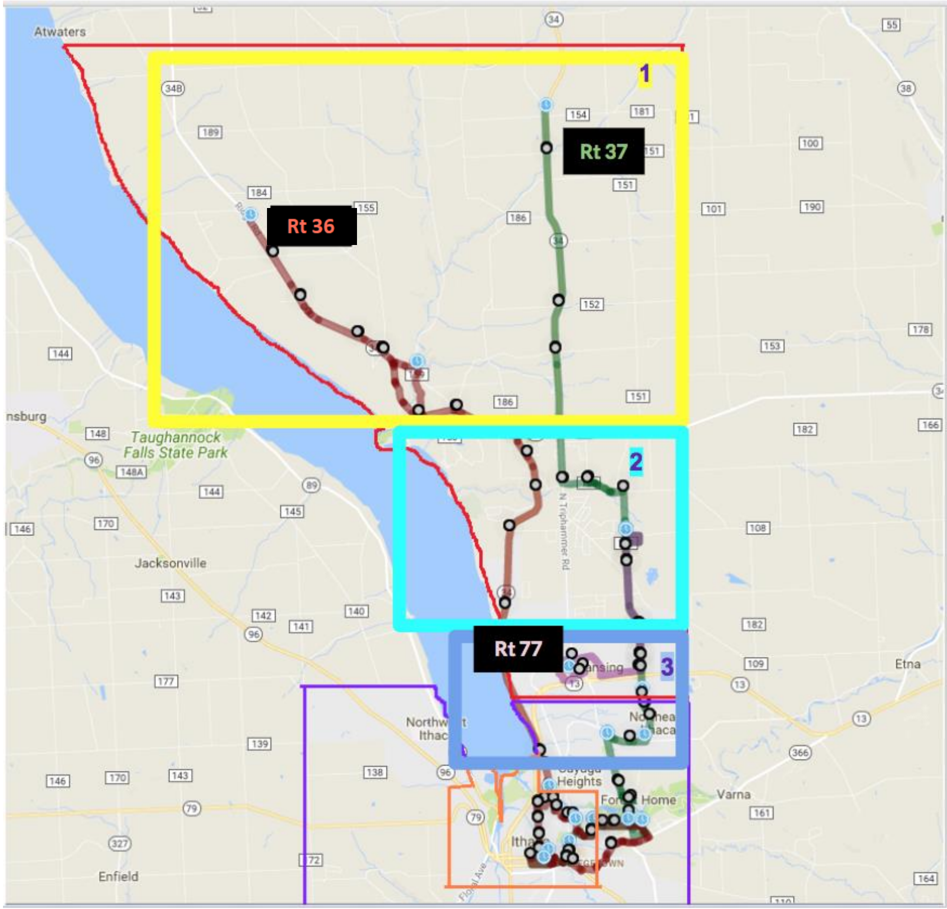


*Figure 54: Fields of Action for Lansing Challenge*

In order to be efficient with our empathy fieldwork we researched and designated predicted "hotspots", or places where there were believed to be centers of activity. These were generally cafes, commercial centers, or places of local governance, but we also considered the park & ride 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.

## 3.2.2 Fieldwork

Our team split into sub-groups of three that each applied 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.

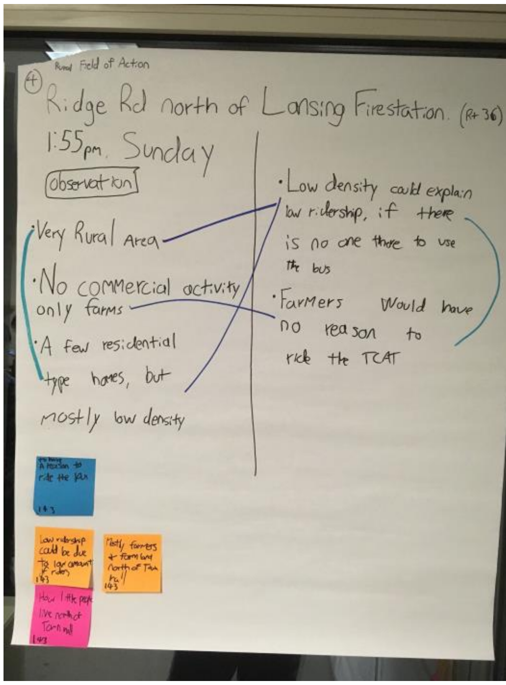
### 3.2.2.1 Unpacking Empathy Fieldwork

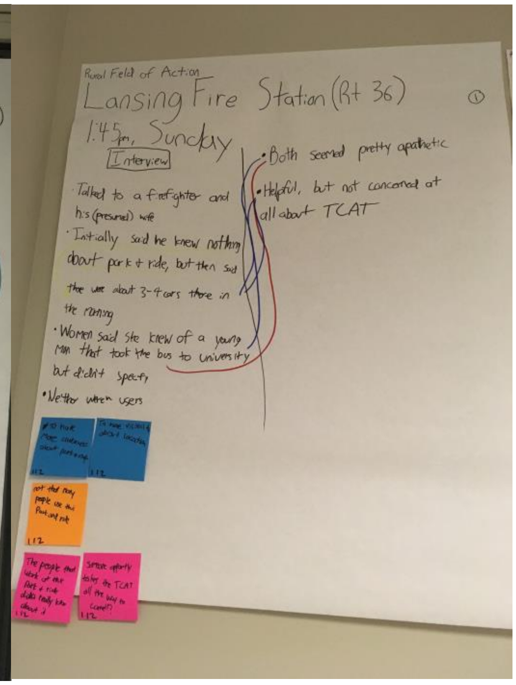
After the end of the empathy fieldwork process, the group members for each field of action regrouped, and began to unpack the information obtained during the fieldwork. In this process, each empathy fieldwork group created multiple poster sheets, as shown on the following pages, detailing their experiences 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.

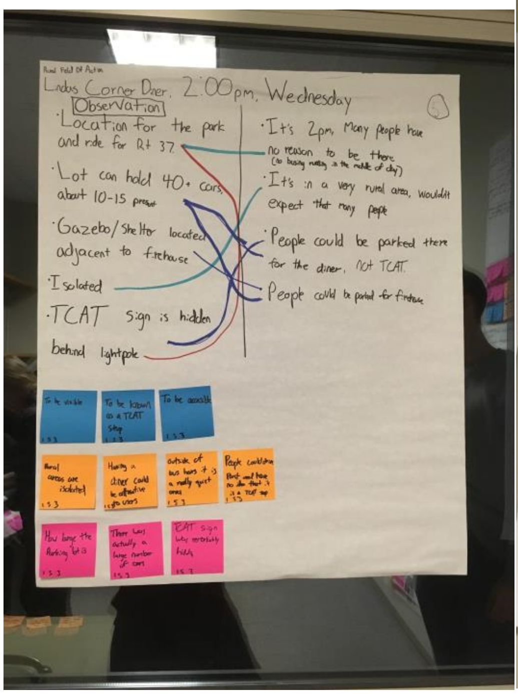
After recording these findings down on the top half of the poster sheet, team members used color-coded markers to highlight and classify the connections and contradictions between the statements recorded on a particular sheet.

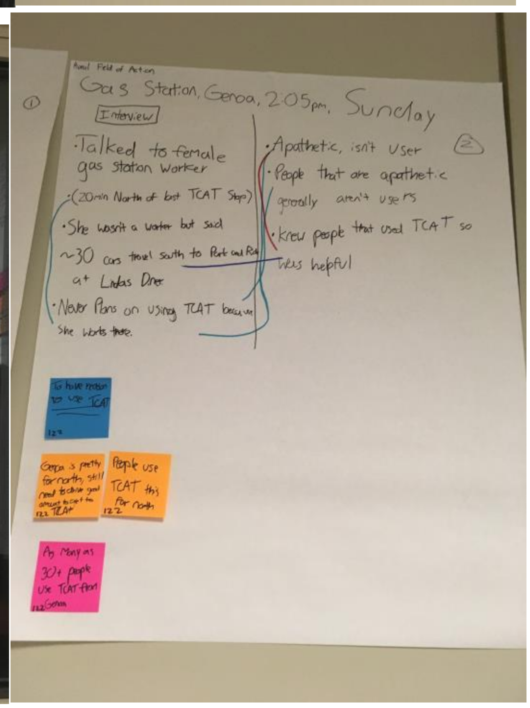
## 3.2.2.2 Rural Lansing

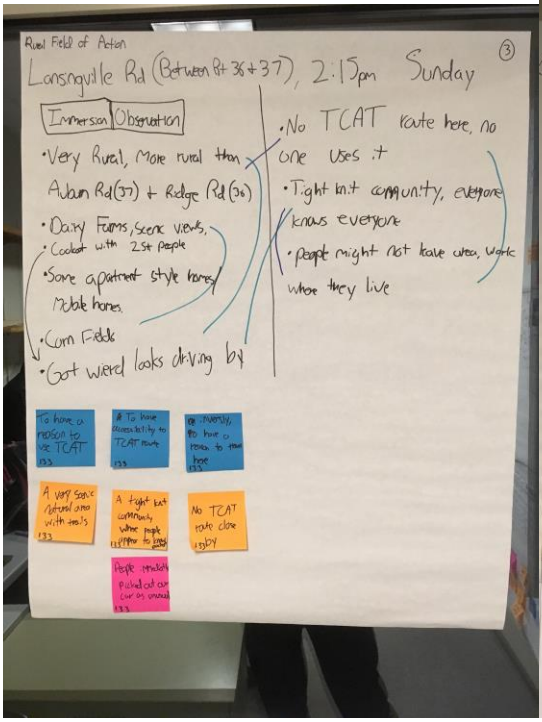
Provided below are images of the unpacked empathy data for Rural Lansing.

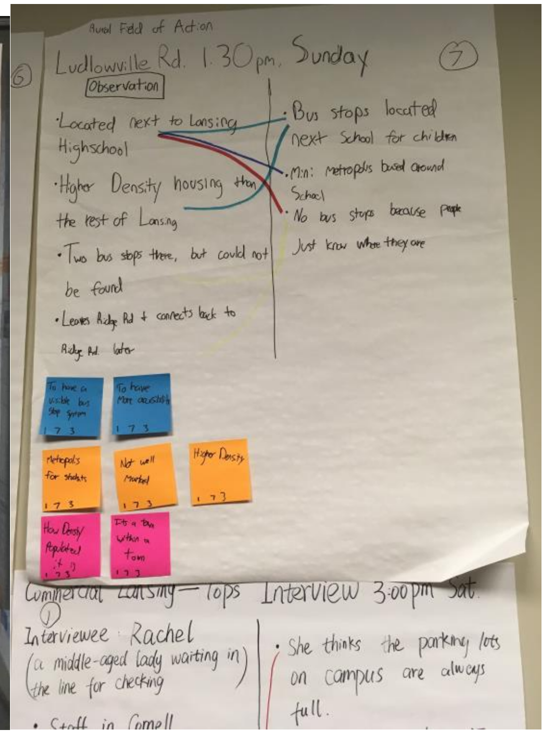


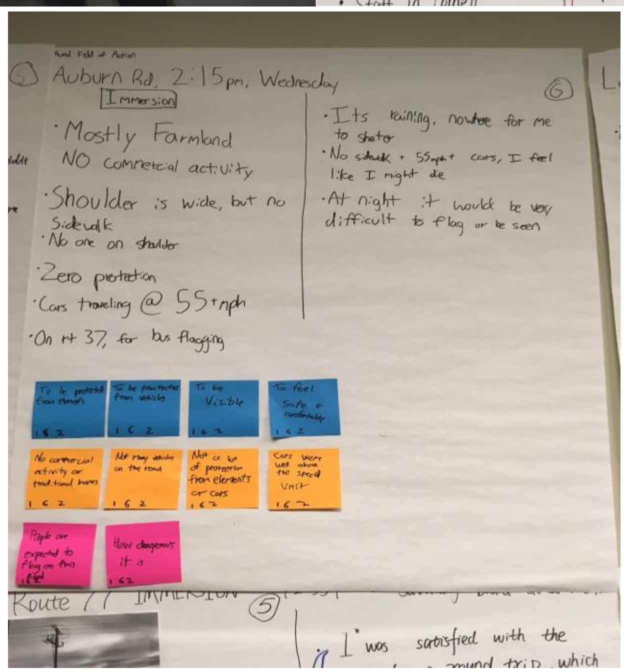



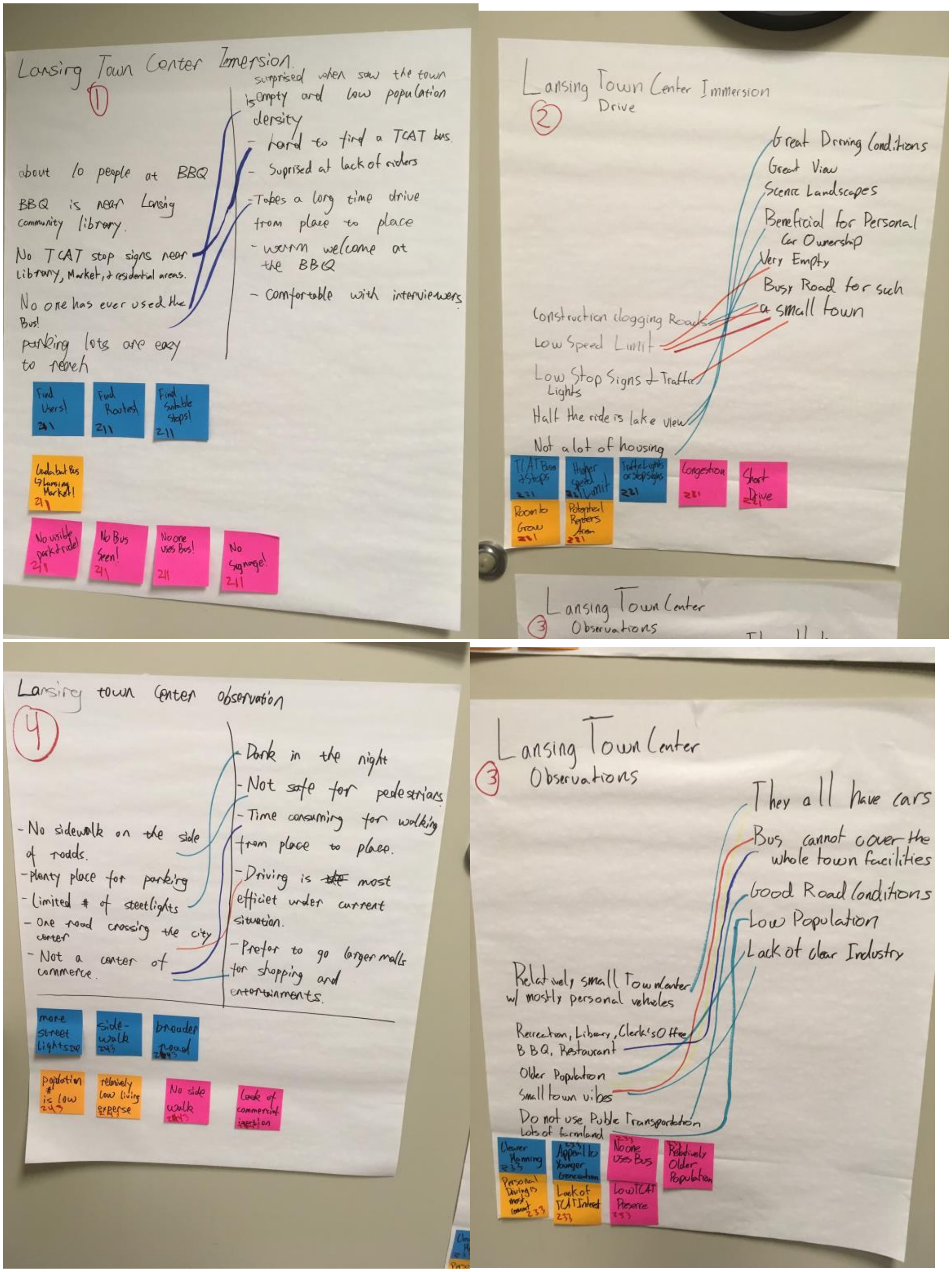

Rural Field of Action
Lansingville Rd (Between Rt 36 + 37), 2:15pm Sunday
3
Immersion
Observation
·Very Rural, More rural than Auburn Rd (37) + Ridge Rd (36)
·Dairy Farms, scenic views,
·Cookout with 25+ people
·Some apartment style homes/ Mobile homes
·Corn Fields
·Got wierd looks driving by
·No TCAT 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
A very scenic natural area with trails
No TCAT route close by


Rural Field of Action
Ludlowville Rd. 1:30pm, Sunday
7
Observation
·Located next to Lansing Highschool
·Higher Density housing than the rest of Lansing
·Two bus stops there, but could not be found
·Leaves Ridge Rd + connects back to Ridge Rd later
·Bus stops located next School for children
·Min: metropolis based around School
·No bus stops because people Just know where they are
To have a visible bus stop system
To have more accessibility
Metropolis for students
Not well marked
Higher Density
How Densly Populated it is
It's a town within a town
Commercial Lansing — Tops Interview 3:00pm Sat.
1
Interviewee Rachel
(a middle-aged lady waiting in the line for checking)
·She thinks the parking lots on campus are always full.


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

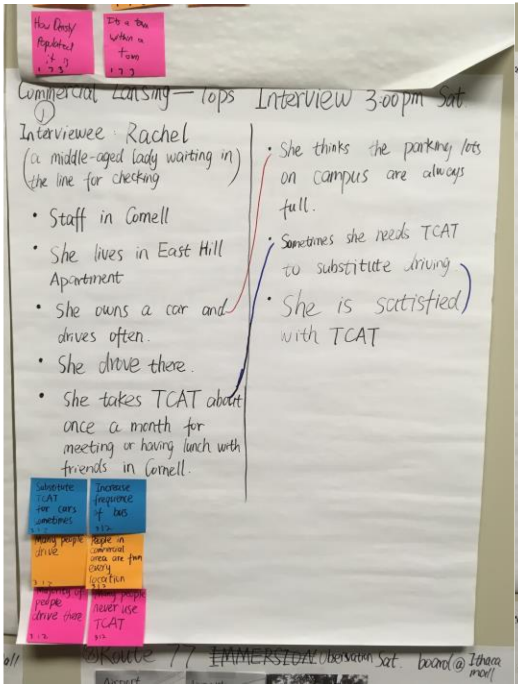
### 3.2.2.3 Lansing Town Center

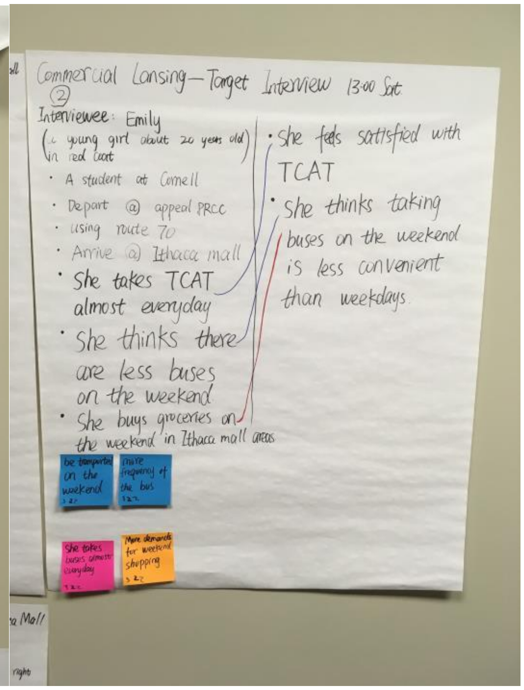
Provided below are images of the unpacked empathy data for the Lansing Town Center.



### 3.2.2.4 Lansing Commercial Hub

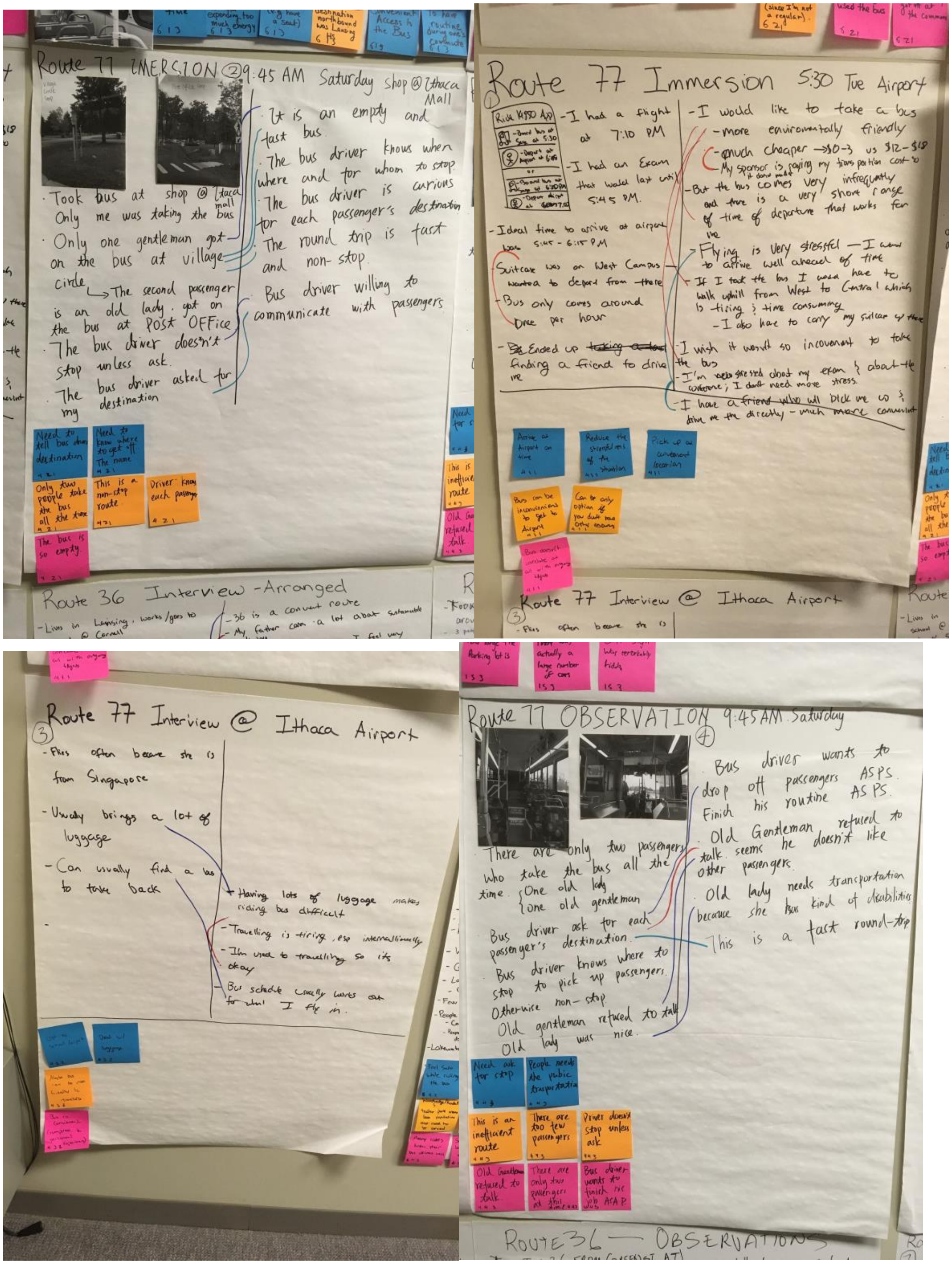
Provided below are images of the unpacked empathy data for the Lansing Commercial Hub.

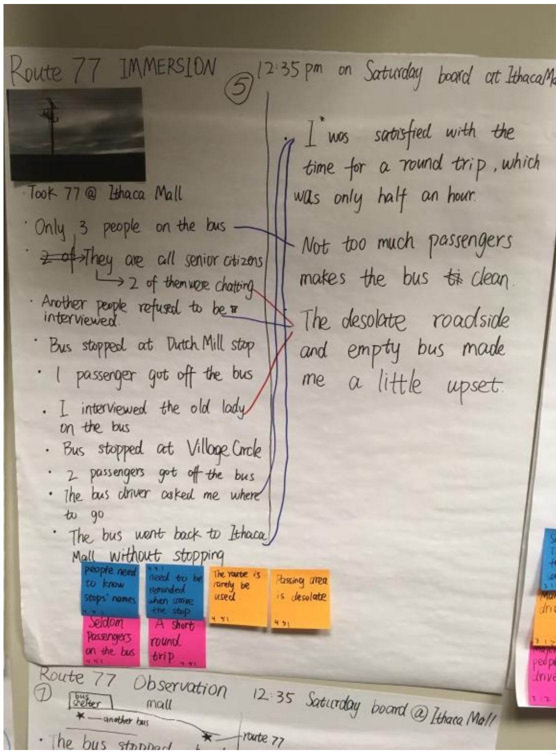


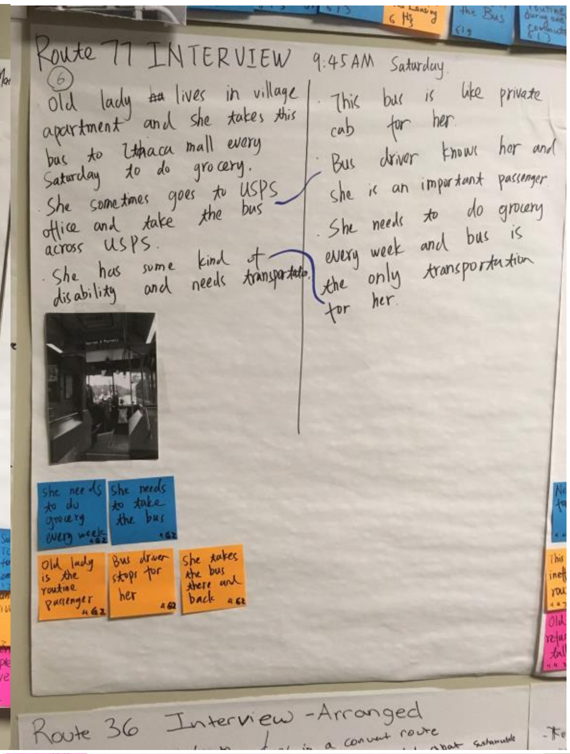



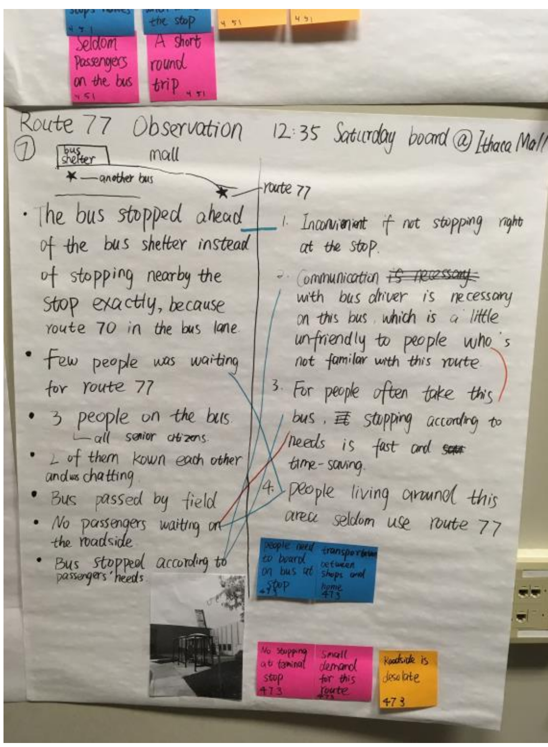
## 3.2.2.5 Route 77

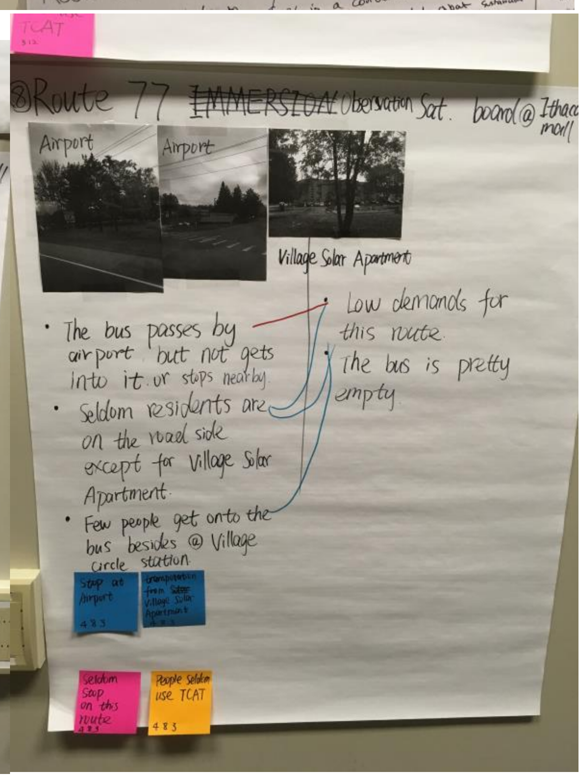
Provided below are images of the unpacked empathy data for Route 77.




Route 77 IMMERSION
5
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 coming 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

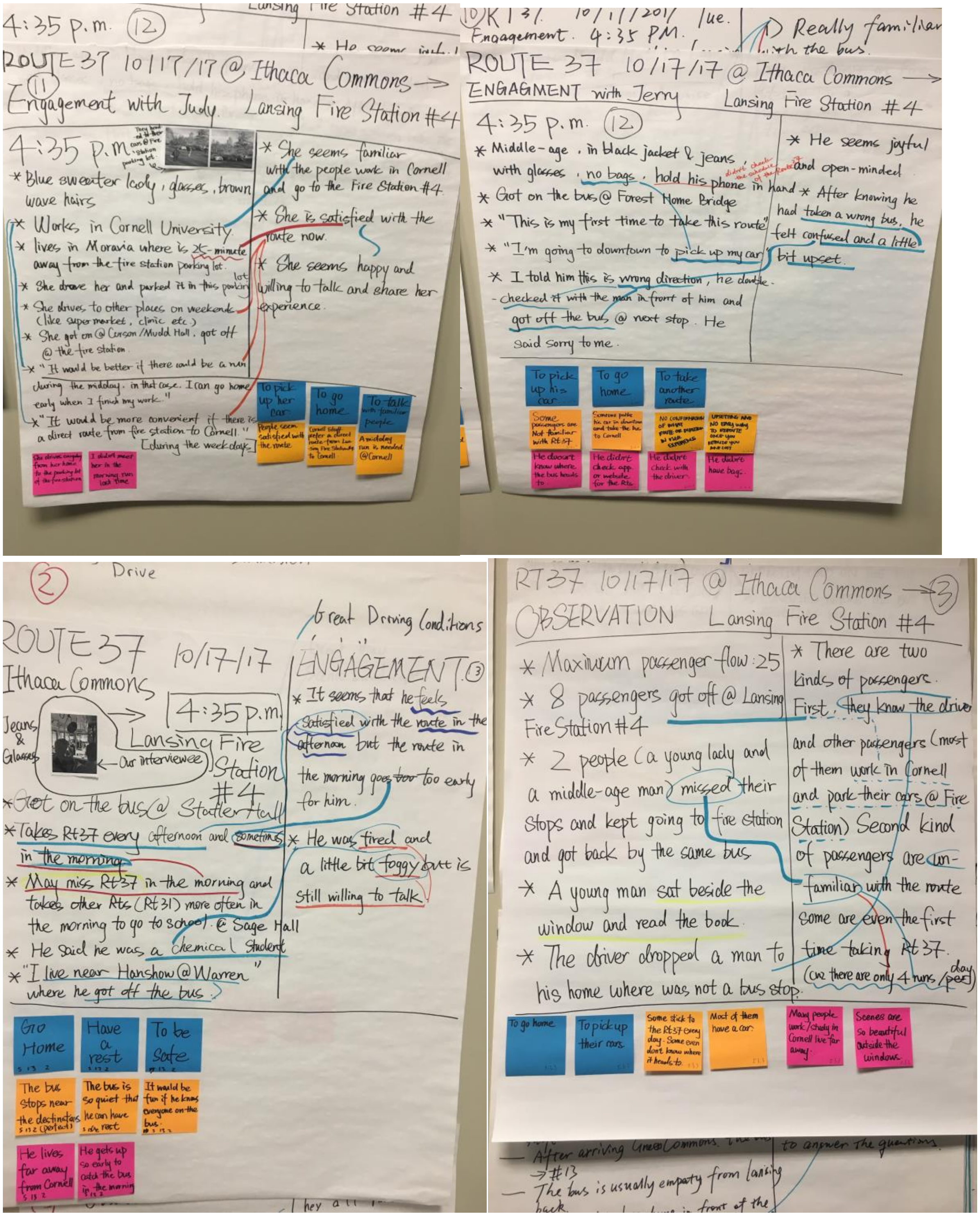

Route 77 INTERVIEW 9:45AM Saturday
6
Old lady lives in village apartment and she takes this bus to Ithaca mall every Saturday to do grocery.
She sometimes goes to USPS office and take the bus across USPS.
She has some kind of disability and needs transportation
This bus is like private cab for her.
Bus driver knows her and she is an important passenger
She needs to do grocery every week and bus is the only transportation for her.
She needs to do grocery every week
She needs to take the bus
Old lady is the routine passenger
Bus driver stops for her
She takes the bus there and back
Route 36 Interview - Arranged

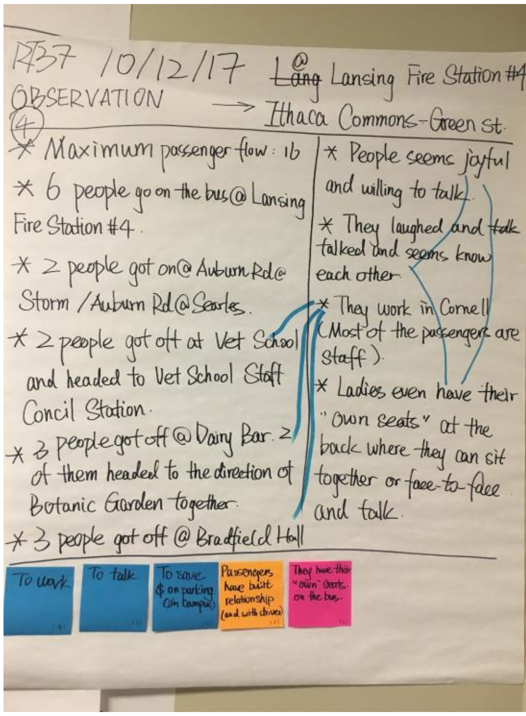

Seldom Passengers on the bus
A short round trip
Route 77 Observation
12:35 Saturday board @ Ithaca Mall
7
bus shelter
mall
another bus
route 77
The bus stopped ahead of the bus shelter instead of stopping nearby the stop exactly, because route 70 in the bus lane
Few people was waiting for route 77
3 people on the bus
all senior citizens
2 of them kown each other and was chatting
Bus passed by field
No passengers waiting on the roadside
Bus stopped according to passengers' needs
1. Inconvenient if not stopping right at the stop.
2. Communication ~~is necessary~~ with bus driver is necessary on this bus, which is a little unfriendly to people who's not familiar with this route
3. For people often take this bus, stopping according to needs is fast and time-saving.
4. People living around this area seldom use route 77
people need to board on bus at stop
transportation between stops and home
No stopping at a typical stop
Small demand for this route
Roadside is desolate

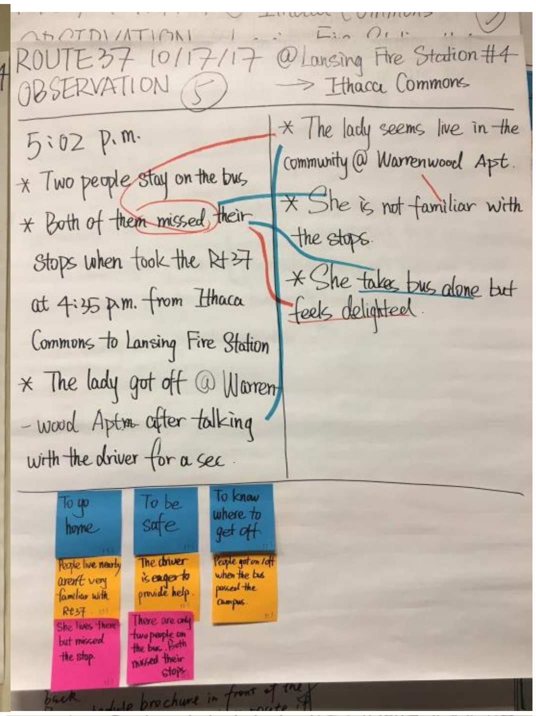

8 Route 77 ~~IMMERSION~~ Observation Sat. board @ Ithaca mall
Airport
Airport
Village Solar Apartment
The bus passes by airport but not gets into it or stops nearby
Seldom residents are on the road side except for Village Solar Apartment
Few people get onto the bus besides @ Village circle station
Low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

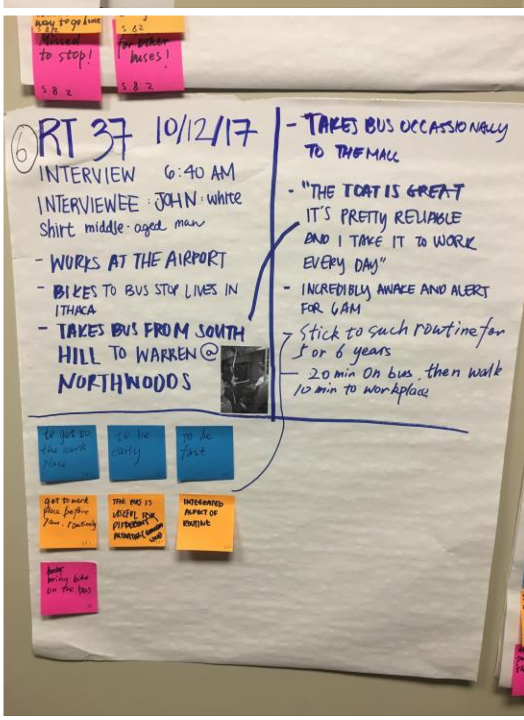
### 3.2.2.6 Route 37

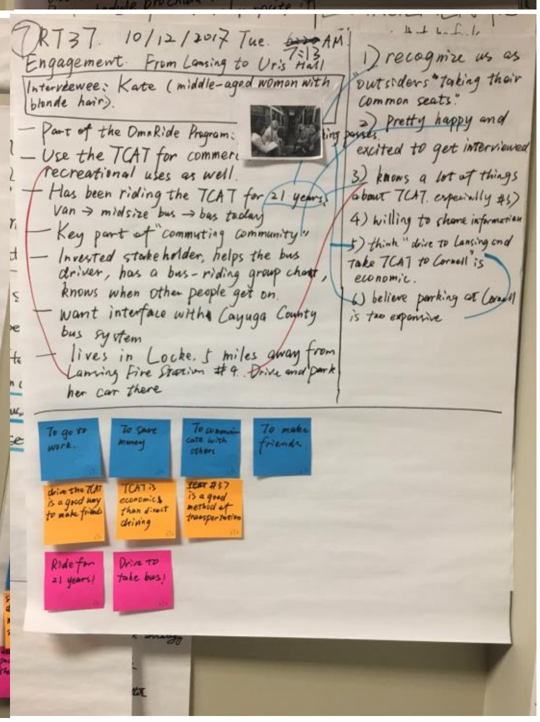
Provided below are images of the unpacked empathy data for the Route 37.

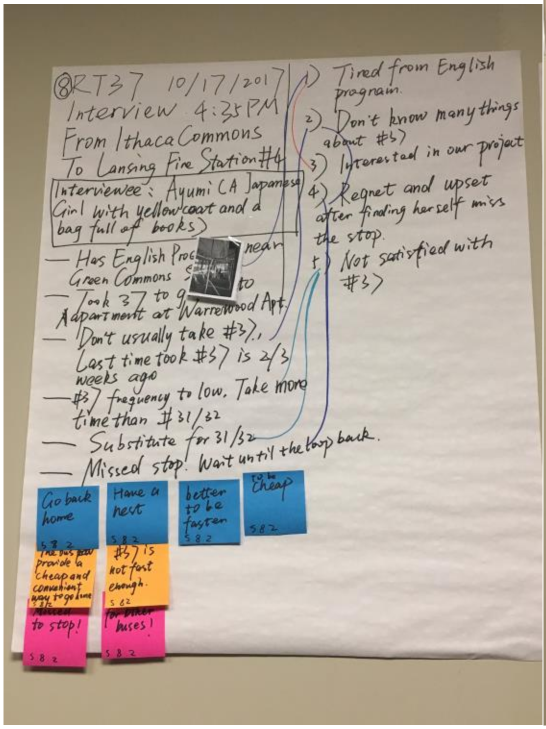


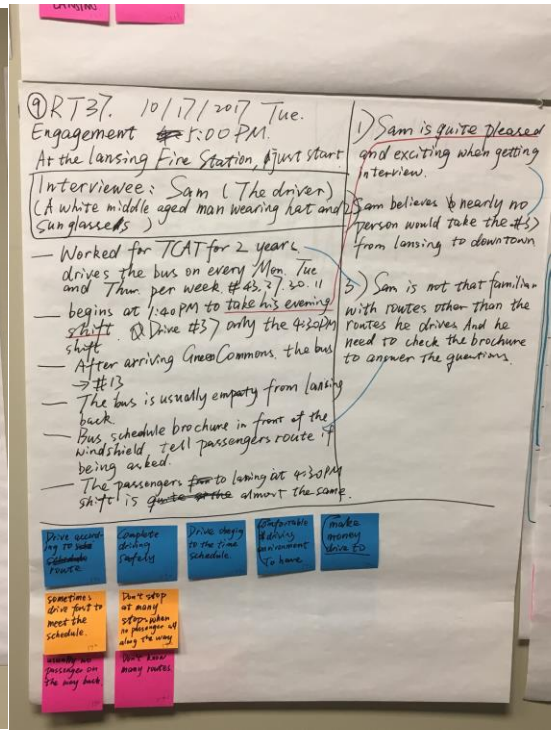

RT37 10/12/17 @ Lansing Fire Station #4
OBSERVATION → Ithaca Commons-Green St.
4
* Maximum passenger flow: 16
* 6 people go on the bus @ Lansing Fire Station #4.
* 2 people got on @ Auburn Rd @ Storm / Auburn Rd @ Searles.
* 2 people got off at Vet School and headed to Vet School Staff Concil Station.
* 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.


ROUTE37 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 Rt37 at 4:35 p.m. from Ithaca Commons to Lansing Fire Station
* The lady got off @ Warren-wood Apts 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 REST
The driver is eager to provide help.
People get 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.


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 OCCASSIONALLY 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
Missed to stop!
for other buses!

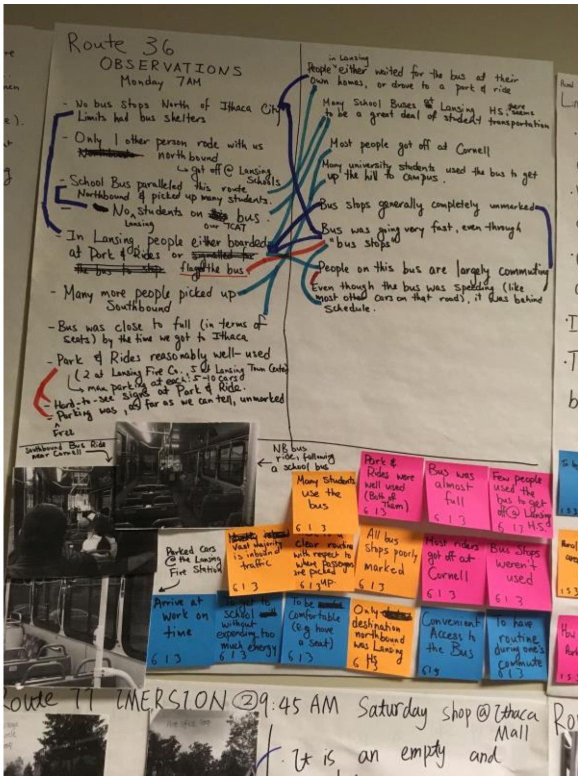

7 RT37 10/12/2017 Tue. 7:13 AM
Engagement From Lansing to Uris Hall
Interviewee: Kate (middle-aged woman with blonde hair).
- Part of the OmniRide Program
- Use the TCAT for commute, recreational uses as well.
- Has been riding the TCAT for 21 years
Van → midsize bus → bus today
- Key part of "commuting community"
- Invested stakeholder, helps the bus driver, has a bus-riding group chat, knows when other people get on.
- want interface with a 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
Ride for 21 years!
Drive to take bus!

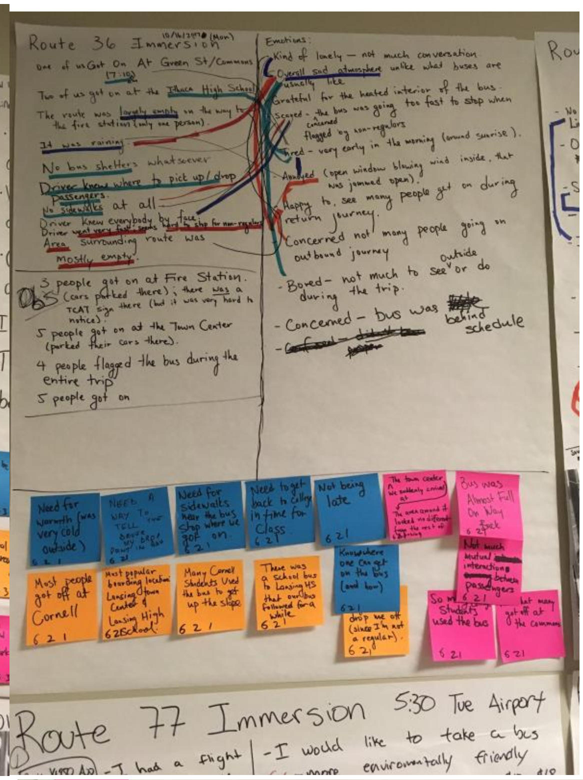


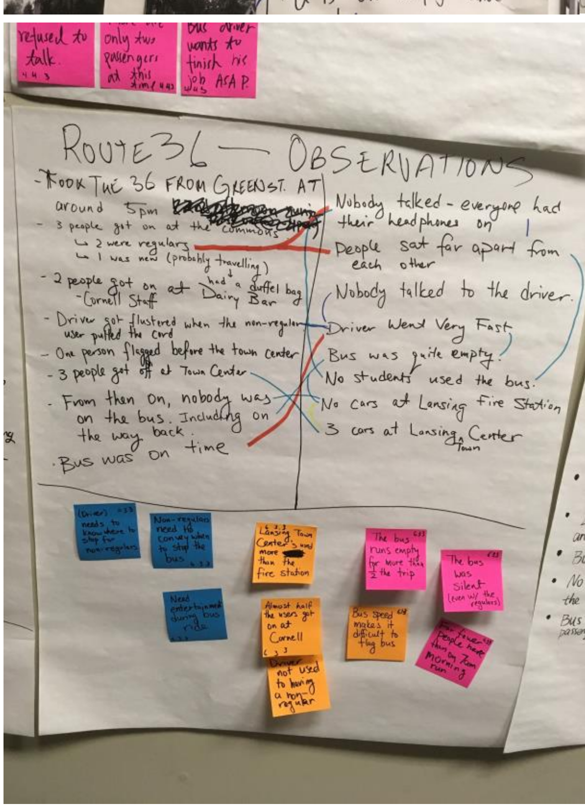


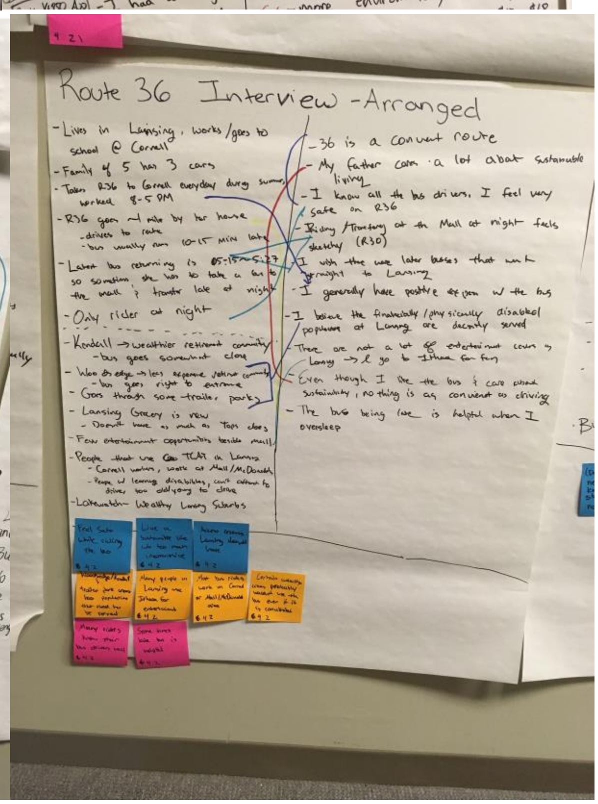
### 3.2.2.7 Route 36

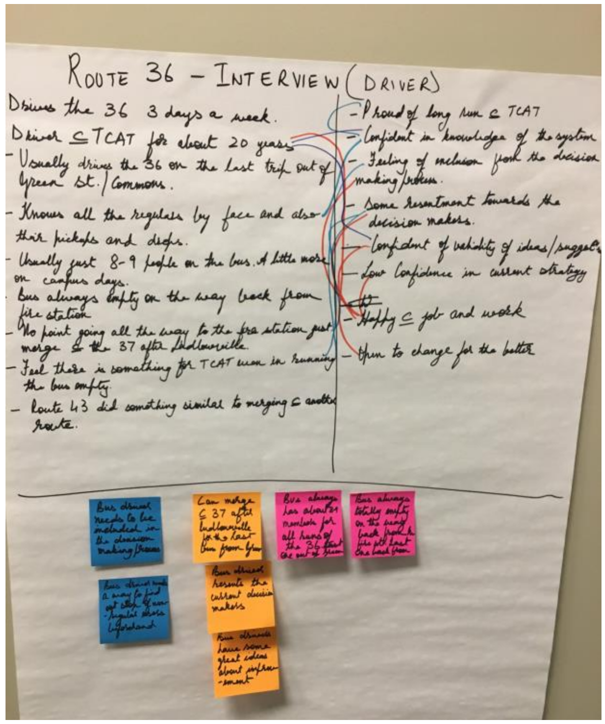
Provided below are images of the unpacked empathy data for the Route 36.












## 3.2.2.8 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 55: Unsorted Needs, Insights, and Surprises*

### 3.2.3 Emotional Data Modeling

In order to model the emotional data collected, we categorized the needs, insights, and surprises into groups and subgroups. The goal of this task was to search for patterns in the fieldwork data in order 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.

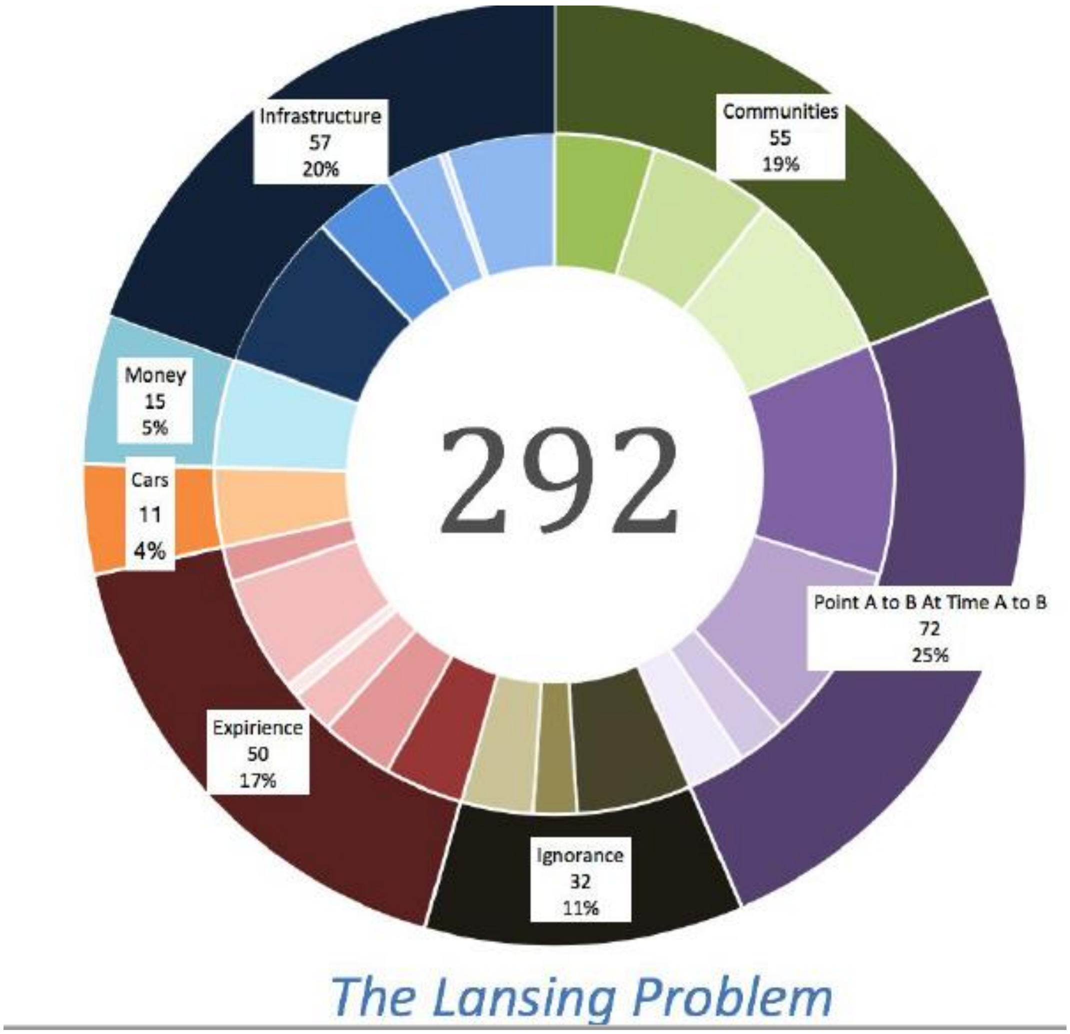



*Figure 56: Data Analysis for the Lansing Problem*

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 way |
| 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 | Its 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 | Its 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 north bound 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 know 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 side walk |
| 2.4.3 | Broader road |
| 2.2.1 | Traffic lights or stop signs |

| | |
|---|---|
| 2.4.3 | Side walk |
| 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*** |

## 3.2.4 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, and many of the frequent passengers enjoyed seeing other familiar passengers and bus drivers throughout their weekly routes, forming 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.

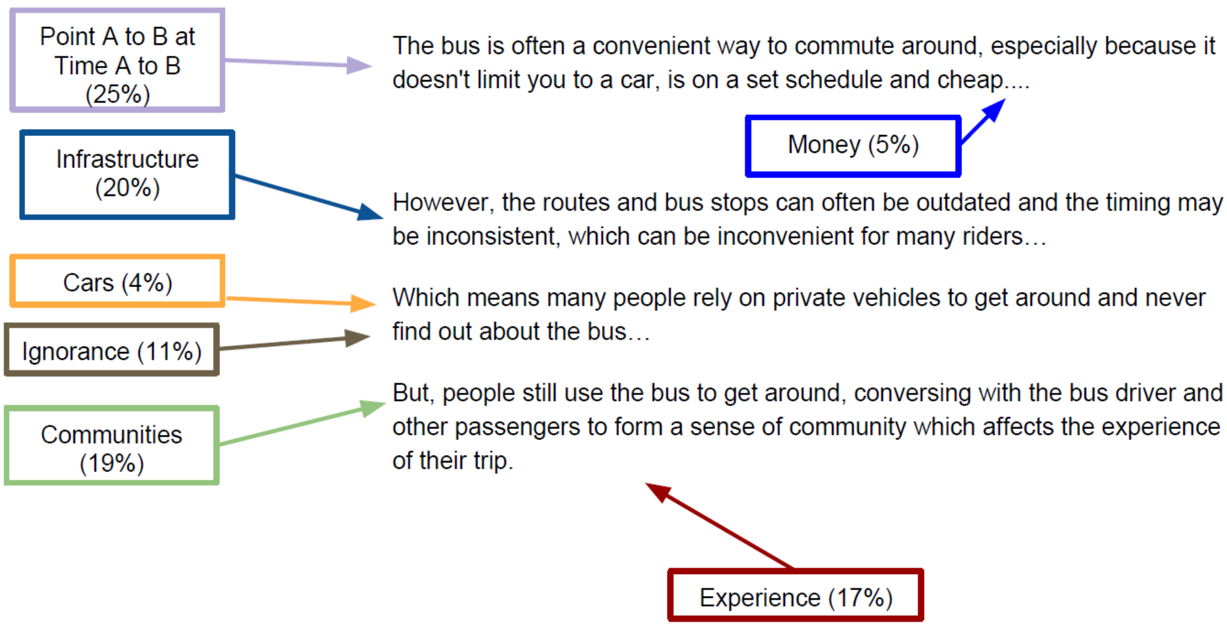



*Figure 57: Flow of Thoughts*

### 3.2.5 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*

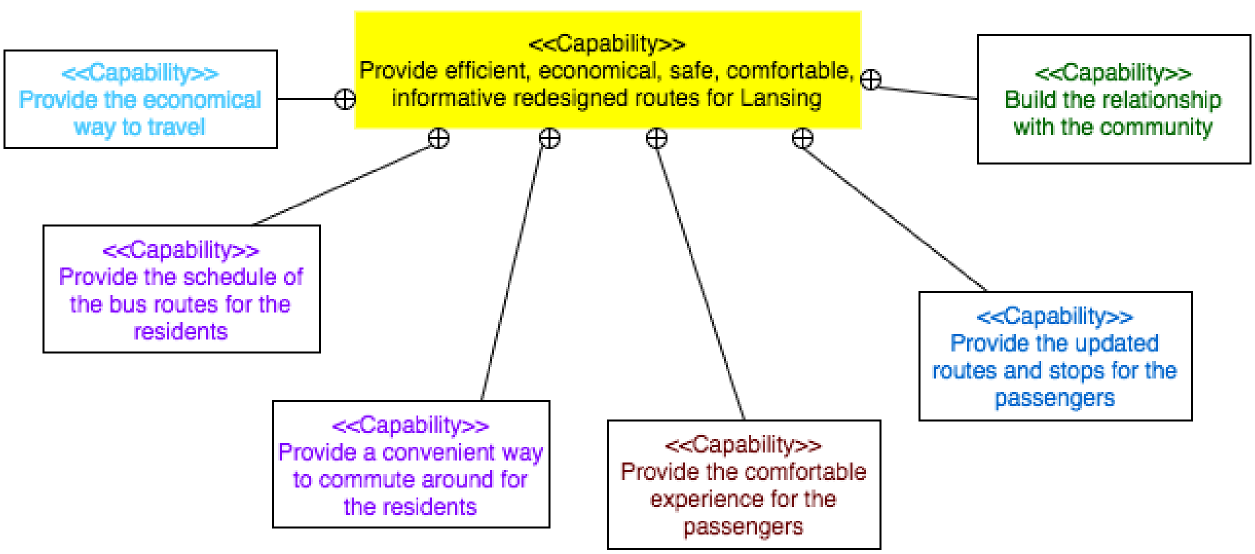
***Quote**: "I live a busy life so using a car to be on my own schedule is very helpful, however I want to explore the option of using the bus to save money on gas so I can spend more on my children. With that being said, I don't know anything about the bus system and I don't know where to start!"*

## 3.2.6 System Diagrams

### 3.2.6.1 Capabilities Diagram

The capability 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.

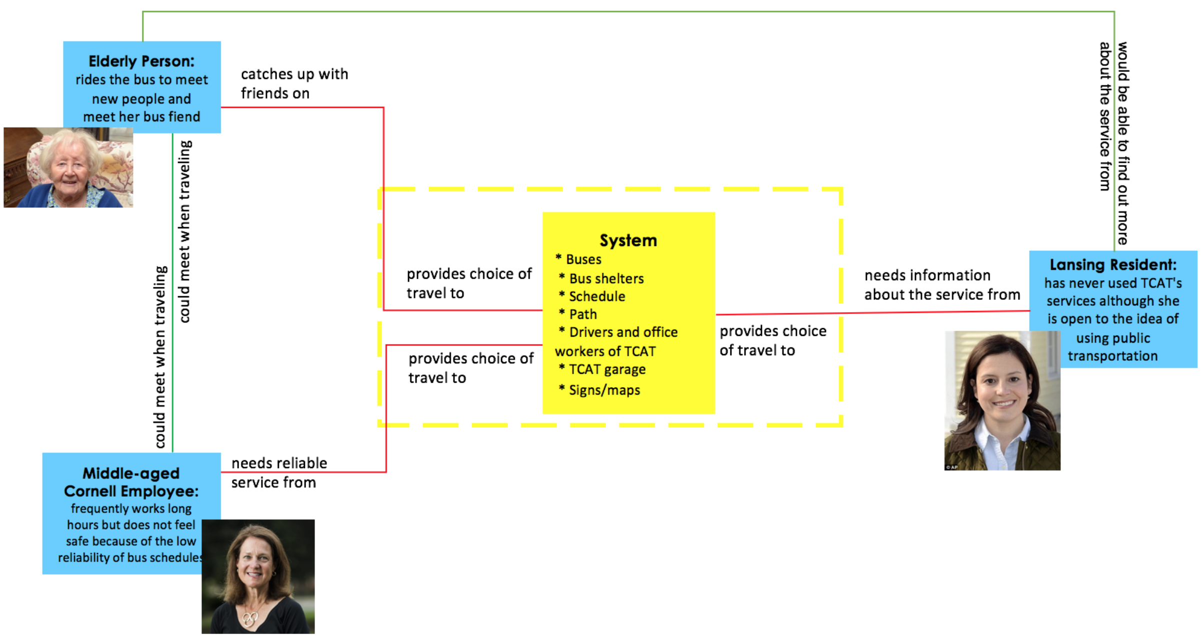
Shown below is the capability diagram of Lansing routing system, which shows key functions of the system.




*System Index 17: Capability Diagram*

### 3.2.6.2 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 18: Personal Context Diagram*

### 3.2.6.3 Next Steps:

We believe after working on all these tools in the context of designing a new routing for TCAT we have enough to work on the Analytical Hierarchy Process, the CVP and originating requirements. Having these will allow us to formally start thinking of a solution space for TCAT's problem. An outline of the steps that we believe should follow this semester's work as we move into the next is as follows:

1. Originating Requirements: These are statements of the capabilities that a system must possess in order to meet customer requirements. Originating requirements are the cornerstone upon which the systems engineering process is based. They are defined in conjunction with all the stakeholders of the systems and are presented in the form of a table. The table consists of three parts: index, originating requirements and abstract functional name. The main entities are originating requirements which can be considered as a list covering all functional requirements to meet the users' demands. In this column, all requirements should be defined in a manner that is correct, precise, unambiguous, complete, objective, verifiable and consistent. Moreover, all of them are stated as "shall" statements. The right column is a short phrase abstracted from the requirement itself and represents each specific requirement. With the help of originating requirements, we design for target functions of the system clearly. From the originating requirements, we can confirm the basic functions of the system which should be taken into account for routing design.

2. Customer Value Proposition: Customer value proposition (CVP) is a document used to summarize the benefits of our system compared to others. It would present the system's superior functional traits caused by structural features. The log line is the first sentence briefly describing what the system is. The paragraph below basically focuses on why a customer should approve our system and what traits of our design are superior to any alternative. The CVP distinguishes our system and provides the connection between design and customers' goals, which instructs us how to promote our system from the perspective of customers.
   With the assistance of CVP, we can get a better understanding of riders' needs and figure out the key characteristics of the routing system, which should be efficient and convenient. Thinking from the perspective of both riders and TCAT will help us develop more requirements. For example, we would have to consider special road conditions caused by heavy snow in winter in Ithaca, and provided alternatives to avoid them. An example of a CVP for routing is provided below:

   ***Customer Value Proposition for Routing***

   The optimized bus routes will allow TCAT to increase its users while limiting any associated costs by optimizing service to new housing projects, errand locations, and places of employment.
   The following are features that have been included with the benefits of each to the user/client:

a) The routes will be timed according to major office timings and class timings in the mornings and evenings.
b) Doctor's offices will be on the routes serving a majority of the senior population.
c) The above-mentioned routes will also have the maximum number of kneeling buses.
d) The wheelchair friendly buses will be concentrated in the routes historically serving the majority of disabled populations.
e) The designated stops will be planned in a manner that minimizes elevation change and distance from all major starting and ending points.
f) While optimizing routes we will also constrain the capital expenditure required by TCAT to the minimum to ensure consistent pricing while improving service.
g) We will also constrain the man hours required to run the optimized routes.
h) The new routes will be optimized to ensure that the new completed housing projects as well as planned housing projects are served.
i) The upcoming town center will be served by all major routes in Lansing to ensure accessibility from all around the town.
j) Distances between designated stops and the number of buses on each route will be planned to minimize the risk of getting late.
k) Available payment methods will be expanded to include more convenient forms of payment like android pay.

3. Other tools that we think will be relevant:
    a. Customer Affinity Process: Helps define major themes of user needs and assign a quantitative measure of relative importance to each by analyzing user comments.
    b. Decision Matrixes: To quantitatively compare alternative solutions to any problem.
    c. Analytical Hierarchy Process: Helps assign a quantitative measure of relative importance to the major themes of user needs based on the system designer's perspective. This helps balance any bias that might have creeped into the Customer Affinity Process as a result of an unrepresentative set of user data
    d. Timeline: To map out the steps in the future progress of the design process and affix responsibilities and deliverables for each step.
    e. Block Definition Diagram: Define all parts/subparts of a system
    f. Internal Block Diagram: Map out all constraints/relationships of the various components defined in the block definition diagram.

## 3.3 Statistical Modeling

### 3.3.1 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 statistical 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 statistical 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 statistical 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.

### 3.3.2 Methodology

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

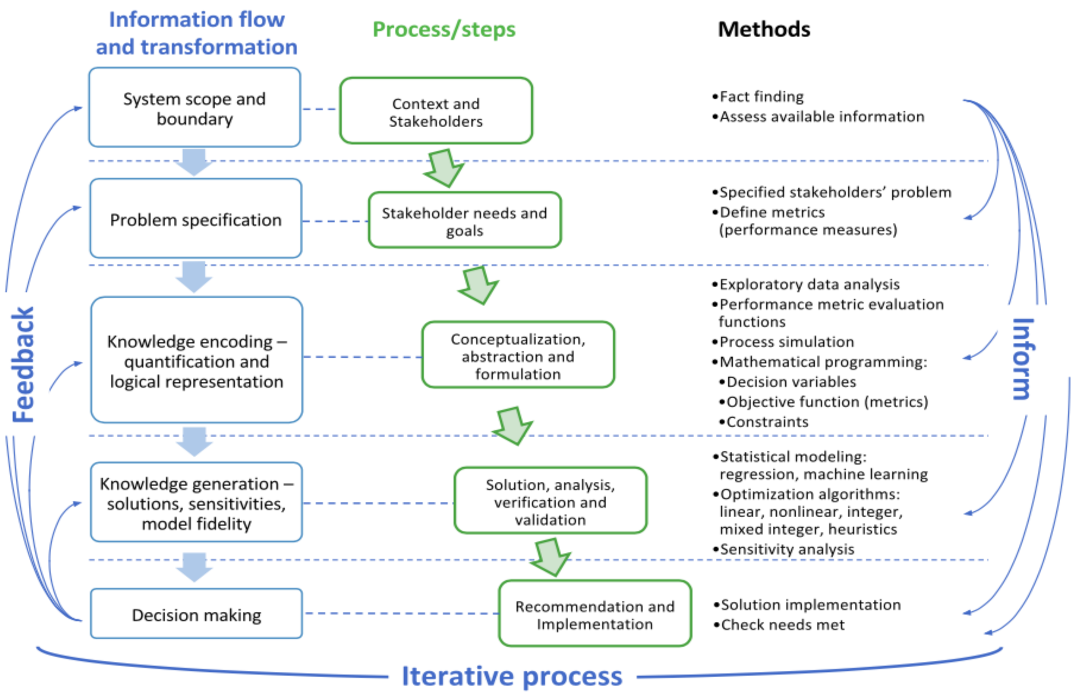
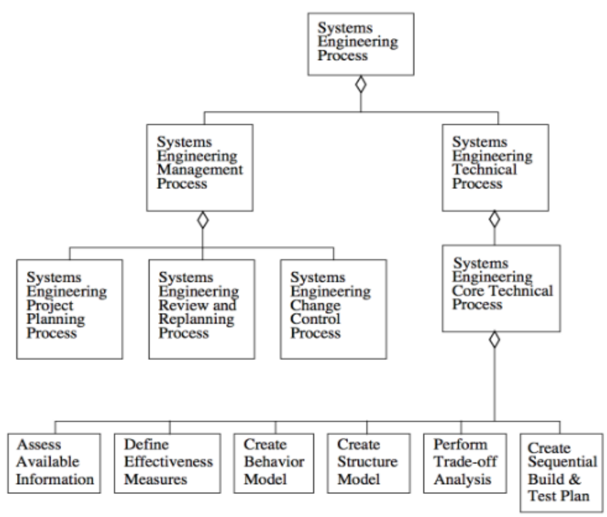



*Figure 58: Mathematical Modeling Process*




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 59: 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, optimizating 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.

### 3.3.3 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 has been carried out on these different scenarios with respect to feasibility, complexity, accessibility and efficiency. Clear definition were 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 level of scenario indicates how much of modification of 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.

Let us take a look at each type of scenario. One of the small scenarios is the following: a short distance of road between Lansing Town Hall and Triphammer at Auburn is connected, and 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.

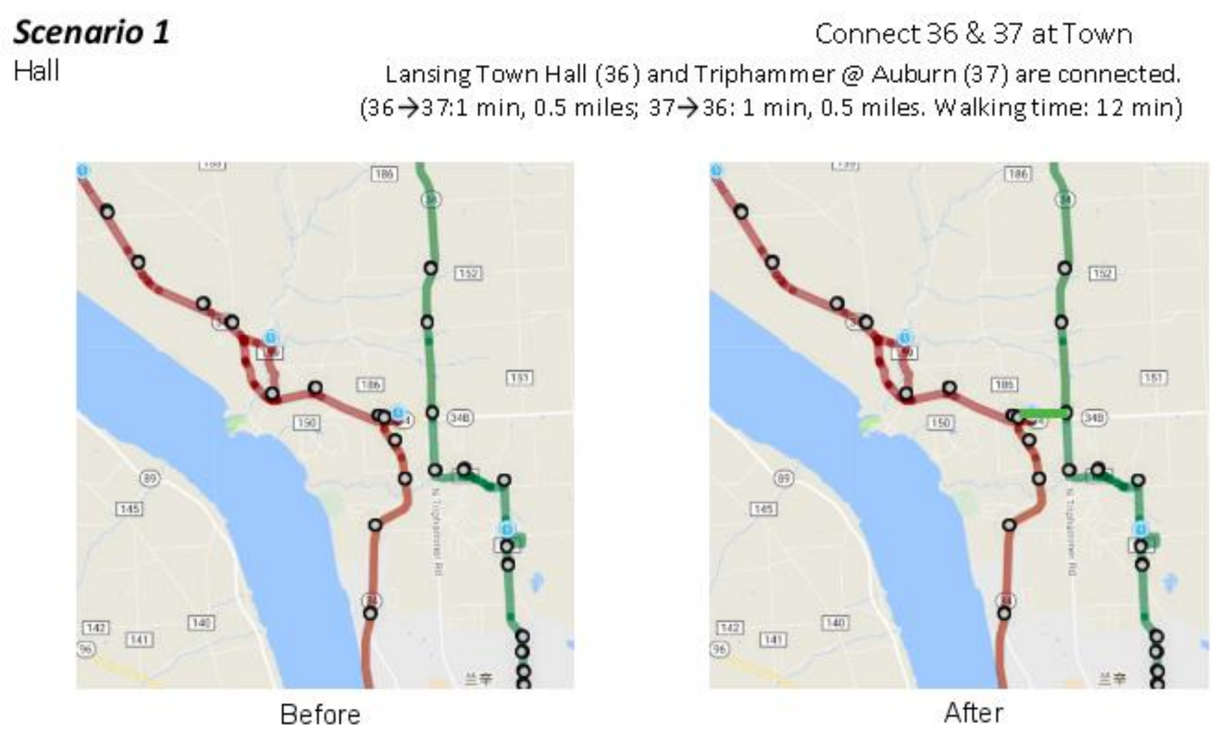



*Figure 60: Example of a Small Change Scenario*

One of the medium scenarios is the following: route 37 reroutes, removing traveling through a neighborhood to travel faster through North Triphammer Road. However, the route 32 will be then modified in order to cover the region that the route 37 forgoes in addition to a district that has not been covered before.

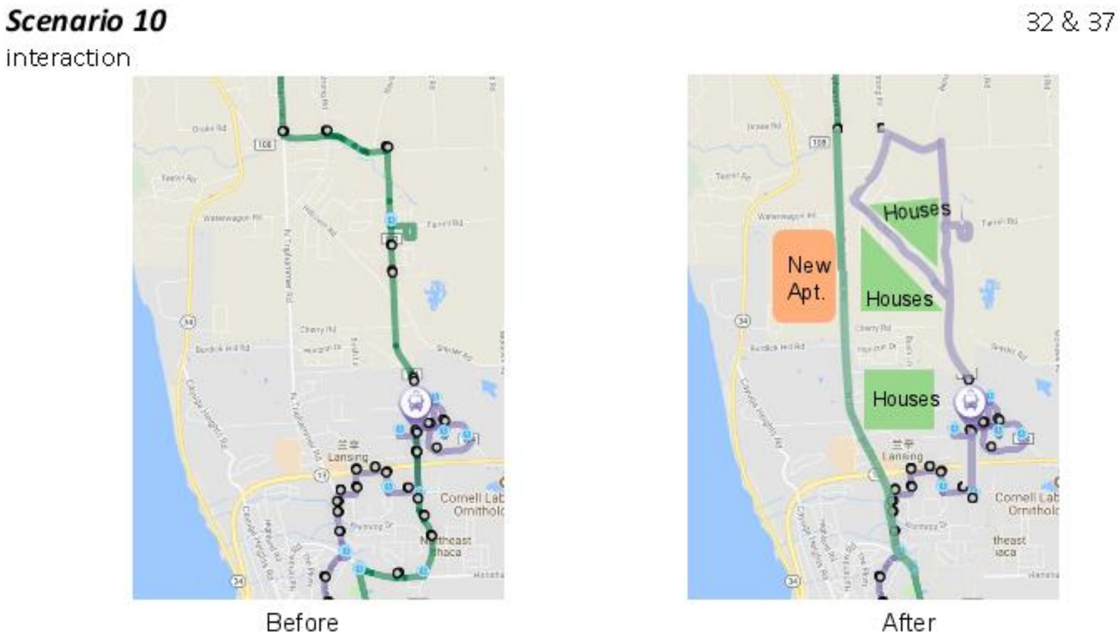



*Figure 61: Example of a Medium Change Scenario*

Finally, a large scenario includes a surgery of current routes, changing significant portions of existing routes to define an almost 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.

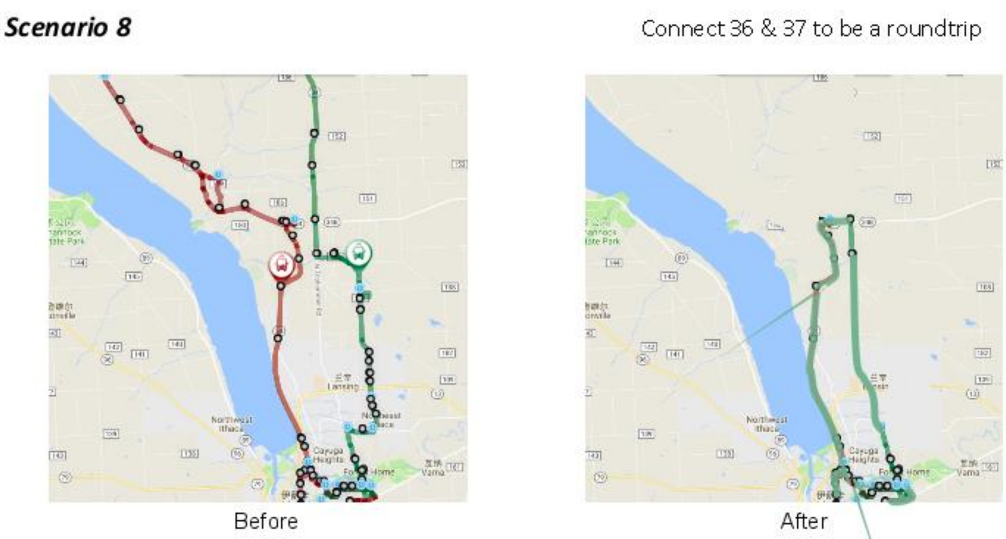



*Figure 62: Example of a Large Change Scenario*

Overall, the scenario analysis itself and the process of conducting it provided insight into a statistical 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 with routes in Lansing, such as 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.

### 3.3.4 Preliminary Model

#### Objectives

The statistical modeling team's goal is to develop a model with the context of the current Lansing route and the basic structure of mathematical modeling. Through communication with TCAT and fieldwork, we are informed that the Lansing area is under insufficient bus service, in part leading towards a large proportion of residents not choosing to commute via bus. There are three alternative objectives:

1. Maximize TCAT's revenue
2. Maximize TCAT's revenue and user's happiness
3. Maximize users' happiness with least TCAT deficit

Whereas system users are primarily expecting option three, the modeling team will be using the second option as our final objective, which maximizes TCAT's revenue and users' happiness in parallel. In turn, this is a multiple objective problem which is more complicated than uni-objective problem. In order to analyze the preliminary model better, the modeling team analyzes the routes stakeholders' interests and needs:

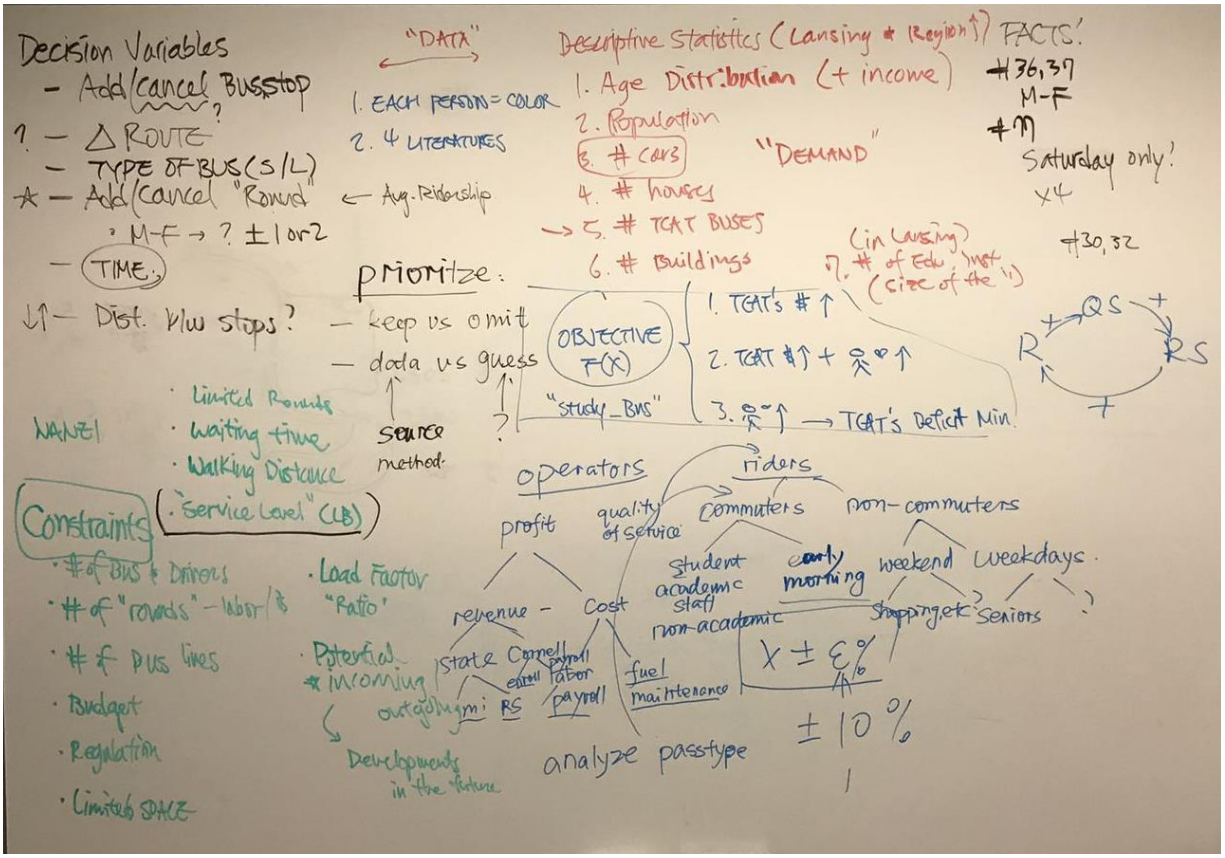



*Figure 63: Brainstorming for Preliminary Model*

In general, there are two major stakeholders in our routing system design: operators and riders(users). Our goal is to maximize the operator's profit and provide the best service for users. For operator's profit, a simple model equates profit to TCAT's revenue minus the running cost of bus service. State funding and Cornell's cooperation are the two major sources of TCAT's revenue. New York state will fund TCAT with the performance of TCAT's service in Ithaca, which is highly related to the total running miles of bus and ridership feedback. Cornell also will pay for TCAT service annually and enrolled students pay for the commuting service after their first year on the campus. For the cost of TCAT service, basic components are labor payroll, fuel cost and maintenance cost.

From rider's perspective, we analyze commuters and non-commuters. Commuters consist of academic staff (students and faculties) and non-academic staff. Currently, TCAT provides early morning and late afternoon bus service for the Lansing area, which generally accommodates commuting demands. There is also some mid-day service which can meet some potential demands, although not perceived by operators. For non-commuters, we in conjunction with the systems design thinking team are focusing their purpose of taking TCAT (i.e. looking for errand patterns and public transportation dependent individuals, like senior citizens).

Decision Variables

In order to design for Lansing routing, the modeling team defined the following decision variables:

1. Add/cancel bus stop
2. Modify current routes
3. Change bus fleet size
4. Add/cancel bus round
5. Alter bus schedule time
6. Distance between stops

Constraints

Constraints are constructed according to our limited resources and some environmental factors. The specific constraints are as follows:

1. Number of bus drivers
2. Number of bus rounds
3. Number of bus lines
4. Total budget for Lansing service
5. Local regulation for bus service
6. Limited geographical space for routing design
7. Load factor
8. Potential Lansing development in the future

Parameters

To flesh out our model, we must further collect descriptive statistics and inferential data to quantify constraints and objectives. The team must define the demands and potential demands of the Lansing community. The aspects that require definition are as follows:

1. Age distribution in Lansing area
2. Income distribution in Lansing area
3. Population distribution in Lansing area
4. Car ownership distribution in Lansing area
5. Housing distribution in Lansing area
6. Current TCAT route distribution in Lansing area
7. Building distribution in Lansing area
8. Number and size of educational institution in Lansing area

With the parameters above, our goal is to make sense of the character of Lansing residents and how life in Lansing. This will allow us to define the potential and current demands. Also, through TCAT's provided real-time data for routes 30, 32, 36, 37 and 77, which can document the current utilization of bus service in Lansing. With this data, the modeling team can deeper immerse with residents in Lansing, so as to better identify their needs.

# 4 CONCLUSION

## 4.1 Acknowledgements

This project would not have been possible without the kind support and help of many individuals and organizations. Through the months of learning, collaboration, and dedication, we would like to extend our sincere thanks to all of them.

The team would like to express their deep gratitude to our faculty advisors, Sirietta Simoncini and Wenqi Yi, for their supervision and guidance throughout the whole process. We are also grateful to the other faculty and stakeholders for their recommendations and advisory.

We also would like to thank everyone who, directly or indirectly, have provided their helping hand in this project.

### 4.1.1 Partners

We would like to thank our partners for their cooperation with us. We express our deepest gratitude to Renovus Solar for their generous contribution of the two 280W solar panels to our project last semester, and to Emma Hewitt for her support and guidance.

We would also like to thank Gary Stewart, Kate Supron, and Penny Givin from the Office of Community Relations for connecting us with on-campus resources.

And last but not least, we would like to thank Matt Yarrow and Marshall McCormick for their relentless support and commitment to our project. Their guidance and constructive feedback has improved our project immensely this semester.

### 4.1.2 Grants

We express our deepest gratitude to the Bartels family for their kind donation to our project. The grant will continue to fund the purchase of materials to build the modular parts of our bus shelter prototype next semester.